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MODES OF URANIUM OCCURRENCES IN COLORADO FRONT RANGE

by Dr. Robert Carpenter

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ABSTRACT

This report is an analysis of the various types of uranium occurrences in the Colorado Front Range and the environments in which they developed. The early Proterozoic crust of this region is believed to have been a platform on which intermediate to felsic volcanic centers formed. Some units in the volcanic stratigraphy as well as in the sediments which were deposited in the shallow, intervening seaways are thought to have been uraniferous.

Tectonism, occurring about 1.7 b.y. ago, was accompanied and followed by three periods of Precambrian igneous activity: the Boulder Creek, 1.7 b.y. ago, the Silver Plume, 1.4 b.y. ago, and the Pikes Peak, 1.0 b.y. ago. The volcanics and sediments were converted to a metavolcanic-metasedimentary sequence known as the Idaho Springs Formation. Some of the syngenetic uranium remaining in the volcanics and sediments after metamorphism may have been mobilized and incorporated within the Silver Plume plutons and the Pikes Peak batholith and concentrated in pegmatite dikes, pegmatites and fractured areas in the hood zones in the apophyses, or along the flanks of these intrusives. Some or most of the uranium found in these sites may have been generated deeper in the continental plate.

Uplift of the Front Range in the Late Mississippian and arching during the Laramide with accompanying faulting set the stage for early and mid-Tertiary igneous activity and associated uranium mineralization. Many of the uranium-bearing veins in the northern part of the Colorado Mineral Belt formed at this time, as did the shear-zone deposits in the Foothills Uranium Belt.

The source of the early and mid-Tertiary uranium mineralization is a point of current debate. Phair and Jenkins (1975) have shown a close association of Tertiary uranium mineralization with late stage monzonite magmas along the Colorado Mineral Belt. Simmons and Hedge (1978) point to a deep crustal source for these silica saturated intrusives. The writers suggest that the associated uranium may have been derived from a) the same deep, magma source, b) it may have been leached in part from the Precambrian metamorphics as indicated by Braddock (1969), or c) supplied in part by supergene-meteoric processes as proposed by Young (1978).

Exploration for uranium in the igneous and metamorphic terrain of the Front Range is summarized, and models of each major uranium occurrence are described. Finally, the Front Range exploration potential for uranium is outlined.

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Bibliography of Radioactive Mineral Occurrences in the
Front Range (Appendix B).

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INTRODUCTION

Objectives

This report attempts to describe the modes of occurrence of uranium in the igneous and metamorphic terrain of the Colorado Front Range, based upon field observations and literature review. Models for each type of uranium occurrence were designated through consideration of the sources and concentration mechanisms of uranium in the various dynamic environments represented by major stages in the evolution of the Front Range: Proterozoic deposition and subsequent metamorphism; middle and late Proterozoic igneous events; Proterozoic and Phanerozoic tectonism; and, finally, late Cretaceous and Tertiary igneous activity.

CHAPTER A

LATE ARCHEAN AND EARLY TO MIDDLE PROTEROZOIC GEOLOGIC DEVELOPMENTS IN SOUTHERN WYOMING AND NORTHERN COLORADO

The purpose of a brief summary of Precambrian developments in southern Wyoming and northern Colorado is to give the reader a broader perspective of the regional geology by fitting early-middle Proterozoic events of the Front Range into a larger, regional setting as developed by Houston, Graff, Karlstrom, and Lanthier of the University of Wyoming, and by Hills, Hedge, and others of the U.S. Geological Survey.

Radiometric age dating in Wyoming and Colorado has revealed two adjacent geological provinces which are distinctly different in age. Wyoming and adjacent areas of South Dakota, Montana, and Utah constitute the Wyoming Archean province. Felsic gneisses and associated metasediments in the Beartooth Mountains have been dated at 3.0 b.y. As this date may reflect isotopic resetting during metamorphism, it is believed that they may be as old as 3.4 b.y. (Hedge, pers. commun.). The ages of the metamorphic rocks which fringe this central core are somewhat younger (2.8 b.y.). Tonalite and granodiorite plutons which intruded these older rocks have ages

in the range of 2.50 to 2.76 b.y. (Hedge and others, 1978). In southern Wyoming, tightly folded lower Proterozoic meta-sediments bear an unconformable relationship to the Archean sequence. In Colorado, maximum ages for igneous rocks fall in the range of 1.8-1.7 b.y. The metasediments which these rocks intrude are believed to be only slightly older, less than 2.0 b.y.

The northeast-trending Mullen Creek-Nash Fork shear zone, 0.1-10 km broad, appears to define the boundary between the two provinces. The development of this shear zone is thought to have been contemporaneous with regional deformation and metamorphism (1.8-1.7 b.y.) and Boulder Creek-age plutonism, which occurred only to the southeast of the shear zone. Evidence suggests that plutonism, deformation, and metamorphism were related to intercratonic subduction, the development of a continental margin-arc or island-arc to the south, and collision between the northern continental margin and this southern continental margin or island-arc (see Plate 2).

Workers believe that the Wyoming Archean province may have been continuous with the Superior Province of Ontario (see Plate 1). Divis (1976, p. 98) has indicated that the Archean gneisses of the northern Sierra Madre represent a volcanic sequence deformed during an orogenic event probably equivalent to the Kenoran of the Canadian Shield and the

(Reproduced from Warner, 1978, Fig. 3, p. 166).

3b

LOWER-MIDDLE PROTEROZOIC MODEL FOR S. WYOMING AND N. CENTRAL COLORADO

(After Hills and Huston, 1978)

Algoman of the Great Lakes region. Therefore, it is believed that a continental margin with a generally northeasterly trend existed in southern Wyoming as early as 2.5-2.6 b.y. ago (Divis, 1976). Hills and Houston (1978) state that this continental margin was probably of the Atlantic type. Presumably, Kenoran-age orogeny and subsequent erosion initiated, along the southern flank of this Archean continental margin, the deposition of a thick wedge (13.5 km) of fluvial, fluvio-marine, and glacio-marine sediments known as the Snowy Range Supergroup (Graff, 1978; see strat. column, Plate 3). This sequence is thought to correspond to the Huronian Supergroup of the Canadian Shield (Graff, pers. commun.).

Uranium-bearing conglomerates, similar to those at Blind River, Ontario, are associated with two unconformities: one within the Phantom Lake Group and the other at the base of the Deep Lake Group. Mineralization in these conglomeratic horizons includes coffinite and thorite together with Ni-Co-Fe sulfides, chalcopyrite, columbite, and rounded grains of carbon. However, a uraninite-placer origin of these deposits is uncertain (Houston, oral commun., [W.G.A. Conference, Laramie, 1978]).

Workers believe that the deformation and metamorphism of this thick lower Proterozoic sequence resulted from a collision between the Archean continent and a margin-arc or

STRATIGRAPHIC COLUMN OF THE SNOWY RANGE
SUPERGROUP, SOUTHERN WYOMING

(After Graff; Karlstrom; Lanthier; 1978)

SUPERGROUP	GROUP	THICKNESS (meters)	FORMATION	LITHOLOGY	ENVIRONMENT OF DEPOSITION
SNOWY RANGE SUPERGROUP	LIBBY CREEK GROUP (Lanthier, 1978) (6.8km)	610	French Slate	Black pyritic shale	
		180-490	Towner G'nstone	Fine-grained amph. w/coarse gabbroic bodies.	
		1980	Nash Fork	Stromatolitic metadolomite w/ lenticular bodies of calc-biotite phyllite and blk. slate	
		580	Sugar loaf	Well-sorted, homogenous, fine-med. grained quartzite	
		0-400	Look Out	Laminated, qtz.-musc. schist	Deep water turbidites
		1700	Medicine Pk quartzite	Coarse-grained quartzite w/quartz pebble layers; tabular and planar x-sets	Fines upward ; delta, prodelta, beach, shallow shelf
		670	Heart	Quartzite w/discontinuous phyllite unit near center of form.	Fluvial; upward transition to marine deposition
		680	Headquarters	<ul style="list-style-type: none">• Quartzite• Phyllite• Qtzite. w/lenticular bodies of diamictite and phyllite• Basal diamictite	Glacio-marine; unconformably overlies Deep Lake Formation (interglacial transgression)
	DEEP LAKE GROUP (3.3km) (Karlstrom, 1978)	380	Rock Knoll	Qtzite, minor phyllite, +qtzite-pebble congl.	Shallow water marine
		350	Vagner	Paracongl., marble, + phyllite	Glacial, glacio-marine, marine ls. + shale
		1500	Cascade	Pebble quartzite w/black chert	Fluvial
		75	Campbell Lake	Thin paracongl. (marker) + marine sh.	Subaerial glacial + marine
		440	Lindsey	Fine-grained, trough x-bedded quartzite	Fluvial
		570	Magnolia	Coarse-gr., trough x-bedded qtzite.; ark. qtz. pebble cong. U-bearing at base	Fluvial; Paleocurrents indicate SW transport from source area of Arch. metased. granite for most of Deep Lake+ Upper Phantom Lake groups
	PHANTOM LAKE GROUP (3.0km)		(UPPER)	<p>DOMINANTLY Micaceous marine quartzite (phyllitic)</p> <p>Arkosic, qtz.-pebble congl.; U-bearing</p>	Marine
			(LOWER)	DOMINANTLY Metavolcanics	U=20X background; lenses of congl. channels, and sheets up to 30m thick; w/ congl., some carbonate, graywackes, metavolcanics, + phyll. quartzite; also granite boulders; lowest part of congl. has highest U content (100ppm); pyrite + pebble matrix. subaerial volcanism
ARCHEAN				Layered amphibolite gneisses, quartzites and metavolcanics interlayered with felsic gneisses	

island-arc complex advancing from the south. Dickinson (1974) illustrates the setting and sequence of such an event involving a continental margin (see Fig. 1). It has been suggested that this volcanic arc environment is represented, in part, by the metasedimentary (Idaho Springs Formation) and igneous rocks of central and northern Colorado. The sedimentary rocks in this environment probably would have included those types associated with fore-arc, intra-arc, and possibly retro-arc basins. Boulder Creek-age (X) intrusions would then represent igneous activity within the arc complex during its advance and collision with the Archean continental margin as shown in Plate 2. Deformation and metamorphism of amphibolite-grade in the region are also attributed to this event.

It is believed that the Mullen Creek-Nash Fork shear zone represents the collision interface. Houston and Parker (1963), noted a displacement of metadolomite which would indicate at least 10 km of left-lateral slip, although actual displacement may have been much more. Northeast-trending shear zones in the Front Range, such as the Idaho Springs-Ralston Creek shear zone, may represent large wrench faults developed in response to the same or a similar stress field (Warner, 1978). Imbricate thrusting southeast of the shear zone allowed intrusion of a series of gabbroic and layered ultramafic bodies which may represent the basal components

Idealized diagrams to illustrate hypothetical sequence of events, and associated sedimentary basins (stippled), during crustal collision between rifted continental margin (see fig. 7) on left and continental margin arc (see fig. 10b) on right: *a*, prior to collision; *b*, initial collision; *c*, final suturing (vertical exaggeration is 10×). Oceanic and quasioceanic crust is crosshatched; continental, quasicontinental, and paracontinental substratum is jackstrawed. Symbols: RMP, rifted-margin prism (horizontal rules); ROB, remnant ocean basin (sea level as dashed line); SC, subduction complex (vertical rules); FAB, fore-arc basin; RAB, retroarc basin; FTB, foreland fold-thrust belts.

COLLISION BETWEEN RIFTED CONTINENTAL MARGIN AND CONTINENTAL MARGIN ARC

(Reproduced from Dickinson, 1974, fig. 11, p. 22.)

of the arc complex. Kyanite in the rocks of the Snowy Range Supergroup northwest of the shear zone is thought to have developed under the high-pressure, low-temperature conditions created by the thrusting of arc material over these rocks. The Front Range, with the widespread occurrence of high-temperature cordierite, is thought to represent the middle-to upper-arc environment.

The following chapter includes descriptions of several sections of metamorphic rocks found within the Front Range and a discussion of their possible parent rock types, with regard to the premetamorphic environment in which these may have occurred. Also included is a discussion of metamorphic, deformational, and subsequent Precambrian intrusive events.

CHAPTER B

AGE RELATIONSHIPS AMONG TECTONICS, METAMORPHISM, AND IGNEOUS ACTIVITY

Precambrian Events

The original accumulation of Proterozoic sediments is thought to exceed 13,700 m in thickness (Peterman and others, 1968). Soon after the deposition of these sediments, metamorphism is thought to have occurred within a relative short span of time (Hedge, 1969). Metamorphism along the Front Range is high grade. A detailed study by Wahlstrom and Kim (1959) provides a good example of the processes which formed these metamorphic rocks. Compressive forces during deformation created elevated temperatures which initiated recrystallization of the sedimentary rocks. Clastic basaltic material formed hornblende-plagioclase gneiss; arenaceous, dolomitic limestone formed banded calcitic rock in the lime-silicate units; and graywackes formed biotite-sillimanite gneisses. As the thermal maximum was obtained, mineralogy common to high-grade metamorphism was developed. Locally, chlorite and epidote formed from calcareous minerals, and muscovite and sericite replaced sillimanite. The formation of these new minerals at the expense of the older

ones indicates moderate metamorphic retrogression. In certain areas, new elements were introduced and the original components were widely redistributed to form migmatites. During the formation of these migmatites, it appears that calcium migrated to the outer fringes, while the alkalis, particularly K_2O , were concentrated within the zone. The occurrence of lit-par-lit gneisses and the parallelism of the gneissic fabric suggest that the migmatizing solutions moved along existing foliation planes.

Mapping in the Black Hawk region, located in the core of the central Front Range, has led Taylor (1975) to describe three phases of deformation:

Period I deformation occurred when temperature and pressure reached the uppermost amphibolite facies. During this thermal event, migmatitic pegmatites formed in the gneisses. Northwest-trending folds with wavelengths of approximately one mile developed during this period.

Period II deformation created folds whose axes trend from north-northwest to north-northeast. It is believed that the emplacement of the Boulder Creek Granodiorite occurred during the later stages of deformation. The metamorphic environment is thought to have been similar to that developed during the Period I deformation.

Period III deformation created the prominent northeast-trending Idaho Springs-Ralston Creek cataclastic zone. This period of tectonism was characterized by initial plastic folding which evolved to shear folding and cataclastic shearing. To the west of the Black Hawk area, the Silver Plume quartz monzonite is reported to exhibit characteristics which indicate that its emplacement was late-synkinematic in relation to this period of folding.

The timing of these three major geologic events can be extended northward along the Front Range, as shown by Peterman and others (1968). They recognize an initial event of deformation and metamorphism which followed sedimentation (Period I). The next event was folding (Period II) accompanied by metamorphism and intrusion of the Boulder Creek Granite and similar plutons. These two events were followed by a time (Period III) of active plutonism and minor tectonism. The Silver Plume and related plutons were emplaced during this last event. Table 1 lists the age dates of the various intrusions along the Front Range, and Plate 4 shows the regional distribution of these plutons.

Lovering and Goddard (1950) describe the Front Range as a large regional anticline which trends northerly and is modified by complex crenulations, cross folds, and longitudinal folds. The major folds on the western flank of the

PRECAMBRIAN & TERTIARY IGNEOUS ROCKS of the FRONT RANGE, COLORADO (SOMEWHAT GENERALIZED)

Table 1

AGE DATES OF FRONT RANGE PRECAMBRIAN EVENTS

(After Hutchinson, 1976)

CENTRAL COLORADO FRONT RANGE

Lake George stock	950 my
Lake Moraine stock	950 my
Mount Rosa complex	950 my
Redskin stock	1010 my
Satellititic stocks	1010-1020 my
Cripple Creek syenite stock	1020 my
Pikes Peak batholith	1040 $\pm$ 13 my
Rosalie lobe	1040 $\pm$ 13 my
Dikes of Pikes Peak Granite	1040 $\pm$ 13 my

CATACLASIS (1300 my)

Cripple Creek Granite	1430 my
Indian Creek plutons	1450 my
Silver Plume batholith	1450 my
Kenosha batholith	1430 my
Elevenmile Canyon quartz monzonite	1460 my
Silver Plume disturbance - thermal event	1470-1390 my

CESSATION OF PLASTIC DEFORMATION (1960 my)

Phanton Canyon-Cripple Creek Augen Gneiss	1690-1700 my
Trout Creek Augen Gneiss	1700 my
Boulder Creek Granodiorite	1710 $\pm$ 40 my
Mount Evans Gneiss	1710 my
"Old Migmatite"	1700-1750 my
Boulder Creek Orogeny	1690-1750 my
Accumulation of very thick sequence of sedimentary and volcanic rocks. Deposition of units of the Idaho Springs Fm.	1800-1900 my

uplift are parallel to the regional axes, while those on the eastern flank are crumpled into tight transverse folds plunging east-northeast. Faulting and shearing in the vicinity of the intersection of the Colorado Mineral Belt and the Front Range have been described by Tweto and Sims (1963). They note that the northeast-trending shear zones are cut by a set of younger, northwest-trending faults and breccia reefs that extend across the shear zones and displace them.

The Rogers fault zone, a northwesterly trending feature, hosts the Schwartzwalder mine. Other principal uranium occurrences along the Front Range also appear to be associated with these northwesterly-trending zones. Tweto and Sims (1963) discuss two kinds of northwesterly trending, cross-cutting shears: large, first-order shear zones or faults which are the same general age as the northeast-trending shear zones, and smaller, second-order faults and breccia reefs which are generally younger than the major shear zones. In addition to these Precambrian structural features, there are also numerous northwest-trending faults, several of which can be traced across the full width of the mineral belt.

Some of these persistent faults appear to have a history of strike-slip movement during the Precambrian and oblique and vertical movement during the Laramide Orogeny.

PRECAMBRIAN METAMORPHICS OF THE FRONT RANGE

The Precambrian Idaho Springs Formation is host rock for the vein-type uranium deposits of the Front Range. This formation is also the country rock for migmatite uranium occurrences as well as pegmatite and cauldron occurrences. The original rocks are believed to have accumulated in a basin during a period of sedimentation 1,700-2,000 m.y. ago. (Hedge, 1969). The original sedimentary sequence is thought to be composed mainly of sandstones, shales, and volcanics (Taylor, 1978, oral communication), and Plate 5 is a generalized sketch map showing the outcrop distribution of rocks which were formed during Precambrian (X) time. The following lithostratigraphic descriptions of three separate areas which are transverse to the strike of the Front Range uplift were taken from the published literature. These three sections are representative of the Precambrian metamorphics of the Front Range. The location of these sections are shown on Plate 5. Unit thickness was not reported for the Ralston Buttes area; however, in the other two locations published thicknesses range from 0 to over 2,500 feet.

Ralston Buttes Area

The following description of the Ralston Buttes area is based on work by Sheridan and others (1967). This portion of

WYOMING
COLORADO

PLATE 5

**GENERALIZED GEOLOGIC SKETCH
MAP OF THE FRONT RANGE
SHOWING METAMORPHIC
ROCKS OF PRECAMBRIAN
"X" TIME
("Idaho Springs" formation)**

(Modified after Tweto, 1976).

the Front Range hosts the most important hard-rock uranium deposits that have been found to date in Colorado. Assuming that the youngest beds of the area are found in the major synclines, Sheridan and others have proposed the stratigraphic sequence discussed below. However, because of the structural complexities of the district, they state that it is possible that the true stratigraphic position of these units could differ from their column. Fisher (1976) discusses a different structural interpretation for this area.

The following lithologic description, after Sheridan and others (1967), begins with the uppermost unit and proceeds down-section. (Plate 6).

A. Quartzite unit

This unit is composed of quartzites and conglomeratic quartzites, with infrequent interbedded schists. Some layers contain sparse lenses of calc-silicate rocks. The conglomeratic layers occur as numerous layers and lenses and range from 1/2 foot up to 20 feet in thickness. The quartzite layers are composed of quartz grains which are generally less than 1 mm, with some up to 2 mm. The contact with the lower interlayered gneiss and schist is believed to be conformable.

B. Interlayered biotite-quartz-plagioclase gneiss and mica schist unit

This unit, which also is referred to as a biotite or mica schist, appears to have conformable contacts. The unit

GENERALIZED LITHOLOGIC UNITS OF METAMORPHIC ROCKS ACROSS THE FRONT RANGE – No Scale Implied.

HALL VALLEY (After Wahlgren and Kim, 1959)

CENTRAL CITY (After Sims and Gable, 1967)

RALSTON BUTTES (After Sheridan and others, 1967)

KEY (See text for description of units.)

QUARTZITE

GNEISS

UNCONFORMITY

SCHIST

LIME-SILICATE

is composed principally of quartz, plagioclase, biotite, and muscovite, with local thin layers of amphibolite, hornblende gneiss, and calc-silicate gneiss.

C. Interlayered gneisses

This multi-layered unit consists predominantly of biotite gneiss, amphibolite, hornblende gneiss, layered calc-silicate gneiss, and lesser amounts of impure marble and quartz gneiss. Three main layers have been described within this unit: 1) a garnetiferous quartz-biotite schist which rests directly above a microcline gneiss and appears to pinch out in a westerly direction; 2) a biotite-quartz-plagioclase gneiss, with interlayered amphibolite and hornblende gneiss, which shows no structural discordance with any of the enclosing rocks; 3) a layered calc-silicate gneiss, amphibolite and hornblende gneiss, quartz gneiss, and impure marble.

D. Microcline-quartz-plagioclase-biotite gneiss complexly interlayered with other rocks

This unit is located in the northeast portion of the district, but its distribution is complex and poorly known. The unit is composed of varying thicknesses of amphibolite, hornblende gneiss, layered calc-silicate gneiss, biotite gneiss, and infrequent quartz gneiss. A garnetiferous-schist layer is generally found along the sharp basal contact with the underlying microcline gneiss.

E. Microcline-quartz-plagioclase-biotite gneiss

This unit, also called a microcline gneiss, displays a sharp upper contact with the interlayered gneisses described above. The lower contact with the hornblende gneiss is sharp over much of the area; however, at one locality, it is gradational over a zone 100-200 feet wide.

F. Hornblende-gneiss unit

The hornblende-gneiss unit is important, as most of the uranium deposits of the district are along faults within the unit or at its contact with the underlying mica schist. The unit is composed of calc-silicate gneiss, amphibolite, and rocks of intermediate nature. The contacts with the other units are sharp, except that the unit is transitional with the lower mica schist. This transitional zone includes garnetiferous biotite-quartz gneiss and is generally 50 feet thick; near the Charlie adit of the Schwartzwalder mine it obtains a thickness of about 300 feet. However, in some areas it may be absent altogether. The transition zone weathers to a rusty-brown color, giving it the appearance of a gossan. This effect is due to the presence of disseminated iron sulfides. The garnetiferous biotite-quartz gneiss locally contains 5-10 percent pyrite and pyrrhotite. At the Aubrey Ladwig mine lithologies are similar to those at the Schwartzwalder mine, and the transition zone is 200-300 feet thick.

Downs and Bird (1965) have mapped a chloritic schist in the vicinity of the Charlie adit. Any relation that it may bear to the ore at the Schwartzwalder is unknown. However, in a paper comparing exploration guides for the northern Australian uranium deposits with those for the uranium deposits of Saskatchewan, Morton (1977, p. 249-251) has emphasized that the "familiar lithologic controls of uranium mineralization" as seen in both countries include sites of faulted chloritic lithologies and pyritic horizons. He further states that the deposits of Ranger One and Jabiluka indicate an important lithologic association in which calc-silicate-bearing horizons pass laterally into more-siliceous or chloritic lithologies. While a detailed stratigraphic and facies analysis was not undertaken during the course of this research, such a study may result in meaningful exploration guides. In this regard, Sheridan and others (1967) have reported that the Mena mine appears to be located near such a facies change within the hornblende-gneiss unit.

G. Mica schist

The mica-schist unit is composed mainly of quartz, muscovite, and biotite, with microcline in sparse amounts. As previously discussed, the upper contact is transitional with the hornblende-gneiss unit. Alternating quartz-rich layers and mica-rich layers, 1-2 mm thick, occur in this unit.

