National Uranium Resource Evaluation

RICHFIELD QUADRANGLE
UTAH

U.S. Geological Survey
Golden, Colorado

Issue Date
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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Nuclear Energy
Grand Junction Area Office, Colorado
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NATIONAL URANIUM RESOURCE EVALUATION
RICHFIELD QUADRANGLE
UTAH

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With a section on
Interpretation of U.S. Geological Survey
Hydrogeochemical Data
by
Keith Robinson, Raymond L. Reed, and Rodney J. Noah

U.S. GEOLOGICAL SURVEY
Golden, Colorado

September 1982

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION AREA OFFICE
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This report has not been edited for conformance with
U.S. Geological Survey stratigraphic nomenclature
or resource classification.
This is the final version of the subject-quadrangle evaluation report to be placed on open file. This report has not been edited. In some instances, reductions in the size of favorable areas on Plate 1 are not reflected in the text.
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* This map, Preliminary geologic map of the Richfield 1° x 2° Quadrangle by T. A. Steven and others, is available as Open-File Report OF78-602 from the Open-File Services, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225.
ABSTRACT

The Richfield Quadrangle in west-central Utah was evaluated to identify areas favorable for the occurrence of uranium deposits known or likely to contain 100 tons of uranium with an average grade of not less than 100 ppm U₃O₈. Geologic reconnaissance was made of all known environments thought to be favorable for uranium deposits, and a representative selection of uranium occurrences reported in the literature was visited. Geochemical analyses from rock and limited water samples were used in the evaluation. Preliminary and incomplete aeroradiometric data and hydrogeochemical and stream-sediment analyses arrived too late in the program to be field-checked or to be adequately analyzed for this report.

Two areas favorable for uranium deposits were delineated: (1) volcanogenic deposits (class 500-599) in association with Miocene Mount Belknap rhyolite, and acidic plutons in the Marysvale Volcanic Field in the Antelope Range and Tushar Mountains; and (2) volcanogenic (class 500-599) and/or magmatic hydrothermal deposits (class 330) associated with Miocene high-silica high-alkali rhyolite tuffs, flows, and hypabyssal intrusives in volcanic or subvolcanic environments in the southern Wah Wah Mountains.

Environments considered unfavorable for uranium deposits containing 100 tons of uranium are: (1) all Precambrian sedimentary and metamorphic rocks; (2) all Paleozoic, Mesozoic, and Tertiary sedimentary rocks; (3) all volcanic rocks except those in the Marysvale Volcanic Field and the southern Wah Wah Mountains; (4) all magmatic-hydrothermal and contact-metasomatic base- and precious-metal deposits except for those associated with the favorable areas; and (5) spring-related occurrences, and occurrences related to the Tertiary and Paleozoic unconformity. Additional data from studies recommended in this report could change the unfavorable classification of some areas such as the Beaver Valley, Sevier-Richfield area and Shauntie Hills.

INTRODUCTION

PURPOSE AND SCOPE

The Richfield 1° x 2° Quadrangle (Fig. 1), Utah, was evaluated to identify and delineate areas and geologic units that exhibit characteristics favorable for the occurrence of uranium deposits. A favorable area or environment, according to the specifications used in this study, is one that is known or is likely to have uranium deposits containing a minimum of 100 tons of U₃O₈ with an average grade of not less than 100 ppm U₃O₈. Geologic environments were evaluated primarily on the basis of surface information; little pertinent subsurface information was available. Each environment was categorized as favorable, unfavorable, or unevaluated for uranium deposits, based on recognition criteria obtained from the study of significant uranium districts worldwide (Mickle and Mathews, eds., 1978).
Figure 1. Location of Richfield Quadrangle.

PROCEDURES

In the planning stage preliminary maps and tables showing known uranium occurrences in the Richfield Quadrangle, a geologic-index map, land-status map, and geologic map, a selected annotated bibliography, and a work plan for the study of this quadrangle were prepared. The geologic map (Steven and others, 1978) was a preliminary product of an ongoing geologic mapping program in the Richfield Quadrangle as part of the U.S. Geological Survey's Conterminous United States Mineral Appraisal Program (CUSMAP). This material was submitted to the DOE Grand Junction Office in June 1978, and field studies were authorized in July 1978.

Field and office investigations included examinations of a representative selection of readily accessible and locatable uranium occurrences within the Richfield Quadrangle and completion of 51 uranium occurrence reports, field examination of uranium host rocks; highly selective sampling and analysis of rocks to provide information on uranium-enriched and barren rocks. Water samples from the east-central part of the quadrangle were collected under the direction of Keith Robinson of the U.S. Geological Survey and the analytical results have been evaluated. Results from the Bendix Field Engineering Corporation (BFEC) reconnaissance-stream-sediment and water sampling program contractor and data from airborne gamma-ray spectrometer survey (ARMS) report by Geodata International, Inc. (1979) were not completed and received until late in the preparation of the text and could not be fully evaluated for this report. In lieu of the timely arrival of the aeroradiometric data, extensive carborne scintillometer road traverses of total gamma radiation were made in the quadrangle. These results provided only a partial and somewhat unsatisfactory substitute. Petrographic studies of selected volcanic and intrusive rocks were made to better understand rocks associated with some uranium deposits. Selected airphotos and Landsat images were inspected to identify any unusual features, such as alteration or structures that might be related to the distribution of uranium. Garry Raines of the U.S. Geological Survey, who has made a study of lineation features of western Utah south of the 40th parallel, was consulted, as was Melvin H. Podwysocki, U.S. Geological Survey, who has made a study of alteration using Landsat images. Michael Reimer, U.S. Geological Survey, in cooperation with the CUSMAP and NURE programs, made a helium survey in and around the Beaver Valley area (Reimer, 1979).

About 350 rock samples were collected and analyzed by delayed-neutron analysis for uranium and thorium, and by semiquantitative spectrographic methods for 44 elements. The samples are of two general types: (1) samples
from known or suspected occurrences and (2) selected samples of rock units, particularly volcanic rocks, to provide information on background uranium concentrations (App. B). Sample localities are shown on Plate 5.

Workings at most uranium occurrences in the area are nearly all caved or otherwise inaccessible. Most samples from occurrences in Appendix B are chiefly grab samples from dumps, or outcrops, and were generally taken from the most radioactive material that could be found; accordingly, they should not be considered as representing average grade of a particular occurrence. The data are not suitable for calculation of tonnage or grade of ore that might be expected, but merely give qualitative information on whatever metal content is present.

ACKNOWLEDGEMENTS

The writers are grateful to Dr. Myron Best of Brigham Young University, who willingly shared his information on the geology of the southwestern part of the Richfield Quadrangle during our field investigations. Rock samples collected during this study were analyzed in the analytical laboratories of the U.S. Geological Survey, and the following analysts are acknowledged: H. T. Millard, Jr., M. W. Solt, M. Coughlin, B. Vaughn, M. N. Schneider, W. Stang, C. Bliss, C. McFee, J. L. Seeley, P. J. Lamothe, T. Fries, G. Kaczanowski, R. Lerner, and M. Retzloff.

GEOLOGIC SETTING

The Richfield Quadrangle, an area of 20,000 km², is located in west-central Utah between latitudes 38° N and 39° N and longitudes 112° W and 114° W (Fig. 1). On the east, the quadrangle contains the High Plateaus subprovince of the Colorado Plateaus physiographic province and extends westward into the adjacent Basin and Range province (Fig. 3A). The highest point, Mount Delano in the Tushar Range, has an elevation of 3,710 m. The lowest elevation, about 1,375 m, is on the playa of Sevier Lake along the north edge of the quadrangle.

In a general way, the mountain ranges in the northern part of the quadrangle are characterized by thick assemblages of Paleozoic carbonate rocks of the Cordilleran miogeosyncline. Mesozoic sedimentary rocks are of limited extent except in the Pavant Range, in the northeast part of the quadrangle. The southern part of the Richfield Quadrangle is dominated by Tertiary volcanic rocks, part of the Pioche igneous province, which extends westward into southeastern Nevada. The north-trending mountain ranges of the Basin and Range province are separated by alluvial-filled basins.

Older Precambrian basement rocks on which the later Cordilleran geosyncline developed in west-central Utah are exposed only in a small area along the northwestern foot of the Mineral Range. Rocks there are chiefly migmatitic gneisses, schists, and phyllites. No local radiometric dates are available, but similar (though not necessarily correlative) Precambrian
Figure 3a. Tectonic features of the Richfield Quadrangle.
Figure 3b. Map showing Pioche mineral belt in Richfield Quadrangle.

- Tertiary intrusives
- Mining districts, as defined by clusters of mines and prospects. Principal commodities are indicated
- Areas of magnetic high interpreted to be related to shallow Tertiary calc-alkaline intrusive rocks (Shaw and Stewart, 1976)
metamorphic basement rocks in the Farmington complex northeast of Salt Lake City were last metamorphosed about 1.6 b.y. ago (Giletti and Gast, 1961).

About 1,500 m of younger Precambrian sedimentary rocks are preserved in the upper plate of the Frisco Thrust in the northern San Francisco and Beaver Mountains. The sequence consists chiefly of quartzite, argillite, slate, and minor carbonate, and has been divided into several formations which can be correlated throughout western Utah and southeastern Idaho (Woodward 1968, 1973, and Crittenden and others, 1971). The sequence is overlain conformably by about 1,200 m of Prospect Mountain Quartzite, which is considered to be of Lower Cambrian age, though the exact Precambrian-Cambrian boundary has not been located confidently. Younger Precambrian strata probably are also present along the west flank of the Wah Wah Range south of Wah Wah Pass. Purple quartzites beneath typical Prospect Mountain Quartzite, as near Pine Grove, are tentatively correlated with the Upper Precambrian Mutual Formation. The younger Precambrian and Cambrian clastics mark the beginning of the Cordilleran geosyncline, which continued to dominate sedimentation patterns in the Great Basin throughout Paleozoic time (Stewart, 1972). Carbonate deposition dominated from Middle Cambrian through Permian time in quiet, relatively shallow waters, only briefly interrupted by deposition of minor sandstones and shales. Shelfward from the miogeosyncline, the section thins by pinching out or non-deposition of units (Pl. 8). The Paleozoic section in the Richfield Quadrangle, though not complete in any range, probably aggregates about 10,000 m in thickness. Mesozoic to Oligocene (?) marine and continental sediments include limestone, mudstone, sandstone, and conglomerate.

The Tertiary volcanic rocks which are so widespread in the southern part of the quadrangle have been the subject of much work in recent years. The results are summarized by Rowley and others (1979) in an excellent paper on the Cenozoic framework of southwestern Utah. The brief description that follows draws largely on this study.

Rowley and others (1979) divide the diverse assemblage of volcanic rocks into a middle Tertiary sequence consisting mostly of upper Oligocene and lower Miocene calc-alkalic volcanic rocks and a younger bimodal basalt-rhyolite sequence (Fig. 2). The older sequence, ranging in age from 35 to about 19 m.y., was erupted from scattered, partly clustered, intermediate-composition stratovolcanoes, and in part from cauldrons, as in the Needles Range (Best and others, 1979; Grant and Best, 1979).

The volcanic centers were separated by broad areas covered by thin but regionally distributed silicic ash-flow tuffs (Rowley and others, 1979). The Marysvale volcanic field is the largest and best known volcanic accumulation formed at this time. Papers by Steven and others (1977) and Cunningham and Steven (1978) give results of modern work in this area. Anderson and Rowley (1975) describe the southern part of this field. Newly published maps of the southwestern part of the Richfield Quadrangle give much needed information in that area (Best, 1979; Best and Keith, 1979; Best and others, 1979; Grant and Best, 1979a and b; Lemmon and Morris, 1979).
Figure 2. Correlation chart of Cenozoic volcanic stratigraphy of the Richfield Quadrangle, Utah. Absence of strata is shown by vertical ruling. Radiometric dates are shown rounded to nearest million years. Chart abbreviated and modified from Rowley and others, 1979; south Wah Wah column simplified from Best, 1979; Best and Keith, 1979; Grant and Best, 1979.
The youngest volcanic sequence consists of bimodal alkali basalt and high-silica alkali rhyolites, both erupted episodically during the same time span which began 21-20 m.y. ago and has continued to the present. The onset of bimodal volcanism was essentially coincident with Basin and Range tectonism (Rowley and others, 1979). Episodic volcanism accompanied normal faulting and basin sedimentation.

The rhyolitic rocks erupted from restricted centers and range in volume from minor flows and small domes to major accumulations. The volume of rhyolite, however, is not nearly so great as that of the older volcanics sequence. The Mount Belknap Volcanics (Fig. 2), the largest accumulation of this period, formed about 21 to 16 m.y. ago around the Mount Belknap cauldron and the smaller Red Hills cauldron (Fig. 3). Another important center of rhyolite volcanism about 22 to 20 m.y. ago was in the southern Wah Wah Mountains and Needle Range.

Basalt flows, which are part of the bimodal basalt-rhyolite sequence, are widespread in the Richfield Quadrangle, although generally of small volume. They range in age from 13.6 m.y. in the southern Wah Wah Mountains to a few thousand years west of Filmore in the Sevier Desert (Pl. 10).

Pre-Cenozoic rocks of the eastern part of the Basin and Range were affected by the Sevier orogeny in Cretaceous time. The orogeny was marked by eastward-thrusting and related folding of miogeosynclinal rocks (Armstrong, 1968). The eastern edge of the Sevier thrust belt extends northeast across the Basin and Range province in the Richfield Quadrangle, and intersects the High Plateaus in the Pavant Range (Fig. 3A).

