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**URANIUM FAVORABILITY OF PRECAMBRIAN ROCKS
IN THE BADGER FLATS - ELKHORN THRUST AREA,
PARK AND TELLER COUNTIES, COLORADO**

BENDIX FIELD ENGINEERING CORPORATION
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PREPARED FOR THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
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SUMMARY

The Badger Flats - Elkhorn Thrust project area in Colorado is approximately 1,800 square miles and extends from Cripple Creek northward to Fairplay and Bailey. The Precambrian rocks include the metamorphic sequences of the Idaho Springs Formation and the Boulder Creek Granodiorite, Silver Plume Granite, Pikes Peak Granite, and Redskin Granite. The area has been deformed numerous times and as a result has a dominant northwest structural trend.

The known uranium deposits in the project area include six vein deposits, three pegmatite occurrences, and one zone of probable secondary enrichment. These occurrences have not yielded any significant production. The vein deposits are probably the result of downward percolation of ground water but should not be considered subeconomic in light of similar economic deposits in France and Australia. The zone of secondary uranium enrichment may have formed above a volcanic pipe, vein, or tuffaceous lake bed. Other similar zones visible on infrared aerial photos should be explored by airborne radiometric surveys and the analysis of aerial photos.

Favorability in the Badger Flats - Elkhorn Thrust project area is considered good for both vein and large, disseminated, low-grade uranium deposits. On the bases of known uranium occurrences, favorable structures and host rocks, and a water-sampling program, specific areas recommended for exploration include:

1. The probable extension of the Last Chance vein into the valley southeast of Badger Mountain near the intersection of Highway 24 and Park County Road 31.
2. The Gold Star deposit and related features that seem to be the result of secondary uranium enrichment.
3. The Rock Creek drainage near the Coleman Ranch, where a water sample contains 14 ppb uranium.

Other structures that seem most favorable for uranium localization are outlined in Plate 1.

The occurrences in the project area have substantial similarities with the Rössing deposit in South-West Africa and the Wheeler Basin uranium occurrence in Grand County, Colorado. (For example, approximately ten miles west of Tarryall reservoir, biotite xenoliths enriched in uranium [40.2 ppm] are contained in a metasomatic granite.) The favorability for large, disseminated, low-grade uranium deposits in the Badger Flats - Elkhorn Thrust area is good.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of the geologic and geochemical study of the Badger Flats - Elkhorn Thrust area is a synthesis of geologic information and an undertaking of surface studies to determine favorable areas for uranium deposits in the Precambrian igneous and metamorphic rocks. Emphasis is directed toward two distinct types of uranium favorability. Primary emphasis of the program is to define potential uranium resources in fractures and shear zones in Precambrian rocks throughout the project area and to study greisen pipes in Badger Flats. A secondary objective is to define favorable areas for large, low-grade uranium deposits, which are similar to the Rössing deposit.

GEOGRAPHIC SETTING

The project area (Fig. 1) includes parts of Park and Teller Counties, Colorado. The area is approximately 1,800 square miles and extends from Cripple Creek northward to Fairplay and Bailey. Badger Flats is a valley that lies between Tarryall and Lake George and is limited by Tarryall Creek to the northeast and by Park County Road 31 to the southwest. The Elkhorn Thrust extends southward to the vicinity of Jefferson (about 18 miles).

PROCEDURES

Field work began June 1, 1975, and was completed September 1, 1975. Rock samples were collected from Precambrian units throughout the project area to determine regional uranium and thorium contents. Each sample was selected as representative of the unit and area from which it was collected. Rock samples from known uranium occurrences in Badger Flats were collected to aid in the description of these deposits. Necessary petrographic studies of specific samples were conducted.

A total of 150 water samples were collected within the project area. Major emphasis was the sampling of Tarryall Creek and the springs in Badger Flats. In addition, water was collected from streams and springs within the Tertiary section for comparison.

A map (Pl. 1) of shear zones in the Precambrian rocks in part of the project area was prepared by IntraSearch, Inc., Denver, Colorado. This map is based on the analysis of low-altitude color aerial photographs. The photographs and detailed maps are available for inspection at the Energy Research and Development Administration (ERDA) Technical Library, Grand Junction, Colorado, or for purchase through IntraSearch, Inc.

All petrographic and chemical analyses were performed in the laboratories of the Grand Junction (Colorado) office operated for ERDA by Bendix Field Engineering Corporation. Equivalent uranium, thorium, and potassium (eU, eTh, and eK) were determined by gamma-ray spectroscopy

Figure 1. Badger Flats - Elkhorn Thrust project area, Park and Teller Counties, Colorado.

with a sodium iodide detector; precision of this method is ± 5 percent. For samples having an equivalent uranium content exceeding 250 ppm, colorimetric analysis for U_3O_8 was performed which is considered to have a precision of ± 5 percent. The precision of fluorimetric uranium analyses is ± 100 percent for water containing less than 100 ppb and ± 20 percent for water containing more than 10 ppb. Silver, copper, lead, and zinc were analyzed by atomic absorption spectroscopy and are precise to ± 5 percent.

ACKNOWLEDGMENTS

The initial investigation and field work were conducted with the assistance of Carl Lipp and Judith Flook. Joseph Huggins, Robert Nystrom, Kathy McGill, and Ricky Newton acted as field assistants during the summer. The cooperation of the local landowners and claim owners is gratefully acknowledged.

GEOLOGY

IGNEOUS AND METAMORPHIC ROCKS

Precambrian igneous and metamorphic rocks in the Badger Flats - Elkhorn Thrust project area are mainly in the rugged mountains of the Front Range. The Precambrian units are in contact with Mesozoic and Cenozoic strata along the Elkhorn Thrust, which forms the eastern boundary of the South Park Basin (Fig. 2). The Precambrian rocks have a complex history of metamorphism, faulting, and intrusion. Hawley and others (1966) divided the Precambrian rocks into three groups, according to age and conditions of formation.

Rocks of the oldest group include the Idaho Springs Formation and the Boulder Creek Granodiorite. The Idaho Springs Formation, a group of metasedimentary units, has wide textural and mineralogic variation. The dominant unit is a fine- to medium-grained biotite gneiss with locally abundant granitic gneiss and migmatite; calc-silicate gneiss, quartzite, and amphibolite are also in small bodies within the formation. The Boulder Creek Granodiorite is a medium- to coarse-grained gray unit that ranges in composition from granite to granodiorite. It locally has a subtle foliation of elongate minerals. The precise age of this unit is uncertain, but Hawley and others (1966) reported ages from 1,600 to 1,730 m.y.

The intermediate age group is represented by the Silver Plume Granite which forms numerous, often irregularly shaped bodies throughout the area. The Silver Plume Granite is a fine- to medium-grained gray granite, composed of quartz, potassium feldspar, plagioclase, muscovite, and biotite. Hawley (1969) assigned an igneous origin to the Silver Plume Granite. The Silver Plume Granite is thought to be about 1,350 m.y. old (Aldrich and others, 1958). Unfoliated Boulder Creek Granodiorite is commonly confused with the Silver Plume Granite.

Figure 2. Geologic map, Badger Flats - Elkhorn Thrust project area, Park and Teller Counties, Colorado.

The youngest units in the area comprise the Pikes Peak Batholith, which includes the Redskin Granite. The Pikes Peak Batholith is an epizonal composite pluton, composed of granite, granodiorite, and quartz monzonite, which include minor amounts of gabbro, syenite, and monzonite (Hawley and others, 1966). The dominant rock type of the Pikes Peak Batholith is the Pikes Peak Granite. This granite is a medium- to coarse-grained pink rock composed of quartz, microcline, and sodium plagioclase. Large microcline phenocrysts characterize the porphyritic facies of the Pikes Peak Granite. Aldrich and others (1958) determined the age span to be 980 to 1,060 m.y. Gabbro, monzonite, and syenite of the Pikes Peak group are the oldest rocks of this unit. Hawley and others (1966) reported gabbro and monzonite in the Badger Flats area, and the Lake George syenite stock has been described in detail by Stewart (1964).