Central City Area

The Central City area is located about 13 miles west of the Ralston Buttes district (Plates 5 and 6). Sims and Gable (1967) have reported that the metamorphic rocks here comprise a stratigraphic sequence of three layers of microcline gneiss with interbedded biotite gneiss units. The microcline gneisses are granitic in appearance and display conspicuous layering. The rocks are light- to medium-gray and fine-to medium-grained. Principal minerals are potassium feldspar, plagioclase, and quartz. There are three types of biotite gneiss: a biotite-quartz-plagioclase gneiss, a sillimanitic biotite gneiss, and cordierite- and garnet-bearing sillimanitic biotite gneiss. Amphibolite is widely dispersed in the microcline gneiss, and less commonly in the biotite gneiss. In this rock, hornblende is more abundant than plagioclase, and quartz is less than 10 percent. The calc-silicate rocks contain various amounts of clinopyroxene and scapolite.

The following lithologic sequence is believed to be from the uppermost unit to the lowermost unit (Sims and Gable, 1967).

A. Biotite gneiss

This unit contains interlayered sillimanitic biotite gneiss and biotite-quartz-plagioclase gneiss.

B. Microcline gneiss (Lawson Layer)

The composition of this unit ranges from a quartz monzonite to a granodiorite containing small bodies of amphibolite and biotite gneiss. The upper contact intertongues with the biotite gneiss.

C. Biotite gneiss

This unit is very similar to the biotite gneiss described in A except that it contains lenses of microcline gneiss, amphibolite, and calc-silicate gneiss.

D. Microcline gneiss (Quartz Hill Layer)

The composition of this unit generally is a granodiorite. Small bodies of biotite-quartz-plagioclase gneiss, amphibolite, calc-silicate gneiss, and cordierite-amphibole gneiss occur locally. This unit thins in a southerly direction.

E. Biotite Gneiss

This unit, mainly a sillimanitic biotite gneiss, appears to pinch out in a southwesterly direction.

F. Microcline gneiss (Big Five Layer)

Small lenses of amphibolite occur along the margins of this unit. It also thins in a southwesterly direction.

G. Biotite gneiss

The lower contact of this sillimanitic biotite gneiss is not exposed.

Hall Valley Area

The Hall Valley section is located about 25 miles southwest of Central City (Plate 5). The following summary and description of the stratigraphic section has been abstracted from Wahlstrom and Kim (1959). The stratigraphic sequence is located to the west of a highly migmatized zone. At this locality, the metamorphic rocks have been divided into two main groups which are separated by an unconformity. The angular discordance between the rocks above and below the unconformity is 5-15°. The upper group consists dominantly of varying amounts of quartz-biotite gneiss and plagioclase-hornblende gneiss. The group below the unconformity can be described in general terms as a repetitive sequence of quartz- and biotite-rich gneisses overlain by lime-silicate rocks. These lower cyclic deposits have been truncated by the Hall Valley unconformity. The occurrence of this unconformity is noteworthy, as there exists an empirical, if not genetic, relationship between Proterozoic unconformities and uranium deposits in other areas of the world.

The following description of the Precambrian stratigraphic sequence at Hall Valley begins with the uppermost unit and proceeds down-section (Plate 6 and Plate 7).

A. Quartz-biotite gneiss

This foliated unit contains quartz, microcline, oligoclase, and biotite; small bodies of plagioclase-hornblende-biotite gneiss

are also present. The basal contact is gradational.

B. Plagioclase-hornblende-biotite gneiss and quartz-biotite gneiss

This unit is mainly a plagioclase-hornblende-biotite schist and gneiss. Also present are locally abundant lenses of quartz-biotite gneiss rich in intermediate plagioclase and/or microcline.

C. Quartz-biotite gneiss and quartz-plagioclase-hornblende gneiss

The upper and lower contacts of this unit are gradational. Alternating layers of gneisses of differing composition are present.

D. Hornblende-plagioclase gneiss

This dark unit contains thin layers of various gneisses.

E. Plagioclase-hornblende-biotite gneiss and augen quartz-biotite gneiss

The upper contact of this foliated unit is gradational. The lower contact rests unconformably on the underlying unit.

F. Quartz-biotite gneiss

The upper contact of this unit is the Hall Valley unconformity. The lower gradational boundary is rich in biotite. Quartzite lenses and layers are abundant in the middle part of the unit. Below the unconformity, numerous muscovite aplite bodies are present.

G. Lime-silicate unit

Both upper and lower contacts are gradational. This unit is also truncated by the Hall Valley unconformity. The unit consists of hornblende-plagioclase gneiss and schist, amphibolite, lime hornfels, pyroxene rock, skarn, marble, and thin quartzite layers.

H. Quartz-biotite gneiss

Both contacts of the unit are gradational. Dominant minerals in this unit are quartz, plagioclase, microcline, and biotite. The Hall Valley unconformity partly truncates the unit.

I. Lime-Silicate rocks

Both contacts of the unit are gradational. Thin layers of pyroxene and/or calcic-plagioclase are contained in hornblende-plagioclase schist and gneiss layers.

J. Quartz-biotite gneiss

Both upper and lower contacts of the unit are gradational. The unit consists dominantly of quartz, microcline, sodic to intermediate plagioclase, and biotite.

K. Biotite-sillimanite gneiss

Both upper and lower contacts of the unit are gradational. Large flakes of biotite and lenses of sillimanite are reported as being characteristic. The principal minerals are quartz, microcline, intermediate plagioclase, biotite, sillimanite, and muscovite.

L. Lime-silicate rock

The upper contact of the unit is gradational, but the lower contact is sharp. The following rock types are complexly interlayered: hornblende-plagioclase schist, pyroxene rock, lime hornfels, and layers of calcite and quartzite.

M. Quartz schist

The upper contact is sharp and the lower one was reported as not being observed. This is the oldest layer in the Hall Valley area. The unit is principally a closely laminated quartz-rich schist with numerous interlayers of quartz-muscovite-sillimanite schist, quartz-sericite schist, and quartz-biotite gneiss.

Origin of the Metamorphic Rocks

The layered metamorphic rocks of the Front Range are the products of metamorphism and deformation of a Precambrian sedimentary sequence which was intercalated with volcanics.

Sims and Gable (1967) believe that the biotite gneisses may represent interlayered shale and graywacke units. The biotite-quartz-plagioclase gneisses, which contain an excess of Na_2O over K_2O , are believed to have been derived from graywacke sediments; the hornblende-bearing biotite gneisses may have been derived from a similar lithology rich in lime. Graywackes rich in iron may have been the source for the garnetiferous biotite gneisses. The quartzite units were originally

quartz-rich sandstones and conglomerates. Calc-silicate gneisses locally grade into impure marble. Sims and Gable (1967) believe that the skarns may have come from iron metasomatism, as their iron content is too high for any common carbonate.

The amphibolites may have originated from several different rock types; one type of parent may have been sedimentary in origin, whereas the others may have been spilites or gabbro sills. Boardman (1976) discusses excellent examples of cross-bedded amphibolites which outcrop in the Salida area. The cordierite-amphibolite gneiss units apparently have no common unmetamorphosed equivalent (Sims and Gable, 1967). However, because of their exceedingly low alkali content, they resemble iron formations in composition.

The parent rock of the microcline gneiss units is a subject of controversy. Moench (1964) and Sims and Gable (1964, 1967) suggest that the original rocks of the microcline gneiss were probably arkosic sands. Hedge (1969) believes that a feldspathic sandstone origin is improbable because of the high percentage of Na-feldspar the sediments would have to contain. However, Middleton (1972) discusses a diagenetic process which led to the formation of high-Na arkose sands of the Cambrian Charny Sandstone. The same process undoubtedly could have occurred during diageneses of Proterozoic sediments. Perhaps

some of the most compelling evidence for a volcanic origin for at least part of the microcline gneiss units can be seen in the Salida area. See Photograph A, page 23a. At this locality, relic-volcanic features have been preserved in a lower-grade metamorphic "island" (Boardman, 1976). Surrounding this island is a high-grade metamorphic facies which has obliterated these features (Table 2). Johnson (1977) describes textural features, observed in the east-central portion of the Front Range, which he believes are relict amygdules, compacted pumice lapilli, and compactional banding of meta-tuffs. The problem of the origin of the feldspar-rich gneisses may be similar to that of the amphibolites, in that the feldspar-rich gneisses also may have been derived from several parent lithologies. Some of these units may have originated from arkosic sands, while others may have had an igneous heritage, having formed from rhyodacitic and dacitic tuffs and tuffaceous sediments (Taylor, 1975). As summarized in the preceding chapter, recent work by Hills and Houston (1978) has shed light on the depositional framework of these units. They suggest that an Atlantic-type continental margin formed during the early Proterozoic along the southern edge of the Wyoming Province. Approximately 1725 to 1635 m.y. ago, this continental margin is believed to have collided with and was partially subducted beneath a volcanic arc. They hypothesize that this subduction zone dipped to the southeast. If such is the case,

A .

**This photo is found in the
back pocket of this report.**

Banded Idaho Springs "Amphibolite"

The amphibolites in the Idaho Springs stratigraphic section at Salida show well-preserved sedimentary depositional features. Note the well-developed cross bedding in the above "siltstone".

PRECAMBRIAN METAMORPHIC ROCKS, COLORADO

METASEDIMENTARY STRATIGRAPHIC SECTION OF "IDAHO SPRINGS" FORMATION AT SALIDA, COLORADO

Measured stratigraphic section in Precambrian metaigneous and metasedimentary rocks of north-central Sec. 10, T.49N., R.9E. The section was measured along a gully extending north from the Arkansas River Valley for approximately one-half km. The sequence is upright and sub-horizontal.

Unit Number	Rock Type	Thickness	Description
7	Banded metasedimentary rock	25 m +	Fine-grained, gray, micaceous quartzite. Relict bedding distinct. Some tuffaceous zones present. Amphibolitic from 15 to 25 m from base. Outcrop becomes poor farther up gully with welded tuff fragments becoming predominant in the float.
6	Meta-lahar	3 m	Medium gray, very fine-grained groundmass with relict feldspar phenocrysts; contains abundant flattened fragments of pelitic material up to 2 cm in length oriented parallel to lithologic layering. Tentatively interpreted as a lahar or mud flow. Upper contact poorly exposed.
5	Metasedimentary rock	5 m	Dark, very fine-grained, massive, pelitic rock. A few thin feldspar-bearing bands may be tuffaceous. Contact with Unit 6 is conformable and sharp.
4	Meta-welded tuff		Lower contact poorly exposed. Fine-grained, gray, with feldspar phenocrysts up to 5 mm in length. Prominent compactional foliation expressed by flattened pumice fragments. Contact with Unit 5 is conformable.
3	Meta-gabbro dike	18 m	Crosscuts Unit 2 near the top. Strike N.80°E., dip approximately 30°NW. Dark, medium-grained, equigranular amphibolite.
2	Banded metasedimentary rocks	150 m	Fine-grained, banded rocks of variable color and composition. Banding up to a few cm thick represents original sedimentary layering. Predominant rock type is quartzite with subordinate pelitic and amphibolite beds. A few thin cherty zones near base. Amphibolite most abundant between 35 and 70 m from base. Amphibolite is dark green on fresh surface and displays excellent sedimentary layering, cross-stratification, penecontemporaneous deformation structures and graded bedding on weathered surfaces.
1 (base of section)	Meta-gabbro sill	70 m	Massive, dark green to black medium to coarse-grained amphibolite with amphibole coarser than plagioclase. Locally mineralized with disseminated biotite and scapolite visible. Finer and more even-grained near upper contact. Upper contact concordant with Unit 2.
	Total thickness measured	323 m	

then the Idaho Springs-type sedimentary and volcanic sequences of the Front Range could have accumulated in inter-arc basins and possibly fore-arc and intra-arc basins similar to those described in Dickinson (1974).

This interpretation is consistent with the published literature concerning these Proterozoic sediments. Camfield and Gough (1977) cite evidence for an extension of a Proterozoic plate boundary from the northern edge of the Front Range to the Wollaston fold belt of Saskatchewan. Hedge (1969) suggested that the depositional environment for these rocks was a eugeosynclinal to an island-arc environment. Sims and Gable (1967) believe that the sediment accumulation was in a eugeosynclinal environment or perhaps in a transition to a miogeosyncline. Turbidite sequences common to inter-arc sedimentation have been identified in at least one locality along the Front Range by Trautwein (1975, pers. commun.). In an outcrop study coupled with a subsurface investigation of the Precambrian basement of Colorado, Edwards (1966) mapped the areal distribution of metasediments and granitic rocks. This study revealed the existence of a meta-sedimentary belt containing granitic igneous rocks adjacent to the Proterozoic continental margin of Hills and Houston (1978).

A possible modern analogue of the Proterozoic stratigraphic setting of the Front Range area may be the Philippine island-arc. Here the clastic wedges and associated volcanics are accumulating in small basins located between volcanic centers. These sedimentary rocks are composed of marine clastics, extensive pyroclastics (tuffs), silty limestones and reef limestones, arkosic and quartzitic clastics, conglomerates, and graywackes and shales which are sometimes intercalated with spilitic, basic, and intermediate flows (Philippine Bureau of Mines, 1962). Plate 8.

Uranium Potential of the Proterozoic

Potential Guide Lithologies

The Proterozoic rocks of the Front Range exhibit some of the same characteristics which have been used as uranium ore guides for certain Precambrian deposits in Australia and Canada (Morton, 1977). The rocks of the Front Range contain pyrite- and chlorite-bearing lithologies which are common to the deposits in northern Australia and Saskatchewan. The association of dolomitic or calc-silicate rocks with uranium mineralization in Australia suggests that further investigation into the calc-silicates of the Front Range may be warranted.

Potential of Unconformities; Hall Valley

The identification of a Proterozoic unconformity in Hall Valley is interesting in that many Precambrian

IDEALIZED SKETCH OF A POSSIBLE PRE-METAMORPHIC VOLCANIC-SEDIMENTARY ENVIRONMENT OF THE FRONT RANGE (not to scale)

uranium deposits occur near unconformities. The layers below this unconformity contain diagnostic uranium ore guides such as pyrite-, graphite-, and chlorite-bearing lithologies in addition to calc-silicate rocks (Wahlstrom and Kim, p. 1223, 1959). The north-south trace of this unconformity is poorly exposed and was not specifically identified by our cursory examination along its southern extent in the area of the calc-silicate rocks. Although Wahlstrom and Kim reported that the unconformity was better exposed in the cirque to the north, snow cover precluded investigation of that area. However, a traverse stratigraphically below but paralleling the strike of the mapped unconformity revealed slightly anomalous radioactivity. A mine dump was found to be 2 to 3 times above background; an aplite dike was twice background; and, at one locality, a gneissic rock was 3 to 4 times background. The presence of favorable lithologies and surface radioactivity in the Hall Valley area suggest that the empirical ore guides of northern Australia and Saskatchewan may be useful in the search for Proterozoic uranium deposits in the Front Range.

Detailed geologic mapping, coupled with reconnaissance drilling and the recognition of the "proven" ore associations of other productive areas, should be helpful in conducting exploration programs in the region. The use of these techniques in evaluating the uranium potential of the Front Range,

if not the Hall Valley area itself, may lead to the identification of individual targets.

Potential of Basin-Fill Sediments

If the structural and stratigraphic interpretation of the Idaho Springs depositional model is correct, then the sites of basin fill might be expected to have originally contained anomalous uranium values. The occurrence of uranium in the basins of the island-arc setting of Japan has been discussed by Hayashi (1970), and in the Philippine island arc by Bryner (1969). The mechanisms of introduction and movement of uranium into this type of environment have been discussed in Gableman (1977). The uranium held in the sediments of these basins would most likely have been mobilized during the subsequent thermal events. The writers believe that the initial uranium may have been mobilized early in the metamorphic process, during dewatering of the sediments. This migration may have continued until a suitable host rock was found. Where the uranium was unable to migrate from a basin or to a lower metamorphic facies within the basin, it would be expected to have concentrated in the anatectic, migmatitic portions of the metamorphic rocks. It is also possible that recurrent transportation and deposition may have occurred with subsequent thermal events (Plate 9).

The presence of lithologies similar to those which host uranium deposits in other parts of the world suggests that an untested potential for uranium accumulation exists in the Proterozoic of the Front Range.

CHAPTER C

PETROLOGY AND DISTRIBUTION OF PRECAMBRIAN IGNEOUS ROCKS

As discussed in the preceeding chapter, plutonic igneous activity began about 1.7 b.y. ago by anatexis during the late stages of mountain building and metamorphism, with the formation of the syntectonic Boulder Creek plutons.

The geologic record indicates the probability of earlier, widespread volcanism, as represented by thick accumulations of volcanics and related clastics dated 1.85 to 2.0 b.y. by Taylor (1978). Underlying stocks and batholiths undoubtedly existed beneath the volcanic centers in a setting perhaps similar in profile to that of the mid-Tertiary San Juan volcanic area of southern Colorado. However, such features have not been specifically identified in the "Idaho Springs" metamorphic complex.

Silver Plume intrusive activity began about 1.45 b.y. ago, during the late stages of cataclasis, and continued until 1.3 b.y. ago in a largely post-tectonic or anorogenic setting. Remobilization of the crust resulted in numerous Silver Plume plutons within the Front Range and adjacent regions of the Southern Rocky Mountains.

Epizonal Pikes Peak intrusive activity occurred during a shorter interval approximately 1.1 to 1.0 b.y. ago. This batholith and its satellites are exposed in the southernmost part of the Front Range and terrain to the southwest. Barker and others (1975) proposed that crustal mobilization to form this intrusive developed as a result of cratonic rifting.

The following are descriptions of the three Precambrian intrusives:

Boulder Creek - This group of granitic rocks includes syntectonic calc-alkalic types ranging from granite to gabbro in composition, but it is principally granodiorite and quartz monzonite. Locally there are minor amounts of aplite, alaskite, hornblende diorite, and pegmatite. These rocks are exposed in many parts of the Front Range, from the Wyoming border to the southern fringe of the range south of Cripple Creek (Plate 4).

Hutchinson (1967, p. 21) describes the Boulder Creek as "inequigranular seriate to slightly porphyritic, dark gray, medium to coarse grained with a gneissic structure due to sub-parallel arrangement of flakes, streaks, and pods of biotite." In its type locality in the Boulder Creek pluton, the rock has a well-defined, primary gneissic or platy structure and shows a preferred linear orientation of elongate grains within the plane of foliation. The platy structure, developed throughout most of the pluton, strikes nearly east and dips 50-70°N.

This Boulder Creek granodiorite pluton shows evidence of reaction with the biotite and hornblende schist and gneiss along the contacts of the pluton and with inclusions. Gradational contacts between the country rock and the intrusion are common.

The Boulder Creek is the least radioactive of the three Precambrian intrusives, averaging 2.2 ppm (Phair and Gottfried, 1964). Allanite, a radioactive mineral containing 80-160 ppm U_3O_8 , which is found at the type locality, was introduced by Silver Plume metasomatism (Hickley and others, 1973). It is believed to have formed in the late stages of metamorphism under deep cover, with no evident fractionation of late-stage exotics and fluid phase to yield uranium concentrations within or around its borders.

Silver Plume Age Plutons - These intrusives also are widely distributed from the Wyoming border to the Cripple Creek area and adjacent regions of the Southern Rocky Mountains (Plate 4). They are both syn- and post-tectonic and range in composition from quartz monzonite to granite. Minor alkaline and mafic varieties also are included. A number of major plutons of Silver Plume age are found within the Front Range, including from north to south, the:

		Average Radioactivity
Sherman	)	5.7 ppm
Log Cabin	)	6.7 ppm
Long's Peak-St. Vrain)	Age range from 1.45	5.8 ppm
Silver Plume	) to 1.39 b.y.	7.0 ppm
Kenosha	)	
Cripple Creek	)	3.2 ppm

(Phair and Gottfried, 1964)

They form generally discordant bodies that cut across older Precambrian fabric and show no evidence of refoliation or recrystallization. A distinguishing feature of the Silver Plume-age plutons is the frequent presence of two micas, as in the case of the "fertile" granites of western Europe (Dubyk, personal communication).

In most occurrences the Silver Plume is a pinkish-gray, medium-grained, slightly porphyritic biotite granite; muscovite usually is present. The Sherman granite, located along the Wyoming border both in the Front Range and Medicine Bow spur, is somewhat different from the other Silver Plume-age plutons. It is coarser-grained, equigranular, and reddish; it contains hornblende, lacks muscovite, and has very few associated pegmatite dikes. It has been dated at 1.42 b.y. (See Petrographic Description #1.)

All of the Silver Plume-age plutons have anomalously high uranium content. It occurs not only within the intrusives themselves, but also in pegmatite dikes and locally in migmatized country rocks included within and

SILVER PLUME GRANITEPETROGRAPHIC DESCRIPTION NO 1PROJECT: Front RangeREQUEST: 101049FIELD NO: MAL-112AASSN: 24552ROCK NAME: GraniteGENERAL TEXTURE AND FEATURES: Medium to coarse-grained hypidiomorphic granular.PETROLOGIST: L. M. Fukui - Bendix Field Engineering Corp.

MINERAL/COMPONENT	%	TEXTURE	CHARACTERISTICS	ALTERATION/REPLACEMENT
Microcline	40	Coarse-grained subhedral	Clear- undulose- composite grains.	Slightly argillized
Quartz	31	Medium-grained anhedral		
Plagioclase	16	Medium-grained subhedral	Pledchroic- Light brown to light yellow. Radiation haloes.	Slightly argillized
Biotite	7	Fine-grained anhedral		
Opaque	4	Fine-grained anhedral		
Muscovite	2	Fine-grained anhedral		
Apatite	tr	Fine-grained euhedral		

OTHER COMMENTS: A primary, thorium-bearing monazite was located by SEM/EDS.

A.

**These photographs are found in
the back pocket of this report.**

B.

Photomicrographs of Sample 24552.

Slightly argillized feldspars and strained, undulose,
composite grains of quartz. 16x, crossed polarizers.

Radioactive haloes around monazites in biotite.
160x, plane polarized light.

**This photo is found in the
back pocket of this report.**

Electron photomicrograph showing monzonite (M), zircon (Z),
euhedral apatite (A), and biotite (B). The monzonite grain occurred
as an inclusion in a microcline grain (K). Sample 24552,
secondary and backscattered electron image, 1100x.

adjacent to contact zones. The northern projection of the hood zone of the Silver Plume pluton itself is particularly anomalous; there are numerous uranium occurrences from its outcrop fringe north of Empire to the South Boulder Creek drainage, including the James Peak area. Silver Plume granite in the mineralized Wheeler Basin-Hell's Hole area, 5 miles north of James Peak (Plate 16), may be an apophysis of this same pluton.

Pikes Peak Batholith - This intrusive is located near the southern end of the Front Range (Plate 4). It is an equigranular, medium-grained, hornblende-bearing, biotite granite and consists of three intrusive centers (Hutchinson, 1976). According to Hutchinson the batholith is zoned along its northern border as:

1. Border zone of medium leucogranite
2. Outer zone of medium to coarse granite
3. Intermediate zone, mainly coarse grained quartz monzonite to granodiorite.
4. Central zone, quartz monzonite to granite, medium to coarse grained.

The Redskin granite intruded along the western edge of the batholith as a late-phase stock (Plate 10). It is a zoned, oval-shaped pluton approximately 6 1/2 miles long and 4 miles wide (Hawley and others, 1969). Both the Pikes Peak and the Redskin are enriched in fluorite, beryllium, lithium, tin, and rubidium when compared with average values for granites (Hawley, 1969).

32a

**GEOLOGIC MAP, BADGER FLATS - ELKHORN THRUST PROJECT AREA,
PARK AND TELLER COUNTIES, COLORADO**

(After Gallagher, 1976)

The China Wall cupola lies adjacent to the west side of the Redskin stock, whereas the Boomer cupola is located a mile south of the stock. The former is about $3/4$ of a mile long and the latter only 500 feet across. Well-developed greisen and beryllium deposits occur in both cupolas. The anomalous Mt. Rosa granite, a sill-like, alkalic riebeckite granite body, located approximately ten miles east of Cripple Creek, also developed as a late segregation in the Pikes Peak batholith. The uranium potential of these late-phase intrusives of Silver Plume and Pikes Peak age is described in the next chapter.

CHAPTER D

SUMMARY OF PRECAMBRIAN MINERALIZATION

Precambrian-age mineralization in the Front Range includes massive, non-uranium-bearing sulfide centers of mineralization which may be pre-metamorphic (1.85-2.0 b.y.) and which probably developed in the volcanic environment of the early seaways. Also included are numerous pegmatites, particularly those associated with the Silver Plume-age plutons, as well as anomalous migmatites many of which occur adjacent to or in the near vicinity of pegmatites and in the metamorphic rocks along contacts with the plutons.