Late Cenozoic time was marked by extensional tectonism and the formation of block-faulted north- or northeast-trending ranges. Concurrently with uplift and erosion, sediments were deposited in down-faulted basins. An east-west structural zone (Fig. 3A) called the Blue Ribbon lineament (Rowley and others, 1978) is defined in part by a combination of structural, topographic, igneous, and magnetic features. The features that mark the zone are believed to have developed generally coincident with northerly trending classical Basin and Range faults.

The uranium occurrences in the Richfield Quadrangle (Pl. 2) are largely confined to a broad belt which trends east-northeast across the area from the southern Needles Range to the Marysvale area. The distribution is coincident with the Pioche-Marysvale igneous or mineral belt. Long recognized, the mineral belt (Butler and others, 1920) is defined by the cluster of Tertiary precious- and base-metal deposits and districts, the general parallel distribution of intrusive igneous rocks, and aeromagnetic anomalies (Fig. 6). Uranium mineralization is closely associated with the high-silica alkali rhyolites at Marysvale, in the western Tushar Mountains, and in the southern Wah Wah Mountains.
Two areas within the Richfield Quadrangle have environments favorable for uranium deposits according to the definition used in the NURE program. To qualify as favorable, the available evidence must suggest the area contains at least 100 tons of uranium with an average grade of not less than 0.01 percent $U_3O_8$. Delineated areas are the Marysvale volcanic field (Area A) and the southern Wah Wah Mountains (Area B). Both these areas have characteristics favorable for the concentration of uranium (Pilcher, 1978, and Mathews, 1978), and both contain uranium occurrences, some of which have yielded small to moderate uranium production. The two favorable environments contain volcanogenic (class 500) and/or magmatic hydrothermal (class 330) occurrences associated with Miocene high-silica alkali rhyolite volcanism and associated subvolcanic intrusives.

Similar volcanogenic and/or magmatic hydrothermal environments with some characteristics favorable for the occurrence of uranium exist elsewhere in the Pioche mineral belt within the Richfield Quadrangle, and although they were not judged to fit the minimum endowment for favorability laid down for this study, some certainly appear to offer reasonable exploration targets. Examples are Beaver Valley and perhaps the Shauntie Hills. These areas will be discussed under "unfavorable" environments.

AREA A, MARYSVALE VOLCANIC FIELD FAVORABLE AREA

General Statement

The Marysvale Volcanic Field Favorable Area (Pl. 1, Area A) contains at least 60 uranium occurrences, has a history of uranium production (in excess of $6.4 \times 10^3$ Kg $U_3O_8$), shows aeroradiometric anomalies and geochemical anomalies for both rock and stream sediment samples, and displays most of the recognition criteria for volcanogenic uranium deposits (Table 3).

The uranium occurrences and deposits in the area are generally tabular veins containing uranium, fluorine, and, in some cases, molybdenum. It is the consensus of investigators that most of the occurrences were deposited by hydrothermal fluids from subvolcanic plutons. Some of the occurrences have been oxidized since their formation and have lost most or all of their primary features.

LOCATION

The favorable area (Pl. 1, Area A) which includes most of the Marysvale volcanic field is located in the east-central portion of the Richfield Quadrangle at the eastern end of the Pioche-Marysvale mineral belt (Fig. 3). It encompasses a portion of the rugged Tushar Mountains, the Antelope Range, and a portion of the Sevier River Valley; all of which are within the High
Plateaus physiographic subprovince which separates the Colorado Plateaus and Basin and Range provinces. The land status of the area is summarized on Plate 12. In the past, several commodities including base and precious metals, mercury, potash, aluminum, and uranium were produced from the region (see Fig. 4 and Callaghan, 1973, for a summary of mining activity).

Geologic Setting, Uranium Hosts and Their Stratigraphy

Uranium is hosted by a variety of lithologies including fine-grained granite, quartz monzonite (this rock type is now generally called granite; however, in consideration of historic usage in the area the term quartz monzonite will be used in this report), and Mount Belknap rhyolites (particularly in the Henry Mining District); volcanic rocks of the Bullion Canyon Volcanics (particularly in the Newton Mining District); and in altered sedimentary rocks that also host manto- and vein-type base- and precious-metal deposits in the Mount Baldy and Ohio Mining Districts.

The Marysvale volcanic field is underlain, at least in part, by Paleozoic and Mesozoic sediments (Pl. 10) that have been described by Bethke and Kerr (1954). These are unconformably overlain by Tertiary and Quaternary volcanics and sediments.

According to Steven and others (1977a, p. 1):

In late Oligocene and early Miocene time (30-21 m.y.) a composite volcanic center consisting of numerous local volcanoes was active in the general Marysvale area. The volcanoes consisted of near-source lava flows, volcanic breccias, and minor pyroclastic deposits of generally intermediate composition flanked by coalescing aprons of volcaniclastic debris. Locally derived ash-flow tuffs form important marker beds within the assemblage. Concurrently with local volcanism, ash flows from distant sources in the Great Basin extended into the Marysvale area to interleave marginally with locally derived volcanic rocks.

Local volcanic activity in the Marysvale area probably began about 30 m.y. ago with eruption of mafic intermediate-composition lava flows and volcanic breccias. About 29 m.y. ago, a widespread sheet of crystal-rich ash-flow tuff (Oligocene Needles Range Formation) was spread across the region from distant as yet unidentified centers to the west or southwest. The Needles Range Formation is exposed all around the Marysvale area, but may have been excluded in places within it by local volcanoes. Accumulation of intermediate-composition volcanic rocks from local centers continued after deposition of the Needles Range Formation, and by 21 m.y. ago, a major pile of volcanic rocks had been built in the Marysvale area. The name Bullion Canyon Volcanics is applied to this assemblage of Oligocene and Miocene volcanic rocks.

During the waning stages of Bullion Canyon volcanism, quartz monzonite stocks were emplaced in the Marysvale volcanic field. Steven and others
Figure 4. Mining districts within the Marysvale Volcanic Field favorable area.
(1977a) have interpreted their geochronologic data to mean that the central intrusive (Karr and others, 1957) was emplaced 22-23 m.y. ago.

A complex sequence of acid volcanics and intrusives unconformably overlies and intrudes the Bullion Canyon Volcanics as described by Steven and others, (1977a, p. 1,2).

Between 21 and 17 m.y. ago, repeated rhyolitic eruptions from two source areas in the Marysvale area produced a heterogeneous assemblage of ash-flow tuffs, lava flows and domes, and associated pyroclastic and mudflow breccias, and emplaced local rhyolite and granite intrusive bodies. Two cauldrons, the major Mount Belknap caldera and the minor Red Hills caldera, subsided in response to ash-flow eruptions. Intracaldera and near-source densely welded tuffs of the Mount Belknap Volcanics (formerly Mount Belknap Rhyolite) are generally equivalent to the less welded outflow facies of the Joe Lott Tuff Member (formerly formation rank), and the whole rhyolitic assemblage is here called the Miocene Mount Belknap Volcanics. The outflow is designated the Joe Lott Tuff Member of the Mount Belknap. The intracaldera and outflow facies from both source areas are divided into several new formal and informal members with complex interrelationships.

An apparent systematic progression of igneous activity in the eastern source area [Red Hills caldera] of the Mount Belknap Volcanics has been interpreted by Cunningham and Steven (1979a) as reflecting the successive emplacement of shallow cupolas above a larger high-level magma chamber (diagrammatic sketch, Fig. 5). 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.

Much of the recent work of Cunningham and Steven has been directed toward understanding the Mount Belknap stratigraphy. Figure 6 summarizes their work and shows their proposed stratigraphic correlations between the Mount Belknap and Red Hills calderas. Steven and others (1977a, p. 2)note:

Basin-range faulting began after eruption of the Mount Belknap Volcanics, and continued through much of the remainder of Cenozoic time. The Sevier River Formation consists of fluviatile and minor lacustrine sediments that were deposited in basins that developed concurrently with faulting. Basalt flows were erupted widely but in low volume during the period of Sevier River sedimentation.

Table 1 summarizes many of the known geologic events, including caldera formation and periods of mineralization in the Marysvale volcanic field, which might relate to uranium mineralization. The ages shown on the table are taken primarily from Steven and others (1977a) and represent their interpretation of the data.
TABLE 1. SELECTED GEOLOGIC EVENTS IN THE MARYSVALE VOLCANIC FIELD
(Except where noted, data and interpretations are from Steven and others, 1977a. This is not a complete listing of mineralization and alteration events.)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Geologic Event</th>
<th>Age (approx. in m.y.)</th>
<th>Mineralization and Alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Peaks Tuff Member,</td>
<td>Three Creeks Cauldron</td>
<td>26-27</td>
<td></td>
</tr>
<tr>
<td>Bullion Canyon Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delano Peak Tuff Member,</td>
<td>Big John Caldera</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Bullion Canyon Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz Monzonite</td>
<td></td>
<td>22-23</td>
<td></td>
</tr>
<tr>
<td>Bullion Canyon Volcanics</td>
<td></td>
<td>21-22</td>
<td>Alunite</td>
</tr>
<tr>
<td>(altered)</td>
<td></td>
<td></td>
<td>Precious-metal quartz-carbonate veins (mineralization may be related to quartz monzonite)</td>
</tr>
<tr>
<td>Teacup dome rhyolite,</td>
<td></td>
<td>20-21</td>
<td></td>
</tr>
<tr>
<td>Mt. Belknap Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine-grained granite,</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Mt. Belknap Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower crystal-rich tuff,</td>
<td></td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Mt. Belknap Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz monzonite, fine-grained granite, Mt. Belknap Volcanics (altered)</td>
<td></td>
<td>19±4/1</td>
<td>Uranium</td>
</tr>
<tr>
<td>Joe Lott Tuff Member,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt. Belknap Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red Hills Tuff Member,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt. Belknap Volcanics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit</td>
<td>Geologic Event</td>
<td>Age (approx. in m.y.)</td>
<td>Mineralization and Alteration</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>---------------------------------------</td>
<td>-----------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Crystal-rich Tuff Member, Mt. Belknap Volcanics</td>
<td></td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Upper Gray Tuff Member, Mt. Belknap Volcanics</td>
<td>Approx. end of major Mt. Belknap volcanism</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Bullion Canyon Volcanics (altered)</td>
<td>Hypothesized plutonism²</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Sedimentary rocks, (altered)</td>
<td></td>
<td>13-14³</td>
<td>Base-metal vein and manto deposits; minor uranium mineralization⁴</td>
</tr>
<tr>
<td>Bullion Canyon Volcanics (altered)</td>
<td></td>
<td>9</td>
<td>Alunite</td>
</tr>
</tbody>
</table>

1 K. R. Ludwig, oral commun. 1979; U-Pb whole-rock isochron.
2 Cunningham and Steven, 1979c.
3 Bassett and others, 1963, sample KA60.
4 Based on Bethke and Kerr, 1954, see text on age of uranium mineralization.
Figure 5. Diagrammatic sketch showing postulated relations in the roots of source areas for the Mount Belknap Volcanics and the projected position of the unexposed, postulated, 14 m.y. old stock at Alunite Ridge (Cunningham and Steven, 1979c). Modified from Cunningham and Steven, 1979a.
Figure 6. Diagrammatic cross section showing stratigraphic relations of the Mount Belknap Volcanics. Heavy lines, faults; arrows show direction of movement. Not to scale.
Distribution of Uranium Occurrences

There are at least 60 known uranium mines and occurrences in the Marysvale volcanic field (Pl. 2, Fig. 7, App. A). At least 19 occurrences, including the major past producers of the favorable area, are in the central area of Kerr and others (1957) (a portion of the Henry Mining district, Fig. 4 and Table 2), and 13 occurrences are in the Indian Creek-North Creek area (Newton Mining district). Callaghan (1973) has summarized much of the information on these occurrences, as have Kerr (1968) and Kerr and others (1957). There is a crude spatial association between uranium occurrences and (1) the Mount Belknap Caldera, (2) the Red Hills Caldera, (3) Tertiary intrusives, (4) base-precious-metal deposits in the Mount Baldy and Ohio Mining districts, (5) faults, and (6) the surficial distribution of Mount Belknap Volcanics (Fig. 7).

Class of Uranium Occurrences

Hypotheses regarding the origin of the uranium are divergent, but not necessarily mutually exclusive. The extreme views have been stated by Carmony (1977) who hypothesized that the uranium was leached from the Mount Belknap Volcanics by ground water which then underwent deep circulation and heating to form the hydrothermal fluid(s) responsible for the veins, and by Cunningham and Steven (1978d) who suggest that the hydrothermal fluid(s) was predominantly magmatic in origin and may have been related to a molybdenum-porphyry system(s). Both Carmony and Cunningham and Steven may be correct. It is obvious from the distribution and diversity of metal deposits and rock alteration patterns that extensive hydrothermal systems operated in the region at different places and times and that there were at least two periods of uranium deposition (at about 14 m.y. and 19 m.y. ago). It may be, however, that the younger system, centered near Deertrail Mountain, merely remobilized some of the older uranium rather than introducing new uranium. Regardless of the age or origin of the uranium, it seems clear that the deposition of uranium was dependent on the spatial and temporal coincidence of conduits for uraniferous hydrothermal fluids and the physical conditions necessary for the precipitation of uranium.

There are insufficient data to confidently define the genesis of the occurrences in the Marysvale Volcanic Field favorable area; however, most of the uranium deposits and occurrences fall, for the purposes of this report, into the pneumatogenic (class 520) group. This classification is based on Pilcher's (1978) use of deposits near the Red Hills Caldera (Fig. 7) as examples of pneumatogenic deposits. It is not at all clear that the uranium in those deposits originated during primary degassing of intrusives and/or extrusives as indicated in Pilcher's model. Further, there is no evidence whatsoever that the mineral phases are the result of transportation and/or deposition from a gas phase, as is implicit in the name of the model. In fact, the fluid inclusion data of Cunningham and others (1979) suggest deposition from a relatively cool liquid phase. It is more likely, and perhaps inferred but not explicitly stated in the model, that some of the
TABLE 2. PAST URANIUM PRODUCTION IN THE MARYSVALE VOLCANIC FIELD FAVORABLE AREA  
(Data from DOE production files.)