The Redskin Granite is the youngest Precambrian intrusion in the area and was designated as a late facies of the Pikes Peak Granite by Hawley (1963). The Redskin stock east of Tarryall, Colorado, is made up of quartz, potassium feldspar, and plagioclase, with trace amounts of topaz and fluorite.

Hawley and others (1966) reported an age of 1,000 m.y. for the Redskin Granite; however, because the Redskin stock cuts across the Pikes Peak Batholith, the Redskin stock must be younger. Similarities in composition, radiometric ages, and trace element content indicate that the two granites are related genetically (Hawley, 1964; Hawley and others, 1966). The Pikes Peak Granite is enriched slightly and the Redskin Granite is enriched more in tin, lithium, rubidium, beryllium, and fluorine relative to common granite.

Modal analyses of the Silver Plume, Pikes Peak, and Redskin Granites are given in Table 1. All values have been rounded to the nearest percent. The high quartz content and the fluorite in all samples of the Redskin Granite are evidence that it has been differentiated more than the Silver Plume and Pikes Peak Granites.

The volcanism, which occurred throughout Tertiary time, is represented by andesite of the Thirtynine Mile volcanic field in the southeastern part of the project area. In the Precambrian terrain, there are remnants of andesite on topographic highs.

STRUCTURAL GEOLOGY

The structural history of the Precambrian rocks in the South Park area is complex: Precambrian faults and shears control later structures. The oldest deformational event is the folding of the metasedimentary and of the metaigneous units. Resultant folds and lineations have a dominant north-northeast trend (Fig. 2). Emplacement of the Silver Plume Granite caused further folding of the metamorphic rocks as well as recrystallization and retrograde metamorphism of the Idaho Springs Formation. The associated deformation and recrystallization varies from local, minor features to strong, large-scale features near the larger plutons.

TABLE 1. MODAL ANALYSES OF GRANITES FROM THE BADGER FLATS AREA

Sample Number	Silver Plume			Pikes Peak			Redskin		
	537-7 (%)	535-14 (%)	535-19 (%)	568-1 (%)	568-2 (%)	568-3 (%)	516-1 (%)	516-2 (%)	516-5 (%)
Quartz	35	31	29	34	21	20	33	37	38
Feldspar	57	60	54	60	44	78	64	58	58
Muscovite	4	3	13	<1	--	tr	tr	tr	tr
Biotite	3	5	2	4	18	--	2	4	3
Hornblende	--	--	--	--	16	<1	--	--	--
Opaque minerals	tr	tr	<1	<1	<1	1	tr	tr	tr
Apatite	--	--	tr	tr	tr	--	--	--	--
Fluorite	--	--	--	tr	--	--	<1	tr	tr

As faulting and shearing occurred in several episodes during Precambrian time, evidence is limited by which to distinguish episodes of structural deformation. Fluorite veins and beryllium-bearing greisen pipes, which are related genetically to a late phase of the Redskin Granite, are along fractures near the stock, which indicates that fracturing occurred approximately 1,000 m.y. ago (Hawley, 1963). The dominant trend of these structures is northwestward, and they dip steeply to the west. The next episode of recorded faulting took place during the Laramide uplift when Precambrian rocks of the Front Range were thrust westward over the strata of the South Park Basin. The resultant Elkhorn Thrust strikes to the north and dips gently to the east.

Hawley and others (1966) think the Precambrian structures were reactivated during Tertiary deformation of this area. They cite at least one Precambrian fault that cuts Tertiary volcanic rocks, which indicates renewed movement during Tertiary time. Evidence for displacement along these faults is lacking; however, many authors believe that displacement along the fractures has been small.

URANIUM DEPOSITS

The Precambrian rocks of the Badger Flats - Elkhorn Thrust area have been mined principally for beryllium, which occurs in greisen pipes associated with the Redskin Granite (Hawley, 1969). The main beryllium deposit is the Boomer mine (Fig. 3) in Badger Flats. In addition, minor amounts of tungsten, molybdenum, lead, zinc, tin, and silver have been produced from the greisen pipes. Minor amounts of fluorite from fissure veins and small amounts of scheelite from tactites have also been mined in the Badger Flats area.

Ten known uranium occurrences (Table 2 and Fig. 2) are within the project area. Nine have been previously reported, but only one has had any production. Information concerning these uranium occurrences is taken from AEC Preliminary Reconnaissance Reports and ERDA production records and may be incomplete.

Six occurrences are in veins, most of which follow along N. 30° W.-trending shears in the Redskin, Pikes Peak, Silver Plume, and Idaho Springs rocks. Autunite, pitchblende, and torbernite have been reported from the veins, but the grade is less than 0.33 percent U_3O_8 .

LAST CHANCE VEIN

The Last Chance prospect was studied as a typical vein uranium deposit. It was chosen because it is well exposed over a distance of at least 2 miles and is accessible. It is approximately 10 miles northwest of Lake George on the east slopes of Badger Mountain (Fig. 3). The reported production is 1 ton of ore containing 0.25 percent U_3O_8 .

The vein follows a N. 30° W.-trending shear in the Silver Plume Granite near the contact with the Idaho Springs Formation. The shear is well-defined topographically and forms three saddles along the side

TABLE 2. URANIUM DEPOSITS IN BADGER FLATS - ELKHORN THRUST PROJECT AREA

Property Name	Location	Type	Country	Rock*	Uranium Minerals	Maximum Reported %U ₃ O ₈	Reference
1. Gem Dandy	Sec. 9, T. 7 S., R. 75 W.	Vein	1		Autunite Torbernite	0.17	E.P. Beroni (Pers. Comm., 1976)
2. Mac George	Secs. 16 and 17, T. 7 S., R. 75 W.	Vein	2		Autunite	-	E.P. Beroni (Pers. Comm., 1976)
3. Last Chance	Sec. 31, T. 11 S., R. 72 W.	Vein	2		Autunite	0.33	E.P. Beroni (Pers. Comm., 1976)
4. Unnamed	Secs. 2 and 3, T. 12 S., R. 73 W.	Vein	1		Autunite	-	PRR 2282 ⁺
5. Redskin	Sec. 15, T. 11 S., R. 72 W.	Vein	3		Pitchblende	-	PRR 2284 ⁺
6. Shamrock-Irish	Sec. 21, T. 11 S., R. 72 W.	Vein	4		Pitchblende	0.03	PRR 2288 ⁺
7. Hill Top	Sec. 12, T. 12 S., R. 72 W.	Pegmatite	1		Autunite	-	PRR 2298 ⁺
8. Unnamed	T. 12 S., R. 73 W.	Pegmatite	2		-	-	PRR 2303 ⁺
9. Hilda May	Sec. 22, T. 11 S., R. 72 W.	Pegmatite	1		Thorite (?)	-	PRR 2448 ⁺
10. Gold Star	Sec. 23, T. 11 S., R. 72 W.	Secondary enrichment	4		Uraninite Schoepite Curite Soddyite	>1.0	This paper

* 1 = Pikes Peak Granite

2 = Silver Plume Granite

3 = Redskin Granite

4 = Idaho Springs Formation

⁺ PRR = Atomic Energy Commission Preliminary Reconnaissance Report, open-filed.

of Badger Mountain. The vein varies in thickness from a few inches to almost 6 ft and dips from 60° W. to vertical.

The vein is composed of 99 percent quartz with trace amounts of zircon, unidentified opaque minerals, autunite, and meta-autunite. The vein material exhibits distinct bands of milky-white and gray varieties of quartz, generally less than one half inch. Vugs as much as one half inch across are common within the vein material. In places, vein material has been broken and recemented, as shown by disruption of banding. Differential movement along shears may account for both undisturbed, banded vein material, and broken and recemented quartz within the same veins (Fig. 4).