Mineralized hood-zone apophyses or cauldrons are evident both in the Silver Plume and Pikes Peak intrusives. Anomalous granite dikes, pegmatites, and migmatites are common in the northern hood zone of the Silver Plume pluton itself, particularly in the James Peak and Wheeler Basin centers, and in the Kenosha pluton. The Redskin granite stock and the Mt. Rosa "sill" represent late-stage accumulations in the hood zone of the Pikes Peak (Plate 4).

The Prairie Divide shear zone along the contact between the Sherman and Log Cabin plutons in the northern Front Range is a promising zone (Verner Johnson, personal communication).

Remote sensing indicate a possible uranium target at the intersection of the Idaho Springs-Ralston Creek shear zone with the northwest-trending Rogers shear zone, some two miles northwest of the Schwartzwalder mine (Kober, 1978, personal comm.). Otherwise, there is little evidence of Silver Plume-age, uranium-bearing veins and shear zones, with the possible exception of carbonate-feldspar-silica mineralization in the northwest-trending shears of the eastern flank of the Range. Minor veins and breccia pipes are related to the Pikes Peak-age Redskin granite stock in the Badger Flats area (Gallagher, 1976). Some may have been eroded from the crestal portions of Silver Plume-age plutons and the Pikes Peak batholith itself.

The most promising centers of mineralization of Precambrian age are the anomalous areas within Silver Plume-age plutons such as the exposure of Kenosha granite immediately north of Kenosha Pass and Redskin granite southeast of Tarryall. These areas may prove to be valuable targets, particularly if upgraded by supergene enrichment. Plate 4.

CHAPTER E
PHANEROZOIC EVENTS

In Colorado, a period of tectonic quiescence prevailed through the Early and Late Paleozoic Era. Three separate marine seas inundated the Front Range area during this time. The main transgressive and regressive periods were the: Cambrian-Early Ordovician sequence, Middle Ordovician-Early Devonian sequence, and Middle Devonian-Mississippian sequence (Kent, 1972). Terrigenous clastic facies formed along the transgressive shore lines which in turn were covered by a carbonate facies as the seas expanded. Near the end of the Mississippian Period, large scale regional faulting preceded the uplift of the Ancestral Rocky Mountains.

The Front Range area was one of six positive areas which formed the Ancestral Rockies. Vertical movement of these uplifted areas may have been in the form of large, broad anticlines which subsequently failed by faulting along their edges. (Kent (1972) gives the following discussion of these Pennsylvanian and Permian mountains:

Elevations of 5,000 to 10,000 feet are postulated for this time. The tectonic pattern also profoundly influenced sedimentation; abrupt facies changes and great variations in thickness occur within short distances. Adjacent to the mountain uplifts great thickness of coarse arkosic clastic sediments were deposited.

In areas removed from the uplifts finer grained detrital sediments and carbonate rocks dominated. And in restricted intermontane basins, such as the Central Colorado trough (Eagle basin) and the Paradox basin, evaporite deposits were formed in areas of restricted circulation.

Erosion during Late Paleozoic time removed the sedimentary cover to expose the Precambrian core of the uplifts. Remnants of the Ancestral Rocky Mountains continued to be positive features throughout the Triassic Period.

The next major marine transgression formed the thick Cretaceous shales which blanketed the area. From Late Cretaceous to Early Tertiary time the Laramide orogeny was responsible for mountain building in the region. This orogenic episode was characterized by arching and uplift, movement along existing structures, new faulting, and recurrence of magmatism which had been essentially absent since Precambrian time (Tweto, 1975).

The following sequence of structural events for the Laramide uplift of the Front Range has been suggested by Lovering and Goddard (1950):

1. Arching of the uplifted area.
2. Northwesterly folding and faulting accompanied by some east-northeasterly fissuring.
3. Overfolding and thrust faulting in the border zone outlined the present day Front Range. The majority of these faults and folds trend northwestward.
4. Northeasterly and east-northeasterly faulting occurred throughout the Mineral Belt.
5. In the northeastern portion of the Mineral Belt, the northwesterly and east-northeasterly faults were rejuvenated.

6. In the northeastern portion of the Mineral Belt, the northwesterly and northeasterly faults were rejuvenated.
7. A wedge-shaped block between Boulder and Nederland was transported slightly to the west.

Intrusive and volcanic activity of the Laramide orogeny was fairly well confined to a broad northeast-trending belt that coincides with the earlier-Precambrian shear zones which trend northeasterly. The tectonic framework of this belt has been shown to be an element of a much larger structural lineament which bisects the western United States (Warner, 1978).

AGE DETERMINATIONS ON MESOZOIC-CENOZOIC IGNEOUS ROCKS, CENTRAL FRONT RANGE, COLORADO

1.	JAMESTOWN STOCK			
	(a) GRANODIORITE	(HORNBLende)	77.6 ± 2.3	
			71.8 ± 2.2	
	(b) GRANODIORITE PLUTON	(BIOTITE)	54.5 ± 1.9	
		(APATITE)	52.9 ± 8	
		(ZIRCON)	51.1 ± 4.2	
	(c) GRANODIORITE STOCK	(VEIN BIOTITE)	58.8 ± 2.0	
		(ZIRCON)	44.9 ± 2.7	CUNNINGHAM, NAESER, AND MARVIN (1977)
	(d) PORPHYRY MTN. STOCK	(ZIRCON)	45.1 ± 3.8	
2.	AUDUBON-ALBION STOCK (Composite)	(BIOTITE)	70. ± 2	
3.	CARIBOU STOCK (Quartz Monzonite)	(ZIRCON)	62.6 ± 6.3	
4.	ELDORA STOCK (Quartz Monzonite)	(COARSE BIOTITE)	54.8	
		(FINE BIOTITE-HORNBLende)	53.7	
		(COARSE BIOTITE)	63.9 ± 9	
		(BIOTITE)	59.1 ± 1.8	
		(APATITE)	73. ± 7.0	
		(SPHENE)	67.1 ± 7.5	
		(ZIRCON)	68.8 ± 5.5	CUNNINGHAM, NAESER, AND MARVIN (1977)
		(ZIRCON)	61.8 ± 5.5	
		(APATITE)	58.5 ± 8.8	
5.	APEX STOCK (Intermediate Quartz Monzonite)	(ZIRCON)	61.7 ± 6.5	
		(APATITE)	71.1 ± 17.7	CUNNINGHAM, NAESER AND MARVIN (1977)
		(APATITE)	66.7 ± 6.7	
		(ZIRCON)	58.8 ± 4.4	
6.	EMPIRE STOCK (Monzonite) 3.4 Mi W. of U.S.40)	(SPHENE)	67.9 ± 5.3	CUNNINGHAM, NAESER AND MARVIN (1977)
		(APATITE)	37.3 ± 2.2	
		(SPHENE)	57.8 ± 4.5	
7.	BALD MTN. (Diorite Monzonite)	(HORNBLende)	44.	
8.	MONTEZUMA STOCK (Quartz Monzonite)	(BIOTITE)	38.6 ± 1.2	
		(ZIRCON)	35.0 ± 2.7	CUNNING, NAESER AND MARVIN (1977)
9.	URAD-HENDERSON			
	(a) MINERALIZED PORPHYRY	(SERICITE)	26.0 ± 0.9	
	(b) RHYOLITE	(ZIRCON)	27.6 ± 2.9	
			27.6 ± 2.7	
			26.9 ± 2.5	
			25.1 ± 2.5	
			22.8 ± 2.3	
			27.6 ± 2.9	
	(c) RHYOLITE PLUG	(SANIDINE)	27. ± 3.0	
10.	CHIPPLE CREEK SYENITE	(AEGIRINE-AUGITE)	33.4 ± 1.0	

Except where indicated, all age dates compiled from: Marvin, R.F. and Naeser, C.W., 1974, Summary of Radiometric Age Determinations on Mesozoic and Cenozoic Igneous Rocks and Uranium and Base Metal Deposits in Colorado: Isochron/West, No. 11, Dec. 1974, pp 10-14.

Cunningham, C.G., Naeser, C.W., Marvin, R.F., 1977, New Ages for Intrusive Rocks in the Colorado Mineral Belt: U.S. Geol. Survey Open-File Rpt. 77-573.

CHAPTER F
UPPER CRETACEOUS AND TERTIARY IGNEOUS ROCKS
OF THE FRONT RANGE

Late Cretaceous and Tertiary igneous activity in Colorado may be grouped into three distinct periods (Tweto, 1975, p. 22) (see Plate 4 and Table 3). The first period (70-50 m.y.) began in the Late Cretaceous during the earliest stages of the Laramide orogeny. It is believed that this activity reached a maximum during the Paleocene. Porphyritic stocks, dikes, and sills of this age are generally of intermediate composition and are largely confined to a narrow, northeast-trending belt (Plate 18), 10-20 km in width and approximately 400 km in length. This "porphyry belt" extends from the western margin of the San Juan Mountains near Durango to the Jamestown district in the northeastern Front Range. Larger phaneritic stocks generally occur along the western flank of the "porphyry belt." In the Front Range (Plate 4), the major portion of igneous rocks of the Phanerozoic belongs to this Laramide-age group. In the central and northern mining districts of the Colorado mineral belt, associated ore deposits occur primarily

as gold- and silver-bearing base-metal ores in veins (fissure fillings) and ore shoots. The vein-type uranium deposits of the Central Front Range occur in association with these ores. Tungsten-bearing ore occurs west of Boulder.

The second period of igneous activity (40-25 m.y.) involved a greater volume and areal extent than the first period and coincided with widespread magmatism in western North America. In Colorado, extensive volcanic fields of intermediate rocks developed in the central, south-central, and southwestern portions of the state including the San Juan Mountains (35-26 m.y.), Spanish Peaks (28-20 m.y.), Wet Mountains (32 m.y.), Thirty-Nine Mile (36-29 m.y.), Cripple Creek, Elm and West Elk Mountains, Mt. Princeton Batholith, Montezuma Batholith, Never Summer Range (Steven, 1975). The Front Range ore deposits associated with this period occur as gold- and silver-bearing base-metal ores in veins (fissure fillings) as in the Montezuma district and as molybdenum ores in porphyry-type stockworks as at the Henderson Mine. In the Cripple Creek district of the southern Front Range, ore deposits occur primarily as gold-tellurides in small veins, shatter zones, and breccia pipes associated with a Miocene-age volcanic complex.

The third period of igneous activity (15-10 m.y.) in Colorado occurred generally outside the Colorado Mineral Belt, in the northwestern, north-central, and south-central portions

of the state. Magmatism was bimodal (basalt and high-silica rhyolite). In the Hohn's Peak and Big Creek districts of northern Routt County, porphyry-type copper mineralization occurred in association with acidic volcanism.

One of the most obvious features of the Laramide "porphyry belt" is its relatively narrow, northeast-trending character which transects north-northwest-trending Laramide structure. Tweto and Sims (1963) have attributed this northeast trend to emplacement along an extensive, re-activated, northeast-trending Precambrian shear zone.

Phair and Fisher (1962) have emphasized the importance of deep Laramide fracturing in shaping the course of magmatic differentiation of the parent magmas and have made some general observations in regard to the distinction and character of the various igneous bodies:

"With one exception (the hornblende granodiorite stock at Jamestown which borders the mineral belt on the northeast), all phaneritic stocks in the region are strung out along a north-trending belt that borders the mineral belt on the west. These phaneritic stocks are at Empire, Bryan Mountain, Caribou, and Lake Albion...Within the highly fractured mineral belt proper, few phaneritic Laramide rocks are found; their place is taken by an immense number and variety of finer-grained porphyries which give the "porphyry belt" its name (Spurr, Garrey, Ball, 1908). The porphyries formed a multitude of stocks and dikes; strong Laramide fracture control is evident in the shapes, directions of elongation, and contact relations of these

intrusives. Dikes of similar composition tend to occur in swarms. Each porphyry stock is relatively uniform in composition. The largest porphyry stocks, at Sunset and Apex, have an outcrop area of 34 square miles and are comparable in size to all but the largest of the phaneritic stocks. Along the borders of the mineral belt proper, bodies of porphyry intruded the early formed phaneritic stocks." (Phair and Fisher, 1962, pp. 485-486)."

Field studies in the Colorado Front Range have shown that a remarkable variety of Upper Cretaceous and Tertiary igneous rocks occur within this area of roughly 12,000 km². In order to introduce this complex group, six publications have been selected which consider the Upper Cretaceous and Tertiary igneous rocks of the Front Range portion of the Colorado Mineral Belt. The rock types, as described in each publication, are summarized in Table 4. The systems and methods used for petrographic analysis and designation may differ from publication to publication. As petrographic correlation may be uncertain in some cases, the definitive characteristics for each rock type are given in Table 4.

Wells (1962) and Braddock (1969) have described and analyzed the igneous rocks within restricted areas, but have drawn conclusions concerning magmatism in the Front Range as a whole. The broader studies (Phair and Fisher, 1962; Phair and Jenkins, 1975; Simmons and Hedge, 1978) have approached the problem of petrogenetic classification and interpretation in different ways. Phair and Fisher (1962)

CORRELATION OF UPPER CRETACEOUS - TERTIARY IGNEOUS ROCKS OF THE FRONT RANGE, COLORADO					
LOVERING AND GODDARD (1938)	WELLS (1960) (Gipin & Clear Creek Cos.)	PHAIR AND FISHER (1962)	BRADDOCK (1969)	PHAIR AND JENKINS (1975)	SIMMONS AND HEDGE (1978)
<ul style="list-style-type: none"> • Biotite Monzonite - Latite Series • Diorite - Syenite - Bostonite Alkaline Series 	<ul style="list-style-type: none"> • Quartz Monzonite Group (Qtz Monzonite Porph., Granite Porph., Alaskite Porph.) • Light Colored Granodiorite Group (Light Colored Granodiorite Porph., Albite Granodiorite Porph., Alkalic Syenite Porph.) 	<ul style="list-style-type: none"> Sodic Subseries • Monzonite 	<ul style="list-style-type: none"> (Empire Quadrangle) • Biotite - Quartz Monzonite Porphyry • Monzonite Porphyry • Hornblende-Pyroxene Monzonite • Quartz-Bearing Monzonite Porph. • Leucocratic Monzonite 	<ul style="list-style-type: none"> • Alkali Calcic Potassic Subseries • Alkali Calcic Sodic Subseries 	<ul style="list-style-type: none"> Monzonite Suite • Alkalic Monzonite Suite (a) Hornblende-Pyroxene Monzonite (b) Quartz-Bearing Monzonite (c) Leucocratic Monzonite • Mafic Monzonite • Quartz Syenite
— ? — ? — ? — ? — ? — ? — ? — ? — ? —	<ul style="list-style-type: none"> • Bostonite Group (Bostonite Porph., Garnetiferous Bost. Porph., Trachytic Bost. Porph., Qtz. Bost. Porph.) 	<ul style="list-style-type: none"> • Quartz-Bearing Trachyte • Sodic Rhyolite 	<ul style="list-style-type: none"> • Bostonite Porphyry • Sanidine 	<ul style="list-style-type: none"> • Bostonites (Late-Stage CaO - Poor, Alkali-Calcic Sodic) 	<ul style="list-style-type: none"> • Latite & Bostonite
			<ul style="list-style-type: none"> • Feldspathoidal Hornblende-Pyroxene Monzonite 	<ul style="list-style-type: none"> • Alkali Potassic Subseries • Alkali Sodic Subseries 	
				<ul style="list-style-type: none"> • Tholeiite - Tholeiitic Andesite Subseries 	<ul style="list-style-type: none"> • Ultramafics
— ? — ? — ? — ? — ? — ? — ? — ? — ? —	<ul style="list-style-type: none"> • Hornblende Granodiorite Group (Hnbde G'nodiorite Porph., Biot. Granodiorite Porph., Biot. Qtz. Monz. Porph., Biot. Qtz. Latite Porph.) 	<ul style="list-style-type: none"> Potassic Subseries • Quartz - Poor Hornblende Granodiorite and Calc-Alkaline Granite End Products • Mafic Monzonite 	<ul style="list-style-type: none"> Granodiorite Group • Hornblende Granodiorite Porphyry • Biotite Granodiorite 	<ul style="list-style-type: none"> Alkali-Calcic Transitional Subseries into Calc-Alkali Subseries • Hornblende Granodiorite • Biotite Quartz Latite 	<ul style="list-style-type: none"> Granodiorite Suite • Group I Granodiorite • Group II Granodiorite

have identified two groups of rocks, the sodic and potassic subseries, based upon the distinctive characteristics of the feldspars, which, they propose reflect a distinctive history of physical and chemical conditions within a magma body. Phair and Jenkins (1975) have sought to identify trends for uranium and thorium in individual stocks in the central and northern Front Range by plotting U and Th contents against variation diagrams for CaO and $\text{K}_2\text{O} + \text{Na}_2\text{O}$ versus SiO_2 . In this study, igneous rocks have been classified by the Peacock Index (Peacock, 1931). Simmons and Hedge (1978) have classified representative samples on the basis of major-element and CIPW normative analyses and interpreted them on the basis of rare-earth-element data and $^{87}\text{Sr}/^{86}\text{Sr}$ and Rb/Sr isotope ratios.

Interpretations of the Petrology of Laramide-Age Igneous Rocks

Although petrographic designations may differ slightly from publication to publication, there appears to be a general recognition, among the authors cited in Table 1, of a dominant silica saturated-rock supergroup and a subordinate supersaturated-rock supergroup. Excepting Phair and Fisher (1962), the authors either suggest or state that these two rock groups were formed from unrelated magmas.

Lovering and Goddard (1938) recognized three rock series: a diorite-quartz monzonite-alaskite series resulting from normal magmatic differentiation from a more-calcic to a more sodic magma; a diorite-syenite-bostonite alkalic series, resulting from "subtractive differentiation" in a parent magma; and a biotite-monzonite-latite series, believed to be the differentiate of a "deep gabbroic magma." The first series would presumably fall into the supersaturated group, while the second and third series would fall into the saturated group.

In a study of Tertiary igneous rocks of Gilpin and Clear Creek counties, Wells (1960) recognizes two coexisting magmatic sources (Table 5 and Fig. 2). A "major series," including the light-colored granodiorite, quartz monzonite, and bostonite groups, formed from one source. Rocks of this series contain abundant albite and potassic feldspar with aegirine-augite as the characteristic ferromagnesian mineral. These rocks were derived from a "broad magmatic chamber." The other magmatic source was responsible for the formation of a "minor series", which includes the hornblende-granodiorite group at Fall River. These rocks are characterized by high contents of calcic oligoclase and by hornblende, pyroxene, and biotite as the ferromagnesian minerals. Wells believes that these rocks were derived from a "smaller, more restricted chamber". There is no mention of a possible source for the magmas themselves.

Petrographic characteristics of the Tertiary igneous rocks

[X indicates mineral is present but variety not determined]

Rock name	Phenocrysts				Groundmass minerals	Remarks
	Potassic feldspar	Plagioclase	Quartz	Ferromagnesian mineral		
Light-colored granodiorite group (granular groundmass, sparse ferromagnesian minerals, generally brownish gray; antiperthitic albite common)						
Light-colored granodiorite porphyry.	Minor anorthoclase.	Oligoclase.....	.....	Sparse bladed mineral.	Same as phenocrysts plus quartz.	Small rounded phenocrysts give "dotted" appearance.
Albite granodiorite porphyry.	Antiperthite.....	Albite and oligoclase.	.....	Aegirine-augite.....	Same as phenocrysts plus quartz.	One body is garnetiferous.
Alkalic syenite porphyry.....	Antiperthite.....	Albite and oligoclase.	.....	Sparse bladed mineral.	Same as phenocrysts plus very minor quartz.	Less than 5 percent quartz. Large albite phenocrysts are diamond shaped.
Quartz monzonite group (granular groundmass, generally sparse but locally minor ferromagnesian content, gray, high quartz content in groundmass)						
Quartz monzonite porphyry.	Sparse sanidine.....	Oligoclase; sparse albite.	.....	Sparse to abundant bladed mineral.	Quartz, potassic feldspar, and plagioclase.	Size and quantity of phenocrysts variable.
Granite porphyry.....	×	Albite-oligoclase.....	.....	Sparse bladed mineral.	Same as phenocrysts plus quartz.	Usually conchoidal porcelaneous or flinty fracture.
Alaskite porphyry.....	×	.....	In one variety.....	Essentially absent.....	Same as phenocrysts plus quartz.	Conchoidal porcelaneous or flinty fracture; pitted weathered surface.
Bostonite group (bostonitic groundmass, sparse ferromagnesian minerals, general reddish brown to lilac)						
Bostonite porphyry.....	×	Albite-oligoclase.....	.....	Bladed mineral.....	Same as phenocrysts plus minor quartz.	Less than 10 percent quartz.
Garnetiferous bostonite porphyry.	×	Albite-oligoclase.....	.....	Aegirine-augite.....	Same as phenocrysts plus minor quartz.	Contains andradite garnet. Less than 10 percent quartz.
Trachytic granite porphyry.	×	Albite-oligoclase.....	.....	Bladed mineral.....	Same as phenocrysts plus anhedral grains between feldspar laths.	
Quartz bostonite porphyry.	Anorthoclase.....	.....	.....	.....	Same as phenocrysts plus anhedral quartz grains between feldspar laths.	
Hornblende granodiorite (granular groundmass, ferromagnesian minerals common, generally gray to black)						
Hornblende granodiorite porphyry.	Minor.....	Oligoclase and some albite.	×	Hornblende and minor augite.	Same minerals as phenocrysts.	
Biotite granodiorite porphyry.	Minor.....	Oligoclase and some albite.	×	Biotite in flakes.....	Same as phenocrysts.....	
Biotite-quartz monzonite porphyry.	×	Oligoclase.....	Many bipyramids.	Biotite books and flakes.	Mostly quartz and potassic feldspar.	
Biotite-quartz latite porphyry.	.....	Oligoclase-andesine.	.....	Biotite books and flakes.	Same as phenocrysts with potassic feldspar.	Very fine grained phase has conchoidal fracture.

(Reproduced from Wells, 1960, Table 1, pp. 234-235).

PETROGRAPHY OF TERTIARY ROCKS, FRONT RANGE, COLO.

Diagram showing the probable sequence of intrusion of the Tertiary igneous rocks.

(Reproduced from Wells, 1960, Fig. 58, p.229)

In Table 3, Phair and Fisher (1962) excluded from consideration the nepheline-bearing rocks at Empire. They recognize a "widespread sodic subseries" of generally porphyritic-aphanitic rocks characterized by low contents of normative quartz and a "less abundant potassic subseries" of phaneritic rocks in which normative quartz is of a higher percentage than in sodic rocks of equivalent An content. The sodic subseries is characterized by high-temperature feldspars, strong fractionation and zoning of plagioclase, and crystallization under drier conditions, as suggested by the replacement of hornblende by anhydrous aegirine-augite. The potassic subseries comprises a continuous K₂O-rich line of descent and is characterized by lower-temperature feldspars, weaker fractionation and zoning of plagioclase, and crystallization under more hydrous conditions, as suggested by the common development of biotite after hornblende and occasionally after augite.

Utilizing phase relationships for feldspars (Tuttle and Bowen, 1958), Phair and Fisher have attempted to trace the development of these two rock series as indicated by the chemical compositions, structural (thermal) states, and textural relationships of the plagioclase and alkali feldspars. They have proposed that the magmas producing both the potassic and sodic subseries evolved from the same magma chamber.

The earlier magmas in this chamber were unusually hydrous and cooled slowly in a closed system. Therefore plagioclase reactions occurred under near-equilibrium conditions, resulting in weakly zoned crystals of a uniform structural state. In these rocks both plagioclase and alkali feldspar are of a low structural state. Plagioclase with less than 4% Or by weight and alkali feldspar with less than 30% Ab + An by weight suggest continuous and thorough reactions between crystals and liquid, with little fractionation. Such circumstances produced liquids of progressively higher Or content and an end product resembling normal calc-alkaline granite or its extrusive equivalents.

By the time these Or-rich liquids had developed in the magma chamber, the Laramide event had progressed to a stage during which deep fracturing throughout the region tapped the magma chamber. A decrease in pressure resulted in partial devolatilization. This loss of water pressure caused a rise in the liquidus and solidus temperatures and effected the immediate precipitation of plagioclase. The process of plagioclase crystallization, an exothermic reaction, raised the temperature of the magma, producing conditions favorable to the formation of high-temperature feldspars: high-temperature sodic plagioclase with up to 16% Or by weight and high-temperature alkali feldspar with up to 47% Ab + An by weight.