<table>
<thead>
<tr>
<th>Mining district</th>
<th>Mine</th>
<th>Locality</th>
<th>No. on Pl. 1</th>
<th>Mg (t) of Ore</th>
<th>kg of U308</th>
<th>Average Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central mining area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Henry mining district</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Cloys mine</td>
<td>37</td>
<td>11,108</td>
<td>22,159</td>
<td>.20</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Potts Fraction</td>
<td>39</td>
<td>12,935</td>
<td>19,652</td>
<td>.15</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Freedom mines</td>
<td>41,47</td>
<td>160,077</td>
<td>360,743</td>
<td>.23</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Farmer John</td>
<td>43</td>
<td>44,830</td>
<td>92,306</td>
<td>.21</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Buddy</td>
<td>49</td>
<td>6,769</td>
<td>14,303</td>
<td>.21</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Lucky Strike</td>
<td>50</td>
<td>78</td>
<td>145</td>
<td>.19</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Prospector</td>
<td>51</td>
<td>55,146</td>
<td>120,471</td>
<td>.22</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>JDC</td>
<td>54</td>
<td>13</td>
<td>5</td>
<td>.04</td>
<td></td>
</tr>
<tr>
<td>&quot; (?)</td>
<td>Vega</td>
<td>*</td>
<td>548</td>
<td>655</td>
<td>.12</td>
<td></td>
</tr>
<tr>
<td>Henry mining district</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>East Slope</td>
<td>19</td>
<td>5</td>
<td>4</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Flat Tire</td>
<td>30</td>
<td>14</td>
<td>15</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>Indian Creek-North Creek area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Newton mining district</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>CDP</td>
<td>80</td>
<td>4</td>
<td>4</td>
<td>.10</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Beehive 5</td>
<td>89</td>
<td>54</td>
<td>59</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Beehive</td>
<td>*</td>
<td>5</td>
<td>0.5</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Little Sisters</td>
<td>91</td>
<td>4</td>
<td>6</td>
<td>.16</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Mystery Sniffer</td>
<td>93</td>
<td>16,372</td>
<td>29,138</td>
<td>.18</td>
<td></td>
</tr>
<tr>
<td>?</td>
<td>Mt. Baldy</td>
<td>*</td>
<td>1</td>
<td>0.5</td>
<td>.05</td>
<td></td>
</tr>
</tbody>
</table>

*Location of mine unknown; only known reference is DOE production record.
Figure 7. Distribution of Tertiary intrusives, Mount Belknap Volcanics, calderas, faults, and uranium occurrences in the Marysvale Volcanic Field favorable area.
magma's volatile components were incorporated in a subcritical hydrothermal fluid from which the solid uranium phases and associated gangue minerals were eventually deposited. Because many of the occurrences have been extensively altered and reworked by ground water, some of the primary features of the deposits have been obscured or totally removed and, hence, their assignment to a specific class can only be accomplished by highly interpretive analogy to better exposed deposits in the area.

Regardless of what we call these occurrences and what was the ultimate source of their uranium, most appear to have formed in a subvolcanic environment from fluids rich in fluorine. In most instances, the occurrences exhibit the characteristics of Pilcher's (1978) pneumatogenic deposits (Table 3). The exceptions are those few occurrences hosted by the pre-Bullion Canyon sediments (Mt. Baldy and Ohio Mining Districts, Fig. 4); however, as discussed in a later section, they need not be excluded from this type of deposit.

There is the possibility that other classes of occurrences will be found within the favorable area. If Cunningham and Steven's (1979a) suggestion that a molybdenum porphyry underlies the central area is correct, there is the possibility that initial-magmatic occurrences (class 510) may provide by-product uranium. Cunningham and Steven (1979c) also suggest that a porphyry system may underlie the Deertrail area. Further, hydroallogenic occurrences (class 540) may be found in the region. This suggestion is supported by Carmony's (1977, p. x) data, which show that the Mount Belknap Volcanics have "lost on the average about 3 ppm uranium as a result of ground water leaching in conjunction with devitrification". Steven and others (1979) have suggested that hydroallogenic deposits may be found in the Big John caldera area. However, based on our current knowledge, the possibility of finding initial-magmatic, hydroallogenic, and/or other class deposits is at best speculative. It should be considered during exploration programs within the Marysvale volcanic field, but definitely should not be factored into any sort of realistic resource evaluation of the area.
TABLE 3. RECOGNITION CRITERIA FOR
PNEUMATOCENIC URANIUM OCCURRENCES (CLASS 520)
(Criteria from Mathews and others, 1979)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Present within area A</th>
<th>Absent or rare within area A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tectonic setting:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin and range system</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rift system</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Major regional structures:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horst and graben</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Volcano-tectonic depressions</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Dominant local structures:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ring fractures</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Shear zones in intrusives</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Breccia pipes</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Faults</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Host rock:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithology:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granite/rhyolite</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Syenite/trachyte</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Texture:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granitic</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Granophyric</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Pumiceous</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Dense welding</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Lithophysae</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Mineralogy:</td>
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<td></td>
</tr>
<tr>
<td>Alkali feldspars</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sodic pyroxene and/or amphiboles</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Fluorite</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sulfides</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Geologic setting:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subvolcanic intrusives</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ring-fracture intrusives</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ash flow</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Criteria</td>
<td>Present within area A</td>
<td>Absent or rare within area A</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-----------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td><strong>Chemistry:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High, SiO₂, Na₂O, K₂O, F</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Na₂O + K₂O/Al₂O₃&gt;1</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Th/U&gt;1</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Geometry of ore concentrations:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Veins</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Pipes</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Stockworks</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Alteration:</strong></td>
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<td></td>
</tr>
<tr>
<td>Silicification</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sericitization</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Albitization</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Argillization</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Hematitization</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>U and U-bearing minerals:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uranium oxides</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Associated elements (within the U-bearing veins):</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Li</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
Controls on Uranium Deposition

The most obvious control on the distribution of uranium occurrences is the presence of porous conduits that allowed the flow of uranium-bearing fluids. Such conduits seem best developed within and marginal to granitic stocks and, to a lesser extent, Mount-Belknap-time calderas. As a generalized conceptual model, the high-grade veins are best developed in granitic rocks which responded to deformation by forming well-defined open-space fractures with relatively impermeable margins; in contrast, volcanic rocks were less likely to form restricted conduits, and the uranium occurrences in them are of more diffuse nature. Hence, to the extent that the granitic rocks responded differently to deformation than the volcanic rocks, they exercised a lithologic control on the deposition of uranium. There are no obvious and consistent variations in the vein chemistry and mineralogy that reflect chemical controls that might have operated on the original hydrothermal systems (with the possible exception of extent of wall-rock alteration and downward increasing pyrite content). However, C. G. Cunningham (oral commun., 1979) suggests that in the upper portions of the Freedom vein system (App. A, occs. nos. 41, 47) redox reactions between the wall rock phases and the hydrothermal fluid may have controlled ore deposition.

Cunningham and Steven (1979a) suggest that the central area represents the upper portion of a molybdenum-porphyry system. The evidence that they use to make this suggestion incorporates structural data indicating distension and intense brittle deformation above the inferred porphyry, and geochemical data indicating anomalous amounts of molybdenum and fluorine in the area. Further, they draw an analogy between their suggested porphyry and those at Henderson and Climax (in Colorado) which contain byproduct or at least minor amounts of uranium, and infer that the central area represents a high-level portion of a similar system. If this is a valid model, the major controls on uranium deposition are the size, shape, and lifetime of the molybdenum porphyry system. An evaluation of this hypothesis must await further, deeper exploration.

If the source of the uranium in the vein deposits is the Mount Belknap Volcanics as suggested by Carmony (1977) the primary controls on the deposition of uranium would be (1) the presence of Mount Belknap Volcanics, (2) the presence of conduits for the circulation of uranium-rich ground water, and (3) the presence of a heat engine to drive the circulating waters. Another possible source of uranium is the Osiris Tuff. Apparently fresh samples of the tuff (App. B, samples MDG 101, 102, 138, 139) have high uranium and thorium values, 22.4 to 25.5 ppm and 82.4 to 92.1 ppm, respectively. If uranium could be leached from the Osiris Tuff in a manner similar to that suggested by Carmony (1977) for the Mount Belknap Volcanics, controls on uranium deposition similar to those listed above for the Mount Belknap Volcanics would apply in a system using the Osiris Tuff as a uranium source.
Uranium and Gangue Mineralogy

The only tetravalent uranium minerals reported are uraninite; uraninite, variety pitchblende; and coffinite. Coffinite has been reported only from the central area. Uranyl phases including sulfates, silicates, phosphates, and vanadates, seem to be present at most of the occurrences. Kerr and others (1957) and Callaghan (1973) have reviewed the species present at many of the occurrences and have both suggested that the uranyl phases represent redistributed, oxidized uranium. Callaghan (1973, p. 50) made the interesting observation that in at least one case in the central area the weathered zone has the same uranium content as the zone containing "primary" ore, suggesting that there has been neither enrichment nor depletion but simply *in situ* oxidation of uranium.

Purple fluorite is the most conspicuous gangue mineral associated with uranium-bearing veins in both the central and Indian Creek-North Creek areas. Pyrite, quartz, adularia, and minor amounts of magnetite are the other ubiquitous gangue phases. In places, molybdenum is an important accessory element in the uranium-bearing veins. It occurs as umohoite, jordisite, and/or ilsemanite.

Formation of uranium-bearing veins was generally accompanied by argillic alteration which has been extensively described by Kerr and others (1957) and El-Mahdy (1966).

Supergene alteration has apparently been superimposed on uranium-bearing veins and argillically altered zones to at least 65 m below the current land surface.

Geometry and Grade of Occurrences

The occurrences are predominantly tabular veins. In the central area (Kerr, 1968), the veins trend northeast, but have many local variations. They are generally vertical or steeply dipping; however, some nearly horizontal structures have been noted. The horizontal extent of the veins varies from less than 30 m to greater than 500 m. The width of the ore-bearing zones is generally about 1 m, but at vein intersections can be as great as 8 m (Kerr, 1968). The vertical extent of the veins is not well documented; some have been proven for at least 300 m and possibly as much as 500 m (Callaghan, 1973). Kerr (1968) also reports a few small lenticular ore bodies in rhyolite hosts. Where veins cut the contact between granite or monzonite and rhyolite, the ore zones generally are richer and wider at the contact than in the intrusive host, and are more diffuse and wider in the rhyolite than in the intrusive host, but apparently maintain a tabular configuration.

Occurrence geometries are assumed to be similar in the intrusive- and volcanic-hosted occurrences outside of the central area. There is very little data available on the occurrences hosted in pre-Bullion Canyon sedimentary rocks, and it can only be guessed that they, to some extent, mimic the shape
of the base-metal deposits with which they are associated.

Even fewer data are available on the grade of occurrences. Table 2 summarizes the known production statistics for the mines in the Marysvale Volcanic Field favorable area. The grades listed are probably not a fair representation of the grades of the deposits because they seem to reflect (especially for the central area) minimum mill head grade requirements (approximately 0.2). There are obvious variations in the grade of several veins within the central area, where there are high-grade zones encompassed by lower-grade or barren zones. Selected samples of greater than 1 kg and in excess of 3 percent U\textsubscript{3}O\textsubscript{8} have been reported from the Freedom vein system, central area (K. R. Ludwig, oral commun., 1980); and selected samples with greater than 1 percent U\textsubscript{3}O\textsubscript{8} have been reported from the U-Beva mine, Indian Creek-North Creek area (Callaghan, 1973). However, there are no hard data available on the actual distribution of grade and tonnage for any of the occurrences.

**Age of Uranium Mineralization**

Many researchers have attempted to determine the age of uranium mineralization in the Marysvale area. Their data range from 9.8±1.2 to 24.0±10 m.y., which are the extreme (very discordant) values of Kulp and others' (1953) U-Pb data on a single pitchblende sample. Bassett and others (1963) report an age of 13 m.y. for uraninite from the Prospector mine (App. A, occ. no. 51). Steven and others (1977a) justifiably question the earlier work and conclude that the only control on the age of the uranium mineralization is that it postdates the Mount Belknap host rocks. Recent work by K. R. Ludwig (oral commun., 1979) on whole-rock samples from uranium-fluorine-molybdenum-bearing veins in the central area has yielded a U/Pb whole-rock isochron of 19±4 m.y.

The major problem in obtaining a reasonable age for the primary uranium mineralization is the obvious oxidation and likely redistribution of the ore. Another possible complication is that there may have been more than one period of uranium mineralization, and there may have been more than a single process of mineralization. The probability of at least two periods of uranium mineralization is strongly suggested by Bethke and Kerr's (1954) observation that uraninite is included in some of the base-metal sulfide phases at the Great Western mine (App. A, occ. no. 74) considering that the base-metal mineralization at the Great Western mine is inferred to be time-equivalent with the base-metal mineralization and wall-rock alteration which produced sericite (13-14 m.y., Bassett and others, 1963) at the Deertrail mine.

Clearly, more work is required before any definitive conclusions can be drawn regarding the age of primary uranium mineralization. However, it can be inferred that there were at least two periods, at about 19 m.y. and 13 m.y. (Table 1) during which uranium minerals were deposited in the Marysvale Volcanic Field.
Recognition Criteria for the Favorable Area

Contained within the favorable area is the Red Hills caldera, one of the type examples for pneumatogenic uranium occurrences; hence, most of the recognition criteria (Table 3) used to define class 520 occurrences are present within the area. While most of the criteria seem to be necessary for the delineation of a favorable area, it is not at all clear which individual criterion or combination of criteria, if any, is sufficient for that purpose. Of particular concern is the nature of the parent magma. Pilcher's (1978) criteria suggest that the parent magma, or at least the extrusives derived from that parent, should be peralkaline. However, the Mount Belknap Volcanics are predominantly, if not totally, peraluminous (data from Carmony, 1977). The implications of this compositional difference as to the genesis of volcanogenic uranium deposits are not known; however, the difference does suggest that the peralkaline criterion is too restrictive.