Autunite and meta-autunite are discrete green to yellow-green sub-hedral grains as much as one half inch in diameter along fractures and coating vugs within the quartz vein. Equivalent uranium, thorium, and potassium values of several channel samples of vein material are shown in Table 3. Samples 530-1 and 582-2 are vein material exposed on the surface; samples 530-2, 586-3, and 586-5 were collected approximately 30 ft below the surface in a drift along the strike of the vein. Equivalent uranium values of <1 ppm to almost 2,000 ppm reflect the irregular distribution of uranium concentration in the vein.

TABLE 3. EQUIVALENT URANIUM, THORIUM, AND POTASSIUM OF THE LAST CHANCE VEIN

Sample No.	eU (ppm)	eTh (ppm)	eK (%)
530-1	720	19	0.52
530-2	2000	65	0.35
582-2	0.8	5.2	0.29
586-1	3.3	0.2	0.21
586-3	540	32	3.5
586-5	420	40	4.6

Silver Plume Granite cut by the vein displays a gradational texture from a metamorphic gneissic texture near the vein to an igneous hypidiomorphic-granular away from the vein. Surface rock samples were taken perpendicular to the vein at 50-ft intervals for 600 ft on both sides of the vein to determine if uranium-bearing fluids had permeated the host rock. The samples show a sporadic distribution of uranium within the granite; there is no correlation between the high uranium values and the proximity to the vein. The 74 samples collected averaged 6.7 ppm equivalent uranium, not significantly higher than the 6.1 ppm uranium value reported by Phair and Gottfried (1964) as an average value for the Silver Plume Granite. Therefore, the fluids that formed the Last Chance vein were probably restricted to the shear zone and did not penetrate the country rock.

Figure 4. Photograph showing typical banded, vuggy quartz of the Last Chance vein

The five other vein deposits resemble the Last Chance vein, as they display wide variations in grade of U_3O_8 and pinch and swell to such an extent that they are of minor economic importance at this time.

GOLD STAR DEPOSIT

The Gold Star uranium deposit is in Badger Flats along Park County Road 77 (Fig. 3). The deposit is a recent discovery that has not been described in the literature. It seems to differ from other deposits in the Front Range. Its geometry, geochemistry, mineralogy, and petrology are evidence of a zone of secondary uranium enrichment.

The country rock is Idaho Springs gneiss and migmatite. In aerial photographs, the deposit forms an obvious circular surface feature approximately 400 ft in diameter. The outer edge of this structure is more resistant than the rock in which it intrudes because the normal trellis drainage pattern of a small stream is interrupted to flow around it, further enhancing the circular surface expression.

The host rock of the Gold Star deposit is a light-brown, highly friable unit that has undergone intense decomposition. The decomposition has obscured all megascopic features, making identification impossible. A 6-ft pit within the deposit exposes a crude, horizontal layering of yellowish-gray (5YR 7/2) to yellowish-orange (10YR 8/6) earthy material. The rock has been identified by petrographic techniques as strongly weathered and decomposed lithic breccia.

Volcanic features of the host rock observed in thin section include (1) grains of sanidine, in some cases with well-developed Carlsbad twinning; (2) quartz grains with volcanic features; (3) volcanic rock fragments; (4) grains of chert, which may be the groundmass of volcanic rocks; and (5) contorted, kinked flakes of biotite and muscovite. From the petrographic analysis, a volcanic host rock can be inferred, but due to the intense alteration, no final conclusions can be made as to its composition.

Four samples were collected for chemical analysis from a small pit within the deposit (Table 4). High, but sporadic, values for U_3O_8 (as much as 3.21 percent) are reported in the upper 6 ft. Lead, zinc, and, to a lesser degree, copper and silver are enriched with respect to felsic rocks, which suggests a hydrothermal origin for this deposit.

TABLE 4. ANALYTICAL RESULTS FROM THE GOLD STAR URANIUM DEPOSIT

Sample No.	Depth Below Surface (ft)	U_3O_8 (%)	Ag (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)
600-1	0.75	0.06	1.0	20	16	83
600-2	1.5	0.18	1.0	26	10	102
507-1	4.0	3.21	4.0	49	441	128
600-3	6.0	0.25	1.0	29	61	80

Uranium minerals were not observed in hand sample, but they were identified by x-ray diffraction techniques (Table 5). Stability fields of uranium minerals present in the Gold Star deposit do not seriously limit the conditions of formation. The stability range of uraninite is broad, and curite and soddyite have been synthesized as primary minerals at temperatures $>180^{\circ}\text{C}$ (Gruner, 1952); although, they are generally reported as secondary alteration products of uraninite. Schoepite is also an alteration product of uraninite. Little information concerning the genesis of this deposit can be added from the initial mineralogic studies of the uranium minerals.

TABLE 5. URANIUM MINERALOGY OF THE
GOLD STAR URANIUM DEPOSIT

Mineral	Formula*
Uraninite	UO_2
Schoepite	$\text{UO}_3 \cdot 2\text{H}_2\text{O}$
Curite	$3\text{PbO} \cdot 8\text{UO}_3 \cdot 5\text{H}_2\text{O}$
Soddyite	$(\text{UO}_2)_3 (\text{SiO}_4)_2 \cdot 5\text{H}_2\text{O}$

*From Frondel and others, 1967.

The earth-like texture, the geochemical suite, and the sporadic distribution of the uranium seem to result from secondary enrichment. The circular surface expression and the volcanic nature of the host rock are evidence of a volcanic pipe or lake bed as the primary source; thus, the Gold Star deposit may be the result of secondary enrichment of a greisen pipe. Uraninite has been reported coating shears in a greisen pipe within the Redskin Granite, and hence, the pipe could possibly be the primary source. The greisens also reportedly contain zinc, lead, and silver (Hawley, 1969). More detailed surface and subsurface studies are needed to determine the exact nature of this deposit.

URANIUM FAVORABILITY

The appraisal of uranium potential in the Badger Flats - Elkhorn Thrust area is based on regional uranium and thorium concentrations, favorable structure and host rocks in the Precambrian units, results of the water sampling program, and adequate sources for the uranium. Each criterion is considered in terms of its similarities and differences to those in known uranium districts and deposits. In addition, the information presented could be used to generate new ideas in terms of uranium favorability and the exploration for new uranium districts.

REGIONAL URANIUM AND THORIUM CONCENTRATIONS

The granitic rocks of the Front Range are enriched in uranium and thorium (Phair and Gottfried, 1964; Malan and Sterling, 1969). Studies show (Table 6) that the granitic rocks of the Front Range have high uranium and thorium concentrations in contrast to low values for

TABLE 6. URANIUM AND THORIUM VALUES FROM GRANITIC IGNEOUS ROCKS

	No. Samples	Average U (ppm)	Average Th (ppm)	Reference
Continental Crust	--	3.0	11.4	Adams and others (1959)
Sierra Nevada Batholith granites	54	2.4	8.0	Rogers (1964)
Idaho Batholith quartz monzonites and granites	9	3.7	17.8	Larsen and Gottfried (1961)
Middle Rocky Mtns. granitic rocks	25	2.2	16.0	Phair and Gottfried (1964)
Front Range, Colorado granitic rocks	38	5.0	25.5	Phair and Gottfried (1964)

similar rock types from other broad geographic areas. Phair and Gottfried (1964) state that the Front Range is the only region in the United States where a twofold enrichment in uranium and thorium can be demonstrated for an area of many thousands of square miles.

Samples of Idaho Springs metamorphic rocks, Pikes Peak Granite, Silver Plume Granite, and Redskin Granite were collected from the Badger Flats - Elkhorn Thrust area to determine if specific units within the Precambrian rocks of the Front Range could be defined as enriched in uranium and thorium with respect to other units. Table 7 shows the results of this work; Figure 5 shows histograms with the distribution and range of uranium and thorium values for each rock type. Appendix A lists each sample location and the eU and eTh values for each sample.