Deep fracturing also provided openings along which this magma could rise and cool more rapidly. Irregularities and constrictions in these fractures may have also served to strain and separate crystals from liquids, resulting in progressively more-sodic liquids, strong fractionation, and moderate to intense zoning in plagioclase. The formation of high temperature, sodic rims of alkali feldspar about early potassic plagioclase accentuated this course of fractionation and partitioning of a sodic liquid residuum. Phair and Fisher suggest that extreme differentiation of this sodic liquid may have produced a magma depleted enough in CaO , FeO , and MgO to form quartz bostonites.

Braddock (1969) has examined the Tertiary intrusive rocks of the Empire quadrangle and has distinguished three series of rock types: a subsaturated, alkalic, nepheline-bearing series; a saturated alkali-calcic series characterized by low normative quartz except at low An contents; and a supersaturated calc-alkaline series characterized by high normative quartz at all An values (Table 7). The calc-alkaline series may be explained by simple differentiation controlled by the removal of plagioclase. The crystallization trend of the alkalic-calcic, monzonitic series is more difficult to explain. Braddock considers individually each rock type of this series. The alkalic, nepheline-bearing rocks are

DESCRIPTION OF UPPER CRETACEOUS-TERTIARY IGNEOUS ROCKS OF THE EMPIRE QUADRANGLE

AFTER BRADDOCK (1969)

ROCK NAME	PHENOCRYSTS							
	ALKALI FELDSPAR	PLAGIOCLASE	QUARTZ	FERROMAGNESIUM MINERALS	OTHER	GROUNDMASS MINERALS	ACCESSORY MINERALS	REMARKS
GRANODIORITE GROUP (HIGH MODAL AND NORMATIVE QUARTZ, PLAGIOCLASE > ALKALI FELDSPAR; MODERATE ABUNDANCE FERROMAGNESIUM MINERALS, PHENOCRYSTS OF PLAGIOCLASE, ALKALI FELDSPAR, QUARTZ, HORNBLENDE, BIOTITE)								
Hornblende Granodiorite Porphyry	30% Orthoclase Weakly perthitic rims on Plagioclase	40% An ₄₀₋₂₅ Moderate - strong zoning	17%	5-10% Hornblende Pale green		Quartz Feldspar	Sphene Apatite Opaques	Phaneritic, Porphyritic - seriate
Biotite Granodiorite Porphyry	7 - 28% Untwinned, slightly perthitic	45-55% An ₃₀₋₁₅ Moderate zoning	15 - 30%	2 - 11% Biotite (subhedral)			Sphene Apatite Opaques	Porphyritic - seriate
MONZONITE GROUP (SCARCITY OR ABSENCE OF MODAL OR NORMATIVE QUARTZ, PLAGIOCLASE > ALKALI FELDSPAR, PRESENCE OF PYROXENE AND AMPHIBOLE)								
1. Feldspathoidal Hornblende - Pyroxene Monzonite	24 - 37%	16 - 26% (a) Subhedral - anhedral, An ₂₅₋₃₀ Weakly zoned, twinned (b) Fine-grained, poorly twinned. Mantles on Nephelins, An ₁₅		10 - 20% Pyroxene Weakly zoned, rimmed by amphibole tr - 23% Hornblende as uraltic rims	6 - 13% Nepheline 1 - 4% Sodalite			Med. - dark gray; V. fine-grain; amphibole lends speckled appearance; nepheline lends greasy luster
2. Hornblende - Pyroxene Monzonite	Alkali Feld = 0.25-0.62 Alk. Feld + Plag Anhedral; slight-mod. perthitic; mantles Plag.	Subhedral, commonly aligned		0 - 20% Hornblende rims or replacement of pyroxene; anhedral grains enclosing Feldspar 0 - 20% Pyroxene rimmed or replaced by green amphibole 0 - 9% Biotite			Sphene Apatite Opaque Oxides	Med. light-gray, fine-grained; equigranular; conspicuous aligned hornblende; some well-developed compositional layering.
3. Porphyritic Hornblende - Pyroxene Monzonite	31 - 77% Weakly perthitic cores Moderately perthitic margins; anhedral mantles on plag.	17 - 50% An ₂₀₋₃₅ Subhedral, weakly zoned		2.5 - 10% Uralitized Clinopyroxene and anhedral Amphibole		Interstitial quartz	Sphene large anhedral grains	Med. light-gray, Phaneritic, Porphyritic, Aligned alk. feld. → Flow Layering
Monzonite Porphyry	Sparse Sanidine	An ₃₅₋₂₅ zoned		Altered to chlorite, epidote, calcite		Subtrachytic feldspar and trace of quartz		Porphyritic Aphanite
Quartz-Bearing Monzonite Porphyry	Or ₅₈ as mantles	An ₃₀₋₄₀ Mod. zoned An ₅ on margins Most of Phen.		Clinopyroxene Amphibole 10% Biotite		Plag. Alk. Feld. Quartz		
Leucocratic Monzonite and L. Monz. Porphyry	Or ₆₀ Ab ₄₀ strongly perthitic Or ₅₆ Ab ₄₄ (Syenite)	Oligoclase mantled by Alk. Feld.		8% Minor Clinopyroxene; salite w/minor acmite 2V ~ 65°, Z RcC=50 - 58°		Phaneritic Alk. Feld.; Oligoclase; Quartz 11%	Sphene Apatite Opaque Oxides	Light gray, predominantly Oligoclase and Alk. Feld; Seriate - strongly porphyritic
Biotite Quartz Monzonite Porphyry	Sanidine subordinate to plag. weakly perthitic 2V _x ~ 40°	An ₁₈₋₂₇ weak-mod. zoned	Subhedral, rounded phenocrysts, commonly embayed	Biotite		Alk. Feld. Plag. Quartz		Porphyritic with granular, V. fine-grained to aphanitic groundmass - commonly highly altered
Bostonite Porphyry						Sanidine Sodic Plag. Quartz		Cuts Biot. Granodiorite Porphyry and Biot.-Qtz. Monz. Porphyry
Sanidine Porphyry	Sanidine Or ₉₅ Ab ₅ 2V _x ~ 45-50°					V. fine-grain, Tabular alk. feld. and minor quartz		

also problematical. Braddock feels that these alkaline rocks could not have evolved from the monzonitic magma, nor could the monzonitic magma have evolved from them. Briefly, Braddock believes that two magmas were involved. One was a calc-alkaline magma from which the granodioritic rocks evolved through simple differentiation. The other was an alkalic-calcic, monzonitic magma. Clinopyroxene removed from a hornblende-pyroxene monzonite magma may have produced a magma responsible for the leucocratic monzonite. Diversification of the parent monzonite magma at depth may have produced secondary magmas from which the other rock types of the series were formed. Assimilation reactions involving the parent monzonite magma and Precambrian hornblende-rich country rocks may have resulted in an undersaturated magma from which the nepheline-bearing rocks were formed. Braddock does not mention the origin of the magmas.

Simmons and Hedge (1978) also recognize two suites: a granodiorite suite characterized by phenocrysts of hornblende or biotite, quartz + feldspar and by a uniform variation diagram; and a monzonite suite characterized by clinopyroxene and less than 15% quartz (Table 6).

The rocks of the granodiorite suite designated group I and group II, exhibit good trends of increasing $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios with decreasing Sr content. Simmons and Hedge

DESCRIPTION OF UPPER CRETACEOUS-TERTIARY IGNEOUS ROCK TYPES OF THE COLORADO MINERAL BELT
AFTER SIMMONS AND HEDGE (1978)

ROCK NAME	SiO ₂	ALKALIES	PLAGIOCLASE	FERROMAGNESIUM MINERALS	ISOTOPE DATA	ACCESSORY MINERALS	GROUNDMASS	REMARKS
GRANODIORITE SUITE (VOLUMETRICALLY MORE ABUNDANT OCCURRING ALONG ENTIRE MINERAL BELT, PHENOCRYSTS OF QUARTZ, FELD., HORNBLende, OR BIOTITE, > 63% SiO ₂ , Na + K ~ 7%, AT LEAST 20% NORMATIVE OR MODAL QTZ., SIMPLE SMOOTH TRENDS OF MAJOR OXIDES IN VARIATION DIAGRAMS, ⁸⁷ Sr/ ⁸⁶ Sr > 0.707)								
GROUP I					Rb/Sr 0.135 Sr > 500 ppm			
GROUP II					Rb/Sr 0.135 Sr > 600 ppm			
MONZONITE SUITE (MORE COMPLEX, RESTRICTED TO THE NORTHEAST PORTION OF COLORADO MINERAL BELT, CONTAIN CLINOPYROXENE AND LESS THAN 15% QUARTZ.)								
ALKALIC MONZONITE SUITE (CLINOPYROXENE RIMMED BY HORNBLende, MAY CONTAIN INTERSTITIAL QUARTZ)						⁸⁷ Sr/ ⁸⁶ Sr < 0.706 Rb 50 - 230 ppm Sr 70 - 2800 ppm		3 Phases
(a) Hornblende - Pyroxene - Monzonite	53 - 58%	8 - 11%		10 - 30%			0-Tr-Qtz.	Early Phase
(b) Quartz-bearing Monzonite	58 - 64%	8 - 12%		< 15%			0 - 15%	Second Phase
(c) Leucocratic Monzonite or Syenite	> 64%	10 - 14%		< 5 - 10%			5-10% Qtz.	Third Phase Representative samples from Empire Stock, Audubon-Albion Eldora-Bryan Mtn., Sunset, Horseshoe Creek.
II: MAFIC MONZONITES (and Latites)								
		Lower Alkalies than I (< 9%)	> An ₄₀	Clinopyroxene enclosed in Biotite Higher MgO, Fe, Mg/Rb Ratios Mg + Fe than I	⁸⁷ Sr/ ⁸⁶ Sr > 0.707 Rb 90 - 170 ppm Sr 500 - 1160 ppm			Occur at Caribou, Bald Mtn. Audubon-Albion, Table Mtn., Valmont
III: QUARTZ SYENITES Hornblende Granodiorite (Wells, 1960) Leucocratic Granodiorite (Gable, 1969)								
			Contain Qtz. Phenocrysts like Granodiorites	Clinopyroxene rimmed by Hornblende like Alkalic Monz. Suite	⁸⁷ Sr/ ⁸⁶ Sr < 0.706 Similar Rb,Sr			Samples: Fall River Road, Apex, Gold Hill Area, Chemistry similar to Ib but presence of Qtz. Pheno. indicates diff. history
IV: ULTRAMAFIC ROCKS Pyroxenites Hornblendes								
			Some Plag.	> 70% Clinopyroxene some Biot.	⁸⁷ Sr/ ⁸⁶ Sr LOW Sr content reflects host	Apatite Opaques		At Caribou Assoc. w/ Mafic Monzonites and at Empire Assoc. w/ Alk. Monz; Assoc. w/ Mafic Monz. at Caribou and at Bald Mtn. and w/ Alk. Monz. at Audubon-Albion.
			Some Plag.	> 70% Hornblende and Clinopyroxene some Biot.	⁸⁷ Sr/ ⁸⁶ Sr Dissimilar	Opaques Sphene		
V: LATITE DIKES BOSTONITE DIKES								
	62 - 70%	10% Alkalies Alkali Feldspar Phenocrysts		Clinopyroxene, Hornblende or Biotite	⁸⁷ Sr/ ⁸⁶ Sr > 0.7074 Rb = 60-80 ppm Sr 1000-1300 ppm ⁸⁷ Sr/ ⁸⁶ Sr > 0.7159 Assimilated Sr from Pre-? Rb 234 ppm Sr 39 ppm		Highly Altered Leucocratic	Commonly found near or within stocks of Alk. Monzonites

interpret this as reflecting evolution by fractional crystallization and assimilation of Precambrian crustal rocks. To derive rocks of the granodiorite suite from an alkaline monzonitic parent magma would require the removal of a high-alkali, low-silica phase. From the interpretation of their data, Simmons and Hedge propose that the granodiorite suite evolved separately by the partial melting of a pyroxene granulite in the lower crust. Differences in the Rb/Sr ratios of Group I and Group II suggest that these rocks evolved from similar but separate partial melts, both of which underwent a very similar crystallization process. To support their argument further, the authors note that pyroxene-granulite nodules have been reported in the kimberlite diatremes at Stateline on the Colorado-Wyoming border (Eggler and McCallum, 1974).

The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and rare-earth-element variations among the monzonitic rocks suggest that they were derived from separate, slightly different magmas. These monzonite magmas were progressively leucocratic and fairly alkaline, with a composition lying close to the plagioclase-alkali feldspar join and low-pressure thermal divide. Simmons and Hedge (1978) state that garnet, rather than feldspar, played the significant role in the genesis of these magmas. They believe that the monzonite magmas evolved by the partial melting of a rock of an alkali-basalt composition, which left

an eclogitic residue into which the heavy rare-earth elements partitioned. The depth of this source is uncertain, but it is believed to be below that for the granodiorites. Simmons and Hedge note that alkalic-eclogite nodules have also been found in the kimberlite diatremes at Stateline. The variation in $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios in the monzonitic rocks suggests that the variations among the monzonitic magmas reflect the partial melting of a heterogeneous source rather than varying degrees of crustal contamination. Isotope data also indicate that the source rocks for both suites are Precambrian.

Simmons and Hedge (pers. commun.) have suggested that the alkalic character and Precambrian age of the parent material, from which the monzonite was derived would effectively eliminate the possibility that the parent material evolved from subducted oceanic tholeiite, as outlined by Lipman, Prostka, and Christiansen (1972). McBirney (1969) has suggested that volatiles released by a subducting slab may have the effect of lowering the melting point of overlying materials.

Lovering and Goddard (1938), Tweto (1975), and Steven (1975) have suggested that the immediate source of these magmas was a batholith or a string of batholiths underlying central and southern Colorado. Simmons and Hedge (1978) feel that some of the larger plutons, such as at Mt. Princeton and Montezuma, may be underlain by much larger bodies. The geochemistry

of these plutons indicates that they represent relatively fractionated magmas which would be expected to occur near the top of a much larger magma body. They have observed that these characteristics are lacking in the smaller plutons whose more mafic phases appear to be partially cumulative in origin; a feature not expected to be a higher level expression of a larger magma body. The characteristics of other smaller plutons indicate that they are primary or only slightly fractionated magmas.

MODE OF INTRUSION

Wells (1960) discusses the mode of intrusion:

"The Tertiary igneous rocks were intruded largely into pre-existing fractures in the Precambrian country rock. Joints, foliation surfaces, contacts, faults, and axial planes of folds were particularly favorable sites for emplacement of the bodies. The fractures not only controlled the localization of the intrusive rocks, but also to a marked degree controlled the shape and trend of the bodies. The older intrusive rocks formed plutons, which only locally appear to be related to the structural fabric of the Precambrian rocks, whereas the younger intrusive rocks formed dikes, which are dominantly controlled by linear fractures in the Precambrian rocks. Intrusion of all types of bodies was probably dominantly passive, with the magma stopping its way in or rarely being forced into the fractures that offered the least resistance to its movement. Intrusive breccias are associated with some of the plutons and probably resulted from local explosive force."

"At many places throughout the region, it can be demonstrated that the igneous bodies are localized by joints, foliation surfaces, axial planes of tight folds, faults, and contacts. Many dikes trend parallel to well-defined joint sets and in detail are seen to occur in particular joints. A close correlation between dikes and joint sets is particularly striking in the Central City district. The intersecting northwestward-trending and northeastward-trending quartz bostonite porphyry dikes, which form a prominent grid pattern in the Central City district...respectively occupy northwestward-striking and northeastward-striking joints... Foliation surfaces and axial planes of tight folds are the dominant structural features controlling the localization of dikes in the Chicao Creek area... and probably also the southern part of the Idaho Springs district...In these areas the dikes trend mainly northeastward, parallel to the prevailing structural fabric of the Precambrian country rock.

"The localization of the igneous plutons of earlier structural features is not conspicuous, but most of these bodies are elongate parallel to a conspicuous joint direction. Most plutons in the eastern part of the region...are elongated in a northeast direction subparallel to a prominent joint set. Commonly, dikes associated with these same bodies extend outward from the margins of these bodies in the same direction.

"Although all the intrusive bodies were largely localized by pre-existing planar structural features in the Precambrian bedrock, the influence of these features on the shape of the bodies was more pronounced in the younger members of the sequence (Wells, 1960, pp. 262-263).

"The rocks of the Tertiary igneous sequence were intruded during the Laramide uplift; and, as erosion stripped off some of the rock load during uplift, confining pressures were reduced and fractures were allowed to open more easily. This change in lithostatic pressure is indicated by the gradual change in the form of the intrusive bodies from the nearly equidimensional granodiorite porphyry plutons to the long narrow dikes of the bostonite and biotite quartz latite porphyry." (Wells, 1960, p. 266).

Lovering and Goddard (1950) have summarized the general order of igneous activity in the framework of the Laramide orogenic events.

"1. The intrusion of sills and dikes of felsite porphyry...and hornblende andesite in the southwestern part of the porphyry belt during Late Laramide and early Denver time, while dikes and stocks of aluminous augite andesite were being intruded in the central part of the rising Front Range arch, with attendant extrusive activity.

2. The beginning of folding and faulting along northwesterly axes throughout the Front Range, accompanied by the intrusion of dikes and small irregular stocks of porphyritic augite diorite on the western slope and extensive northwesterly dikes of gabbro and diabase...on the eastern slope; also by the extrusion of basalt and mafic andesite from many scattered vents in the central part of the Front Range.

3. The intrusion of rhyolite and some quartz monzonite porphyry in South Park, the intrusion of porphyritic hornblende-quartz monzonite and andesite in the region near Ward and the extrusion of rhyolite and rhyolite tuff near the Pikes Peak volcanic vent somewhat later, near the close of Denver and Dawson time.

4. The culmination of northwesterly faulting and overthrusting and the intrusion of stocks and sills of porphyritic hornblende diorite...and hornblende monzonite in the southwestern part of the mineral belt; also the intrusion of stocks and dikes of porphyritic granodiorite...hornblende monzonite, hornblende diorite, and of andesite porphyry in the northeastern half of the porphyry belt. It is probably that the porphyritic rocks of the Radial Mountain-Home belt were intruded at about this time also.

5. The intrusion of hornblende and biotite-quartz monzonite porphyries as sills and dikes throughout the porphyry belt."

- "6. The intrusion of coarsely porphyritic biotite-quartz monzonite of the Lincoln porphyry type...in the southwestern half of the mineral belt and the intrusion of medium-grained biotite-quartz monzonite porphyries in the northeastern half of the belt, together with sodic quartz monzonite and latite porphyries. The great bulk of the porphyritic rocks in the southwestern half of the mineral belt were intruded during epochs 4, 5, and 6.
7. The intrusion of rhyolite...alaskite, and felsite porphyries throughout the mineral belt and formation of lead-silver ores in the region from Caribou southward.
8. The intrusion of alkalic syenite, alkalic diorite, and sodic granite...in the northeastern half of the mineral belt, followed by pyritic gold and sparse lead-silver-zinc mineralization.
9. The intrusion of bostonite porphyry...and alkalic trachyte porphyry in the northeastern half of the mineral belt, followed by extensive pyritic gold mineralization.
10. The intrusion of biotite-latite...and biotite monzonite porphyries rich in volatiles in the northeasternmost portion of the mineral belt.
11. The injection of latitic intrusion breccias...in dikes and pipes in the northeastern half of the mineral belt, followed almost immediately by gold-telluride mineralization.
12. Intrusion of limburgite...dikes in the tungsten belt followed by the formation of tungsten ore bodies." (Lovering and Goddard, 1950, p. 47).

Uranium Enrichment in Laramide-Age Igneous Rocks

Vein-type uranium deposits in the central Colorado Front Range appear to bear close spatial and temporal relationships to Laramide-age monzonitic igneous rocks of the monzonitic

suite, notably bostonite and quartz bostonite.

They have separated the Mesozoic-Cenozoic age igneous rocks of the Central Front Range into the following suites:

1. Tholeiitic-Tholeiitic Andesite Subseries, Represented by the 62 km-long Iron Dike. Uranium, 0.4-2.6 ppm.
2. Alkalic Potassic Series, Represented by the Nepheline-bearing Phaneritic Audubon-Albion Stock. Uranium, 0.8-3.0 ppm.
3. Alkali Calcic Potassic Subseries, a Widespread Suite Represented by the Latite Flows of Table Mountain, by a Latite Dike Near Rollinsville, and by the Phaneritic Caribou and North Bryan Mountain Stock. Uranium, 0.7-7.6 ppm.
4. Alakali Calcic Subseries Transitional into Calc-Alkalic Represented by a Phaneritic Granodiorite Stock at Jamestown and Presumably by Dikes and Sills of Dellenite and Biotite Quartz Latite along the Adjacent Mountain Front. Uranium, 2.1-5.5 ppm.
5. Alkali Calcic, Sodic Subseries includes the Phaneritic Bryan Mountain Granodiorite Stock as well as the Great Majority of the Abundant Porphyritic Aphanitic Stocks and Dikes that give the "Porphyry Belt" its Name. Uranium, 1.8-19.0 ppm.
6. Alkalic Sodic Subseries Represented by the Phaneritic Nepheline-bearing Empire Stock. Uranium, 3.8-18.00 ppm.
7. Late Stage, CaO-poor Dikes, The End Products of Magmatic Differentiation along the Alkali-Calcic, Sodic Line of Descent. Uranium, 7.0-138.6 ppm.

(Phair and Jenkins, 1975, p. 6.)

Phair and Jenkins (1975) have attempted to identify mechanisms for uranium enrichment in individual intrusive bodies by plotting the variation of uranium and thorium values against the variation of values for the major rock-forming

oxides. CaO and $\text{Na}_2\text{O} + \text{K}_2\text{O}$ were plotted against corresponding values for SiO_2 , resulting in a Peacock variation diagram for a suite of rocks associated with a particular intrusive body. The uranium and thorium values at the Peacock Index, where $\text{CaO} = \text{Na}_2\text{O} + \text{K}_2\text{O}$, may be used to represent the degree of uranium and thorium enrichment in differing magma bodies at an equivalent stage of magmatic differentiation (Figure 4).

Phair and Jenkins found that the uranium-enriched phaneritic stocks also are enriched in thorium (Table 8 and Figure 3). The presence of thorium, they believe, supports the conclusion that these two elements are primary constituents rather than later epigenetic or supergene additions, which would preclude the incorporation of significant quantities of thorium.

Phair and Jenkins have observed a distinct behavior in the U-SiO_2 and Th-SiO_2 curves in the enriched phaneritic stocks, such as the Bryan Mountain granodiorite stock west of Eldora, and especially the nepheline-bearing Empire stock. The variation diagrams for these stocks show two U-Th maxima separated by a minimum (Figure 4). In the Empire stock, which intrudes the thorium-rich (79.1 ppm Th) Silver Plume pluton, the first U-Th maximum coincides with a maximum nepheline content (Figure 5). By this observation, they conclude that U-Th enrichment at this stage occurred without any appre-

ppmU, Th, and % Major Oxides at the Peacock Index of some Mesozoic-Cenozoic Stocks of the Central Front Range, Colorado
(after Tables 17, 18, Phair and Jenkins, 1975)

Stock	P. I. (%SiO ₂)	CaO	Na ₂ O	K ₂ O	Na ₂ O/K ₂ O	D.I.*	ppmU	ppmTh	Magma type
N. CENTRAL SUBPROVINCE									
JAMESTOWN STOCK	55.6	7.0	2.9	4.1	0.70	55.0	3.3	10.0	Alk.-Calc., Potassic ↔ Calc.-Alk.
CENTRAL SUBPROVINCE									
AUDUBON-ALBION	50.9	8.0	3.3	4.7	0.70	51.0	2.6	10.3	Alk., Potassic ↔ Alk.-Calc.
CARIBOU	52.0	7.1	3.4	3.7	0.87	51.1	21.0	26.0	
N. BRYAN MTN.	53.15	7.1	3.2	3.2	0.82	50.7	1.2	7.0	Alk.- Calc., Potassic
TABLE MTN. FLOWS	52.45	7.1	3.0	4.1	0.73	50.0	3.8	6.5	
S. CENTRAL SUBPROVINCE									
BRYAN MTN.	54.30	6.3	4.3	2.0	2.15	55.0	5.4	53.5	Alk.- Calc., Sodic
EMPIRE	49.6	8.3	4.2	4.1	1.02	12.2	12.2	~50.0	Alk., Sodic
MONTEZUMA	54.0	25.0					~5.0	~20.0	Alk.- Calc., Potassic

*Differentiation Index

56c

FIGURE 4

URANIUM IN LARAMIDE IGNEOUS INTRUSIVES

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ciable assimilation of wall rock. Assimilation of wall rock would have added a substantial amount of SiO_2 to the system, which would have inhibited the crystallization of feldspathoids.