It should also be pointed out that a model involving subvolcanic hydrothermal fluids need not have as restricted a range of host rock compositions as listed by Pilcher (1978). While the acidic volcanic and plutonic rocks listed by Pilcher undoubtedly have a strong genetic tie to uranium occurrences, they are not necessarily the hosts for those deposits. Hydrothermal fluids could circulate through other than volcanic and plutonic rocks; indeed, some of the occurrences in the Mount Baldy and Ohio mining districts (Fig. 4) are hosted by pre-volcanic sedimentary rocks. Further, as pointed out by Pilcher (1978) several different classes of volcanogenic deposits could occur in such a volcanic terrane. In addition, there could be several different periods of mineralization, and the uranium involved could have different sources and could be cycled one or more times. However, as discussed above (see section on class of occurrences), our current data are insufficient to reliably predict the occurrence of other than class 520 deposits.

Definition of the Favorable Area

The boundaries of the Marysvale Volcanic Field favorable area were estimated by consideration of factors in a volcanogenic model of uranium deposits (see previous discussion, especially the section on class of uranium occurrences). Those factors include: (1) distribution of favorable host rocks (primarily Mount Belknap Volcanics and granitic rocks and to a lesser extent Bullion Canyon Volcanics and prevolcanic sedimentary rocks), (2) distribution of temporally appropriate porous conduits (primarily faults related to Mount Belknap-time calderas and inferred subvolcanic intrusives); and (3) distribution of indicators of significant hydrothermal systems (primarily zones of argillic alteration and/or fluorite deposition). Consideration was also given to the distribution of uranium occurrences in rocks of the appropriate age and type (see Fig. 7). Subjectivity in the application of the model is a function of the purely reconnaissance nature of our fieldwork which has necessitated the interpolation of data over large areas where little or no data are available. The available geochemical and
geophysical data support the conclusion that the area is favorable.

Available stream-sediment geochemical data (Jones, 1979) from the favorable area are restricted to a few samples along the westernmost margin of the area. The data are summarized on Plate 4A. The stream sediments have relatively high uranium values (3.6 to 18.3 ppm with an average for 27 samples of 10.5 ppm) and low Th/U values (0.8 to 3.3 with an average for 23 samples of 2.4). The sediments apparently reflect the anomalously uraniferous rocks from which they were derived—most of the unaltered Mount Belknap Volcanics contain greater than 10 ppm U (Carmody, 1977); and the mineralized zones of the Indian Creek–North Creek area contain as much as several percent uranium and have Th/U values ranging from about 1 to 5, averaging about 3.

The aerial radiometric data (Geodata International Inc., 1979) show that much of the surface exposure in the area is rich in $^{214}\text{Bi}$ (uranium daughter) and $^{208}\text{Tl}$ (thorium daughter) and that three regions have high $^{214}\text{Bi}/^{208}\text{Tl}$ values. The largest $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly is over the central mining district (Fig. 4, and flight line ML12E, Geodata International, Inc., 1979). The second most intense anomaly (flight line ML13E, Geodata International Inc., 1979) is over a group of prospects that are in an area of alunite alteration (the Silica Hills alunite area of Kerr and others, 1957) which surrounds at least two small granitic intrusions. The third anomaly (located at the intersection of flight lines TL8 and ML9E, Geodata International Inc., 1979) is not directly correlatable with any known uranium occurrences. The occurrences in the Indian Creek–North Creek area (flight line TL7, Geodata International Inc., 1979) show up as minor positive $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies. The intensities of all the anomalies may well be a function of the amount of surface disturbance brought about by mining activity and by the size of dumps and ore stockpiles left at the end of activity in the area.

There are positive $^{214}\text{Bi}$ and $^{208}\text{Tl}$ anomalies on the east ends of flight lines ML11, 12, and 13E (Geodata International, Inc., 1979) which are outside the east-central limits of the favorable area. The geology in this region is not well known (shown as undifferentiated intermediate composition Tertiary volcanics on Pl. 10). The radiometric pattern indicates the presence of several different lithologies, some of which have a radiometric signature similar to the Osiris Tuff, the Mount Belknap Volcanics, and/or granitic intrusives. However, because of the preliminary nature of the geologic mapping, lack of known uranium occurrences, and sympathetic variability of $^{214}\text{Bi}$ and $^{208}\text{Tl}$, this region has been excluded from the favorable area; but, it should be considered for future exploration.

Size and Volume of Favorable Area A

The size of the favorable area is approximately 1,165 km$^2$. The depth to which mineralization might occur in the area is not known. However, if an analogy can be drawn between the deposits in the central area and those in the USSR described by Kazansky and Laverov (1977) mineralization can occur within a depth interval from 300 to 1,500 m or 500 to 3,000 m depending on which USSR
model is used. Kerr (1968) has calculated that uranium mineralization in the central area occurs within a minimum interval of approximately 610 m. Hence, if a flat land surface is assumed and 610 m is used as a minimum thickness of potentially mineralized ground and 1,500 m is used as a maximum thickness of potentially mineralized ground (this later number is based on the Kazansky and Laverov [1977] model which indicates that mineralization could occur somewhere within an interval of 2,500 m and on the DOE specified cut off of 1,500 m) the volume of favorable rock in area A can be considered as being somewhere in the range of 710 km$^3$ and 1,750 km$^3$.

AREA B, SOUTHERN WAH WAH MOUNTAINS

Introduction

Favorable area B contains about 440 km$^2$ in the southern Wah Wah Mountains in southwestern Beaver County and northern Iron County (Pl. 1). The area contains 14 uranium occurrences, and yielded a small production of about 5,000 kg of U$_3$O$_8$. In addition, some volcanic rocks in the area have anomalous uranium content; the area has aeroradiometric and stream-sediment anomalies, has similarities to other areas with uranium deposits, and has many of the recognition criteria for volcanogenic (class 500) and/or hydrothermal magmatic (class 330) uranium deposits (Pilcher, 1978; Mathews, 1978; Mathews and others, 1979). Uranium occurs in close association with Miocene high-silica alkali rhyolites, and has been concentrated by volcanogenic (or magmatic hydrothermal) and initial magmatic processes. In places, the uranium concentrations have been modified by supergene processes.

The southern Wah Wah area has also yielded a small production of fluorite, mercury, red beryl gemstone, iron ores for smelter flux, silver, lead, and zinc. Extensive hydrothermal alteration has formed deposits of alunite and kaolinite which have been explored north of Blawn Mountain. Recently, the discovery at depth of a molybdenum-porphyry deposit in Pine Grove was announced (Wall Street Journal, Jan. 6, 1978). The area lies within the Pioche Mineral Belt (Shawe and Stewart, 1978) and is crossed by the Blue Ribbon lineament of Rowley and others (1978) (Fig. 3).

Timely publication of maps by Best and Keith (1979), Best (1979), and Grant and Best (1979), though not available at the time of our fieldwork, has shed light on the structure, volcanic stratigraphy, and distribution of alteration in the region. Plate 7, a generalized geologic map, is based in part on this work.

Geologic Setting

The oldest rocks exposed in the area are clastic and carbonate rocks ranging in age from Late Precambrian to Pennsylvanian. This section, part of a regional allochthon, is cut by two major thrusts and numerous minor tear faults which are part of the Sevier orogenic belt of Cretaceous age (Fig.
3). The thrusts bring the allochthonous rocks over an autochthon of Triassic and Jurassic sedimentary rocks, exposed in a window on Blue Mountain (Miller, 1966).

Beginning in Oligocene time, ash-flow tuffs, related epiclastic rocks, intermediate to rhyolitic flows, and a few minor mafic flows (Pl. 7, columnar section) were erupted onto an irregular erosion surface cut on the Paleozoic and Mesozoic terrain. For the most part, these are widespread regional units (Fig. 4) derived beyond the local area of the southern Wah Wah Mountains.

An abrupt change took place in Miocene time with the intrusion and eruption of high-silica alkali rhyolites and rhyolite tuffs. Regionally, these are part of a bimodal basalt-rhyolite suite that was erupted widely from many centers in the Basin and Range Province during late Cenozoic extensional tectonics (Cunningham and Steven, 1979). Lindsay and Osmonson (1978) suggested that the topaz-rhyolite of the Staats plug (Pl. 7) was a local center for the eruption of some of the nearby flow-banded rhyolites and rhyolitic ash-flow tuffs. Keith (1979) believes that some of the ash-flow tuffs of the formation of Blawn Wash vented from the Pine Grove porphyry (Pl. 7). He indicates that this porphyry has enrichment in U, Pb, Y, Mo, Th, and Nb. M. G. Best (oral commun., 1979) also believes that the rhyolitic ash-flow tuffs are precursory extrusive facies of local intrusive rhyolites.

Following the period of rhyolitic eruptions, the record of volcanic activity in the area was closed with the eruption of basalt, now exposed mainly in the northeast corner of the area (Pl. 7).

The volcanic and sedimentary rocks are cut and tilted by normal faults. The faults are predominantly of north-northeast trend, but some major faults are northwest or west, as at Blawn Mountain. Most faults cut the Miocene formation of Blawn Wash, but near the Tetons (Pl. 7, sec. A-A') the earlier volcanic units, the Escalante and Needles Range Formations, are tilted and overlain unconformably by Blawn. Faulting is thus probably pre- and post-Blawn Wash in age.

Hydrothermal alteration affects all the rocks, except perhaps the basalt which caps the older volcanic rocks in the northeast part of the area. Distribution of alteration is shown by stipple pattern on Plate 7. Alteration ranges in intensity from mild propylitic to heavy argillic. Areas of jasperoid are found in Paleozoic carbonate rocks. Common on Blawn Mountain is a thorough, acidic alteration of the volcanic rocks, characterized by alunite, kaolinite, iron, and silicified rock (Lindsay and Osmonson, 1978; Whelan, 1965). Similar alteration characterizes the area northeast of Blawn Mountain. The alteration is closely associated with the rhyolite in its distribution, and strongly suggests a relationship between the two. Alteration also appears to be partly constrained and controlled by faults in the area (M. G. Best, oral commun., 1979). Plate 7 shows that the alteration extends from northeast of Blawn Mountain south at least to the boundary of the map, elongate along the north-northeast fault grain. Uranium mineralization appears to be closely associated with the rhyolites and areas of alteration.
Uranium Deposits and Occurrences

Uranium occurrences are known from the headwaters of Blawn Wash, north of Blawn Mountain, south to the upper part of Four Mile Creek drainage (Pl. 7), a distance of about 15 km. Uranium is believed to be associated both in time and space with high-silica alkali rhyolites and rhyolitic ash-flow tuffs of the Blawn Wash volcanic rocks and associated hydrothermal alteration. The occurrences are divided into three groups: (1) deposits in the Staats mine area (occ. nos. 113-116, App. A, Pls. 2 and 7); (2) occurrences on and near Blawn Mountain (occ. nos. 110-112); and (3) other occurrences (occ. nos. 107, 109, 118-121).

In the Staats mine area, uraniferous fluorspar occurs along the margin of a small topaz-bearing alkali rhyolite plug intruded into Paleozoic carbonate rocks (Pl. 7). The Staats mine (also variously referred to as the Monarch or Monarch-Eureka mine) has been described by several authors. Thurston and others (1954) in a report on fluorspar in Utah, which is based on fieldwork in 1943 and 1945 before discovery of uranium, were the first to describe the geology in any detail. They describe the deposit and its setting as follows:

The fluorspar deposits occur along the faulted contact of a Tertiary rhyolite porphyry and a Cambrian limestone. The wall rocks were altered only slightly, but irregular boundaries of some fragments of country rock enclosed in massive fluorspar suggest partial replacement. The silica content of the ore is low and is probably derived from inclusions of rhyolite porphyry; quartz veins are not present in the ore. Some CaCO₃ is present, owing to included limestone fragments. The SiO₂ and CaCO₃ content did not exceed 5 percent, respectively, and averaged about 2 percent of each. Autunite and uranophane were found by Wyant [1947, USGS unpub. report] as local coatings on the fluorite. Two grab samples of material from some of the pits northeast of the main shaft contained 50 and 68 percent of CaF₂. Assays of carload shipments of fluorspar that had been selectively mined and sorted ranged from 80 to 91 percent of CaF₂ and averaged in excess of 85 percent of CaF₂.

The fluorspar [and uranium] occurs in lenticular shoots within larger podlike ore zones. The waste between shoots is composed of brecciated limestone and rhyolite porphyry. Apparently the depth of each shoot is greater than the length: the shoots range from 2 to 6 feet wide and from 5 to 10 feet long, but are reported to extend more than 25 feet in depth. The shoots are oriented roughly parallel to the irregular contact zone of the limestone and rhyolite porphyry. The contact zone is intricately faulted, with many variations in strike and dip and sharp undulations in the trace.

Two separate areas of fluorspar mineralization on the Staats property have been explored. Most of the prospecting centers around the main deposit at the head of the valley but a small deposit has been opened about half a mile southeast [the Daisy, occ. 114].
The principal workings at the main deposit (the Staats mine) are an 85-foot shaft, an opencut, and an adit. This deposit was first explored by an opencut; then a shaft was sunk about the middle of the opencut, and stopes were driven at various levels from the shaft. At the 85-foot level a drift extends 65 feet southward. About 400 feet southeast of the shaft an adit exposed several pockets of fluorspar along a faulted segment of the contact between the rhyolite porphyry and limestone. Because of caving ground, only a small part of the shaft-workings was accessible for examination. Apparently enough fluorspar remains in the vicinity of the shaft to be worth recovering. Within 600 feet to the north, northeast, and southeast, several pits and trenches show fluorspar in the contact zone.