TABLE 7. AVERAGE URANIUM AND THORIUM CONTENTS OF PRECAMBRIAN ROCKS IN THE BADGER FLATS - ELKHORN THRUST AREA

Unit	No. Samples	eU (ppm)	eTh (ppm)
Idaho Springs Formation	12	3.7	16
Silver Plume Granite	82	6.2	29
Pikes Peak Granite	10	2.8	25
Redskin Granite	37	7.2	57

Table 7 clearly shows that the Redskin Granite is enriched in uranium and greatly enriched in thorium with respect to the granitic rocks of the Colorado Front Range. The Silver Plume Granite also shows an enrichment in uranium and thorium. Although the number of samples from the Pikes Peak and Idaho Springs units is insufficient to provide a statistically valid basis for comparison, the lower values for uranium and thorium are consistent with those reported by Malan and Sterling (1969).

Comparison of these units, with similar rocks that are associated with uranium deposits throughout the world, permits broad generalizations in terms of uranium potential. Two such areas where information is available are the Rum Jungle, Northern Australia, and Elliot Lake, Ontario, Canada. The Rum Jungle complex has been described as an area of uranium-copper mineralization in metasedimentary rocks adjacent to and mantling granitic rocks (Heier and Rhodes, 1966). The uranium may be related to the granites by remobilization and by concentration into structurally controlled locations in the metasedimentary rocks during metamorphism. Heier and Rhodes (1966) report average uranium and thorium values of 10.3 and 45.7 ppm, respectively, from the granitic rocks of the Rum Jungle complex. Uranium deposits in the Elliot Lake district are in weakly metamorphosed and folded Precambrian uraniferous conglomerates (Pienaar, 1959). These units lie unconformably on granites and intensely metamorphosed volcanic and sedimentary rocks. Values reported by Roscoe and Steacy (1958) for 26 granitic rock samples from this area average 11.0 ppm uranium and 27.6 ppm thorium.

Figure 5. Histograms of equivalent uranium and thorium content.

Although average uranium values in the Redskin and Silver Plume granites are less than those reported in the Rum Jungle and Elliot Lake areas, these units of the Colorado Front Range are sufficiently enriched to allow speculation about uranium favorability. Rich and others (1975) note that in some uranium districts there is a strong positive correlation between the distribution of pitchblende veins and granites containing >5 ppm uranium. On the basis of similarities of uranium and thorium values to those of known uranium districts, uranium favorability for vein deposits in fractures within the Precambrian igneous and metamorphic rocks of the Badger Flats - Elkhorn Thrust area is considered good.

URANIUM CONTENT OF WATER SAMPLES

Water samples in the Precambrian terrain were collected from Tarryall Creek and its tributaries and from the springs in Badger Flats (Fig. 6). Only 1 of the 39 stream samples contained more than 3 ppb uranium. The anomalous sample (14 ppb) was collected from Rock Creek, a small tributary of Tarryall Creek, southeast of Jefferson. In comparison with data reported in the literature and the samples collected from Tarryall Creek, the sample from Rock Creek is considered anomalous, and further work in this drainage is recommended.

Uranium values and total dissolved solids are shown in Table 8 for the 7 springs samples in Badger Flats (for spring locations, see Fig. 3). Values range from 14 ppb to 140 ppb uranium in these springs; most springs in Badger Flats can be considered anomalous. The consistently anomalous values for all springs in Badger Flats indicate that the area is favorable for potential uranium resources.

TABLE 8. WATER SAMPLES FROM SPRINGS IN BADGER FLATS

Location	U (ppb)	Total Dissolved Solids (ppm)
Upper Tarryall Rd.	132	565
Badger Spring	14	186
Alexander Draw	67	271
Badger Gulch	42	325
O'Brian Gulch	28	241
Marksbury Gulch	34	251
North O'Brian Gulch	140	447

Of specific interest in Badger Flats are the upper Tarryall Road spring, at the intersection of Highway 24 and Park County Road 96, and the North O'Brian Gulch spring along County Road 77. The upper Tarryall Road spring (132 ppb U) is southeast along strike of the Last Chance vein (Fig. 3). The high uranium content in the spring water can be attributed to a concealed part of the vein that

Figure 6 Water sample map
Numbers refer to Table 2.

continues into the valley, across Highway 24, and probably farther into the hills to the southeast. Based on this information, the valley southeast of Badger Mountain and the hills south and east of the intersection of Highway 24 and Park County Road 31 are considered to have excellent favorability for vein uranium deposits.

The North O'Brian Gulch spring (140 ppb U) is of interest due to its relation to the Gold Star deposit. The spring is 1 mile N. 30° W. of the Gold Star prospect which is along the dominant structural direction in the area. If the Gold Star deposit is aligned along a shear or fault, the spring water content probably reflects the uranium concentrations along that structure. Hence, the potential favorability of the structure northwest of the Gold Star locality is good.

STRUCTURES AND HOST ROCKS

Evaluation of favorability in the project area for vein uranium deposits is based on the number, density, and type of fractures and shears, and the nature of the host rock. Shears in the Precambrian igneous and metamorphic rocks probably developed in Precambrian time and were reactivated during the Laramide uplift of the Front Range (Hawley and others, 1966). Plate 1 shows the dominant N. 30° W. direction of the shear zones throughout the area. The shears cut all Precambrian rock types. Each shear can be considered a potential location for a vein uranium deposit.

These shears can be further delineated with respect to uranium potential by the rock type intercepted. Lithology controls the size and shape of the fractures, as well as the chemical environment that may favor precipitation of uranium. Because vein uranium deposits fill open spaces along faults and fractures, potential favorability can be considered in terms of the physical factors that cause these open spaces. Numerous open spaces tend to form during the fracturing and brecciation of competent and brittle rocks. Garnetiferous biotite-quartz gneiss, hornblende gneiss, granite, and related rocks are considered favorable for the formation of open spaces during fracturing (Sheridan and others, 1967). In contrast, less competent rocks such as schists tend to form tight fractures. Fractures are deflected commonly from one rock type to another in units that have different competency and that form branching structures. These branching structures are considered most favorable for ore deposition (Sheridan and others, 1967). Movement along faults that are parallel to foliation tends to produce fractures that are generally tight, whereas movement along faults that are perpendicular to foliation produces fractures with more open space.

In terms of space available for mineralization, the most favorable fractures are those which cut units of different competency at angles normal, or near normal, to their foliation. Rocks of Idaho Springs Formation are the only Precambrian units in the project area that have such variable competency and, therefore, are most favorable for ore deposits where fractures intersect them normal to their foliation. The granites must also be considered favorable structural locations because they

are brittle; although, they lack the variable competency of the metamorphic rocks.

In addition to structural control of ore deposition, chemical control by the country rock may be important. Adams and Stugard (1956) suggested that ferrous iron is released from the alteration of hornblende by uranium-bearing fluids. During this process, the iron is oxidized to hematite while the uranium is reduced and deposited as pitchblende. Wall rocks that are rich in ferrous iron are, therefore, favorable for the precipitation of the pitchblende ore.

Bird (1957) suggested a similar process at the Schwartzwalder uranium mine in the Ralston Buttes area, Colorado, where ferrous iron from the garnetiferous biotite gneiss reduced the uranium and caused precipitation of pitchblende. Where faults cut iron-deficient rock, such as quartzite and microcline gneiss in the Ralston Buttes area, no significant uranium deposits are known. Although the process of reduction of uranium during a reaction with iron-rich rocks (Adams and Stugard, 1956; Bird, 1957) cannot be proved from the available information, it appears that some chemical control by the wall rock is important in ore localization.

Favorability for vein uranium deposits in the Badger Flats - Elkhorn Thrust area is considered good on the basis of structural and petrologic criteria presented. Numerous faults and shears cut units of varying competency normal to their foliation. Such structures in the iron-rich units of the Idaho Springs Formation are favorable for vein uranium deposits. Specific locations of these most favorable areas are outlined on Plate 1.