On the basis of petrographic evidence, Phair and Jenkins believe that a fluid phase, developed in the upper, outer margins of an intruding magma body during the early stages of differentiation, could have provided a medium capable of leaching uranium and thorium from the wall rock. Such a fluid phase could introduce these elements into the magma without introducing, at the same time, major quantities of rock-forming constituents (Figure 5).

Early separation of a fluid phase is suggested by rimming and replacement relationships in mafic minerals. In the relatively unenriched stocks such as at Jamestown, the hydrous mafic minerals, hornblende and/or biotite, were abundant in the earliest phases and were dominant throughout the course of differentiation. It is believed that much of the water content of these unenriched magmas was tied up in these hydrous mafic minerals at an early stage and that insufficient quantities of free water were available in solution to form a separate fluid phase during crystallization. In contrast, the more enriched porphyritic-aphanitic stocks are often characterized by reversals in Bowen's reaction series, in which early hornblende and/or biotite are replaced by sodic augite. In addition, biotite may be rimmed by horn-

blende which, in turn, may be rimmed by sodic augite.

Other factors also indicate the separation of a fluid phase during differentiation. The structural state of feldspars is generally high in enriched stocks, while it is low in unenriched stocks. The high and low structural states of feldspars develop in stability ranges which are largely temperature dependent, but which may be affected by water pressures as well. Therefore, the high structural state of feldspars in relatively enriched stocks may be indicative of higher water pressure.

Phair and Jenkins believe that the minimum values for uranium and thorium in the variation diagrams are probably related to two factors: first, the magma has been partially devolatilized, having given up uranium- and thorium-bearing volatiles to the earliest members which have formed the crystalline hood zone; secondly, this crystalline hood zone has served to insulate the wall rocks from further reaction with the magma.

Differentiation, accompanied by a recharge in volatiles, is thought to be responsible for the second U-Th maximum. The degree of concentration of uranium and thorium in the melt appears to have been directly related to the degree of fractional crystallization that had taken place within the magma. The relatively high charge and large ionic radii of thorium, and especially, uranium ions normally exclude them from

the common rock-forming silicates. Therefore, it would be expected that even a slight excess of uranium and thorium, present at an early stage of magmatic differentiation, would undergo a proportionate increase in concentration in the residual magma as differentiation progressed.

This concentration mechanism is dramatically displayed by the CaO-poor, late-stage differentiates found in the central Front Range. These rocks are end members of the alkali-calcic, sodic subseries and occur as small intrusive bodies and long, narrow dikes of bostonite and quartz bostonite. These rocks are of special interest for several reasons: first, their unusually high uranium and thorium contents demonstrate the efficacy of magmatic differentiation as a concentrating mechanism; second, extremely high uranium-thorium contents make some bostonites worthy of consideration as low grade ore for the recovery, through leaching processes, of rare earths, base metals, and precious metals, in addition to uranium and thorium; third, bostonites appear to bear a close spatial and temporal relationship to pitchblende-bearing base-metal sulfide and fluorspar vein deposits.

The petrographic term "bostonite" was originally proposed by Hunter and Rosenbusch in 1890 to describe a dike rock of trachytic habit which was commonly found in association with "eleolite-syenite". The term originated from the description of such rocks found in the vicinity of Marblehead Neck in

Essec County just north of Boston, Massachusetts.^{1/} As it was realized that these rocks did not always occur in the above association, Kemp and Marsters formally introduced it into American literature in 1893 with their description of very similar rocks found along the shores of Lake Champlain.

According to Phair and Jenkins, bostonites and quartz bostonites are usually fine-grained, aphanitic to porphyritic-aphanitic rocks. Feldspar laths in the groundmass display a typical bostonitic texture in which they are mutually sutured against one another in divergent clusters and subparallel trachytic whorls.

Chemically, bostonites are distinguished by their extremely low MgO and CaO contents, by very low femic indices (1.2-7.4), and by silica values in the range of 65-72 percent.

Mineralogically, bostonites are characterized by the presence of alkali feldspar as phenocrysts and as crystals in the groundmass. Sodid plagioclase may occur in the groundmass. Quartz may occur in the groundmass as large irregular patches in amounts of 5-25 percent. Mafic minerals are primarily iron oxides, hematite, and magnetite. They may lend a lavender blue to gray coloration in fresh rock and a purplish-brown to reddish-brown coloration in altered rocks.

^{1/} Hyatt; Bouve; Wadsworth; Crosby, 1876: individual articles in volumes 18 and 21 of The Proceedings of the Boston Society of Natural History and by Dillers and Sears in volume 7 and 16, respectively, of the Bulletin of the Museum of Comparative Zoology.

Phair and Jenkins believe that the host mineral for uranium in bostonites is primarily zircon, as bostonites exhibit increases in uranium content proportional to increase in zircon content. Thorium contents exhibit no such relationship. Instead, it is believed that the thorium hosts are primarily allanite and thorite.

Phair and Jenkins have observed that the uranium content in bostonite and quartz bostonite in the central Front Range may vary considerably. The higher uranium content in some appears to be related to the proximity of the bostonite to Silver Plume-age uraninite-bearing pegmatites in the Central City and Idaho Springs districts.

These proximal relationships--enriched pegmatite to enriched bostonite and enriched bostonite to vein deposit suggest to us a continual cycle of concentration, remobilization, and reconcentration of at least a part of the uranium content. If we take this idea a step further, uranium concentrations in migmatite (Jasper Cut) and pegmatite (Highlander-Hudson) in the same area may have been remobilized, in part, from the lower Proterozoic metasediments of the Idaho Springs Formation. However, what little work has been done to identify radioactive source beds within the Idaho Springs Formation has not provided any results, as yet, which are encouraging to this hypothesis. Considering the extreme mobility of uranium in the metamorphic environment and the high grade of metamorphism in the Front Range, this hypothesis is probably impossible to establish by the direct

evaluation of uranium content in the metasedimentary formations.

Gableman (1975) has expressed doubt that the bostonites of the Central City district are the source of the uranium of the vein-type pitchblende deposits found there. He states that there is not enough uranium in the bostonite dikes to have supplied the quantity of uranium found in the veins.

Second, he states that there is no evidence that the uranium in the bostonite dikes has moved. He does not elaborate on this point in the given reference. These observations, however, do not preclude the possibility that most of the original uranium content in the bostonitic differentiate may have been drawn off in a hydrothermal phase nor the possibility of a common source for both.

CHAPTER G
SUMMARY OF TERTIARY URANIUM MINERALIZATION

The greatest concentration of uranium in the Front Range developed in the early Tertiary within two major zones: the Foothills Uranium Belt immediately west of Denver and in the northern part of the Colorado Mineral Belt, from Idaho Springs to Jamestown. The uranium in both may have shared a common source. Many prospects were opened in both belts during the 1950's, but only the Schwartzwalder mine in the Foothills Belt has maintained continuous production to the present.

All of the mines and prospects in the Foothills Belt lie within the major northwest-trending shear systems which extend from the mountain front to and beyond the Mineral Belt. The major faults of these systems may have formed as early as late Precambrian; "breccia reefs" occur along portions of these early structures. Uranium and sulfide mineralization formed in subsidiary structures in early Tertiary time.

Appreciable uranium mineralization also occurred during the early and mid-Tertiary in the northern part of the Mineral Belt, in close association with late-stage differentiates of the monzonitic intrusive suite described in Chapter F.

Uranium-bearing veins in close proximity to anomalous bostonite dikes in the Idaho Springs, Central City, and Jamestown districts suggest this relationship. The Foothills Belt uranium mineralization may also have been derived from these monzonitic intrusives.

Uranium is also anomalous in some of the mid-Tertiary molybdenum-bearing stocks, including the Henderson multi-intrusive center 26 to 32 m.y. age and the Jamestown stock of 42 m.y. age. Locally, the uranium content of the latter is reported to be up to eight times background (Bob Jenkins, pers. commun.).

The volcanic center at Cripple Creek is another anomalous uranium occurrence of Tertiary age; it has been dated at 42 m.y. also. Uranium occurs with fluorite veins, and along shear zones and has been upgraded by supergene enrichment (Newcomb, 1958). Plate 4.

CHAPTER H

A SUMMARY OF MAJOR ASPECTS OF URANIUM GEOCHEMISTRY*

The geochemistry of uranium is complicated and not well understood. The present level of understanding is rooted in studies developed during the 1950's of the Colorado Plateau-type uranium deposits. These studies dealt primarily with relatively low temperature solutions ($\sim 25^{\circ}\text{C}$), but were important in two respects. First, they led to a basic and preliminary understanding of the solution chemistry of uranium with regard to the identification of various uranium complexes and their stability fields. Secondly, the studies have highlighted certain chemical characteristics which are recognized as important factors in the solution, transport, and deposition of uranium in hydrothermal media and which have important implications for its behavior in the igneous and metamorphic environment.

* The major portion of the solution chemistry of uranium discussed in this chapter was selectively abstracted from: Rich, R.A., Holland, H.D., Petersen, Ulrich, 1975, Vein-type Uranium Deposits: U.S. Energy Research and Development Administration. GJO-1640.

Essential information pertaining to U

atomic number 92

atomic mass 238.029; the heaviest naturally occurring element

atomic radius U^0 0.142 nm

U^4 +0.097

U^6 +0.080

valence states U^0 , U^{3+} , U^{4+} , U^{5+} , U^{6+}

isotopes and isotopic abundance U_{238} 99.28%

all isotopes are radioactive U_{235} 0.71%

U_{234} 0.0054%

average crustal abundance c. 2 ppm

Introduction

Studies of the Plateau-type uranium-vanadium deposits and Wyoming uranium roll-front type deposits have consistently shown that the most important factors in the solution, transportation, and deposition of uranium are oxidation and reduction reactions involving U^{4+} and U^{6+} . Uranium may be transported as either U^{4+} or U^{6+} complexes. U^{4+} forms important complexes at temperatures above 200°C. At lower temperatures (<200°C) the most important solution and transport mechanisms involve the oxidation of U^{4+} in stable minerals to U^{6+} and the formation of the highly mobile uranyl ion UO_2^{2+} . Depending upon the physical and chemical conditions, UO_2^{2+} may travel in its ionic form or combine with carbonate, fluoride, sulfate,

or phosphate anions to form highly mobile complexes. Precipitation involves the destabilization of the uranium complex, the reduction of U^{6+} to U^{4+} by some reducing agent, and the formation of the anhydrous uranium oxide, uraninite (UO_2). Less common hydrated or uranium carbonate complexes containing the species UO_3 may form as secondary minerals from the primary oxide complex, UO_{2+x} .

Investigations into uranium geochemistry have focused primarily upon possible uranium complexes and their stability fields. The solution, transportation, and precipitation of uranium is ultimately dependent upon behavior of available anions and the stability of uranium complexes under varying physical and chemical conditions. Variables are temperature, pressure, Eh, pH, P_{H_2O} , P_{O_2} , and the abundance of the components which may form the various anion species.

Solution and Transport of Uranium

Uranium Solubility

The solubility of UO_2 increases with oxygen fugacity and solution acidity. However, increases in solution alkalinity (i.e. higher than neutral pH values) do not significantly decrease solubility.

The response of uranium complexes to changes in pressure is not significant except when uranium solubility is critical.

In near neutral solutions, UO_2 has been found to be 500 times more soluble at 100°C than at 25°C . However, Lemoine (1975) has found that, although uranium solubility in the system $UO_2-UO_3-H_2O$ increases with a rise in temperature, it decreases markedly above a temperature of 260°C . This ideal condition is not representative of actual hydrothermal conditions which would, of course, include a considerable quantity of other complexes that might affect solubility. In alkaline solutions, a rise in temperature may either increase or decrease UO_2 solubility depending upon the activity of HCO_3 . It has also been found that, in alkaline solutions, NaCl increases the solubility of UO_2 and UO_3 hydrates by raising the ionic strength of carbonate complexes. NaCl also serves to increase the activity of $UO_2(OH)$ and UO_2^{2+} in acidic solutions.

Uranium Complexing

It must be remembered that the abundance of a particular uranium complex depends upon the activity of the associated anions in a solution and the stability of the complex under varying physical and chemical conditions.

The consistent abundance of CO_2 in fluid inclusions of vein-type uranium deposits has caused workers to study the role of carbonate anions in uranium transport. It was found that uranyl dicarbonate (UDC) and uranyl tricarbonat (UTC) are important in alkaline to neutral solutions.

$UO_2(OH)_2$ and UO_2CO_3 are the most abundant complexes in near-neutral to weakly acid solutions. Under more acidic conditions, the more acidic species $UO_2(OH)^+$ and UO_2^{2+} are the most abundant. Fluoride, sulfate, chloride, and phosphate complexes may be important where these anions are abundant.

Romberger (pers. commun.) has indicated that, at higher temperatures ($>200^\circ\text{C}$), UDC and UTC are important only at extremely high pH values (>13). Such conditions are geologically improbable. He has calculated that, if fluorine is readily available, fluoride complexes would be important at these higher temperatures in neutral to slightly acidic solutions.* The types of fluoride complex depends upon the activity of F^- .

* At higher temperatures, neutral pH shifts to lower values (e.g. at 300°C , neutrality is about 6).

at pH 1-6, 300°C, 1000 ppm $F^- \rightarrow UO_2F_6^{4-}$

10 ppm $F^- \rightarrow UF_4$

(Romberger, pers. commun.)

Phosphate will combine with the uranyl ion to form a complex $UO_2(PO_4)_2^{2-}$ which is stable over a broad range of pH values (4-8). With a phosphate concentration of only 0.1 ppm, uranyl phosphate complexes will dominate over all other types for pH values of 4.5-7.0. However, if Ca^{2+} is present, phosphate complexing of uranium will be inhibited by the formation of apatite.

Silica may also form a weak uranyl complex $UO_2SiO(OH)_3^+$ in near-neutral solutions.

Precipitation of Uranium from Solution

Workers in the Plateau-type uranium-vanadium and Wyoming uranium roll-type and Texas-type deposits have found that uranium ore has often replaced recognizable carbonaceous trash including twigs, logs, etc. Observations of this type suggest that elemental carbon reduction of uranium complexes was largely responsible for deposition in these sedimentary occurrences.

Rich, Holland, and Petersen (1975, Page 21) have noted the frequency of occurrence of the following minerals in 41 vein-type deposits:

pyrite/marcasite	100%
base metal suflides	90%
quartz	83%
hematite	76%
carbonates	51%
fluorite	34%
barite	20%

In 28 of 41 deposits pitchblende preceded pyrite/marcasite.

In 13 of 41 deposits pitchblende followed pyrite/marcasite.

The occurrence of sulfides with pitchblende clearly indicates a change to more reducing conditions in the system (Rich, Holland, Petersen, 1975, p. 77).

C^0 , Fe^{2+} , CH_4 , S^{2-} , and H_2S have been suggested as potential reducing agents. Carbonaceous trash, humic matter, biogenic gases, petroleum, graphite, and sulfides are examples of gaseous and solid matter which might effect reduction. It is believed by some that the reduction capacity of the ferrous ion is probably subordinate to those mentioned above but may be significant when other, more effective, reducing agents are absent. Romberger (pers. commun.) suggests that the oxidation of Fe^{2+} to form hematite may be an effect rather than a cause of deposition.

The loss of CO_2 has also been cited as a possible mechanism for U deposition. In the Limousin deposits in France, there is a close relation between ore grade and the CO_2 content of fluid inclusions formed prior to devolatilization. In the Erzgebirge deposits of Germany (Saxony), there are much higher

concentrations of CO_2 in fluid inclusions in minerals formed prior to pitchblende deposition than in minerals formed after deposition.

The equilibrium constant for this reaction is

$$K_{5-1} = \frac{a_{\text{UO}_2(\text{CO}_3)_2}^{-2} \cdot a_{\text{H}^+}^2}{a_{\text{CO}_2} \cdot f_{\text{O}_2}^{1/2}};$$

This equilibrium constant equation (Rich, Holland, Petersen, 1975, p. 83) for the above reaction indicates that the reduction of UDC activity and the precipitation of UO_2 would be expected as the result of a decrease in CO_2 activity. However, this equilibrium relationship is valid only under constant f_{O_2} and pH conditions. CO_2 loss from a solution will cause the pH of that solution to rise. Such a trend toward alkalinity will increase the solubility of UDC in the solution and thus inhibit further precipitation of uranium. It has been suggested that, under such circumstances solution-wall-rock reactions may exercise an important control on the pH of the solution. However, the degree of wallrock alteration in many vein-type uranium deposits suggests only minor wall-rock reaction. At lower temperatures ($<150^\circ\text{C}$) then the significance of CO_2 loss and the precipitation of UO_2 from carbonate complexes is still unclear. With regard to other

uranium complexes, Romberger (pers. commun.) has indicated that CO_2 -loss, accompanied by rises in pH and Eh, is probably important in the precipitation of UO_2 from sulfate and higher temperature fluoride complexes.

Consideration of Uranium in the Magmatic Environment

In the magmatic environment, uranium generally occurs in greatest abundance in the more acidic and alkalic rocks.

<u>Rock Type</u>	<u>Ave. ppm</u>
dunite	0.02
eclogite	0.20
pyroxenite	0.70
gabbro	0.90
diorite & quartz diorite	2.00
granodiorite	2.60
granite	4.00
alkalic intrusives	0.04-140.00

(Rogers & Adams, 1967)

In the more enriched series cited above, uranium concentration is proportionately greater in their late-stage differentiates. The abundance of uranium is generally 1.5-2.0 times higher in volcanic rocks than in their plutonic equivalents.

The behavior of uranium in the magmatic environment is directly related to the atomic structure and natural abundance of uranium in magmas. The high valence states of magmatic uranium (U^{++}) coupled with its large atomic radius to give it a relatively high charge-density and coordination requirements. This relatively high charge-density and relatively low abundance ensure only very minor ionic substitution in the common rock-forming silicates and little or no possibility of precipitation of

uranium minerals during normal magmatic differentiation. The uranium content of a magma is therefore progressively concentrated in the magmatic residuum. At low pressures (<1.5 kbar) uranium will often be drawn off during devolatilization and concentrated in hydrothermal solutions.

However, at higher pressures (5-10 kbar), significant amounts of alkalies and silica may remain in highly hydrous residual solutions to form pegmatites which may or may not be uraniferous. In this setting U^{4+} may substitute in rare earth minerals. In some cases, the presence of the ferrous ion Fe^{2+} may cause the preferential crystallization of uraninite between the (0.10) leaves of biotite as at Wheeler Basin.

Extreme degrees of fractional crystallization may cause uranium to concentrate in the late-stage differentiates of a magma series. Mg and Ca deficient, alkali feldspar-rich, porphyritic-aphanitic rocks such as bostonites and quartz bostonites may show values of several hundred ppm where uranium has concentrated in various host minerals. U^{4+} may substitute for Ca^{2+} , Th^{4+} , and Zr^{4+} in the crystal structures of accessory minerals such as apatite, sphene, zircon, monazite, and, to a much lesser extent, the common

rock-forming silicates. U^{4+} may also occur as molecular ionic disseminations along grain boundaries, structural defects, cleavage planes, and in fluid inclusions. These molecular disseminations are readily available for reaction with oxidizing hydrothermal fluids which may remobilize 20-60% of this readily available uranium without the necessity of breaking down host minerals. In the Central City district, the uranium content of bostonite dikes and pitchblende veins appears to be related to their proximity to uraniferous Silver Plume-age pegmatites. A part of the uraninite content of these pegmatites may have been leached by hydrothermal solutions which are perhaps genetically related to the bostonites.

Consideration of Uranium in the Metamorphic Environment

The mobility of uranium in the metamorphic environment appears to be governed by the grade of metamorphism. More specifically, uranium mobility is related to the pressure-temperature regime responsible for mineral and textural transformations and the generation and separation of volatile components. The extent to which these processes take place is, of course, also dependent upon the composition and texture of the original rock.

Mineral and textural transformations are largely responsible for the escape of uranium fractions from host minerals during metamorphism. The recrystallization of host minerals

during progressive metamorphism will tend to purge that mineral of ionic substitutes such as uranium. Recrystallization may also result in a reduction in the surface area of a mineral and thereby effect the release of adsorbed uranium complexes. Recrystallization may also inhibit uranium mobility by reducing the porosity and permeability of the original rock. As in magmatic-hydrothermal solutions, volatiles generated during metamorphism are important to the solution complexing, transportation, and precipitation of uranium liberated during progressive metamorphism. Two important processes are 1) the generation and dispersion of a fluid phase related to the dehydration of hydrous minerals or of connate waters, and 2) the generation of CO_2 from carbonate rocks and CH_4 , H_2 , CO , and CO_2 from organic-rich sediments. H_2O and CH_4 generation is important in the greenschist to amphibolite grades. CO_2 generation becomes increasingly important in the amphibolite to granulite metamorphic grades. Therefore, under a lower moderate metamorphic regime, liberated uranium may form carbonate complexes and travel in a fluid phase towards zones of lower pressure or to areas representing lower temperature regimes.

In this setting, uranium may precipitate in response to temperature-pressure changes or changes in solution chemistry as discussed earlier. Uranium may be concentrated in zones

of lower pressure such as shear zones, faults, joints, and other similar structures. It may also be concentrated or dispersed in lower grade metamorphic rocks representing a lower temperature regime related to the same metamorphic event. Precipitation may also be controlled by changes in solution chemistry effected by fluid-wallrock reactions.

During a regional high-grade metamorphic event, high temperatures and consequent dehydration may raise the P_{H_2O} sufficiently to initiate anatexis. Liberated uranium may then be concentrated in the mechanism responsible for the Rossing uranium deposit in South-West Africa and possibly for the Wheeler Basin mineralization in the Colorado Front Range.

CHAPTER I

URANIUM EXPLORATION IN A HARD-ROCK TERRAIN

1. Introduction

Recent major uranium discoveries in similar hard-rock terrain in northern Australia, and northern Saskatchewan have caused a great deal of attention to be focused upon the igneous and metamorphic rocks of similar Proterozoic and early Phanerozoic provinces elsewhere in the world. Most discoveries have resulted from a systematic, detailed unraveling of the historical geology of the uranium province and the consideration of uranium genesis, transport, and concentration controls of ore deposition. Pre-metamorphic sedimentary and volcanic environments have been established or clarified; regional and, where possible, local pre-metamorphic fabric has been determined; and the sequence of pre-, syn-, and post-tectonic igneous activity has been pinned down. As a consequence, genetic sources of uranium have been made more apparent and, in some instances, have been specified and target areas established. Such a program in a relatively unmapped, area may take years to complete. Where regional and local

mapping and supporting data are available, the program may be shortened considerably, though the geology of the area will still require an evaluation at depth. Once target areas have been outlined and models of occurrences identified, individual anomalous targets should be evaluated as to their discovery potential.

2. Objective of an Exploration Program

The objective of an exploration program is to find a uranium orebody in the shortest time possible, at the least expense, and with minimal problems.

Approval of exploration funding for a project is based to a considerable degree on company, syndicate, partnership, or individual risk restraints. Some groups prefer to purchase an interest in ore reserves; some insist on projects involving high discovery potential in areas of known uranium occurrences or production and favorable political environment; while others are willing to enter relatively unmapped regions with promising overall uranium discovery potential even though the political atmosphere may be marginally unfavorable. Overall risk must be defined as clearly as possible for the investor in each case.

Size requirement of the orebody may be a second criterion influencing the type and scale of an exploration program.

The scale of funding for exploration and capital investment requirements, if the project is carried forward, also has a direct bearing on where to search and the type of targets to search for.

There also may be time requirements for return on the investment which would dictate the grade and type of deposit to be searched for. Small, high grade deposits usually may be brought into production within two to three years if other conditions are favorable, whereas larger deposits may require six to ten years depending upon geologic, engineering, political and environmental aspects.

Once these and other criteria required by the investor have been defined the exploration program is formulated.

3. Execution of a Hard-Rock Program

The following is proposed as a broad-scale exploration program for large, hard-rock, uranium deposits in developing areas such as Alaska, northern Saskatchewan, Iran, the Andean countries of South America, and similar regions:

Phase A: Data gathering on a selected region begins (Fig. 6-x) with a preliminary evaluation of discovery potential: analysis of regional potential with regard to the identification of favorable uranium environments; development of geologic history with consideration of early source rocks, mobilization and transport mechanisms during metamorphism and intrusive activity, and concentration in potential host rocks or structures in target areas.