An adit about half a mile to the southeast leads to a winze operation from which 200 tons of ore was mined in 1944. The ore in the winze formed a shoot 10 feet long, 6 feet wide, and about 55 feet deep [Daisy, occ. 114].

Uranium mineralization was recognized in the late 1940's, and subsequently the Staats mine produced about 45,360 Kg of $U_3O_8$.

Bullock (1976) notes some additional details on the mineralogy and size of the ore shoots:

The Staats mine has been the source of commercial production for both fluorspar and uranium ores. Mineralization is along the faulted contact between dolomite and rhyolite porphyry. The zone consists of mylonized and argillized breccia. The zone is as much as 400 feet wide. Rock fragments include dolomite, rhyolite, and other volcanic and sedimentary debris. The varied mineral composition includes feldspar, quartz, calcite, dolomite, clays, fluorspar, uranium minerals, sericite, pyrite, and hematite. Montmorillonite, nontronite, sericite, kaolinite, and chlorite are products of argillic alteration resulting from hydrothermal solutions.

Purple, massive, and crystalline fluorspar occurs in the altered brecciated zone as lenticular shoots within large podlike ore zones. The ore shoots are composed primarily of fluorite with little or no vein quartz or calcite, but they do contain relatively small amounts of dolomite and rhyolite breccia fragments. The fluorspar ore was selectively mined, containing from 80 to 91 percent fluorite and averaging over 85 percent fluorite. Waste rock between the fluorspar ore shoots consists mainly of brecciated dolomite and rhyolite porphyry. The ore shoots range from 2 to 6 feet in length, and to more than 25 feet in depth. The shoots are oriented roughly parallel with the north-trending contact zone. The contact is intricately faulted with considerable variations in strike and dip.

Uranium minerals occur as coatings on fluorite and as impregnations in the argillized breccia. After uranium ore was discovered with
fluorite, the property was mined for uranium and the fluorspar was ignored. The ore was shipped to Vitro Corporation of Murray. The primary uranium mineral is uraninite, and the secondary minerals include autunite, uranophane, and metatorbernite. The Staats mine is currently under lease to Western Nuclear for uranium exploration. The future commercial potential of the Staats mine for fluorspar ore appears to be negligible.

Three other occurrences, the Daisy, Producer, and Desert View, (occ. no. 114-16, Pl. 2 and Pl. 7) are found south of the Staats, and, like that mine, are located along the argillized breccia zone between the rhyolite porphyry and the Paleozoic carbonate rocks. All were caved and inaccessible in 1978, but the nature of the occurrences is believed similar to the Staats. Bullock mentions uraninite at both the Daisy and Producer mines. Fluorspar was mined from the Daisy (Pl. 7), but not from the Producer. The three mines yielded a total of 1,776 kg of $U_3O_8$.

Three occurrences are found in the Blawn Mountain area (occ. nos. 110-112, Pl. 2). Exposures are poor, but all are found at and near the contact of pervasively altered ash-flow tuffs of the formation of Blawn Wash, with underlying Ordovician to Devonian dolomite. The rocks are faulted. Lindsay and Osmonson (1978) describe the area:

The [Miocene] rhyolite [formation of Blawn Wash] is extensively brecciated and silicified for more than 1.5 km along the crest of Blawn Mountain. This brecciated zone is next to an east-west fault that follows the Blue Ribbon lineament of Rowley and others (1978). The breccia contains relic quartz phenocrysts scattered in a matrix of fine-grained quartz, disseminated hematite, and trace amounts of barite. It grades northward into silicified rhyolite containing kaolinite and alunite and southward to an area of kaolinite and iron oxide alteration along small faults that cross the dolomite-rhyolite contact on Blawn Mountain. The faults post-date the main period of brecciation there. The iron oxide veins contain mostly hematite and magnetite with a trace of fluorite, and they are anomalously radioactive. Euhedral grains of hematite after magnetite are dispersed in the kaolinite near the iron oxide veins. Whelan (1965) reports nearly pure alunite replacing rhyolite adjacent to some of the iron oxide occurrences.

Taylor (1953) was the first to describe uranium in this area:

Two low-grade uranium occurrences were discovered about half a mile northeast of the Staats mine [on Blawn Mountain]. One occurrence is a vein consisting of highly altered rhyolite porphyry [formation of Blawn Wash] containing small amounts of fluorite and autunite. Samples assayed contained from .017 to 0.30 percent U. The other occurrence is at the contact of rhyolite porphyry and dolomite. Irregular masses of iron oxide gossan are exposed along the contact over a distance of about 1,000 feet. Samples taken from the most highly radioactive areas
contain .015 to .030 percent U.

The original character of the sulfide mineralization in the gossan deposit is unknown. No secondary lead, zinc or copper minerals were observed. Before oxidation the iron gossan deposits may have been composed predominantly of pyrite. If so, considerable amounts of uranium may have been removed in solution as uranium sulfate during the oxidation of the pyritic masses.

Whelan (1965) states that:

Radioactivity, determined with a portable Geiger-Mueller counter, was noted in the large cut at the southwest end of the [Blawn Mountain] area, and seemed to be associated with heavily iron stained clays.

On the basis of seven drill holes, E. M. Garrick (1958) has plotted an indicated and inferred uranium ore body approximately 400 feet long by 75 feet wide, at depths of 49 to 90 feet below the surface. This mineralized zone is about 15 feet thick. At a depth of about 130 feet, a second 10 foot thick zone, 200 feet long, is plotted. The width of this zone is not known. Both radioactive zones run northwest from the large cut at the southwest end of the map area.

No assay data are available. It is believed that the holes were qualitatively logged with a portable radiation counter.

The radioactive minerals were not identified either in the field or in the laboratory studies.

Two samples taken during the present study from a prospect trench at the west end of Blawn Mountain (occ. no. 112; MDG-183, 184; App. B) show uranium content of 477 and 175 ppm (Table 4).

A sample (occ. no. 111, MDG-307) from bulldozer cuts in the Iron Queen area of argillized and hematized rock near the contact of the rhyolite tuff and Paleozoic carbonate rocks showed a uranium content of 175 ppm.

Two kilometers northeast in the headwaters of Blawn Wash are the U-V claims (occ. no. 110). The claims have been relocated several times under different names and have been called the Blawn Wash iron mine, and at the time of our visit were located as the Silveranium claims. A shaft about 10 m deep and a glory hole immediately north expose Devonian carbonate rocks dipping 30° S replaced by a gossan along steep-dipping northeast and northwest faults. The gossan contains iron and manganese oxides. Also common is purple and white, iron-stained clay. Altered Blawn Wash rhyolite tuff and Needles Range Formation crop out within a 100 m or so to the south and southeast (Pl. 7). Sample MDG-117, a sample of iron-rich altered material from the dump which gave a radiometric reading of 5X background, had a U content of 58.9 ppm.
TABLE 4. SELECTED CHEMICAL ANALYSES FROM URANIUM OCCURRENCES IN THE SOUTHERN WAH WAH MOUNTAINS (AREA B) (in parts per million)

<table>
<thead>
<tr>
<th>Occur. No.</th>
<th>Sample No.</th>
<th>U</th>
<th>Mn</th>
<th>B</th>
<th>Ba</th>
<th>Be</th>
<th>Co</th>
<th>Mo</th>
<th>Ni</th>
<th>Sr</th>
<th>Zn</th>
<th>Li</th>
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<td>STAA TS MINE AREA</td>
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<tr>
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<td>--</td>
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<td>44</td>
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H = Constituent not determined because of interference
-- = Fluorite-containing sample, U not determined
Other occurrences (occ. nos. 107, 117-121) are found scattered from the Tetons (occ. no. 117) south to the Broken Ridge area (occ. no. 121). At the Kay claims (occ. no. 118) moderate radioactivity is associated with extensively altered, undifferentiated volcanics, that may include Blawn rhyolite tuff and perhaps part of the Needles Range Formation. A sample (MDG-035, App. B) collected from the most radioactive iron-stained material by a shallow shaft west of the jeep trail showed 95.2 ppm U. A sample (MDG-112, App. B) collected from altered, bleached, and hematite-stained rock, exposed in bulldozer trenches on the low hill east of the shaft showed a uranium content of 127 ppm. At the King Iron prospect area (occ. no. 120) abnormal radioactivity is associated with hematitic gossan along a northerly trending fault separating Paleozoic carbonate rocks on the east from dense bleached rhyolite of the Blawn Wash by Best and Keith (1979). A soft, purple, hematitic breccia exposed in a trench along this north-trending fault gave total gamma-count readings of 500 to 1700 cps. A sample (MDG-232, App. B) collected from purple-stained fault gouge in an adit along the fault contact at the eastern limit of the claim area contained 279 ppm uranium and high iron (>20 percent), manganese (>5,000 ppm), beryllium (60 ppm), nickel (220 ppm), cobalt (320 ppm), and yttrium (1,000 ppm). Bismuth, molybdenum, lead, zinc, tin, tungsten, and cerium may also be present but interferences prevented their detection (Table 4). A major company was drilling in this area in 1979, but no information is available.

On the east side of Broken Ridge, about 6 km southwest of the King Iron prospect, high radioactivity is associated with flow-banded and brecciated rhyolite, part of the formation of Blawn Wash. A sample of rock with the highest total gamma count (1600 cps) taken from a pit (occ. no. 121) in brecciated (autobreccia?) rhyolite, contained 279 ppm U. Within a meter radioactivity was only 780 cps and a sample of this rock (MDG-336) contained only 31 ppm U. The rhyolite of Broken Ridge, a local thick accumulation of flow-banded topaz-bearing rhyolite, extends about 10 km in a north-south direction, and is at least 5 km east-west, and may be a rhyolite dome. The rhyolite has high background radioactivity (200-400 cps), and samples normally contain 10-15 ppm U (MDG-337, 338, and 340).

Little or no work has been done on the genesis of uranium occurrences in favorable area B; however, it appears likely that most of the deposits are magmatic hydrothermal (class 330) or pneumatogenic (class 520) of Pilcher (1978). The recognition criteria for the two are quite similar and thus the distinction in reconnaissance work is difficult to establish. Recognition criteria observed in the southern Wah Wah Mountains favorable area are tabulated in Table 5. As in the Thomas Range (Lindsey, 1979, p. 77) uranium in the favorable area probably was introduced initially by (1) magmatic fluids (initial magmatic, class 510), and (2) hydrothermal fluids (pneumatogenic, class 520), and modified to various degrees by supergene processes involving meteoric waters (hydroallogenic, class 540). The only occurrence classified as initial magmatic is that on Broken Ridge, previously mentioned.
<table>
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<tr>
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<tr>
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<tr>
<td>Albitization</td>
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</table>
Favorable Area B

Favorable area B was defined principally on the basis of the distribution of uranium occurrences, extensive hydrothermal alteration of volcanic rocks, and the distribution of intrusive and extrusive topaz-bearing alkali rhyolites, which are believed to be associated in time and space with uranium-fluorite mineralization and alteration. Geochemical and aeroradiometric data support the designation of the area as favorable. The northern limit is extended to Pine Grove to include the altered intrusive porphyry found there (Pl. 7). Keith (1979) believes this to be a local source of some extrusive rhyolites in the southern Wah Wah Mountains; and, in addition, molybdenum, commonly associated with uranium, has been discovered at depth by drilling (Wall Street Journal, Jan 6, 1978).

The eastern, western, and southern boundaries have been generally drawn to include known uranium occurrences, alkali rhyolites, and areas of hydrothermal alteration.

Area B has an area of 440 km$^2$. The depth of favorable ground is uncertain. All occurrences are either in the altered volcanic terrane, near the contact with the underlying Paleozoic carbonate rocks, or, as in the case of the Staats mine area, associated with a subvolcanic intrusive, probably a feeder of rhyolite flows and tuffs (Lindsey and Osmonson, 1978). In the volcanic terrane evidence for uranium mineralization has been found over a topographic range of about 800 m, and a cumulative stratigraphic interval that might average about 2,000 m. If a flat land surface is assumed and 800 m is used as a minimum thickness the volume of potentially favorable ground is 352 km$^3$. If 1,500 m is used as the maximum thickness (the DOE specified depth of evaluation) the volume is 660 km$^3$.

Land status

All land within the favorable area is under the supervision of the U.S. Bureau of Land Management.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

Several environments in the sedimentary, plutonic igneous, and volcanic rocks of the Richfield Quadrangle are not considered favorable for uranium deposits, although some of these environments have produced deposits elsewhere. These environments include Precambrian sedimentary and metamorphic rocks, Paleozoic and Mesozoic sedimentary rocks, pre-volcanic Tertiary sedimentary rocks, Tertiary and Quaternary basin-fill sedimentary rocks, magmatic-hydrothermal and contact-metasomatic environments associated with plutons, intermediate to silicic volcanic rocks, hot springs and the Tertiary-pre-Tertiary unconformity. In general, the lack of uranium occurrences, radiometric or geochemical anomalies, and absence of criteria as outlined in Mickle and Mathews (1978) suggest that deposits of minimum endowment are unlikely. Deposits may exist, and the unfavorable assessment of some
environments may of course be modified if new data becomes available.