SOURCE OF URANIUM

The source of the uranium-bearing fluids, although not a primary consideration in evaluating prospects, is important in defining favorable areas for exploration. The four possible sources which must be considered are: (1) late-stage mineralization associated with Precambrian intrusions; (2) hydrothermal fluids of Laramide age; (3) supergene deposition due to ground-water percolation; and (4) uranium concentration and remobilization during metamorphism.

Precambrian Igneous Activity

A possible source for uranium-bearing fluids is late-stage differentiation of the Precambrian intrusions. Precambrian uranium deposits occur as segregations in pegmatites associated with thorium and the rare earth elements (Malan, 1968). Samples of six Precambrian pegmatites in the Badger Flats area, which show equivalent uranium ranging from 0.0 to 6.1 ppm with an average of 2.4 ppm eU, were compared with three pegmatitic uranium occurrences (Table 2), which have grades less than 0.01 percent U_3O_8 . These low values and the fact that so few uranium-bearing

pegmatites are known in the Front Range indicate that igneous pegmatites are a poor rock type for uranium localization in the project area.

Whitfield and others (1959), however, proposed a model that may be applicable in the Badger Flats area. Behavior of uranium and thorium during petrogenic evolution of igneous rocks is fairly consistent and both tend to increase in the liquid fraction during late magmatic stages. The two elements are so similar when in the tetravalent state that large variations in the Th/U ratio cannot be explained by the slight differences in chemical characteristics.

Separation of the two elements takes place if uranium is oxidized to the hexavalent state, a valence state in which thorium cannot exist. As hexavalent uranium is much more soluble than tetravalent thorium, it forms many soluble compounds. Hence, if uranium is oxidized, it will tend to enter a volatile phase and escape from the magma. This model could explain the irregular uranium distribution in certain igneous rocks that exhibit a more constant thorium content. A granite that has gone through this process would be thorium-rich relative to the uranium content and predominantly red in color. The red color is due to similar oxidation potentials for uranium and ferrous iron, so that during oxidation of uranium to the hexavalent state, iron is also oxidized.

The Redskin Granite is similar to the above-mentioned rock type, described by Whitfield and others (1959). Its average uranium content is 7.2 ppm and average thorium content is 57.1 ppm. The Th/U ratio of 7.9 is almost twice the mean value of 4.0 for granitic rocks. In addition, red color is a characteristic feature of the Redskin Granite. The Redskin Granite may, therefore, have lost uranium during its intrusion and may have produced uranium deposits adjacent to the stock. Therefore, the area adjacent to the Redskin stock should also be considered favorable for uranium.

Laramide Hydrothermal Activity

Hydrothermal activity associated with Laramide igneous and volcanic events is the source of most mineralization in Colorado (Lovering and Goddard, 1950). The Colorado "mineral belt" includes (1) uranium associated with base-metal sulfides in the Central City district and (2) pitchblende veins of the Ralston Buttes area, which include in the Schwartzwalder mine. The pitchblende vein deposits of the Ralston Buttes area have been dated at 73 ± 5 m.y., and the ages of the uraninites of the Central City district range from 55 ± 6 to 70 ± 7 m.y. (Sheridan and others, 1967).

Although the Precambrian rocks of the Badger Flats - Elkhorn Thrust area are not in the Colorado "mineral belt," the area was affected by similar Laramide igneous activity, and hence, hydrothermal fluids similar to those that produced deposits in the Ralston Buttes and Central City districts were possible. The southern quarter of the project area is covered by the Thirtynine Mile volcanic field, described in detail by Chapin (1965). Ages reported from this volcanic complex range from 34 to

60 m.y. Chapin (1965) presents evidence that may support a hydrothermal origin related to these volcanic rocks for the Tallahassee Creek uranium district in north-central Fremont County, Colorado. The presence of a possible source for uranium-bearing fluids in a geologic environment similar to ones in which uranium ore is known strengthens the favorability for uranium vein deposits.

Supergene Deposition

A supergene origin should be considered for the uranium occurrences in the project area. Moreau and others (1966) and Langford (1974) suggest that at least some uranium vein deposits are formed by the downward percolation of surface water through fracture zones. Evidence to support this hypothesis includes shallow depth and a simple vein mineralogy (Rich and others, 1975). Moreau and others (1966) state that economic uranium values in veins in France are rarely deeper than 200m. In the Beaverlodge area of Canada, most veins are less than 300 m deep.

Hydrothermal fluids can carry copper, lead, zinc, and other metals in addition to uranium (Knipping, 1974). In the Central City district where the predominant ores are gold and silver with some copper, lead, and zinc, pitchblende occurs as a local variant of the gold and silver veins (Lovering and Goddard, 1950). In contrast, the simple mineralogy of the Last Chance vein suggests an origin related to ground-water percolation, although no evidence is available at this time concerning its depth. The numerous uranium veins throughout the Front Range, which appear to pinch out at depth and show a simple vein mineralogy, could be the product of downward ground-water percolation. This process should not be considered as subeconomic because the Australian deposit (Langford, 1974) and the French deposits (Moreau and others, 1966), which have been attributed to similar sources, are economic.

Another process related to the percolation of ground water is supergene enrichment of a low-grade hypogene uranium deposit. Nash (1975) suggests secondary enrichment of uranium at the Midnight mine in Washington, and Tremblay (1972) cites a similar process in the Beaverlodge area, Canada. Both authors suggest that uranium concentrations probably resulted from the downward percolation of acidic, sulfur-rich solutions that precipitated uranium when the fluids reacted with the more alkaline fluids at the water table.

The Gold Star deposit in Badger Flats may have been formed by supergene enrichment. This could explain its sporadic uranium content and the strongly altered, unconsolidated nature of the host rock. Tremblay (1972) identified a striking example of secondary enrichment in the Beaverlodge area, where a uranium-rich, earthy material, averaging 0.7 percent U_3O_8 , was located above a small vein-type ore body. If the correlation of the genesis of the Gold Star property and the Beaverlodge area is valid, then the favorability for a uranium deposit at depth is excellent at the Gold Star. In addition, other zones of uranium enrichment should be explored in the Badger Flats - Elkhorn Thrust area. Infrared photography of the Badger Flats area was studied to determine if features similar to the Gold Star deposit could be located. A small circular feature, approximately 100 ft in diameter, was observed along Park County Highway 31 near the

Badger Flats airstrip. No anomalous radiation or any obvious expression of the circularity was noted in the field. A rock sample (75-4; Fig. 3) collected from the area was identified as quartz diorite that may have undergone pneumatolytic alteration in which 99 percent of the feldspar was replaced by muscovite and sericite. The process may resemble the greisenization that produces abundant sericite and fluorite. The altered quartz diorite contains 5.9 ppm eU, 15 ppm eTh, 5 ppm Ag, 1,270 ppm Cu, 430 ppm Zn, and 0 ppm Pb. Although the uranium content was low, copper, zinc, and silver values indicate that metalliferous fluids passed through the rock. The chemistry and circular surface expression are indications that this feature may be similar to the Gold Star deposit where the uranium distribution is sporadic.