Phase B: (Figure 6-x ¹)	Field reconnaissance including preliminary air and ground evaluation of geologic potential of the region to verify the possibility of favorable uranium environments and discovery potential.
Phase C: (Figure 6-x ¹)	Broad-scale mapping and evaluation to establish target areas.
Phase D: (Figure 6-x ¹¹)	Semi-detailed mapping to locate specific targets.
Phase E: (Figure 6-x ¹¹¹)	Detailed evaluation of targets including drilling.

Figure 6 illustrates the steps in a multi-phase, hard-rock uranium exploration program in a developing region with minimal regional and local data available. In a successful program, each phase further clarifies the presence or absence of favorable environments and, hence, the discovery potential. Discovery is represented as a final phase.

A hard rock uranium exploration program in the Front Range would begin in Column 3 or 4 of Figure 6 instead of 2 because of the availability of a great deal of valuable background data developed by the U. S. Geological Survey and other groups.

4. Uranium Exploration Methods and Techniques

a. Airborne

Broad-scale airborne exploration techniques are used as an initial step in evaluating a promising region for its overall discovery potential. They include the following:

1. Geophysical

- a. Airborne radiometric survey to identify areas of anomalous radioactivity. Much of the United

Figure 6

States was flown in the early 1950's by the Atomic Energy Commission for this purpose. It is being reflown now under a D. O. E.-Bendix program. Much of the exploration of the 1950's was based on these early surveys. Although limited to 400 feet, present-day equipment establishes the distribution of U, Th, K, rare earths such as Lanthanum¹⁹⁰, and the U/Th, U/K⁴⁰, and Th/K⁴⁰ ratios. The determination of the potassium isotope assists in identifying areas of strong hydrothermal alteration as well as areas of migmatization. Low-level helicopter traversing is used for more specific identification of targets. Scintillation counters and gamma-ray spectrometers are used.

- b. Airborne magnetic and electromagnetic surveys to identify centers of intense hydrothermal alteration and associated contact and vein mineralization together with geologic contacts and structures.

2. Remote Sensing

- a. Photography forms the backbone of most early exploration programs. ERTS and LANDSAT imagery may be used to identify gross structural features of the province; black and white to specify more

detailed fabric; color infra-red to identify vegetation changes and alteration; and multi-band spectral photography to identify alteration patterns, indicator plants, mineral, rock and soil types.

- b. Side-looking radar often is helpful in locating faults and zones of fracturing.
- c. Thermal infra-red is used to identify thermal centers resulting from the oxidation of sulfide ore bodies.

A multi-spectral scanning technique developed by Dr. Kober and his associates and described in GJBX-4 (77) has identified surface, vein, metasediment, igneous and sedimentary mineral occurrences in the western United States from LANDSAT imagery, and is applicable to Front Range-type terrain. Where exposures are favorable, the maps produced have established alteration halos over and around known uranium mineralization, and may prove to be a useful tool in helping to locate new uranium targets. Four color bands are used ranging from visible to infra-red.

b. Ground Techniques

Followup ground techniques are critical in supporting and clarifying both broad-scale and specific geologic mapping

and interpretation. They include the following:

1. Geophysical Methods

- a. Geiger-Mueller tube, scintillation counter, and gamma-ray spectrometer equipment is used to identify radioactivity in ground surveys. The first instrument identifies gamma radiation from all energy levels from all sources. It has a low sensitivity, but is inexpensive (\$50-200). The second instrument is also non-selective and relatively inexpensive (\$400-1500), but has a higher sensitivity. The third instrument can distinguish between radioactive sources such as U, Th, or K^{40} by electronic selection of the gamma radiation characteristic of a particular source. However, the instrument is more expensive (\$2,000-\$20,000) and more time consuming.
- b. Magnetic surveys are contributive to ground exploration in the broad-scale mapping of contacts and faults which separate rock units of magnetic concentration.

- c. Gravity surveys also contribute to mapping broad-scale geology and concentrations of high-density minerals.
- d. Resistivity surveys are very helpful in locating covered fault zones in the igneous-metamorphic terrain.
- e. Electromagnetic surveys identify magnetite-hematite and pyrite concentrations. The very-low-frequency technique may be used to locate covered fault zones and to approximate structural dips.
- f. Induced polarization is an effective tool in outlining broad-scale pyrite and other metal-sulfide concentrations. It also is used in detailed evaluation and in the identification of graphite bodies as well.
- g. Self-potential can establish the presence of near-surface, oxidizing ore bodies.
- h. Seismic surveys, although mainly used in sedimentary terrains, are helpful in delineating depths to bedrock surfaces, faults, and unconformities.
- i. Bore hole logging techniques available or pending include gross-count gamma-ray, gamma-ray spectrometry, delayed-neutron, self-potential-resistivity, induced polarization, magnetic susceptibility

and Eh-log methods. These are valuable tools in the search for and evaluation of targets. Gross-count natural gamma is widely used; it can aid in establishing the presence of uranium mineralization, but measures both eU_3O_8 as well as chemical U_3O_8 . Research is progressing on the delayed-neutron method which measures uranium directly and which will aid in establishing the grade of a deposit. The self-potential-resistivity method yields data on faulting, fracturing, and lithology; induced polarization on the presence of sulfides and clay minerals; and magnetic susceptibility on loss of magnetite as a result of alteration and weathering. Eh-log gives an indication of the chemistry of the contained waters in the lithology encountered. It is important to select a suite of logs which are pertinent to the character of rocks which occur in a target area and the type of deposit anticipated.*

* Care should be taken to caliper each hole if caving occurs. A different set of conditions exist for air, water, and mud drilling.

2. Geochemical Methods

Geochemical exploration methods and techniques also yield valuable support to a hard rock uranium exploration program. In some instances, they have been the key to discoveries as in the case of some geophysical methods. The following is a summation of those which have been valuable contributors:

- a. Determination of uranium and radium in surface and ground waters. Background values are established in each terrain in the metamorphic stratigraphic units or sub-units; in batholiths, stocks or areas of dike swarms; in volcanic basin or volcanic piles; and in areas of extensive hydrothermal alteration (Plate 11). Uranium, radium, helium, oxygen, Eh, pH, alkalinity and conductivity are determined and interpreted with regard to the identification of sources of the radioactivity in the immediate area, and at depth. Water sampling is a guide to the location of concealed veins, mineralized fault zones, and widespread, low grade, fracture mineralization.
- b. Sediment sampling from streams and lakes yields data related to uranium mineralization in stream drainages and has guided exploration geologists into target areas, and occasionally to specific target sites.

AREAS OF ANOMALOUS SEDIMENT SAMPLES IN THE FRONT RANGE

○ ANOMALOUS AREA

(Boliver and others, 1978)

- c. Radon-alpha measurements are considered to be a direct exploration method by many for radon, the gaseous daughter product of U^{238} . It tends to move upward through the rocks from a source of uranium. Detection methods include: a) the alpha-track film and photographic film, b) ionization chamber, c) silicon detector-alpha meter and zinc-sulfide-scintillator with photomultiplier. Radon is detected both in soil gas and in surface and underground waters. The analysis of water samples from boreholes is useful in detailed exploration.
- d. Helium, also a product of uranium decay, is measured by field or laboratory mass spectrometers. Samples of soil gas and ground water are analyzed. Helium forms a broad anomaly over a specific target. It also may become a specific guide in exploration drilling.
- e. Measurement of sulfur dioxide in soils is another technique which identifies the presence of nearby oxidizing iron and base-metal sulfides which often are associated with pitchblende, particularly in shear zone and vein deposits.

- f. Soil geochemistry is one of the most widely used exploration methods both in regional reconnaissance with radiometric surveys to establish target areas and in evaluating near surface expressions of individual targets. Both B and C horizons are sampled, depending upon the soil profile and the geologic environment, for uranium, copper, molybdenum, silver, selenium, arsenic, lead, zinc, nickel, iron, thorium and other trace elements which may be diagnostic in specific environments. In some instances analysis for uranium daughter elements may be useful.
- g. Geochemical analysis of joint-and fracture-filling materials may be more significant than soil analyses provided the openings have not been filled by surficial materials. Primary iron and manganese oxides, clays and other included minerals may reflect halo mineralization and alteration products specifically related to a stage of uranium mineralization within a hydrothermal system.
- h. Geochemical analysis of rock samples may be more reliable than soil samples particularly in areas of transported soils or steep, talus-covered sites

3. Biogeochemical

Biogeochemical sampling, although a valuable guide in some areas is not as widely accepted as soil, rock, stream sediment and water techniques.

4. Thermoluminescence

Preliminary results of research conducted over the Schwartzwalder mine by C. Spirakis of the U.S.G.S. (pers. commun., 1978) indicate thermoluminescence may be a valuable supporting tool in uranium exploration along the Front Range.

This technique utilizes the generation of light in crystals when electrons, displaced by gamma radiation bombardement, move to more stable positions when the crystal is heated to between 160°C to 400°C . Displaced electrons after bombardement usually occupy defects in the crystal and move about to more stable positions as the crystal is heated. There is a tendency for an electron to go from a high energy state to a lower energy state represented by a more stable position. While moving to these more stable

positions, they give off light. This technique measures the light given off by electrons caught in defects which were created 1 to 2 million years ago.

Quartz and feldspar are used in this detection technique. Tests are run in a nitrogen atmosphere in which the crystal is heated in the dark from 0°C to 400°C. Some instruments use hot gas on the crystal. Samples from the outcrop may be used as well as samples from the C soil horizon. The latter should be sieved to 125-149 microns (fine sand size).

A detailed discussion of the theory of thermoluminescence by Spirakis and others (1977) is given in Appendix E.

CHAPTER J

MODELS OF PRECAMBRIAN URANIUM OCCURRENCES

Pegmatite Model

In the Front Range, uranium may occur as uraninite or as an ionic substitute in rare-earth minerals in simple-pegmatitic assemblages which may or may not be associated with migmatization. Uraninite-bearing complex pegmatites have not been reported in the Front Range. However, uranium does occur in trace amounts as an ionic substitute in rare-earth minerals of the White Cloud pegmatite, 1/2 mile south of South Platte in Southern Jefferson County.

1. Central City Pegmatites

a. Description

Simple pegmatitic assemblages have concordantly injected the biotite gneisses of the Central City district to form discrete pegmatitic bodies and migmatites. Sims and Gable (1964, p. 31) state that:

"...pegmatite and associated granite gneiss constitute at least 20 percent and probably more of the biotite gneiss and an estimated 5 percent or more of the microcline gneiss unit in the district. It occurs in a variety of forms, but typically as
1) thin, lenticular stringers and vein-form bodies

along the foliation of the biotite gneisses to constitute migmatite, 2) discrete generally conformable tabular bodies of varying size in the same schistose rocks, 3) generally thin stringers that anastomose through the relatively massive rocks such as amphibolite and calc-silicate gneiss, and 4) conformable lense-shaped bodies along the contacts of all the layered rocks."

Sims and Gable (1964, p. 31) describe the pegmatite and associated granite gneisses as:

"...a light gray, yellowish-gray, or grayish-pink, medium-to-coarse-grained rock of variable grain size that consists predominantly of microcline, quartz, and plagioclase and contains minor amounts of biotite, muscovite, sillimanite, and rarely, tourmaline, garnet, and other minerals. It ranges widely in composition--from a potassic leucogranite to quartz monzonite--and includes rare magnetite-bearing silicites."

The uranium-bearing pegmatites in the district appear to be related to the common pegmatite, but differ slightly in mineralogy.

The "light-gray to nearly white, massive, coarse-grained" pegmatites of Jasper Cuts, 4/5 mile south of Central City, is predominantly plagioclase (Sims and Gable, 1964, Table 5, p. 32) and contains a trace of rare-earth-bearing xenotime and subordinate monazite. The pegmatites sandwich a migmatitic biotite gneiss layer in which the xenotime and monazite content may range from 3-5 percent in a 5-foot rare-earth zone. The highest concentrations of xenotime and monazite occur in coarse-grained clots and lenses of biotite. Two samples from this migmatitic rare-earth zone show 0.022% and 0.070%

chemical U and 0.15% and 0.7% Th (Young and Sims, 1961, Table 3, p. 285). The Yttrium group of rare-earths (2.2%, 4.5%) dominates the Cerium group (1.6%, 3.5%). Similar occurrences in the district are located in Four-Mile Gulch and Illinois Gulch.

Young and Sims believe that the rare-earth minerals were concentrated at their present sites during migmatization of the biotite gneiss country rock, in a period of Precambrian plastic flow (deformation). Presumably, granitic fluids derived during the deformation selectively mobilized rare-earth cations and phosphate from the biotite gneiss country rock. These ions crystallized with biotite and locally with magnetite to form zones of xenotime and monazite concentration in migmatized parts of the gneiss.

GAMMA RAY SPECTROMETER DATA, CENTRAL CITY AREA

<u>Jasper Cut (#1)</u>	<u>CPS</u>	<u>U</u>	<u>Th</u>	<u>K</u>
Middle of 3-4' pegmatite sill (north of cut)	1769	292	3269	
	1843	292	3267	
Migmatite just below sill	1040	1554	9294	
	1415	1498	3237	
Small shear zone, west end of pit (below pegmatite sill)	4816	650	8330	
	4749	656	8185	
Surface - north edge of pit (instr. held waist-high)	1310	307	2355	
	1317	255	2287	

The second type of uranium-bearing pegmatite in the district contains disseminated uraninite and has been noted

on the dump of the Waterloo Mine at the head of Russell Gulch.

This pegmatite is

"...pinkish-gray, nearly massive, coarse-grained composed mostly of plagioclase, microcline and biotite...Biotite is irregularly dispersed and forms books a quarter of an inch or less thick and as much as an inch in diameter, and, locally, elongate aggregates of books as much as 6 inches long. The biotite in the form of clots of books shows little or no preferred orientation, but that in the elongate aggregates tends to have a preferred orientation that imparts a crude planar structure to the pegmatite...Uraninite in euhedral cubes that average 0.5 mm on a side are dispersed through the rock but are apparently concentrated slightly in the more biotitic parts..." (Sims and Gable, 1964, p. 35).

Uraninite in this pegmatite has been dated (Pb-U) at 1300 ± 100 m.y. which falls in the age range of Silver Plume intrusions.

The Waterloo pegmatite is very similar to those described by Sims and others (1963). These pegmatites occur as discontinuous bodies along a narrow, east-northeast-trending belt which extends from Clear Creek between the mouths of Trail Creek and Fall River, across Virginia Canyon, to the head of Robinson Gulch. This pegmatite belt lies just within and along the northwest margin of cataclasis of the Idaho Springs-Ralston Creek shear zone. Sims and others (1963, p. 10) state that these pegmatites may be 40 to 50 times more radioactive than most of the Precambrian gneisses and granites in the area. They were observed at the Hudson-Highlander claims at the mouth of Robinson

Gulch in Virginia Canyon. Plate 12 (Sims and others, 1963, Fig. 5, p. 12) shows the geology of the immediate area.

"The radioactive pegmatites on the Highlander and adjacent claims are generally conformable bodies in interlayered biotite gneisses and amphibolite, which constitute a 450-foot-wide zone in the thick layer of microcline-bearing gneiss...The pegmatite lenses range from less than 1 to about 50 feet in width and from a few feet to several tens of feet in length, and most of them contain thin layers of the metamorphic gneisses.

The pegmatites are white, buff, or pink unzoned bodies that consist dominantly of feldspar, quartz, and biotite. The biotite forms irregular-shaped books that show little if any preferred orientation and which tend to be clustered...

The pegmatites and associated rocks are cataclastically deformed; at places the deformation was sufficiently intense to form a fine-grained, streaked mylonite...

The uraninite occurs as tiny cubic crystals disseminated through the rock; it is most abundant in biotite, but also occurs in the feldspar. Its distribution leaves no doubt that it is a primary constituent of the pegmatite ..." (Sims and others, 1963, p. 11).

Sims and others (1963, p. 11) sampled individual pegmatite bodies and estimated grades in the range of 0.01-0.06% uranium and an average of about 0.04%. Sims (in Moench and Drake, 1966, pp. 117-118) relates that, in 1955, the Uncompahgre Mining Corporation shipped 42 tons of hand-sorted uraninite-bearing pegmatite mined largely from surface pits on the Highlander claim. This pegmatite assayed at 0.13% U_3O_8 . Also shipped the same year were 9.5 tons of gravity-

concentrated uraninite-bearing pegmatite mined from the Hudson tunnel (Plate 12). The operation was not profitable. A 1954 map of the Hudson adit by Sims is available as a plate in Moench and Drake (1966).

The claims were visited in November, 1977. The Highlander pegmatite is exposed along the Robinson Gulch road about 100-125 feet northeast of the Virginia Canyon road. A caved incline shaft or prospect on the trend of the Hudson tunnel marks the location (Plate 13). Here the strike of the pegmatite is approximately N55E and is concordant with the foliation of the enclosing migmatitic biotite gneiss and schist. Pods and lenses of biotite gneiss may be interspersed in the pegmatites. Their contacts with the pegmatitic material are relatively sharp. However, outward from the contacts, there is often a peripheral zone, 1-2 feet wide, or irregular clots and selvages of unassimilated or recrystallized, coarse-grained biotite. These may be 3-5 inches long and 1/4-1/2 inch thick. In the two locations observed, the highest uranium counts were associated with concentrations of coarse-grained biotite clots and selvages. Uraninite was not observed in the hand specimens. However, the biotites of samples taken from the zone of biotite clots and selvages (Plate 13) often showed a very fine-grained, yellow mineral coating on their (010) cleavage surfaces.

FIGURE 5.—Outcrop map of the Highlander and adjacent mining claims, Idaho Springs district.

(REPRODUCED FROM SIMS & SHERIDAN, 1964)

Cross-Section of Radioactive Pegmatite at Highlander Claims:
(IS-2 Location, N.E. Face In Caved Incline on Trend of Hudson Adit,
on Robinson Gulch Road, 100 Feet N.E. of Virginia Canyon Road)

Though not yet identified, it is believed that this mineral is a secondary hydrated uranium mineral after uraninite. It is believed that the (010) cleavage surfaces of the biotite may have provided very suitable nucleation sites for uraninite crystallization. Preference for these nucleation sites may have been responsible for greater concentrations of uraninite in the biotite selvages. It is unclear, however, what role, if any, may have been played by the ferrous ion in this environment.

b. Genesis

Pegmatite in the migmatitized biotite gneiss may represent both primary (Silver Plume) and secondary (anatectic) material. The heat flux associated with Silver Plume intrusion may have mobilized water in the metasediments (2-3% H₂O) and raised P_{H₂O} sufficiently to cause fusion of the quartzofeldspathic fraction of the metasediments. An anatectic origin for these pegmatites might explain their leucocratic character. Some might be more accurately described as alaskites.

c. Economic Potential

As described above, individual uraniferous pegmatite in the Central City-Idaho Springs area of the Front Range contributed a small volume of uranium ore during the 1950's and may be important in the future during emergency periods. But, as in the case of migmatities, their importance probably would be as a contributor to larger centers of mineralization which might constitute a large, low-grade deposit. Photograph B is of the Spencer Heights pegmatite from which limited uranium ore was mined in the 1950's.

B.

**This photo is found in the
back pocket of this report.**

W

E

Spencer Heights Pegmatite

This well-mineralized pegmatite dike is exposed in an adit a mile west of the Spencer Heights resort in the upper Poudre River Canyon. Note the biotite concentration along the east side whereas the west contact is sharp. The count is about 2,000/sec.

d. Exploration Approach

The most favorable areas in which to search for mineralized pegmatites in the Front Range are along the fringes or in the hood zone of Silver Plume age and Pikes Peak intrusives, the same locations in which cauldron and low-grade, uraniferous centers are known or anticipated. Pegmatite may serve as a guide in the identification of such centers.

e. Comparison With the Bancroft District, Ontario

The Bancroft district in southern Ontario is another example of uranium production from pegmatite dikes during the late 1950's. The following is a description of the geology of the Bancroft area from The Geology and Economic Minerals of Canada, editor, R.W.J. Douglas, 1969):

"The Bancroft area is underlain by three fairly circular masses, called the Cheddar granite, Cardiff complex, and Faraday granite; each is about 6 miles in diameter, and is composed of granite, syenite, gneisses and related rocks. They are separated by metamorphic rocks of various kinds that exhibit concentric structure. These are mainly marble, paragneiss, para-amphibolite and meta-gabbro. The principal uranium deposits are in bodies of granite and syenite with pegmatitic and metasomatic phases that either cut the wall rocks or replace them. The most favorable rocks were pegmatitic pyroxene granite or syenite, leucogranite, and cataclastic quartz-rich granite-pegmatite. All are commonly higher in sodium. Many ore shoots were associated with concentrations of mafic minerals and magnetite."

"The Bancroft mine is in paragneiss and amphibolite on the east flank of the Cardiff complex. Its ores were in an echelon swarm of lenticular dykes in a zone half a mile wide and 3 1/2 miles long. The ore minerals were uraninite and uraninite, the ore averaging about 0.1 percent U_3O_8 . The Faraday mine is in a belt of meta-gabbro and amphibolite on the south flank of the Faraday granite. The ores were

parts of a zone of irregular pegmatitic granite dykes, with metasomatic phases, extending at intervals over about 6,000 feet. The ore minerals were uraninite and uranothorite, with minor uranophane; ore averaged about 0.1 percent U_3O_8 . The Canadian Dyno mine is in a belt of paragneiss and other rocks on the east flank of the Cheddar granite. The property contains a series of pegmatitic granite dykes only some of which were ore grade. The ore minerals were uraninite and uranothorite. The Greyhawk mine is in meta-gabbro on the south flank of the Faraday granite. Its ores were in dykes of pegmatitic granite containing uraninite and uranothorite."

Hall Valley Migmatite Model

The Hall Valley migmatite occurrence is typical of migmatite occurrences related to the hood zone of the Silver Plume-age intrusives. It is located at the entrance to Hall Valley canyon approximately one mile north of the old Webster townsite which is situated on U.S. Highway 285 at the foot of the eastern approach to Kenosha Pass (Plate 4).

a. Description

This highly anomalous migmatite band is exposed in a 75-foot adit which cuts across the southerly dipping Idaho Springs metamorphic foliation: the granite contact is situated immediately south of the adit cut. See Photographs C, D, and E, pages 100a, 100b. The contact zone of the Silver Plume developed as a progressive metasomatic front which moved into Idaho Springs gneisses and schists. Ghost fabric of the metamorphics is evident in the upper 30 feet of the intrusive. The metamorphic rocks in the contact zone contain numerous lit-par-lit "pegmatite" bands and cross-cutting dikes, indicating strong anatectic mobilization for more than 100 feet outward into the country rocks.

c

D.

**These photographs are found in
the back pocket of this report.**

Hall Valley Contact Zone

Kenosha granite is exposed to the right of the Aspen tree and migmatized biotite gneiss and schist are exposed on the left. The contact is transitional.

Hall Valley Mitmaqites

Partly migmatized biotite gneiss and schist are exposed in the adit trench. The granite-pegmatite sill is shown in the upper left.

E.

**This photo is found in the
back pocket of this report.**

Hall Valley Kenosha Granite Contact Zone

The metasomatic, transitional contact of the Kenosha granite is shown in this view. "Normal" biotite schist and gneiss lie some 10 feet above the pick in the upper left. Note the partly "digested" 1-foot gneiss band on the right.