URANIUM OCCURRENCES IN SEDIMENTARY ROCKS (CLASSES 100-299)

Precambrian Sedimentary and Metamorphic Rocks

Precambrian quartzite, marble, slate, argillite, and minor conglomerate belonging to various formations (Woodward, 1973) and Precambrian-Cambrian Prospect Mountain Quartzite crop out in the Beaver, Cricket, San Francisco, and central Wah Wah Mountains. These units were probably deposited in the near-shelf parts of the Cordilleran miogeosyncline. These units are not known to be a host for mineral deposits in the area nor have any uranium occurrences been reported in them. The paleoenvironment of these units does not closely resemble the setting for any known significant uranium deposits in the Precambrian, such as Precambrian quartz pebble conglomerates (Elliott Lake), unconformity related vein deposits (Saskatchewan), or Precambrian sandstone deposits (Gabon). Minor placer concentrations of thorium- or uranium-bearing resistate minerals may be present in the Prospect Mountain Quartzite. These rocks are classed as unfavorable.

Precambrian metamorphic rocks exposed in the northern Mineral Mountains are not known to contain uranium occurrences, uranium source rocks, or rock types known to be favorable for uranium deposits elsewhere. This terrain is classed as unfavorable.

Paleozoic Sedimentary Rocks

Sedimentary rocks of Paleozoic age are considered to be among the least favorable rocks for uranium deposits in the Richfield Quadrangle. These rocks are characterized by a thick miogeosynclinal massive carbonate assemblage (dolomite and limestone) with subordinate associated clean quartzite and a little shale. The aggregate thickness of the Paleozoic section is large, possibly 7,600 to 9,200 m and it makes up most of the bedrock exposures in the mountain ranges in the northern portions of the quadrangle, and in most places probably underlies the volcanics in the southern portions of the quadrangle.

Limestone and dolomite formations range in age from Cambrian to Permian (Pl. 8). No deposits of class 230 (epigenetic deposits in limestone) are known or can be predicted to occur in the quadrangle. Sandstone or quartzite formations are found in the Cambrian Prospect Mountain Quartzite, Watson Ranch Quartzite, Eureka Quartzite, and Talisman Quartzite; but no deposits of class 240 (epigenetic deposits in sandstone) are known, nor have any areas of anomalous radioactivity been found.

Marine black shale is present in the Mississippian Chainman Shale and was judged to warrant special attention. This unit was given close inspection because of its possible similarity to uraniferous black shales, such as the Chattanooga Shale. No uranium occurrences have been reported in the Chainman Shale.
Shale within the Richfield Quadrangle, and examination of the formation did not disclose any. A radiometric traverse made along a measured section in the northern Needle Range revealed no anomalies. Furthermore, analysis of the most radioactive material encountered showed only 10.1 ppm U (App. B, MDG 177).

Consequently, because of the absence of uranium occurrences, the negative field and analytical results, and the minor areal extent of the Chainman Shale in the quadrangle (outcrops are present only in the northern Needle Range and Burbank Hills), no deposits of class 130 can be predicted.

The Paleozoic rocks are considered unfavorable because they (1) lack uranium occurrences, (2) have generally the lowest total gamma-radiation levels of any rock types within the quadrangle as measured by surveys with a hand-held scintillometer, and (3) do not meet recognition criteria of areas suitable for uranium deposition.

Mesozoic Sedimentary Rocks

Mesozoic sedimentary rocks within the Richfield Quadrangle are not considered favorable because they lack most recognition criteria for uranium deposits in sedimentary rocks (Jones, in Mickle and Mathews, 1978) and contain no known occurrences.

Only in the Pavant Range are Mesozoic sedimentary rocks widespread (Pl. 10), elsewhere outcrops of the Mesozoic are limited in extent, commonly intensely faulted, thermally metamorphosed and altered. They crop out on the east flank of the Tushar Mountains, the southern end of the Mineral Mountains, the southern Rocky Range, the Star Range, and on Blue Mountain in the southern Wah Wah Mountains. Mesozoic rocks comprise a varied assemblage of sandstone, siltstones, mudstones, shales, limestones, and conglomerates. Formations recognized are the Triassic Moenkopi and Chinle Formations, including the basal Shinarump Conglomerate Member of the Chinle, the Jurassic and Triassic (?) Navajo Sandstone, Jurassic Arapien Formation, and Cretaceous Price River Formation. On the Colorado Plateau the Chinle, particularly the basal conglomerate member, contains important uranium deposits. The nearest significant deposits are 75 km east of the Richfield Quadrangle near the San Rafael Swell. However, in the quadrangle no occurrences are known in the Shinarump Member of the Chinle Formation, no zones of abnormal radioactivity have been found, and no significant aeroradiometric or stream sediment anomalies have been noted; it is concluded that there is no data to suggest the presence of 100 tons of $U_3O_8$.

Pre-volcanic Tertiary Sedimentary Rocks

Sedimentary rocks of pre-volcanic Tertiary age are composed of a varied assemblage of fluviatile and lacustrine limestone, mudstone, sandstone, and conglomerate. They include the Paleocene and/or Eocene Flagstaff Formation,
Eocene Green River and Crazy Hollow Formations and the Eocene or Oligocene Bald Knolls and Gray Gulch Formations north of the Tushar Mountains and the Claron Formation south of the Tushars. These rocks were examined to determine their favorability for sedimentary uranium deposits (classes 100-299) and especially for sandstone deposits (class 240). All of these formations except the Crazy Hollow Formation lack the appropriate recognition criteria for uranium deposits, have no known uranium occurrences and no radiometric or stream-sediment anomalies.

Three uranium occurrences are found in the Crazy Hollow Formation in the Flat Canyon area, west of Richfield in the foothills of the Pavant Range (Pl. 2, occ. nos. 1, 2, 3). One locality, the Blue Bird claims (Pl. 2, occ. no. 3) has a recorded production of 816 lbs of U₃O₈ from 139 tons of ore. The Crazy Hollow Formation consists of about 80 m (Schneider, 1964) of fluvial red and yellow or tan sandstone interbedded with red and purple siltstone and fine-grained sandstone, and minor shale. Channel sands are common. A cut at the Bluebird claims in Flat Canyon exposes a lenticular carbon-bearing gray shale or mudstone occurring at the base of a tan medium- to coarse-grained channel sandstone. The shale lens is about 10 m long and about 3 to 5 m thick and contains scattered black coaly trash. Sample MDG-085 taken of the gray shale contained 741 ppm U. Sample MDG-137 of another gray shale lens of comparable size at occurrence no. 2 (Pl. 2) contained about 80 ppm U. On the ridge north of Flat Canyon a yellow to brown coarse sand and granule channel sandstone was found to be anomalously radioactive in an area of one or two square meters. A sample of the sand contained 189 ppm U. The Crazy Hollow dips at low angles to the east and is well exposed in several small canyons that cut through the section. Extensive radiometric reconnaissance along the exposures afforded by the stream network identified no other zones of anomalous radioactivity, or other carbon-rich mudstones in channels at the base of the tan sandstones. We conclude that although these occurrences display some of the recognition criteria associated with epigenetic deposits in sandstone (class 240), the deposits are too small and not continuous enough at the outcrop to qualify the Crazy Hollow Formation as a favorable environment for 100 tons U₃O₈.

Tertiary and Quaternary Basin-Fill Sedimentary Rocks

Basin-fill sedimentary rocks are known throughout the Richfield Quadrangle (Pl. 10). The basins east of the Mineral Mountains have undergone substantial recent tectonism and erosion, and the late Miocene and Pleistocene sedimentary section is in places well exposed. West of the Mineral Mountains, the valleys are characterized by large, relatively young, coalescing alluvial fans that feed directly or ultimately into playa basins. The drainage basin of the Sevier Lake playa includes the eastern two-thirds of the study area, whereas the drainage basins of the Pine valley and Wah Wah valley playas dominate the western third of the quadrangle (Pl. 6).

The Sevier River Formation crops out over a large part of the eastern third of the Richfield Quadrangle. It comprises alluvial and lacustrine rocks deposited in a Miocene(?) to Pleistocene basin that is now being deeply
dissected by the modern Sevier River. Volcanic detritus and lesser ash-fall material make up most of the unit. Samples of ash-fall tuff ranged from 6.8 to 10.6 ppm uranium (App. B, MDG-092 to 094). Uranium occurs in dark lacustrine cherts, clays, and zeolitized tuffs near the town of Sevier (App. A, occ. no. 8). Analysis shows that these rocks contain as much as 130 ppm uranium (MDG-256, Appendix B). Although the lacustrine facies of the Sevier River Formation bear superficial similarities to rocks that contain uranium deposits in the Date Creek basin (general sandstone class 240), the dissimilarities, notably the lack of abundant plant material, are significant. The basin-fill sediments of the Sevier River Formation do not appear favorable based on present information. It is possible that more organic-rich lacustrine facies or potential sandstone hosts may be developed in Sevier River Formation rocks now buried beneath younger rocks in the valley between Sevier and Richfield. Additionally, Sevier River Formation rocks may have been altered by hydrothermal systems like that found at Monroe (App. A, occ. no. 4). If so, then the favorability of parts of the Sevier River Formation could be enhanced.

Beaver valley is filled by late Miocene through Quaternary sedimentary and volcanic rocks that probably exceed 1,400 m in thickness (M. N. Machette, oral commun., 1979). The basinal rocks have been tilted to the south, and thus progressively older rocks are exposed northward. A broad north-south trending antiform occupies the axis of the basin. The section is disrupted by numerous normal faults that cut all but the youngest alluvium. The basin-fill sediments include conglomerate, sandstone, siltstone, tuffaceous lacustrine siltstone and mudstone, and several thin ash beds. Samples of mudstone and tuff ranged from 5.5 ppm to 8.4 ppm uranium (App. B, MDG-099, 100, 229). Lacustrine rocks, largely found in the upper part of the basin-fill sequence, contain various lacustrine faunal remains. No silicified or carbonaceous plant detritus has been observed. Gypsum beds are locally present. The basin appears to have been closed until the middle Pleistocene, when it breached its southwestern edge and established exterior drainage (Anderson and others, 1978). All basinal sediments appear to be locally derived. With the exception of the green tuffaceous lacustrine rocks, the color of most of the sedimentary units suggests that oxidizing conditions predominated during sedimentation or that the rocks have been subsequently oxidized. No uranium occurrences are known in the basin-fill sediments.

The Tushar Mountains, whose volcanic rocks are generally high in uranium and thorium content, lie immediately to the east. Several uranium properties are known in the Tushar Mountains. Clastic detritus derived from the Tushars shows a high uranium and thorium aeroradiometric signature where exposed in the basin (Pl. 3). The uranium and thorium content of modern stream-sediment samples is high from drainages leaving the Tushars (Pl. 4A). The uranium content of shallow ground waters increases from east to west across the basin from values less than 1 ppb east of Beaver to values of about 25 ppb near the Minersville Reservoir (Pl. 4B). These shallow ground waters, largely derived from the Tushar Mountains, appear to leach uranium from basin detritus as they cross the basin or possibly mix with deeper, more uraniferous ground waters coming to the surface near the basin discharge area. Helium values in
soil gas (Reimer, 1979) show a similar pattern of increase. These data support the suggestion of Steven and Cunningham (1979) that the volcanics of the Tushar Mountains have been a source of uraniferous sediment.

In spite of these indications that there is a good source terrain for uranium, Beaver Valley cannot be considered favorable because of the lack of evidence, in surface exposures, for suitable traps. Plant detritus, reduced permeable sandstones, and highly silicified or zeolitized tuff beds were not observed, and so real favorability for deposits of the sandstone class (240) or other unclassified deposits in the Basin and Range (Virgin valley and Reese River, Nevada; Date Creek basin, Arizona) cannot be demonstrated. A great thickness of basin-fill rocks is not exposed, however, especially in the southern part of the valley, and there is a possibility that parts of the section may contain suitable environments for uranium entrapment. Several companies have acquired ground in the valley and are considering drilling. The gravity low observed in gravity data just west of Beaver (D. R. Mabey, written commun., 1979) could be a locus of basinal lacustrine sedimentation and might be a favorable area for future exploration (Otton and Wynn, 1979).

Hydrologic studies of the Pine valley (Stephens, 1976), Wah Wah valley (Stephens, 1973) and the Beaver River valley near Milford (Mower and Cordova, 1974) show that basin-fill rocks include alluvial and lacustrine rocks and spring deposits to depths of a few hundred meters. Extensive surface and shallow auger hole sampling of playa sands, silts, and clays and spring deposits in the basins of the western two thirds of the Richfield Quadrangle shows that uranium contents range from 0.3 ppm to 13.5 ppm (App. B, MDG-263 to 300, 401 to 428). Surface sediments from the Sevier Lake, Wah Wah, and Pine Valley playas are probably the least uraniferous rocks in the area. They show very low aeroradiometric signatures (Geodata International Inc., 1979) and uranium contents of 1 ppm or less.

Basin-fill deposits in the Beaver River valley near Minersville and in southern Pine Valley show anomalous uranium and thorium aeroradiometric signatures (Pl. 3) that are likely related to spillover from uraniferous sediment in Beaver Valley and a favorable terrain in the southern Wah Wah Mountains, respectively. Ground waters along the Beaver River valley vary considerably in uranium content with one 38 ppb value from a well about 24 km north of Milford (Pl. 4B).

At present, basin-fill rocks of the western part of the Richfield Quadrangle cannot be considered favorable. Although locally there are some possible uranium sources (hot spring waters, uranium-enriched volcanic terrane), no environments likely to trap uranium have yet been identified in surface or subsurface geology. Conditions favorable for formation of calcrete, gypcrete, or silcrete deposits (class 220) are not evident, although some pedogenic caliche is present.