Metamorphism

Papers by Young and Hauff (1975) and Shannon (1975) suggest the possibility that there may be large-tonnage, low-grade deposits in the Idaho Springs Formation similar to the Rössing deposit of South-West Africa. Berning and others (1976), Smith (1965), and Von Backstrom (1970) describe the Rössing deposit as complex alaskitic pegmatites intruding gneiss, migmatites, amphibolite, and limestone. Smith (1965) indicates that the uranium occurs as uraninite in inclusions in biotite selvages within the pegmatites. Young (1975) describes an occurrence in Wheeler Basin, Grand County, Colorado, where uraninite is disseminated in biotite concentrations that occur in gneiss, migmatite, and pegmatites of the Idaho Springs Formation, which was intruded by Silver Plume Granite. The age of the uraninite is dated as $1,446 \pm 20$ m.y., which corresponds to the age of the Silver Plume intrusion (Ludwig and Young, 1975). Young and Hauff (1975) conclude that the Silver Plume intrusion provided the heat, and possibly the solutions, to mobilize and concentrate some elements within the Idaho Springs Formation, including the uranium. Young presents a comparison of the Wheeler Basin occurrence with the Rössing deposit and indicates a substantial number of similarities in both the general geologic environment and the petrology. Sample 585-1 (see Pl. 1 for location) is from a unit of the Idaho Springs Formation that is often erroneously mapped as Pikes Peak Granite. This sample is a coarse-grained, metasomatic alaskite that has xenoliths of biotite schist throughout. The xenoliths are irregular in shape and as much as 6 in. across. Gamma spectrometric analyses of the alaskite and the xenoliths are shown in Table 9. Both the alaskite and the xenoliths

TABLE 9. URANIUM AND THORIUM VALUES FOR
SAMPLE 585-1

	eU (ppm)	eTh (ppm)	eK (%)
Alaskite	16.4	122	7.9
Xenoliths	40.2	228	3.8

are greatly enriched in uranium and thorium. The similarities of the petrology (alaskite and uranium-enriched biotite schists) and the meta-sedimentary terrane at Rossing and Wheeler Basin with those at sample location 585-1 are an indication that there may be a large, low-grade uranium deposit near site 585-1.

FAVORABLE AREAS FOR URANIUM

Favorability for uranium deposits in the Badger Flats - Elkhorn Thrust project area is considered good for both vein and disseminated, low-grade, large-tonnage uranium deposits. The Badger Flats area is considered to have maximum favorability for vein deposits within the project area. Criteria used for this estimate include the two known uranium occurrences in Badger Flats, an excellent geologic environment for vein deposits, and the results of the water-sampling program. The Last Chance property, an autunite-bearing vein, and the Gold Star property, a zone of secondary enrichment that is probably formed over a vein or pipe, are both in the Badger Flats area. Numerous shears, in the brittle Idaho Springs Formation and the Silver Plume Granite, allow sufficient space for vein deposits in the area. Water samples of the springs in Badger Flats contain 14 to 140 ppb uranium. All evidence indicates that the Badger Flats area has very good potential for vein deposits.

Trends A and B in Plate 1 have maximum favorability in the Badger Flats area. Trend A is the valley southeast of Badger Mountain and the area adjacent to and southeast of the intersection of Highway 24 and County Road 31. On the probable extension of the Last Chance vein near this intersection, a spring sample contains 132 ppb uranium. Trend B might be a zone of secondary enrichment above a lake bed or greisen pipe. A water sample from North O'Brian Gulch taken along this structure contains 140 ppb uranium.

A water sample from Rock Creek near its junction with Tarryall Creek contains 14 ppb uranium. The area drained by Rock Creek (labeled C, Pl. 1) southeast of Jefferson, is recommended for further exploration on the basis of the anomalous water sample, structural setting, and host rock. This drainage basin is considered to be favorable.

The limited time and the number of water samples collected did not allow a complete evaluation of the area. Based on the Rock Creek sample, a program of water sampling is recommended for the drainages of the Lost Park area in the northeastern section of the project area.

The remaining Precambrian rocks in the project area have undetermined potential for uranium vein deposits. Because of regional uranium enrichment, numerous shears, excellent host rocks, and available source mechanisms, the whole area is considered potentially favorable for uranium vein deposits. There are regional similarities between the project area and the Ralston Buttes area, which includes the Schwartzwalder mine. Specific trends for future exploration where N. 30° W. shears intersect Idaho Springs metamorphic units normal, or near normal, to the foliation are outlined on Plate 1 (A through E).

Research and exploration for Rössing-type, low-grade uranium deposits should be encouraged in the Badger Flats - Elkhorn Thrust project area. Favorability for large-tonnage, low-grade uranium deposits is considered good in terms of geologic environment. The geologic history of intrusion, metamorphism, and granitization within the project area is similar to that described in the vicinity of the Rössing deposit. Further exploration for low-grade, large-tonnage uranium deposits in the Badger Flats - Elkhorn Thrust area is warranted because of the similarities to other terranes that have major uranium deposits.

REFERENCES CITED

- Adams, J.A.S., Osmond, J. K., and Rogers, J.J.W., 1959, The geochemistry of thorium and uranium, in Ahrens, C. H., ed., Physics and chemistry of the Earth, Vol. 3: London, Pergamon Press, p. 298-348.
- Adams, J. W., and Stugard, F. S., 1956, Wall rock control of certain pitchblende deposits in Golden Gate Canyon, Jefferson County, Colorado: U.S. Geol. Survey Bull. 1030-G, p. 187-209.
- Aldrich, L. T., Weatherill, G. W., Davis, G. L., and Tilton, G. R., 1958, Radioactive ages of micas from granitic rocks by Rb-Sr and K-Ar methods: Am. Geophys. Union Trans., v. 39, p. 1124-1134.
- Backstrom, J. W. von, 1970, The Rössing uranium deposit near Swakopmund, South West Africa - A preliminary report, in Uranium exploration geology: Vienna, Internat. Atomic Energy Agency, Panel Proc. Ser., p. 143-150.
- Berning, J., and others, 1976, The Rössing uranium deposit, South West Africa: Econ. Geology, v. 71, p. 351-368.
- Bird, A. G., 1957, The petrology and ore deposits of the Schwartzwalder uranium mine, Jefferson County, Colorado [M.S. thesis]: Boulder, Univ. Colorado, 64 p.
- Bryant, Bruce, and Wobus, R. A., 1975, Preliminary geologic map of the southwestern quarter of the Denver 1° x 2° quadrangle, Colorado: U.S. Geol. Survey Open-File Rept. 75-340.
- Chapin, C. E., 1965, Geologic and petrologic features of the Thirtynine Mile volcanic field, central Colorado [D.Sc. thesis]: Golden, Colorado School Mines, 177 p.
- Epis, R. C., Wobus, R. A., Wrucke, C. T., Scott, G. R., and Taylor, R. B., 1975, Geologic map of the northwestern part of the Pueblo 1° x 2° quadrangle, Colorado: U.S. Geol. Survey Open-File Rept. 75-339.
- Fronzel, J. W., Fleischer, Michael, and Jones, R. F., 1967, Glossary of uranium- and thorium-bearing minerals: U.S. Geol. Survey Bull. 1250, 69 p.
- Gruner, J. W., 1952, New data from synthesis of uranium minerals, Pt. I. Ann. Rept., July 1, 1951 to June 30, 1952: Tech. Inf. Service, Oak Ridge, Tenn., U.S. Atomic Energy Comm., RMO-983, 17 p.
- Hawley, C. C., 1963, Geology of the Pikes Peak Granite and associated ore deposits, Lake George beryllium area, Park County, Colorado [Ph.D. dissert.]: Boulder, Univ. Colorado, 291 p.
- _____, 1964, Genetic relation of Pikes Peak Granite and beryllium-bearing greisens, Lake George area, Park County, Colorado [abs.]: Geol. Soc. America Spec. Paper 76, p. 287.