For the first 20 feet, the adit-trench cuts well-banded biotite gneiss and schist with numerous lit-par-lit bands to medium-to-coarse-grained "granite" grading to "pegmatite" which appears to have been derived from the country rock during metamorphism; also present are small lenses and dikes of injected pegmatites, some of which crosscut the foliation. In the 20-30 foot interval, which includes a small stope, cross-cutting pegmatite dikes up to 3 feet in width are numerous. The dikes, gneisses and schists in this interval show an increasing radioactivity. On the north wall of the stope a 1-2-foot wide, northerly dipping pegmatite dike cuts through the southerly dipping country rocks. A 1/4- to 3-inch wide, coarse-grained, quartz-biotite-garnet migmatite zone has formed on the hanging wall contact of the pegmatite; the next 3-6 inches consist of a finer-grained migmatite which lacks clear-cut banding. It consists of quartz, occasional books of biotite and feldspar which obviously has replaced partially recrystallized biotite schist. The pegmatite dike assays 0.047% U_3O_8 and the recrystallized migmatite 0.052% U_3O_8 (Plate 14). Petrographic Description No. 2, and 3 and accompanying photomicrographs of the migmatite and pegmatite are included on the following pages.

b. Genesis

Many of the anomalous migmatite occurrences studied by the writers, particularly in the hood zone contact of the

Kenosha Pass Area
Park County, Colorado
Scale: 1" to 10'

HALL VALLEY MIGMATITE MODELPETROGRAPHIC DESCRIPTION NO 2PROJECT: Denver 12-77-7208REQUEST: 101096FIELD NO: MAL-122AASSN: 24997ROCK NAME: Biotite-Garnet SchistGENERAL TEXTURE AND FEATURES: Porphyroblastic, schistose, with mineral segregation bands.PETROLOGIST: M. D. Dixon - Bendix Field Engineering Corp.

MINERAL/COMPONENT	%	TEXTURE	CHARACTERISTICS	ALTERATION/REPLACEMENT
Quartz	41	Fine- to medium-grained, xenoblastic.	Strongly undulose, poly- and monocrystalline varieties present.	Argillized.
Biotite	43	Slender flakes.	Contorted flakes. Pleochroic brown to yellow. Radiation haloes.	
Garnet	5	Fine- to medium-grained, idiomorphic to xenoblastic.	Light pink, abundant inclusions.	
Plagioclase	6	Fine-grained, xenoblastic.	Fresh.	
K-feldspar	2	Fine-grained, xenoblastic.		
Opaque	3	Fine-grained, xenoblastic to idiomorphic.		
Monazite*	tr	Very fine-grained idiomorphic.	Inclusions in biotite with pleochroic haloes. Minor thorium.	
Zircon	tr	Very fine-grained idiomorphic.	Inclusions in biotite.	

OTHER COMMENTS: * Confirmed by SEM/EDS.

Positive identification of ferruginous staining could not be made by X-ray analysis. SEM/EDS analysis revealed Fe and S suggesting an iron sulfate.

Figure 1. Photomicrographs of sample 24997.

A.) General texture showing foliation and garnet xenoblasts. 16x, crossed polarizers.

**These photographs are found in
the back pocket of this report.**

B.) Pleochroic haloes around inclusions in biotite. Note: zircon in lower left corner. 40x, plane polarized light.

HAIL VALLEY MIGMATITE MOUNTAIN

PETROGRAPHIC DESCRIPTION

PROJECT: Denver Quaternary 11-77 1908

REQUEST: 101095

FIELD NO: MAL-121

AASSN: 24994

ROCK NAME: Protomylonite (Pegmatite-migmatite)

GENERAL TEXTURE AND FEATURES: This rock shows evidence of cataclasis and recrystallization and contains coarse porphyroclasts (~ 2-5 mm. average size).

PETROLOGIST: M. J. Dixon (Bendix Field Engineering Corp.)

MINERAL/COMPONENT	Z	TEXTURE	CHARACTERISTICS	ALTERATION/REPLACEMENT
Quartz	12	Anhedral, fine-grained.	Occurs predominantly as a fine-grained mortar which is largely recrystallized with some stretched undulose types. Stretched undulose porphyroclasts are rare.	
Plagioclase	56	Anhedral to subhedral, coarse porphyroclasts.	Zoned. Bent twinning lamellae. Inclusions of opaques, biotite, apatite, zircon, and quartz.	Slight to moderate. Extensive argillic at some cores.
Biotite	29	Subhedral books which contort around plagioclase porphyroclasts and also as thick bands or mats.	Inclusions of zircon and uraninite display pleochroic haloes. Thin bands of quartz occasionally occur between biotite flakes.	Replaced by opaques.
Muscovite	1	Fine subhedral flakes.	Intergrown with biotite and ilmenite.	
Zircon	tr	Fine euhedral inclusions in biotite and plagioclase.	Commonly coated by iron oxides,	
Apatite	tr	Subhedral to euhedral.	As inclusions in plagioclase.	

OTHER COMMENTS:

(CONTINUED ON NEXT PAGE)

A.)

**These photographs are found in
the back pocket of this report.**

Figure 1. Photomicrographs of large plagioclase
porphyroclasts surrounded by a mortar of mus-
covite, biotite, clay, quartz, and opaques.
Sample 24994.

A.) Plane polarized light, 16x.

B.) Crossed polarizers, 16x.

B.)

HALL VALLEY MIGMATITE MODEL

PETROGRAPHIC DESCRIPTION

NO. 3 CONT.

PROJECT: Denver Quadrangle 12-77-7208

REQUEST: 101095

FIELD NO: MAL-121

AASSN: 24994 (cont.)

ROCK NAME: Protomylonite

GENERAL TEXTURE AND FEATURES:

<u>MINERAL/COMPONENT</u>	<u>%</u>	<u>TEXTURE</u>	<u>CHARACTERISTICS</u>	<u>ALTERATION/REPLACEMENT</u>
Uraninite *	tr	Anhedral lobate to subhedral, fine-grained.	Rimmed or included in biotite.	
Ilmenite	tr	Equant and acicular grains.	With muscovite.	
Graphite (?)	tr	Prismatic grains.	Found in biotite masses.	
Magnetite	tr	Anhedral, fine-grained.	With uraninite.	

OTHER COMMENTS: * An uranium - lead (oxide ?) mineral, probably uraninite, was found by SEM/EDS analysis.

**This photo is found in the
back pocket of this report.**

Figure 2. Photomicrograph showing contorted/
sheared biotite with quartz occurring
as fine interlayered bands. Sample
24994, crossed polarizers, 40x.

D.

**This photo is found in the
back pocket of this report.**

Electron photomicrograph showing a
subhedral grain of uraninite which is rimmed
by biotite in sample 24994.

U = Uraninite

B = Biotite

P = Plagioclase

Secondary and backscattered electron image, 250x.

Silver Plume-age plutons in the Front Range are spatially associated with pegmatite dikes. These pegmatites also are anomalous and may have contributed to the introduction of uranium into the migmatites by loss of aqueous phase. As discussed in the previous section on pegmatites, Young and Sims (1961, p. 273) propose that the xenotime and monazite, which occur in the migmatites in the Central City district of Colorado as sand-size crystals in thin layers and clots of biotite, formed during migmatization of the biotite gneiss country rock during a period of Precambrian plastic deformation. They suggest that "granitic fluids derived during deformation selectively mobilized rare-earth cations and phosphate from the biotite gneiss country rock. These ions crystallized with biotite and locally with magnetite to form zones of xenotime and monazite concentrations in migmatitized parts of the gneiss."

The uranium concentration in the Hall Valley migmatite formed in the contact zone of a cross-cutting pegmatite dike. Radioactivity decreases rapidly as one moves outward from this contact zone into less affected metamorphic rocks. For this reason the writers prefer the interpretation that uranium was introduced by pegmatite dikes in this prospect rather than by mobilization from the country rocks during the plastic stage of metamorphism. The magmas which formed

the cross-cutting pegmatites, in turn must have been evolved in the underlying Kenosha pluton which contains 5.2 ppm U_3O_8 on the average (Phair & Gottfried, 1964). The contact zone between the granite and the metamorphics in the near vicinity of this prospect ranges up to 200 percent of background.

c. Comparison with the Baie Johan Beetz deposit, Quebec

An example of a very promising migmatite target is the Baie Johan Beetz migmatitic granite area located in southern Quebec (Hauseux, 1977). The granite in this area was deeply emplaced in the Grenvillian Orogenic Belt by the profound metasomatism and granitization of mafic schists, granulites and amphibolites. It is believed that the uranium in this area was from primary, uraniferous and zirconiferous sediments. Uranium appears to have migrated to axial zones of folds during metamorphism and occurs as concentrations in elongated lenses within a "hybrid" granite developed during granitization.

As yet there is no evidence to support the possibility that there may have been appreciable uraniferous sediments or volcanics in the nearby Hall Valley metamorphic section described by Wahlstrom and Kim (1959). It is possible that any uranium formerly present was driven out of the local basin during the initial stages of metamorphism. However, it also is possible that "digestion" of slightly uraniferous metamorphics by the Kenosha pluton could have supplied the uranium concentrated in the migmatite and pegmatite dike

found at this prospect; or that the uranium may have been derived from deep within the craton from the sub-Idaho Springs basement.

d. Economic Potential

Uraniferous migmatites in the Front Range thus far observed or reported are of two types: 1) localized zones of replacement along the foliation of biotite gneisses and schists; and 2) pods or lenses along pegmatite dikes or in contact zones. For this reason, an appreciable contribution of uranium reserves cannot be expected from uraniferous migmatites unless they occur in conjunction with uraniferous pegmatites and/or with mineralized, fractured granite. A contribution from supergene enrichment may be required to reach economic grade in most instances.

e. Exploration Approach

Exploration for migmatites should be pursued in conjunction with the search for low-grade cauldron-type centers of mineralization.

Wheeler Basin "Cauldron" Model

a. Description

The highly anomalous Wheeler Basin exposure of the hood zone of the Silver Plume Pluton is located in an extensive cirque basin immediately west of the Continental Divide approximately 12 miles east of Granby, Colorado (Frontice Piece, Photograph F by Dubyk, page 104a and Plate 16). It has many features of a contained crestal apophysis or "cauldron". The following description of the geology of this center was developed by Dubyk, Johnson, and Edmond, who completed a

F.

**This photo is found in the
back pocket of this report.**

"Cauldron Center" - Wheeler Basin

The mineralized area in Wheeler Basin lies in the central part of the picture with Silver Plume granite, migmatite, and pegmatite and alaskite dike exposures.

a three-day examination of a portion of the cirque in August of 1977 for Bendix Field Engineering Corporation, and by Young, 1975:

The Silver Plume in this location is highly differentiated and ranges from a granodiorite to a fluorite-bearing alkalic granite and includes alaskite and microcline-rich granite dikes. In this location, the Silver Plume is more porphyritic and lighter in color than in the type locality. The crystal size ranges from aplitic to pegmatitic with feldspar crystals ranging up to 10 cm. in length. A typical specimen averages about 40% quartz and 10% biotite. Muscovite also is present. It is light gray to white in color, except in the case of the microcline-bearing dikes which are reddish. The texture is porphyritic and trachytoidal.

There is rapid merging and blending of the various textural types indicating an environment of late-stage concentration of differentiates. The contact between the intrusive and the metamorphic country rocks is sharp with evident assimilation of the latter. Numerous Silver Plume offshoots form dikes and satellitic bodies in the metamorphics. To the east, along the Continental Divide, there are reddish, fluorite-bearing, potash-rich dikes which occur in a north-trending zone.

Uranium is concentrated by migmatization in coarse-grained biotite clots and selvages along the contact with pegmatite dikes and in zones of migmatization within the biotite gneisses. It occurs as small cubes of urananite 0.1-0.3 mm in size (Young, 1975?) between biotite flakes and is often accompanied by monazite and xenotime (Young, 1977, pers. commun.). It also is connected at the Bennett prospect in granite as well as in the adjacent gneisses; the count in the former is 20,000 cps while, in the latter, it is somewhat less. An analysis of a sample of the granite at this prospect yielded 1.25% U_3O_8 . A count for secondary biotite in shears outward from the contact gives approximately 1,000 cps. In a coarse k-feldspar-enriched granite the count rises to 8,000 cps. Locally, the average count in the country rocks in a 30 square-foot area near this prospect is 4,000 cps. Photographs G and H, by Dubyk, pg. 106a.

A uranium-bearing, biotite-bearing, K-feldspar, pegmatite occurs near the Bennett prospect. Purple fluorite is visible near the location of the highest count (2500 cps). The adjacent granite is pink, coarse-grained, locally porphyritic and, in places, almost graphic.

Uranium also is anomalous at the Puzzler mine developed along a silicified vein which ranges up to 3 feet in width.

**This photo is found in the
back pocket of this report.**

Uraniferous Wheeler Basin Migmatite

Reddish, highly mineralized migmatite encompassed in coarsely crystalline Silver Plume granite. Note the scintillometer for scale.

H.

**This photo is found in the
back pocket of this report.**

Mineralized Alaskite

Coarsely crystalline alaskite dike in the Wheeler Basin mineralized center.

The highest anomaly, 1200 cps, is on the lower John Drift, along a silicified, sulfide-bearing vein. The sulfides are concentrated largely in subsidiary horsetail fractures adjacent to the vein.

Dubyk summarizes the geologic observations by the Bendix team as follows:

- "1. The presence of a high differentiated Silver Plume (PCb Y) batholith, ranging in composition from granodiorite to fluorite-bearing alkalic granites. This is quite unlike typical Silver Plume (PCb Y) granites which are usually even-grained and do not vary greatly in composition throughout their outcrop. One product of magmatic differentiation, alaskite, is a common dike rock in the Wheeler Basin area.
2. The presence of a highly migmatized terrane, which again is not typical of the host rock of most other Silver Plume (PCb Y) granites. This might indicate:
 - a. Greater depth of intrusion of the Wheeler Basin granites,
 - b. Higher geothermal gradient during time of intrusion, or
 - c. a greater percentage of volatile or "granitizing" fraction in the Wheeler Basin granites. One or all of these may have played a role in concentrating uranium.
3. The presence of more than one type of uranium deposit in this area, including:
 - a. Uraninite-bearing biotite segregations, such as at the Bennett prospect.

Such segregations are common in Wheeler Basin, and range in size from a few centimeters across to 3-meters across at the Bennett Prospect and range from a few thousand to 16,000 cps. These concentrations may be of pegmatitic origin but their intimate association with the metamorphic rocks implies a "mixed" origin, possibly reaction of granitic volatiles with host rocks.

- "b. Fluorite-bearing alkali feldspar granite. This granite is exposed in prospect pits above the Bennett prospect. It is typically a brick-red granite, and unlike most of the granites in the Wheeler Basin, contains microcline as the predominant feldspar. A dark purple fluorite was observed in outcrop and on the dumps of prospect pits and of the Bennett prospect. This granite shows gradational contact with the country rock, unlike most of the plagioclase-bearing granites. The uranium may be contained in either biotite or feldspar grains. This granite ranges from 2,000 to 8,000 cps.
- c. Radioactive pegmatites and alaskites; a multitude of dikes invade the migmatized country rock at Wheeler Basin, but only certain ones are anomalously radioactive. As mentioned above, those bearing microcline are typically radioactive. Other leucocratic dikes without or with only minor microcline are anomalously radioactive, however. Uranium occurs in scattered biotite or feldspar crystals throughout the dikes, and many tens of square feet may exhibit radioactivity in excess of 1,000 cps. It appears that only certain "generations" of dikes were radioactive; most dikes, even those in close spatial association with radioactive rocks, are not anomalously radioactive."

b. Genesis

Some compare Wheeler Basin mineralization to that at Rossing in southwest Africa. Both appear to have been collecting centers of aqueomagmatic fluids in the crest of an intrusive center yielding uraniferous leucocratic granite, alaskite pegmatite and enriched migmatites. However, there appears to have been a greater concentration of uranium in a localized center at Rossing which, in turn, has been enhanced by considerable supergene enrichment. Such supergene enrichment is largely lacking at Wheeler Basin because of severe relief.

c. Exploration Approach

A suggested exploration approach to evaluate the uranium potential of Wheeler Basin would be:

1. Geologic mapping of that portion of the Basin including Hells Hole on a scale of 1 inch to 500 feet.
2. Airborne helicopter gamma-ray spectrometry survey to outline specific areas of radioactivity.
3. Subsequent ground geophysical and geochemical transversing to establish possible targets of possible economic or paramarginal-long term potential.
4. Detailed geologic mapping of local sites of anomalous radioactivity.

d. Comparison with the Rossing Cauldron Center, S.W. Africa

According to Berning, Cook, and Hiemstra (1976), the Rossing mineralized center occupies an area some 700 meters in diameter. The mineralization occurs in a migmatite zone in deformed metasomatized metasediments and metavolcanics into which uraniferous, coarse grained, alaskitic granite, and pegmatites have intruded with concordant, discordant and gradational relationships.

Most of the uranium mineralization formed in a pyroxene-garnet/amphibolite unit and in an amphibolite-biotite schist and lower cordierite-biotite gneiss unit. The following paragraphs are quoted from their paper on mineralization and origin:

"Alaskite hosts all the primary uranium minerals and most of the secondary. The latter do, in certain localities show a spread into the country rock and/or into a sporadically developed layer of surficial secondary limestone. Within the uraniferous zone enrichment is present along biotite-rich selvages of the alaskite, at those spots where robust alaskite bodies display

sharp upward narrowing to form dikes or veins, in alaskite emplaced along the axial planes of folds and in those localities where amphibolite originally present in the ore zone has been replaced by alaskite."

"During a process of syntaxis uranium minerals are considered to have been concentrated in a residual melt of simple alaskitic composition. The localization of mineralization in certain sectors only of the alaskite spread is probably a simple reflection of the uraniferous content of the basement rocks before melting resulted in their upward emplacement into cover rocks. Further concentration could conceivably have involved processes of vertical mineral zoning coupled with interplay of mechanical and chemical factors that resulted in the trapping of uraniferous melt in fold culminations of marble layers and the fixation of the mobile U^{6+} ions as following upon assimilation of basic country rock by acid magma."

The close association in time and space between the Wheeler Basin Silver Plume granite and the microcline-rich, alaskitic, and pegmatitic dikes suggests that the uranium in each was derived from a fractionated fluid phase of the same parent Silver Plume magma. The unit cell dimensions of the uraninite lend support (Young, 1975). A large part of the uranium found in the migmatized biotite gneiss probably occurred within the thermal halo of the Silver Plume intrusive and must have been introduced by ion exchange related to the aqueous phase. There are no reported anomalous uranium concentrations in the Idaho Springs Formation in the Wheeler Basin (Young, 1975), but this area has not been mapped. For this reason migmatization and remobilization may have contributed, to some degree, to the concentration and redistribution of syngenetic uranium which may have been present within the formation.

Wheeler Basin is within a Wilderness Area, but does, nonetheless, serve as a valuable example of the "cauldron-type" model. The results of the above geologic-geophysical studies would greatly enhance Wheeler Basin as a type model for inspection by exploration groups.

DISSEMINATED, FRACTURE-CONTROLLED IN GRANITIC ROCKS
WITH SUPERGENE ENRICHMENT

Low-Grade Granitic Models

The discovery potential for low-grade uranium deposits in anomalous centers within Silver Plume and Pikes Peak age intrusives is promising. These intrusives include the Kenosha, the Red Skin, the Mt. Rosa, and for its overall potential, the Sherman granite. Supergene enrichment would be a vital addition in each.

Kenosha Granite Model

The Kenosha pluton is located between Hall Valley and Kenosha Pass in Park County. It is traversed by U.S. Highway 285 (Plate 16). According to Phair and Gottfried (1964), the uranium content averages 5.2 ppm (U_3O_8). Walstrom and Kim (1959) describe the Kenosha granite in Hall Valley immediately to the north as light-gray to pinkish-gray, medium-to-coarse-grained, massive to slightly gneissoid, consisting of quartz, feldspars, micas and minor accessory minerals.

a. Description

The strongest mineralization in the Kenosha pluton is located near Drake Lake in an area north of Highway 285 and south of the Hall Valley drainage. There are three types of uranium occurrences: in shear-zone breccias, in pegmatite-migmatite, and "disseminated" in granite. Supergene enrichment

appears to have contributed to uranium concentration in each. Autunite has been identified both in the Gem Dandy and the McGeorge prospects (E.P. Beroni, pers. commun., 1977).

The shear-zone breccias are similar to the "breccia reefs" of the Foothills Uranium Belt described on page 123. They are silica-flooded, consisting of angular silicified fragments with secondary brecciation; iron oxide is prominent in the matrix occurring with probably supergene uranium. These breccias range up to 4 feet in width and trend north-westerly. The radioactivity on outcrop ranges up to 2,000 cps.

The pegmatite-migmatite occurrences include 1) the Gem Dandy, located on the divide east of Drake Lake, from which some 400 tons of 0.25% U_3O_8 were shipped during the 1950's; and 2) the McGeorge prospect, located further to the north above the Hall Valley drainage from which there was only small production. The biotite gneisses have been cut by pegmatite dikes and migmatized near the granite contact. Rocks in the Gem Dandy pit have been highly fractured, altered and oxidized. Gamma-ray spectrometry indicates 15.8 ppm U_3O_8 and 56.0 ppm Th content from a specimen of Kenosha granite near the pit (Dubyk, pers. commun.) The following pages include a Petrographic Description of this granite (MAL 120) by L. M. Fukui, Petrologist at the Bendix Field Engineering Laboratory at Grand Junction, and accompanying photomicrographs, and Photographs I and J of fractured Kenosha granite.

KENOSHA GRANITE
(Gem Dandy Prospect)

PETROGRAPHIC DESCRIPTION NO 4

PROJECT: Denver 12-77-7208

REQUEST: 101093

FIELD NO: MAL-120

AASSN: 24993

ROCK NAME: Granite

GENERAL TEXTURE AND FEATURES: Medium- to coarse-grained allotriomorphic.

PETROLOGIST: L. M. Fukui - Bendix Field Engineering Corp.

MINERAL/COMPONENT	%	TEXTURE	CHARACTERISTICS	ALTERATION/REPLACEMENT
K-feldspar	50	Medium- to coarse-grained, anhedral.	Undulose, abundant inclusions orthoclase and microcline.	Argillized.
Plagioclase	10	Medium- to coarse-grained, anhedral.		Argillized.
Quartz	30	Medium- to coarse-grained, anhedral.	Undulose, polycrystalline.	
Biotite	7	Medium-grained, subhedral.	Pleochroic- greenish-yellow to brownish-green, zircon inclusions.	Chloritized.
Muscovite	3	Slender flakes and sericitic patches.		
Opaques	tr	Fine-grained, interstitial to euhedral.		
Zircon*	tr	Fine-grained, subhedral to euhedral.	Some zoned with ferruginous clayey cores. As inclusions in biotite.	
Chlorite	tr		In patches.	
Apatite	tr	Very fine-grained.	Inclusions in biotite.	
Monazite*	tr	Fine-grained, subhedral.	Metamict thorium- rare earth phosphate.	

OTHER COMMENTS: * Confirmed by SEM/EDS: zircon contained minor Ca and Fe.

Photomicrographs of sample 24993.

A.) General texture of rock. 40x, crossed polarizers.

**These photographs are found in
the back pocket of this report.**

B.) Zircon with pleochroic halo in biotite.
160x, plane polarized light.

**This photo is found in the
back pocket of this report.**

Blocky, Fractured Kenosha Granite at the Hall Valley Prospect

This exposure is approximately 300 feet below the granite-migmatite contact zone at the prospect. The counts per second are from 500-600.

J.

**This photo is found in the
back pocket of this report.**

Mineralized Kenosha Granite

This exposure of oxidized, highly fractured and mineralized Kenosha granite is located 2 miles N-NW of Kenosha Pass.

b. Comparison with the Cunha Baixa and Nisa Deposits, Portugal

The low-grade, supergene-enriched granite type of occurrence is of considerable interest. Exposures in the vicinity of Drake Lake are typical of a well-jointed, shattered, deeply-weathered oxidized granite with strong iron oxide filling of openings and staining throughout the rock. Counts range up to 2,000 cps.

A combination of highly anomalous primary uranium mineralization in granite, together with additions from migmatites, shear zone mineralization and supergene enrichment may offer the possibility of low-grade, open pit production. Some drilling has been completed, but industrial data are confidential.

c. Genesis

The Kenosha granite mineralization has similarities to the Portuguese uranium deposits which occur in Hercynian (Permo-Carboniferous) granites which themselves have a high background radioactivity. These deposits are located in joints, fractures, and disseminations in the roof zones and fringes of the plutons and in contact metasediments. Pitchblende and pyrite are referred to as supergene products, whereas gummite and other secondary minerals are believed to be alteration products. Vein deposits occur around the contact of the granite intrusive at Cunha Baixa; at the Nisa deposit there is peripheral dissemination-type mineralization. The grade at the Nisa deposit ranges from 0.1 to 0.15% U_3O_8 .

d. Other Examples in the Front Range

Red Skin Granite

Uranium is anomalous throughout much of the Red Skin granite. This 4 x 6 1/2 mile lobe of the Pikes Peak batholith crops out along the northeast fringe of the Badger Flats area in northern Teller County about 8 miles northwest of Lake George (Plate 10).