It is possible that deep basinal sediments not anywhere exposed at the surface may contain environments favorable for the enrichment of uranium. Two deep drill holes in basin-fill sediments near Delta, Utah, several miles north
of the Richfield Quadrangle, intercepted over 8,000 ft of basin-fill alluvial lacustrine and playa sediments and basalts. The basal part of the section was late Oligocene in age (D. A. Lindsey, written commun., 1980). Although the uranium content of the upper 1,500 m was uniformly low (<8 ppm), some lignitic sediments were encountered. It seems possible that parts of some basins in the Richfield Quadrangle might contain favorable environments in older basin-fill sediments at depth, but further work is needed.

OCCURRENCES ASSOCIATED WITH PLUTONIC IGNEOUS ROCKS
(CLASSES 300-399)

Magmatic Hydrothermal

The Pioche mineral belt contains several mining districts that contain classical magmatic-hydrothermal deposits of base and precious metals. However, during the present study only a few uranium occurrences classed as magmatic hydrothermal (class 330) were found in these districts. They include the Old Hickory mine (Pl. 2, occ. no. 100) in the Rocky Range district, the Horn Silver-King David mines (Pl. 2, occ. no. 102) in the Frisco district, and the New Arrowhead (Pl. 2, occ. no 122) in the Washington district (Fig. 3B). None of these occurrences appears to be of high enough grade, nor displays large enough areas of anomalous radioactivity at the outcrop to suggest existence of minimum grade or tonnage—that is, as likely to contain 100 tons of $U_3O_8$ with an average grade not less than 100 ppm $U_3O_8$.

The Horn Silver-King David mine produced over 14 million ounces of silver, as well as important amounts of lead, copper, and zinc, from a replacement ore body at the contact of Paleozoic carbonate rocks with Oligocene volcanic rocks. Anglesite, cerargyrite, and plumbojarosite were important in the oxidized zone, but sulfides were present at depth (Butler and Gale, 1912; Butler and others, 1920). Radiometric examination on the King David dump shows local spots of moderate radioactivity. A sample from the dump of rock that had the highest radioactivity (750 cps) contained only 10 ppm U, but 212 ppm Th. A small spot of radioactivity on brecciated gossan on the Horn Silver dump, less than a meter across, gave a total gamma count of 400 to 600 cps. A sample of this (App. B, MDG-056) contained 64 ppm U and 386 ppm Th. D. L. Everhart, who visited the area in 1950 (unnumbered PRR), analyzed a selected high-count sample from the dump that contained 0.035 percent $U_3O_8$, 7.31 percent $ThO_2$, and 0.41 percent rare earths. It appears that much of the radioactivity is due to thorium content.

In the Old Hickory mine area (Pl. 2, occ. no. 100), irregular stocks and apophyses of granodiorite to quartz monzonite intrude Permian and Triassic carbonate and clastic sedimentary rocks. The rocks are thermally metamorphosed to skarns and hornfels. Copper ores have been produced from the Old Hickory mine and nearby open pits. Some tungsten (scheelite ores) was recovered during World War II. Much of the ore is oxidized and contains malachite and lesser chrysocolla. Bornite and chalcocypite are present. Magnetite and a variety of calc-silicate minerals make up the gangue. Two
samples of the intrusive rocks from surface cuts near the shaft and underground workings (App. B, MDG 241, 242) showed 12.9 ppm and 22 ppm uranium and 48.5 ppm and 97.2 ppm thorium, respectively. Copper-sulfide ore (MDG 243) from the same cuts showed 5.8 ppm uranium. Copper ore containing malachite and chrysocolla from the large open pit north of the underground workings showed 375 ppm uranium. Although it seems likely that some of the copper ore mined here contained uranium values of 100 to 200 ppm; most of this probably represents only local possibly supergene enrichment of uranium.

The New Arrowhead mine, in the southern Needles Range is reported to have been a small producer of lead and zinc. The outcrops at the surface are of undifferentiated Paleozoic carbonate rocks and quartzite which, according to the map by Grant and Best (1979), may be megabreccia blocks derived from caving of the walls of the Indian Peak cauldron (Fig. 3B). In view of the low radioactivity on the dumps and outcrops (maximum 180 cps) and low uranium content (10.6 ppm U) of a sample of the most radioactive material that could be found (App. B, MDG-121), no deposits of class 330 seem likely on the basis of available information.

Contact-Metasomatic (Class 340)

Mathews (1978, p. 147) pointed out that because the same general petrogenetic processes are involved in the formation of contact-metasomatic and magmatic-hydrothermal deposits, distinction between the two may be difficult. It is, indeed, difficult to distinguish between those occurrences discussed above as Class 330 and those discussed here as Class 340. However artificial the distinction may be, the occurrences discussed here are classified as contact-metasomatic because of their location within tactites that are considered to be metasomatic in origin. It may be that the occurrences belong in some totally different class and that their location within tactites is fortuitous, being controlled only by fracture zones which are superimposed on the tactites and mimic their orientation. During the present study only a few occurrences were identified within tactites. They are restricted to the Mineral Mountains and include the Sunrise property (App. A, occ. no. 96), the Galena claims (App. A, occ. no. 97), and the P. and H. claims (Appendix A, no. 98). None of these occurrences appears to be of high enough grade, nor shows areas of continuous enough radioactivity at the outcrop to be classified as favorable—that is, as likely to contain 100 tons of U₃O₈ with a minimum grade of 100 ppm U₃O₈.

The tactite zones of the Mineral Mountains have produced base and precious metals, iron, and tungsten. They are irregularly developed at the contact between the Mineral Mountains granitic plutonic rocks and Paleozoic limestones (primarily the Kaibab Formation). Condie (1960) noted that the tactites are best developed—that is they exceed a few centimeters in thickness—only where they are in close (less than 150 m) proximity to rhyolite and rhyodacite porphyry dikes that intrude the granitic rocks. The genetic meaning, if any, of this spatial association is unknown.
The Galena claims, which are the only occurrences that could be located, were developed in the 1950's for uranium, but apparently none was produced. The uranium development may have been superimposed on older workings related to tungsten and/or precious metals. Pyrite, galena, garnet, tremolite, Mn-oxides, and Cu-oxides were observed in the main dump and in some of the open pits. No uranium phases have been identified. The surface radioactivity seems to follow the trace of a fracture zone that trends approximately NE (generally parallel to the contact between the granitic pluton and the limestone). Sample MDG 501 from a NNE-trending shear zone has 54.7 ppm U and 676 ppm Th. The most radioactive sample (MDG-502) collected from the dump has 112 ppm U and 1,590 ppm Th. It appears, therefore, that much of the radioactivity is due to thorium.

The Iron mine (which is not an occurrence) is located in a zoned tactite on the margin of a granitic inselberg on the west flank of the Mineral Mountains. Apparently small quantities of magnetite were mined. A sample of the magnetite ore, MDG-509, contains 4.78 ppm U and <2.6 ppm Th. A sample of the epidote zone (MDG-513), however, contains 64.3 ppm U and <14 ppm Th. The lack of surface continuity of radioactivity and apparently only local development of the epidote zone suggest that no deposits of Class 340 can be predicted for this area.

Although the tactite zones of the Mineral Mountains cannot be defined as favorable they should not be excluded from future exploration. There are three lines of evidence that lead to this conclusion; (1) some of the surface samples contain anomalous amounts of uranium—sample MDG-502 with 112 ppm U and sample MDG-513 with 64.3 ppm U, (2) the Geyser Basin occurrence (App. A, occ. no. 99) may be the surface expression of a hydrothermal system that is leaching uranium from deposits within or near the tactite zone, and (3) a reconnaissance geochemical survey conducted by Miller and others (1979) indicates that a few water and stream-sediment samples along the contact zones of the Mineral Mountains—that is, the zones where tactites should be found—have anomalously high uranium values.

VOLCANOGENIC OCCURRENCES (CLASSES 500-599)

Extensive ash-flow tuff and related volcanic rocks belonging to several formations are known throughout the Richfield Quadrangle. Outside of the Marysvale-Tushar and southern Wah Wah Mountains favorable areas, only a few uranium occurrences are known, principally in the southern Needles Range and the Shauntie Hills.

Tertiary volcanic rocks belonging to the Needles Range Formation underlie most of the Needles Range; however, Paleozoic sedimentary rocks crop out in the northern and southern parts of the range, and the section has locally been intruded by hypabyssal plutons. A volcanic cauldron in the central part of the range has been identified (Grant and Best, 1979; Best and others, 1979). Several fluorspar mines and occurrences are known in the range, and some base- and precious-metal mining occurred. Although a few of the fluorspar
properties and some of the base-metal properties have been reported as minor uranium occurrences, no significant anomalous radioactivity was noted at any of the properties. Purple uraniferous fluorite was not observed, in contrast to properties in the southernmost Wah Wah Mountains. Based on the dissimilarity of mineralization and environments in this area to other known mineralized areas, volcanic rocks outside the favorable areas cannot be considered favorable.

Exposed in the Shauntie Hills are Paleozoic limestones covered locally by Tertiary volcanic and volcaniclastic sedimentary rocks. The rocks apparently have been intruded by a few small silicic plugs. The section is cut by normal faults. Locally hydrothermal alteration has occurred along faults and near the plugs. Two uranium occurrences were found in altered volcanic rocks near fault contacts with the Paleozoic limestones (Pl. 2, occ. no. 204 and 105). In spite of these occurrences, this area cannot presently be considered favorable for the minimum endowment, although it seems reasonable that further work might change this assessment.

OCCURRENCES OF UNCERTAIN CLASSIFICATION

Spring-Related Occurrences

Uranium occurrences have been reported at Monroe (App. A, occ. no. 4), near Sevier (App. A, occ. no. 5) and northwest of Minersville (App. A, occ. no. 99). An additional sharp aeroradiometric anomaly was observed over hot springs 19 km southwest of Fillmore. The Monroe and Minersville occurrences were the only ones investigated during this study. The aeroradiometric data were not received in time to investigate the hot springs near Fillmore.

The Monroe occurrence consists of local radioactive zones in extensive hot-spring deposits that occur along the alluvial fans just east of Monroe. Counts on a hand-held scintillometer ranged from 40 to 3,500 cps on the travertine and silica deposits. Limonitic siliceous sinter near active springs was the most radioactive. Uranium contents of two spring samples were less than 10 ppm, however, suggesting that all radioactivity in the springs is related to daughter products. One sample of limonitic siliceous sinter from the most active spring showed greater than 20 percent Fe, greater than 5,000 ppm Mn, 8,500 ppm As, 85 ppm B, 60 ppm Be, and 1,500 ppm Sb. Interferences for Bi, Sn, W, Zn, and Ce prevented their determination.

The Geyser basin prospect near Minersville consists of hot-spring deposits that extend over a few hundred square meters in dissected alluvial fan sediments above a pediment surface cut on older basin-fill sediments. The springs are not presently active. Counts on a hand-held scintillometer ranged from 45 to 220 cps, which was 1 to 5 times background count for alluvium upslope from the deposit. Two samples from outcrop and from the dump showed 1,150 and 2,300 ppm uranium (App. B, MDG-227 and MDG-508), respectively, however, giving credence to reports of minor production of 25 lbs of \( U_3O_8 \) from 18 tons of rock. Analyses of one sample showed 100 ppm Mo and 210 ppm V (App. 47.
The springs deposits examined do not appear to constitute a significant uranium resource due to their small areal extent or lack of uranium. No favorability can be projected for the areas surrounding these occurrences. The deposits do raise questions, however. What is the source for the U, Mo, and V present at Geyser basin? Is there alteration or mineralization at depth at the Monroe hot springs? Further work answering these questions may change our perceptions regarding favorability.

Occurrences at Tertiary-Paleozoic Unconformity

Virtually the entire Richfield Quadrangle is, or was, underlain by an unconformity between Tertiary sediments or volcanics and pre-Tertiary rocks. Two uranium occurrences occur at or near the unconformity between a basal Tertiary conglomerate and overlying ash-fall tuff and underlying Paleozoic rocks in the southern end of the Barn Hills and adjacent parts of the Confusion Range. Although the setting for these two occurrences resembles known deposits at or near Tertiary unconformities elsewhere in the United States, other characteristics such as arkosic sands, plant detritus, uraniiferous tuffaceous debris, or reducing environments in the underlying rocks were not observed; thus no favorability can be assigned based on present information.

Some aeroradiometric anomalies occur over the Tertiary-Paleozoic unconformity in the northern Pavant Range east and southeast of Fillmore. Although aeroradiometric data was received too late to allow these anomalies to be investigated in the field, they are believed to be false anomalies related to abrupt lithology changes or topography.

INTERPRETATION OF U.S. GEOLOGICAL SURVEY
HYDROGEOCHEMICAL DATA,

by
Keith Robinson, Raymond L. Reed and Rodney J. Noah

In the spring of 1979, a hydrogeochemical survey was conducted in selected areas of the Richfield, Utah 20° Quadrangle. The primary objective was to identify areas that possibly contain anomalous concentrations of uranium.

This study incorporates the results of analyses for uranium from well and spring water samples. The samples were collected by members of the U.S. Geological Survey and analyzed under contract by GEOCO, Inc., Wheatridge, Colorado.
Stream sediment sampling was conducted in the quadrangle by the Lawrence Livermore Laboratory (LLL), under the auspices of the NURE Program. The samples obtained by LLL were analyzed for uranium and other elements by the Savannah River Laboratory (SRL) and the results are contained in a report by Jones (1979). The original intent was that USGS geochemical sampling would be confined to areas of apparent uranium anomalies delineated by the LLL data. The LLL Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) data, however, was not available in time to serve as a basis for the USGS sampling. As a consequence, no stream sediment samples were collected in the quadrangle by the USGS.

A total of 90 ground-water samples were collected in the Richfield Quadrangle, as part of the USGS sampling program. On the basis of the existence of favorable source rocks for uranium in the Tushar and Mineral Mountains, water sampling was confined to the Beaver River drainage basin. The northern part of the Wah Wah Valley was also sampled for comparative purposes. Known areas of uranium mineralization were deliberately excluded. Sample sites were located wherever water was available and an effort was made to afford optimum density, coverage, access, and integrity of the resultant geochemical data. Replicate water samples were collected at two localities in order to test the variance of analytical results. Analyses of the replicate samples indicates that reproducibility of analytical data is within the precision required by the USGS.