REFERENCES CITED (continued)

- Hawley, C. C., 1969, Geology and beryllium deposits of the Lake George beryllium area, Park and Jefferson Counties, Colorado: U.S. Geol. Survey Prof. Paper 608-A, 44 p.
- Hawley, C. C., Huffman, Claude, Jr., Hamilton, J. C., and Rader, L. F., 1966, Geologic and geochemical features of the Redskin Granite and associated rocks, Lake George beryllium area, Colorado: U.S. Geol. Survey Prof. Paper 550-C, p. 138-147.
- Heier, K. S., and Rhodes, J. M., 1966, Thorium, uranium, and potassium concentrations in granites and gneisses of the Rum Jungle complex, Northern Territory, Australia: Econ. Geology, v. 61, p. 563-571.
- Knipping, H. P., 1974, The concepts of supergene versus hypogene emplacement of uranium at Rabbit Lake, Saskatchewan, Canada, in Formation of uranium ore deposits: Athens, Proc. of Internat. Atomic Energy Agency Symposium, p. 531-549.
- Langford, F. F., 1974, A supergene origin for vein-type uranium ores in light of the Western Australian calcrete-carnotite deposits: Econ. Geology, v. 69, p. 516-526.
- Larsen, E. S., and Gottfried, David, 1961, Distribution of uranium in rocks and minerals of Mesozoic batholiths in western United States: U.S. Geol. Survey Bull. 1070-C, 103 p.
- Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. Paper 223, 319 p.
- Lugwig, K. R., and Young, E. J., 1975, Absolute age of disseminated uraninite in Wheeler Basin, Grand County, Colorado: U.S. Geol. Survey Jour. Research, v. 3, no. 6, p. 747-751.
- Malan, R. C., 1968, Relationship of uranium in the Rocky Mountains of southwestern Colorado to local and regional metallogenesis, in New Mexico Geol. Soc. Guidebook, Nineteenth Field Conf.: p. 185-192.
- Malan, R. C., and Sterling, D. A., 1969, An introduction to the distribution of uranium and thorium in Precambrian rocks including the results of preliminary studies in the southwestern United States: U.S. Atomic Energy Comm. AEC-RD-9, Open-File Rept., 54 p.
- Moreau, M., Poughon, A., Puibaraud, Y., and Sanselme, H., 1966, L'uranium et les granites: Chronique Mines et Recherche Minière, no. 350, p. 47-51.

REFERENCES CITED (continued)

- Nash, J. T., 1975, Secondary enrichment of uranium at the Midnight mine, Washington, in Abstracts of the 1975 Uranium and Thorium Research and Resources Conferences: U.S. Geol. Survey Open-File Rept. 75-595, p. 32.
- Phair, George, and Gottfried, David, 1964, The Colorado Front Range, Colorado, U.S.A., as a uranium and thorium province, in Adams, J.A.S., and Lowder, W. M., eds., The natural radiation environment: Chicago, Univ. Chicago Press, p. 7-38.
- Pienaar, P. J., 1959, Stratigraphy, petrography and genesis of the Elliot Group including the uraniferous conglomerates, Quirke Lake Syncline, Blind River area, Ontario [Ph.D. dissert.]: Kingston, Ontario, Canada, Queen's Univ.
- Rich, R. A., Holland, H. D., and Peterson, Ulrich, 1975, Vein-type uranium deposits: U.S. Energy Research and Devel. Adm., GJO-1640, Open-File Rept., 380 p.
- Rogers, J.J.W., 1964, Statistical tests of the homogeneity of the radioactive components of granitic rocks, in Adams, J.A.S., and Lowder, W. M., eds., The natural radiation environment: Chicago, Univ. Chicago Press, p. 51-62.
- Roscoe, S. M., and Steacy, H. R., 1958, On the geology and radioactive deposits of Blind River region, in Second U.N. Internat. Conf. on the Peaceful Uses of Atomic Energy: p. 475-483.
- Shannon, S. S., 1975, Isochemical metamorphism of uranium deposits, in Abstracts of the 1975 Uranium and Thorium Research and Resources Conf.: U.S. Geol. Survey Open-File Rept. 75-595, p. 45.
- Sheridan, D. M., Maxwell, C. H., and Albee, A. L., 1967, Geology and uranium deposits of the Ralston Buttes District, Jefferson County, Colorado: U.S. Geol. Survey Prof. Paper 520, 121 p.
- Sims, P. K., and Sheridan, D. M., 1964, Geology of uranium deposits in the Front Range, Colorado: U.S. Geol. Survey Bull. 1159, 116 p.
- Smith, D.A.M., 1965, The geology of the area around the Khan and Swakop Rivers in South West Africa: South Africa Geol. Survey Mem., South West Africa Ser. 3, 113 p.
- Stewart, D. D., 1964, The geology and petrology of the Lake George syenite stock, Park and Teller Counties, Colorado [M.S. thesis]: Golden, Colorado School Mines, 115 p.
- Tremblay, L. P., 1972, Geology of the Beaverlodge mining area, Saskatchewan: Canada Geol. Survey Mem. 367, 265 p.

REFERENCES CITED (continued)

- Whitfield, J. M., Rogers, J.J.W., and Adams, J.A.S., 1959, The relationship between the petrology and the thorium and uranium contents of some granitic rocks: *Geochim. et Cosmochim. Acta*, v. 17, p. 248-271.
- Young, E. J., and Hauff, P. L., 1975, An occurrence of disseminated uraninite in Wheeler Basin, Grand County, Colorado: *U.S. Geol. Survey Jour. Research*, v. 3, no. 3, p. 305-311.

APPENDIX A.
LOCATIONS AND CHEMICAL VALUES OF SAMPLES USED IN DETERMINING
REGIONAL URANIUM AND THORIUM CONCENTRATIONS

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LOCATIONS AND CHEMICAL VALUES OF SAMPLES USED IN DETERMINING
REGIONAL URANIUM AND THORIUM CONCENTRATIONS

Sample No.	Location	Unit	eU ppm	eTh ppm
500-1	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	4.8	62.2
500-2	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	6.3	60.4
500-3	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	8.9	56.4
500-4	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	7.0	61.4
500-5	NE $\frac{1}{4}$ sec. 15, T. 11 S., R. 72 W.	Redskin	4.4	60.7
501-1	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	7.4	62.2
501-2	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	6.7	62.1
501-3	SE $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	4.1	57.5
501-4	NE $\frac{1}{4}$ sec. 15, T. 11 S., R. 72 W.	Redskin	7.4	58.2
501-5	NE $\frac{1}{4}$ sec. 15, T. 11 S., R. 72 W.	Redskin	6.9	56.4
502-1	SW $\frac{1}{4}$ sec. 11, T. 11 S., R. 72 W.	Redskin	10.6	62.3
502-2	SW $\frac{1}{4}$ sec. 11, T. 11 S., R. 72 W.	Redskin	11.3	59.9
502-3	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	8.7	61.0
502-5	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	7.9	56.9
502-6	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	7.3	58.7
502-7	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	6.3	57.0
503-1	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	5.8	59.4
503-2	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	6.2	59.8
503-3	NW $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	5.1	61.3
506-1	SW $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	4.2	55.2
506-2	SW $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	5.7	55.0
506-3	SW $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	3.8	50.3
506-4	SW $\frac{1}{4}$ sec. 10, T. 11 S., R. 72 W.	Redskin	5.4	57.1
510-1	NW $\frac{1}{4}$ sec. 11, T. 11 S., R. 72 W.	Redskin	10.5	63.1
511-1	SE $\frac{1}{4}$ sec. 11, T. 11 S., R. 72 W.	Redskin	6.6	61.4
512-1	SE $\frac{1}{4}$ sec. 11, T. 11 S., R. 72 W.	Redskin	12.0	61.5
513-1	NE $\frac{1}{4}$ sec. 15, T. 11 S., R. 72 W.	Redskin	6.2	61.5
514-1	NE $\frac{1}{4}$ sec. 15, T. 11 S., R. 72 W.	Redskin	6.8	62.4
515-2	NE $\frac{1}{4}$ sec. 13, T. 11 S., R. 72 W.	Silver Plume	3.0	3.0
516-1	NE $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	8.3	64.5
516-2	NE $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	13.9	59.1
516-3	NE $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	8.1	60.3
516-4	NE $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	12.1	61.4
516-5	NE $\frac{1}{4}$ sec. 14, T. 11 S., R. 72 W.	Redskin	12.7	59.2
525-1	NE $\frac{1}{4}$ sec. 18, T. 11 S., R. 72 W.	Idaho Springs	3.9	2.2
534-1	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	7.5	8.6
534-2	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	7.0	29.4
534-3	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	5.6	32.8
534-4	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	6.4	33.0
534-5	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	4.9	32.0
534-6	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	6.1	33.6
534-7	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	8.7	30.9

APPENDIX A.
LOCATIONS AND CHEMICAL VALUES OF SAMPLES USED IN DETERMINING
REGIONAL URANIUM AND THORIUM CONCENTRATIONS
(continued)

Sample No.	Location	Unit	eU ppm	eTh ppm
534-8	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	8.1	31.6
534-9	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	5.3	31.6
534-10	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	7.6	33.1
534-11	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	6.1	31.5
534-12	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	6.7	30.3
534-13	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	5.3	31.9
534-14	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	8.3	7.9
534-15	SW $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	6.5	32.2
534-16	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	8.5	29.4
534-17	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	6.9	34.0
534-18	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	5.8	32.5
534-19	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	7.1	13.6
534-20	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	6.7	15.5
534-21	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	10.2	33.7
534-22	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	13.5	35.1
534-23	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	6.9	37.1
534-24	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	7.4	29.9
534-25	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	5.8	34.0
534-26	NW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	7.6	27.3
535-1	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Idaho Springs	3.0	2.6
535-2	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Idaho Springs	3.6	13.3
535-3	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Idaho Springs	8.3	21.1
535-4	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Idaho Springs	4.7	16.2
535-5	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Idaho Springs	4.0	12.8
535-6	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	7.6	26.4
535-7	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	10.4	26.0
535-8	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	8.4	23.0
535-9	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	8.8	25.2
535-10	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	7.9	28.6
535-11	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.3	27.3
535-12	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	7.4	30.8
535-13	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.5	19.3
535-14	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	6.9	29.0
535-15	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	6.1	26.3
535-16	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	6.5	25.3
535-17	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.4	25.0
535-19	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.7	25.1
535-20	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.9	26.1
535-21	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.2	24.7
535-22	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	6.7	27.2
535-23	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	0.6	0.8
535-24	NW $\frac{1}{4}$ sec. 5, T. 12 S., R. 72 W.	Silver Plume	5.8	18.4
537-1	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	3.8	27.4
537-2	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	4.7	33.0

APPENDIX A.
LOCATIONS AND CHEMICAL VALUES OF SAMPLES USED IN DETERMINING
REGIONAL URANIUM AND THORIUM CONCENTRATIONS
(continued)

Sample No.	Location	Unit	eU ppm	eTh ppm
537-3	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	9.1	32.7
537-4	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	10.6	32.6
537-5	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	6.2	30.4
537-6	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	5.9	29.9
537-7	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	8.0	26.6
537-8	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	9.7	29.8
537-9	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	3.3	3.7
537-10	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	6.2	28.5
537-11	NE $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	10.0	21.4
537-12	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	11.2	23.4
537-13	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	7.8	32.6
537-14	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	10.9	21.9
537-15	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	12.7	39.9
537-16	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	7.4	31.7
537-17	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	4.6	22.7
537-18	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	4.3	12.6
537-19	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	7.9	28.8
537-20	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	5.9	29.2
537-21	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	5.3	26.6
537-22	SW $\frac{1}{4}$ sec. 31, T. 11 S., R. 72 W.	Silver Plume	10.6	30.5
538-1	SW $\frac{1}{4}$ sec. 24, T. 11 S., R. 73 W.	Silver Plume	3.0	13.6
538-2	SW $\frac{1}{4}$ sec. 24, T. 11 S., R. 73 W.	Silver Plume	3.3	23.7
538-3	SW $\frac{1}{4}$ sec. 24, T. 11 S., R. 73 W.	Silver Plume	4.7	18.7
538-4	SW $\frac{1}{4}$ sec. 24, T. 11 S., R. 73 W.	Silver Plume	3.3	19.2
538-5	SW $\frac{1}{4}$ sec. 24, T. 11 S., R. 73 W.	Silver Plume	1.1	1.7
538-6	SW $\frac{1}{4}$ sec. 24, T. 11 S., R. 73 W.	Silver Plume	4.4	57.2
541-1	NE $\frac{1}{4}$ sec. 25, T. 11 S., R. 72 W.	Silver Plume	5.5	22.3
542-1	C sec. 26, T. 11 S., R. 72 W.	Redskin	7.6	8.7
542-2	C sec. 26, T. 11 S., R. 72 W.	Redskin	4.5	69.5
542-3	C sec. 26, T. 11 S., R. 72 W.	Redskin	4.3	61.7
543-1	SW $\frac{1}{4}$ sec. 12, T. 11 S., R. 73 W.	Silver Plume	8.7	41.4
544-1	SE $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	6.8	28.7
544-2	SE $\frac{1}{4}$ sec. 30, T. 11 S., R. 72 W.	Silver Plume	7.0	56.1
545-1	NE $\frac{1}{4}$ sec. 27, T. 12 S., R. 72 W.	Pikes Peak	1.6	61.3
546-1	NW $\frac{1}{4}$ sec. 24, T. 10 S., R. 73 W.	Pikes Peak	2.5	21.3
547-1	NE $\frac{1}{4}$ sec. 30, T. 10 S., R. 72 W.	Pikes Peak	5.9	49.4
548-1	NW $\frac{1}{4}$ sec. 16, T. 13 S., R. 70 W.	Pikes Peak	1.8	20.6
550-1	NW $\frac{1}{4}$ sec. 24, T. 11 S., R. 71 W.	Pikes Peak	2.3	16.7
552-1	SW $\frac{1}{4}$ sec. 21, T. 12 S., R. 71 W.	Pikes Peak	2.8	16.1
552-2	SW $\frac{1}{4}$ sec. 21, T. 12 S., R. 71 W.	Pikes Peak	4.8	33.6
554-1	NW $\frac{1}{4}$ sec. 3, T. 12 S., R. 73 W.	Silver Plume	1.1	10.4
554-2	NW $\frac{1}{4}$ sec. 3, T. 12 S., R. 73 W.	Silver Plume	2.7	2.7

APPENDIX A.
LOCATIONS AND CHEMICAL VALUES OF SAMPLES USED IN DETERMINING
REGIONAL URANIUM AND THORIUM CONCENTRATIONS
(continued)

Sample No.	Location	Unit	eU ppm	eTh ppm
555-1	NE $\frac{1}{4}$ sec. 28, T. 11 S., R. 73 W.	Idaho Springs	4.1	13.7
556-1	NE $\frac{1}{4}$ sec. 20, T. 11 S., R. 73 W.	Silver Plume	10.2	39.8
557-1	NW $\frac{1}{4}$ sec. 13, T. 11 S., R. 74 W.	Silver Plume	6.0	53.5
558-1	NW $\frac{1}{4}$ sec. 36, T. 10 S., R. 74 W.	Silver Plume	4.5	41.5
560-1	SW $\frac{1}{4}$ sec. 36, T. 9 S., R. 74 W.	Pikes Peak	1.4	2.0
561-1	NE $\frac{1}{4}$ sec. 21, T. 8 S., R. 75 W.	Pikes Peak	3.4	25.4
562-1	SW $\frac{1}{4}$ sec. 35, T. 8 S., R. 75 W.	Pikes Peak	3.5	30.8
564-1	SE $\frac{1}{4}$ sec. 17, T. 8 S., R. 74 W.	Idaho Springs	3.8	11.6
567-1	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	3.8	23.9
567-2	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	1.6	2.3
567-3	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	1.2	1.7
567-4	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	1.3	15.6
567-5	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	1.0	1.8
567-6	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	1.1	5.9
567-7	NE $\frac{1}{4}$ sec. 17, T. 12 S., R. 72 W.	Idaho Springs	1.4	2.3
568-1	SW $\frac{1}{4}$ sec. 20, T. 12 S., R. 71 W.	Redskin	7.5	61.2

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