The water samples were collected from wells and springs. Water temperature, specific conductance, pH, and dissolved oxygen were measured at each site, and three separate water samples were obtained. A 1000-ml sample was collected, filtered through a 0.45-mm membrane filter into an acid rinsed polyethylene bottle and then acidified with an ultrex-grade concentrated nitric acid to a pH of <2. This sample was analyzed for uranium by an extraction fluorimetry method. An untreated and unfiltered 250-ml water sample was obtained and analysed for the degree of alkalinity by titration with sulfuric acid to give equivalent CaCO$_3$ in mg/. A 125-ml filtered, but untreated, sample was collected and analyzed by ion chromatography for sulfate, phosphate and nitrate. The latter sample was kept at a near freezing temperature until analysis was complete.

The areal distribution and relative concentrations of uranium in the water samples are shown on Plates 4B and C. Each plate contains an accompanying histogram and cumulative-frequency probability plot of the distribution of uranium concentration in the sample media. Uranium values are represented by symbols on the map and have been grouped into specific class intervals based on a logarithmic scale. The symbols and their range of values are annotated on the histogram and cumulative frequency probability plots. A graphical representation of analytical values, categorized into specific class intervals, permits easy observation of large variations in geographically clustered sample analyses and results in a smoothing of the data.
GEOCHEMISTRY OF GROUND WATERS

The distribution and relative concentration of uranium, measured in parts per billion (ppb), in ground waters, is shown on Plate 4B, together with a histogram, a cumulative frequency probability plot, and other statistical parameters. The results of analyses, field data, and the coordinate locations of samples collected in these areas are given in Appendix B-2, under the heading of "Ground Water". An explanation of the codes used in the columnar entries of Appendix B-2 is included. A summary of the chemical analyses and measured physical parameters of water samples is given in Table 6.

A complete statistical summary of selected geochemical data from water samples is given in Appendix B-3.

The ground water samples were normalized for comparative purposes by multiplying the uranium concentration in ppb times 1000, and dividing by conductivity (mhos/cm). This procedure has the effect of normalizing the data in samples collected from different sources and correcting for dilution effects, by giving a measure of the uranium content compared to the total amount of dissolved material in solution. The distribution and relative concentration of uranium in water samples, normalized by conductivity, is shown on Plate 4C, together with a histogram, a cumulative frequency probability plot and other statistical parameters. Those samples whose uranium content was below the lower limit of detection have not been included in the normalized data set. The locations of these samples are indicated on Plate 4C, using the standard symbol for below the lower limit of detection.

A comparison of the median value for uranium of 3 ppb in Table 6, with the arithmetic mean of 6.17 ppb and the geometric mean of 3.34 ppb, suggests that the uranium concentration in water samples is lognormally distributed. This same conclusion appears true for the uranium concentration normalized by conductivity, the median and geometric means being similar. The semilogarithmic histogram of frequency distribution for uranium in water samples, shown on Plate 4B, suggests a single sample population. This is substantiated by the close correspondence between median and geometric mean uranium values. The cumulative logarithmic probability plot on Plate 4B shows a break in slope at the 20 ppb uranium value. If the water samples are representative of a single population, and if the threshold value between anomalous and background values is placed at two geometric deviations above the geometric mean, then water samples containing more than 37.9 ppb uranium may be significantly anomalous, and samples containing uranium values in the range 20-37.9 ppb may be considered marginal or weakly anomalous.

The histogram of frequency distribution for uranium concentration in water samples, normalized by conductivity, shown on Plate 4C, suggests the possibility of a bimodal distribution. The apparent bimodal distribution is supported by clearly defined breaks in slope at 0.5 and 1 Ux1000/conductivity values on the cumulative frequency probability plot. It is possible that the effect of normalizing the water data by dividing by conductivity emphasizes the difference in the source rocks and aquifers from which the samples were
Table 6.--Summary of chemical analyses and physical parameters in Spring and Well Water Samples

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<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
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<th>Geometric Mean</th>
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</table>

N--not detected at the lower limit of determination, in parentheses.
L--detected, but below the lower limit of determination, in parentheses.
G--detected, but at a value greater than the upper limit of determination, in parentheses.

Practically all of the values in the range 0.05 to 1 Ux1000/conductivity units are confined to water samples from the Sevier Desert region in the northern part of the quadrangle, which serves as part of the sump for the Sevier River.

**INTERPRETATION OF RESULTS**

A general agreement exists between the distribution of uranium obtained in water samples collected by the U.S. Geological Survey and in stream sediment samples collected by LLL. In those localities sampled by the USGS, both the SRL sediment data and the USGS water data sets show the highest concentration of uranium to be in the Beaver Valley area. Here, stream sediments and ground waters are largely derived from uranium-rich volcanic rocks in the Tushar Mountains to the east and north. The uranium content of the ground waters increases from less than 1 ppb northeast of Beaver to 29 ppb near Minersville Reservoir. This suggests the water is leaching uranium from sediments in the Beaver Valley Basin.

At the 95 percent confidence level, ground-water samples collected in the Richfield Quadrangle show a statistically significant correlation between uranium with sulphate content. This suggests the oxidation and leaching of pyrite-rich ore bodies associated with uranium in the Tushar and Mineral Mountains.

Within the geographic and severely restricted sample density limitations of the hydrogeochemical survey, conducted by the USGS in the Richfield Quadrangle, only one area appears to contain slightly elevated concentrations of uranium in ground-water samples. The area is located in the Beaver Valley Basin west of the town of Beaver and is shown on Plate 4B. The slightly enriched uranium content in water samples collected from this locality is substantiated by the normalized uranium values shown on Plate 4C. None of the samples from this area, however, contain significantly anomalous concentrations of uranium. At best they are only marginally anomalous.

Only two samples, MDH-508 and MDH-552, contain a statistically significant anomalous amount of uranium. Sample MDH-508 contains 38 ppb uranium, but was obtained from water draining the abandoned Cactus mine south of Frisco Peak, on the west side of Wah Wah Valley. Sulfide ores mined in the area are associated with a granodiorite-quartz monzonite stock. Sample MDH-552 was obtained from an abandoned windmill well in the Beaver Bottoms. On normalizing the uranium content by conductivity, the uranium concentration does not appear significantly anomalous, which suggests the sample may have been artificially concentrated by evaporation at the sample site. Water well samples collected south of the town of Milford show a very slight enrichment in uranium. Water samples collected from wells to the west of Fillmore contain the lowest concentration of uranium in the data set. It appears that the dilution effects of additional ground water is a significant factor in progressively lowering the uranium content in ground water samples collected further west and north, along the Beaver River drainage from the town of
Beaver.

In summary, geochemical data from spring and well water samples collected in the Richfield Quadrangle suggest that ground waters in the Beaver Valley area, to the west of the town of Beaver, show enrichment in uranium due to the probable leaching of uranium-rich sediments in the basin. The concentration of uranium is not significantly anomalous, but the area may warrant further investigation.

RECOMMENDATIONS TO IMPROVE EVALUATION

Recommendations to improve this study fall into two general categories: (1) additional detailed studies within the favorable areas to outline the character and extent of the favorable environments; and (2) additional reconnaissance and detailed studies to determine whether unfavorable environments that show some favorable criteria might show additional favorable criteria elsewhere and to evaluate some possibly favorable environments which cannot presently be fit into the classification scheme used here (Mickle and Mathews, eds., 1978).

In the southern Wah Wah Mountains, it seems likely that there are additional near-surface rhyolite plugs like that near the Staats mine. Areas of extensive tuff alteration should be investigated either using geophysical studies or studies of alteration facies to determine possible positions of subsurface plugs. Detailed helicopter-borne gamma-ray spectrometer surveys may help. Similar studies plus detailed geologic mapping in the nearby Shauntie Hills area is also recommended.

On the Marysvale-Tushar Mountains area the following studies are recommended:

1) Determination of the source of the uraniferous Osiris Tuff
2) Deep drilling in the central mining district
3) Additional detailed geologic mapping of hypabyssal plutons and associated alteration like that seen in the Monroe Canyon area
4) Detailed mapping of volcanioclastic sedimentary rocks in the caldera environment as suggested by Steven and Cunningham (1979) for the Big John caldera.

The Tertiary and Quaternary basin-fill rocks are probably the least known of the units in the quadrangle. Improvement in the evaluation of these rocks could be enhanced by: (1) detailed study of all available oil and gas, water, and geothermal drillholes in the Richfield Quadrangle including studies
of cuttings, core, electric logs, lithologic logs and, where possible, relogging of holes; and, (2) stratigraphic test drilling, detailed hydrogeochemistry, detailed gravity studies and detailed surface mapping and facies analysis of possibly favorable environments in Beaver valley and the lower Sevier River area.

The hot springs in the quadrangle are not well understood, yet some uranium and locally high radioactivity are associated with some of them. We suggest the following: (1) reconnaissance geochemical sampling of waters and deposits of all hot springs in the quadrangle; and (2) detailed geologic mapping and geochemical sampling along the western flank of the Mineral Mountains from the Roosevelt Hot Spring area to the Geyser basin prospect, with follow-up drilling and attention to sub-pediment older basin-fill section as a possible uranium source.

Additional studies might include the following: (1) reconnaissance along the Paleozoic-Tertiary unconformity in the northern Tushar Mountains east of Fillmore to check aeroradiometric anomalies along contact; and (2) detailed radiometric traverses, stream-sediment and water sampling along entire contact zone in the Mineral Mountains to check anomalous samples described by Miller (1979).
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PLATE 1.— AREAS FAVORABLE FOR URANIUM DEPOSITS
Compiled by
Calvin S. Bromfield, U.S. Geological Survey
PLATE 2.--URANIUM OCCURRENCE MAP
Compiled by
Calvin S. Bromfield and Lee M. Osmonson, U.S. Geological Survey

EXPLANATION
URANIUM OCCURRENCES
CLASSIFICATION
Sedimentary
Plutonic
Volcanic
Other
Minor prospect
or mineral occurrence
Prospect or mine, production unknown
Significant prospect or mine reporting minor production
Mine having production over 200,000 pounds U
Not visited
Not found
Mining District

Area of crowded uranium occurrences

Uranium Occurrences 35-54:
35,36
37
38
39
40
41
42
43
44-48
49,50
51
52-53
54

1/20,000 scale map

Plate 2
1979
PLATE 3.—PRELIMINARY MAP OF MAJOR AERIAL RADIOMETRIC ANOMALIES

Compiled by
Margaret D. Montaigne and Calvin S. Bromfield,
U.S. Geological Survey

EXPLANATION

Contour intervals showing values of uranium in ppm

Lower Limit of Detection (LLD) = 0.00 ppm
Median = 3.10 ppm
Maximum = 31.00 ppm
Total Number of Samples = 735
Number of Samples < LLD = 5

Plate 4A.

PLATE 4A--CONTOUR MAP SHOWING URANIUM DISTRIBUTION (PPM) IN STREAM–SEDIMENT SAMPLES

Compiled by
Cheryl W. Adkisson, U.S. Geological Survey

Plate 4A
1980
PLATE 4B—DISTRIBUTION AND CONCENTRATION OF URANIUM (PPB) IN GROUND WATER SAMPLES

Compiled by

Sample locality and symbols indicating U (ppb) value
Data in any interval are greater than or equal to the lower limit and less than the upper limit for that class.

- < 0.05
- 0.05-0.1
- 0.1-0.2
- 0.2-0.5
- 0.5-1.0
- 1.0-2.0
- 2.0-5.0
- 5.0-10
- 10-20
- 20-50

Samples located and plotted compiled by
the following U.S. Geological Survey personnel:
J.W. Samson, R.H. Stark, and R.J. Maas

Samples analyzed by
GEOCO Inc., Wheatridge, Colorado

Explanatory

- Lower Limit of Detection (LLD) = 0.05 ppb
- Median = 3.0 ppb
- Maximum = 38.0 ppb

Number of samples > LLD = 86
Total number of samples = 90

Sample locality number: all numbers are prefixed by MDH
In locations where replicate samples were collected, only the highest relative value is shown.
All samples are ground water samples.
PLATE 4C.--DISTRIBUTION AND CONCENTRATION OF URANIUM (PPB) X 1000 / CONDUCTIVITY IN GROUND WATER SAMPLES

Compiled by

EXPLANATION

Cumulative frequency distribution of uranium (ppb) X 1000 / conductivity in ground water samples

U (ppb) X 1000 / conductivity

Cumulative Probability

Data in any interval greater than or equal to the lower limit, and less than the upper limit for that class.

Median = 4.7
Minimum = 0.05
Maximum = 290
Total Number of Samples = 86

Sample locality and symbols indicating U (ppb) X 1000 / conductivity value

Plate 4C. 1980
EXPLANATION
- Location of rock samples
All numbers prefixed by MDG
Analytical results are shown in Appendix B

PLATE 5.--ROCK SAMPLE LOCALITY MAP
Compiled by
Russell F. Dubiel and Lee M. Osmonson, U.S. Geological Survey
PLATE 8.--SELECTED PRE-VOLCANIC STRATIGRAPHIC SECTIONS

Compiled by
Calvin S. Bromfield and Lee M. Osmonson,
U.S. Geological Survey

U.S. Department of Energy
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Compiled by
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I. Sevier River Basin
J. Oil Shale Withdrawals
K. National Trails
L. Dominguez Escalante Trail
M. Indian Peak Wildlife Management Area
N. Desert Range Experimental Farm-U.S. Forest Service

This map compiled prior to August 1979.