This granite is a pink to reddish, medium-grained, equigranular, biotite granite which consists mainly of microcline perthite quartz and sodic plagioclase. It is somewhat porphyritic locally, and has a strong, reddish color where well-oxidized. A somewhat higher count occurs in areas of strong jointing and fracturing suggesting supergene enrichment.

Anomalous uranium occurs over an extensive area in Sections 10, 11, 14, and 15 in T.11S., R.72W. (Gallagher, 1976). Gallagher found values ranging up to 13.9 ppm eU; anomalous tin and niobium values ranging up to 500 ppm and 400 ppm, respectively, accompany the uranium. Thirty-seven samples analyzed contained an average of 7.2 ppm eU and 57 ppm eTh.

At Badger Flats itself (Plate 15), both shear zone and breccia pipe mineralization is promising. Located on the east slope of Badger Mountain, the Last Chance fault-vein traverses anomalous Silver Plume granite which averages 6.2 ppm eU (Gallagher, 1976). This vein extends for approximately 2 miles. It ranges from a few inches to 6 feet in width and may offer both depth- and strike-production potential. The

115a

GEOLOGIC MAP OF BADGER FLATS INCLUDING URANIUM OCCURRENCES AND SPRING LOCALITIES

poorly exposed Gold Star supergene uranium deposit is situated within a circular feature approximately 400 feet in diameter in which volcanic debris has been recognized. This "pipe" may offer primary uranium potential at depth and be similar to the beryllium and greissen-bearing breccia-pipes, such as the Boomer reported elsewhere in Badger Flats and described by Hawley (1969). If this is the case the Gold Star "pipe" may be enriched in primary uranium at depth, particularly in the root zone of this feature. This environment provided a rapid drop in temperature and pressure which caused boiling of the aqueous phase, and may have resulted in precipitation of uranium if the uranium was being transported in the U^{+6} valance state and if reductants were available.

The presence of fault-vein and possible breccia-pipe uranium mineralization enhances the probability that the Red Skin granite offshoot of the Pikes Peak batholith was a "cauldron" collecting center for uranium as well as Be, F, Li, Mo, Rb, Sn, W and rare-earth elements, which together formed a greissen environment. The Red Skin granite lobe resulted from a volatile, fluid-rich, late-stage magma with high oxygen fugacity as indicated by the reddish color of the granite.

As suggested by Dubyk (pers. commun., 1977), specific targets for uranium concentration in the crest or hood zone

of the cauldron would include "any rock type or structure providing a reducing environment for hexavalent uranium-bearing fluids." This might include jointed and fractured Red Skin granite, shear zones, breccia pipes or other tectonic features, particularly the deeper portions of such features where a rapid decrease in the pressure-temperature gradients may have occurred. Exposed, anomalous, uranium-enriched centers representing the crest of the Red Skin granite may have been collecting areas of such centers, or local "collecting center traps" of the late, metal-bearing, aqueous phase.

Mt. Rosa Granite

This anomalous, uranium-bearing, alkalic, riebeckite granite sill, 4 miles long, up to a mile wide, and 150 feet thick, occurs within the Pikes Peak batholith approximately 10 miles east of Cripple Creek in Sections 7 and 8 in the southeast corner of the Manitou Springs topographic sheet (Plate 16). It may offer large tonnage, low-grade potential. Access is from the Manitou Springs-Cripple Creek road, Colorado 336.

Mineralization associated with this sill occurs as exotic pegmatites, veins, and altered, mineralized portions of the riebeckite granite itself. The pegmatites include quartz, microcline, riebeckite, radioactive zircon, fluorite,

STRUCTURAL FABRIC AND URANIUM
OCCURRENCES OF THE FRONT RANGE

EXPLANATION

FAULT	THRUST FAULT
BALL ON DOWNWARD SIDE OF FAULT	SHEAR ZONE

PARTIAL LIST OF URANIUM OCCURRENCES

1. SISK	10. JO REYNOLDS	20. AUBREY LADWIG LEASE	31. URANIUM QUEEN
2. FAIR DAY	11. ALMADEN	21. UNION PACIFIC PROSPECT	32. SPENCER HEIGHTS
3. BLUE JAY	12. GOLCONDA	22. GRAPEVINE	33. BOSTON PEAK
4. BLACK CLOUD	13. MARY	23. FOOTHILLS (WRIGHT LEASE)	34. JAMES PEAK
5. CARIBOU	14. GOLD ANCHOR	24. FOUR CORNERS	35. WHEELER BASIN
5a. SHIRLEY	15. BANKERS LODGE	25. MANN NO. 1	36. CRIPPLE CREEK
6. CARROLL	16. MENA	26. BLACK KNIGHT & BILLIKIN LODGES	37. BADGER FLATS
7. KIRK	17. NORTH STAR	27. SEVEN DEVILS	38. MT. ROSA
8. WOOD	18. SCHWARTZWALDER	28. ASCENSION	39. KENOSHA PASS
9. UNKNOWN MINE	19. OLD LEYDEN COAL MINE	29. OHMAN	40. GEORGIA PASS
		30. COPPER KING	41. JEFFERSON LAKE
			42. HALL VALLEY

astrophyllite, thorite, and smaller amounts of pyrochlore, rutile, niobian rutile, columbite, bertrandite, and rare alumino-fluorides uranothorite and thorogummite (Gross and Heinrich, 1966). Some 500 tons of this mineralized rock was shipped in the 1950's from a location 3 miles northeast of Rosemont on the Summit Wye Road. Core drilling was completed to depths of 100 feet. According to Heinrich (1966) the ore bodies occur as irregularly shaped pods along a northeasterly trend.

More recent studies by Loraine Edmond (pers. commun., 1978) indicated that "altered granite" vein material from the south side of Mt. Rosa was assayed at 2000 ppm U_3O_8 and, at another location, on the north side of the mountain, granite peripheral to a pegmatite dike was assayed at 2500 ppm U_3O_8 . (Figure 7).

As with the Red Skin granite, this sill-like body also represents a late-stage, magmatic segregate of the Pikes Peak batholith in which a metal-bearing aqueous phase was concentrated. It appears to have served as a trap for the buildup of exotics. Pegmatite dikes, veins and mineralized riebeckite granite offer potential, but extraction of the uranium from the exotics may be difficult and expensive.

The Sherman Granite

The Sherman granite of Silver Plume age also offers low-grade exploration possibilities. It occupies the northernmost part of the Front Range, extending from Prairie Divide

GEOLOGIC MAP OF THE MT. ROSA AREA, COLORADO

(After Gross and Heinrich, 1965). From LLB 7029-GJBX-78.

into Wyoming (Plate 4). It is equigranular to porphyritic and consists largely of microcline, orthoclase, quartz, and biotite. It has been dated by Phair and Gottfried (1964) at 1.4 b.y.; they estimated the average U_3O_8 content at 5.7 ppm.

Alan Divis completed a preliminary reconnaissance study of the exploration potential of the Sherman granite for this project in August, 1977. He divides the Sherman granite into four phases:

1. A coarse-grained central core located in the vicinity of Virginia Dale, a settlement on U.S. 287, in which uranium content is low, averaging 3 ppm eU.
2. An intermediate zone of massive, medium-grained granite.
3. A fine-grained phase.
4. Granitic gneiss within and around the fringes of the batholith. The feldspathic gneiss within the Idaho Springs country rock is believed to be the equivalent of the granite gneiss. Both may have formed as a result of thermal metasomatism.

i. Exploration Approach

A gamma-ray scintillometer approach supported by laboratory fluorimetry can assist in the search for low grade, large tonnage uranium target which may be present in the Sherman and other favorable granites as a result of anomalously high uranium concentrations upgraded by supergene enrichment. Diagnostic "path-finder" elements should be utilized as part of an overall air-ground exploration program.

The low grade Kenosha, Red Skin, Mt. Rosa and Sherman granite "targets" are similar in an overall sense to the Portuguese supergene enriched, anomalous deposits of Northern Portugal described above.

CHAPTER K

TERTIARY MODELS

Foothills Uranium Belt

Shear Zone Mineralization

Introduction

The most productive uranium occurrences in the Front Range are found along the eastern foothills fringe west and northwest of Denver. They occur within Precambrian rocks in a zone approximately 3 miles wide in a westerly direction and 30 miles long in a northerly direction. Specifically, they are located between Coal Creek Canyon on the north and the South Platte River on the south. The locations of the well-known Schwartzwalder mine and smaller properties are shown on Plate 17. Production from the Schwartzwalder property from 1954 to 1977 has amounted to approximately 9.6 million pounds of 0.6% U_3O_8 (Young, 1977). In the 1950's each of the smaller mines produced from 1500 to 8500 tons of ore of 0.25 to 0.17% U_3O_8 . They are being re-examined at the present time.

General Geology of the Belt

Uranium mineralization in the Foothills Uranium Belt occurred almost exclusively in complexly folded and metamorphosed sediments and volcanics of Precambrian age within the major northwest-trending shear zones of the eastern slope of the Front Range (Plate 17). It occurred in all of the metamorphic rock types present and in pegmatites, but favored the most brittle and easily fractured rock-units.

The stratigraphic section, established by Sheridan, Maxwell, and Albee (1967, p. 6) in the metamorphic rocks northwest of Golden, is typical of that found throughout the Foothills Uranium Belt. They divided the section into seven main geologic units:

1. Mica schists with conglomeratic and calc-silicate lenses.
2. Hornblende gneiss
3. Microcline-quartz-plagioclase-biotite gneiss.
4. Microcline-quartz-plagioclase-biotite gneiss complexly interlayered with other rocks.
5. Interlayered gneisses.
6. Interlayered biotite-quartz-plagioclase gneiss and mica schist
7. Quartzite

Igneous rocks within the Foothills Uranium Belt include Precambrian Boulder Creek granodiorite, quartz monzonite, smaller hornblende diorite bodies and dikes of Pikes Peak

REGIONAL GEOLOGY OF THE FOOTHILLS BELT

Index map showing location of map area.

EXPLANATION	
	Sedimentary rocks — PALEOZOIC AND MESOZOIC
	Mafic monzonite — PALEOCENE
	Quartzite
	Granite gneiss
	Mica schist
	Hornblende gneiss
	Granodiorite and quartz monzonite
PRECAMBRIAN	

Precambrian faults are identified as follows: A, Black Hawk; B, Junction Ranch; C, Hurricane Hill; D, Rogers, east and west branches; E, Livingston (southern extension of Livingston fault is known as the Golden fault in Golden area). Idaho Springs - Ralston Creek cataclastic zone outlined by dashed lines. (Modified after Young, 1977).

granite. Tertiary dikes and sills of hornblende-biotite lamprophyre (mafic monzonite of Ralston dike) occur in the Schwartzwalder mine area.

Structural Fabric

The predominantly northwest-trending shear zones, which occur along the eastern fringe of the Front Range from the Wyoming border to the South Platte River, constitute the major structural features within the Foothills Uranium Belt. According to Tweto and Sims (1960, p. B-8; 1963, p. 101), some of the northwest-trending zones may have initially formed during the Precambrian: all were active as the Front Range arch developed during the Laramide orogeny. The most prominent shears zones, from north to south, are the Livingston-Golden, Rogers, Hurricane Hill, Junction Ranch, and Floyd Hill-Black Hawk. They can be traced northwestward to the Colorado Mineral Belt. The Black Hawk and Rogers shear zones extend across the Colorado Mineral Belt (Plate 18).

The general trend of these fault systems is N30-50°W, although there are numerous splits and branches which have variable trends. Most of the major faults of each system dip steeply to the northeast; a few dip to the southwest. Subsidiary low-angle faults are common, with dips from 20 to 40 degrees. These are well-mineralized in some of the mines.

GEOLOGICAL SKETCH MAP OF THE CENTRAL FRONT RANGE

EXPLANATION

IGNEOUS AND METAMORPHIC ROCKS

SEDIMENTARY ROCKS

EXPLANATION

- Tertiary Intrusives**

 1. Montezuma stock
 2. Empire stock
 3. Apex stock
 4. Eldora stock
 5. Caribou stock
 6. Albion-Audubon stock
 7. Sunset stock
 8. Jamestown stock
 9. Ralston Dike stock
- Shear Systems**

 - A. Idaho Springs
 - B. Floyd Hill - Black Hawk
 - C. Junction Ranch
 - D. Hurricane Hill
 - E. Rogers
 - F. Livingston-Golden
 - G. Idaho Springs-Ralston Creek

(Letter refers to locality discussed in text.)

Well-cemented and mineralized breccias occur along portions of both the major shears and subsidiary faults and fractures of these systems. Where well silicified, they form prominent topographic features several tens of feet on height which have been referred to as "breccia reefs." The character of the faults within the northwest-trending systems varies greatly. Some are simple faults with related fracturing and contain little gouge or breccia; others are broad zones consisting of well-developed breccia or shattered rock up to a thousand feet wide and several thousand feet long. Generally, however, the breccia-filled zones range from less than an inch to ten feet in width and a few tens to a few hundreds of feet along strike.

These breccias consist of country rock fragments cemented by ankerite, potash feldspar and variable amounts of quartz. Frequently, the rock-fragments may be extensively replaced by these same minerals to the point where most of the fragments have lost their identity. Northwestward toward the Mineral Belt they have been flooded by quartz, fluorite, and hematite. At the Ralston Creek Ranch, the western side of a prominent "breccia reef" within the Hurricane Hill system has been flooded by dense, white silica, and is cliff forming whereas the eastern side has been mineralized by ankerite, potash feldspar and minor silica, and has little relief. The latter gangue assemblage is dominant southeast of this area. The

strong carbonate-feldspar flooding of the major "breccia reef" zones may have been the first stage of mineralization in the Foothills Uranium Belt. Photograph K., page 125a.

The metals present in these breccias generally reflect the anomalous metals of the respective districts. This relationship is described by Lovering and Tweto (1953) in Appendix C, and is supported by the results of the analyses of eleven breccia reef samples given on pages 125, 126, and 127. Higher U, F, Ba, Pb, Ag, and Cu values were found in the Black Hawk carbonate type breccia reef Sample No. 11, in the silica type Hurricane Hill breccia reef Sample No. 12, and the Rogers silica type breccia reef Sample No. 13, all of which were collected close to the southeastern fringe of the Mineral Belt. Strontium and zinc are generally higher in the samples from the breccia reefs in the breccia reef samples collected in the Foothills Uranium Belt. Additional sampling of these breccia reefs may lead to diagnostic features useful in exploration.

Ore occurs locally along the breccia reef portions of these major northwest-trending shear systems where the breccia zones have been refractured and reopened permitting the later ore-bearing fluids to mineralize the breccias and newly-opened fractures. This is particularly evident within the northwest-trending subsidiary Illinois and related veins within the Rogers zone at the Schwartzwalder mine. Photograph L., pg. 125b

K.

**This photo is found in the
back pocket of this report.**

Hurricane Hill Breccia Reef in Golden Gate Canyon

The 100 foot wide reddish zone on the west is the carbonate-K-feldspar flooded part of the Hurricane Hill shear zone. Highly fractured Idaho Springs gneiss are exposed on the east.

L.

**This photo is found in the
back pocket of this report.**

Rogers Shear Zone - Looking Southeast

The northwest-trending Rogers Shear Zone encompasses lower Ralston Creek Valley at the Schwartzwalder mine. The trace of the Rogers East branch crosses the skyline ridge in the left center part of the print and projects northeast along the mid-part of the slope on the left. The trace of the Rogers West branch follows the saddles in the upper right. The trace of the heavily mineralized Illinois fault-vein is from the heavily timbered slope on the right to the stream in the center part of the picture.

LOCATIONS

1. Breccia reef, Mena mine
2. Saddle breccia 1/2 miles south of Mena mine
3. Ralston Creek Ranch - siliceous
4. Ralston Creek Ranch - carbonate
5. Coal Canyon townsite
6. Breccia 1/2 mile west of Idledale

ITEM	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
	B-1	B-2	6	6-E	7	B-8
ELEMENT						
Fe	10%	10%	0.2%	10%	2%	2%
Ca	7%	10%	2%	2%	1%	3%
Mg	2%	5%	0.1%	0.15%	0.07%	1%
Ag	< 1	< 1	< 1	< 1	5	< 1
As	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	< 10
Ba	<u>100</u>	< 10	< 10	< 10	<u>50</u>	<u>200</u>
Be	< 2	< 2	< 2	< 2	< 2	< 2
Bi	< 10	< 10	< 10	< 10	< 10	< 10
Cd	< 50	< 50	< 50	< 50	< 50	< 50
Co	<u>20</u>	<u>30</u>	< 5	<u>15</u>	< <u>10</u>	< 5
Cr	50	70	< 10	<u>500</u>	20	< 10
Cu	20	3	5	<u>20</u>	10	20
Ga	10	< 10	< 10	10	< 10	20
Ge	< 20	< 20	< 20	< 20	< 20	< 20
La	< 20	< 20	20	< 20	20	< 20
Mn	<u>1000</u>	<u>700</u>	20	50	<u>1000</u>	<u>200</u>
Mo	<u>2</u>	<u>2</u>	< 2	5	< <u>2</u>	< <u>2</u>
Nb	20	20	< 20	20	20	20
Ni	<u>50</u>	<u>70</u>	< 5	<u>200</u>	7	5
Pb	<u>50</u>	<u>20</u>	10	<u>50</u>	20	20
Sb	< <u>100</u>	< <u>100</u>	< <u>100</u>	<u>100</u>	< <u>100</u>	< <u>100</u>
Sc	10	10	< 10	<u>20</u>	< <u>30</u>	< 10
Sn	< 10	< 10	< 10	< 10	< 10	< 10
Sr	200	100	200	200	<u>1000</u>	200
Ti	<u>1500</u>	<u>1500</u>	<u>5000</u>	<u>5000</u>	<u>1000</u>	<u>1500</u>
V	<u>500</u>	<u>200</u>	300	<u>300</u>	<u>300</u>	<u>100</u>
W	< 50	< 50	< 50	< 50	< 50	< 50
Y	< 10	10	< 10	10	< 30	10
Zn	<u>200</u>	< <u>200</u>	< <u>200</u>	<u>200</u>	< <u>200</u>	< <u>200</u>
Zr	< <u>20</u>	<u>20</u>	< 20	<u>30</u>	<u>70</u>	<u>30</u>

LOCATIONS

7. Cut below North Star mine
8. Black Hawk fault 1/2 mile northwest of U.S. 6
9. Below dam 1 1/2 miles east of Nederland on Colorado 119.
10. Approximately 6 miles northeast of Nederland on Colorado 119-siliceous
11. Same but carbonate type.

ITEM	<u>7</u> 8-9	<u>8</u> 10	<u>9</u> 13	<u>10</u> 14	<u>11</u> 14A
ELEMENT					
Fe	7%	5%	5%	10%	10%
Ca	10%	2%	7%	7%	5%
Mg	2%	1%	0.15%	5%	2%
Ag	< 1	< 1	< 1	<u>20</u>	1
As	<500	<500	<500	<500	<500
B	< 10	10	< 10	< 10	10
Ba	70	<u>1000</u>	<u>500</u>	< 10	< 10
Be	< 2	< 2	< 2	< 2	2
Bi	< 10	< 10	< 10	< 10	< 10
Cd	< 50	< 50	< 50	< 50	< 50
Co	10	5	5	30	20
Cr	10	50	50	30	30
Cu	5	100	10	<u>1500</u>	<u>200</u>
Ga	< 10	< 10	20	<u>10</u>	<u>20</u>
Ge	< 20	< 20	< 20	< 20	< 20
La	< 20	<u>30</u>	< 20	< 20	< 20
Mn	<u>700</u>	<u>200</u>	<u>700</u>	<u>500</u>	200
Mo	< 2	2	<u>3</u>	<u>2</u>	2
Nb	20	20	20	20	20
Ni	7	30	30	70	50
Pb	15	15	30	<u>2000</u>	100
Sb	<100	200	<100	<100	<100
Sc	10	15	15	< 10	10
Sn	< 10	< 10	< 10	< 10	< 10
Sr	100	<u>500</u>	<100	100	<100
Ti	<u>700</u>	<u>2000</u>	<u>2000</u>	<u>700</u>	<u>3000</u>
V	<u>200</u>	<u>150</u>	<u>70</u>	<u>200</u>	<u>150</u>
W	< 50	< 50	< 50	< 50	< 50
Y	15	10	10	< 10	< 10
Zn	<u>200</u>	<200	<200	<u>200</u>	<u>200</u>
Zr	<u>20</u>	<u>100</u>	<u>20</u>	<u>20</u>	<u>100</u>

CHEMICAL ANALYSES OF BRECCIA REEF SAMPLES FOR U, F. S. & Hg

<u>ITEM</u>	<u>SAMPLE NO.</u>	<u>U</u> <u>(PPM)</u>	<u>F</u> <u>(%)</u>	<u>S</u> <u>(%)</u>	<u>H_S</u> <u>(PPM)</u>
1	B-1	<2	.028	<.05	.16
2	B-2	<2	.046	<.05	.045
3	6	<2	2.3	<.05	.065
4	6E	3	.	.	.
5	7	5	.	.	.
6	8	<2	.	.	.
7	B-9	2	.025	<.05	.075
8	10	55	.084	<.05	.37
9	13	75	.066	<.05	.045
10	14	12	.02	.12	.55
11	14A	5	.12	<.05	.02

Note: . = Analysis not requested.

Schwartzwalder Mine Model

The Schwartzwalder mine, the classic model of the shear zone type of occurrence, and smaller properties and prospects of note are located within the Foothills Uranium Belt. These include the North Star, Mena, Aubrey Ladwig, the Union Pacific, the Ascension, the Grapevine, the Foothills and the Bonzo.

The Schwartzwalder mine, located approximately 8 miles northwest of Golden in the lower reaches of Ralston Creek, is the major uranium producer in the Precambrian basement rocks of the United States. It is located within the major, northwest-trending Rogers shear system. This zone is approximately 2,000 feet wide in the mine area. The mineralized faults within this zone show little lateral or vertical displacement in the mine area. The ore bodies have formed largely in the central part of the zone within a fault system consisting of the northerly-trending, steep and westerly-dipping Illinois fault, and easterly-trending, gently-dipping, subsidiary, hangingwall faults, which form a "horsetail" pattern and which have easterly dips from 0 to 70 degrees E where they join the Illinois fault-vein (Plate 19). The latter are probably tensional. This complex fabric developed where the Illinois fault forms a "cymoid loop" or S curve (Young, 1977).

The ore bodies occur mainly in rocks with high concentrations of hornblende and biotite, or garnet and biotite, reflecting possible chemical control; however, the degree of

129a

Cross section of Schwartzwalder mine, normal to the plane of the principal veins.
The line of Section extends from A' to A (fig. 2). Viewed looking northwest.
(somewhat generalized)

Downs & Bird, 1965

Mountain Geologist, V.2 No. 4, pp. 183-191

brittleness exhibited by the country rocks appears to have been a more important factor in the development of pervasively fractured, low pressure zones and other factors conducive to fluid transport and ore deposition. Ore formed preferentially where the faults cut across the metamorphic foliation at high angles. Young (1977, p. 4) interprets the foliation in the Schwartzwalder mine area as representing a "steeply dipping, open synform that probably has an overturned limb." The plunge of this feature is west-southwest. The presence of the synform is suggested "both on the surface and underground by a compressed tongue of quartz-biotite schist, partly garnetiferous, and quartzite that is transected by the through-going Illinois fault." The schist is the host for most of the ore in the mine. (Plate 17).

Mineralization in the Schwartzwalder mine developed in the following sequence (as interpreted by Sheridan, Simms, and Albee, 1967, p. 99):

- "1. Brecciation of Precambrian rocks along fault planes, probably during the Laramide.
2. Hydrothermal solutions flooded the open zones, altering the breccia fragments and depositing quartz, ankerite, pyrite, K feldspar and perhaps minor fluorite.
3. The breccias and faults were reopened and new faults formed.
4. A second stage of hydrothermal solutions deposited ankerite, pitchblende and some quartz.

5. Still further fracturing was followed by the main stage of base-metal and sulfo-salt deposition accompanied by ankerite and quartz.
6. Refracturing resulted in a final stage of carbonate, marcasite and pyrite veinlets."

The first stage of ore formation is believed to have involved propylitization of the hornblende gneiss. This resulted in the partial chloritization of hornblende and some sericitization of plagioclase. The sulfide ion concentration of the solutions probably was low as only a very small amount of pyrite was formed from the breakdown of iron-bearing minerals, thus permitting excess iron to deposit as hematite.

Following propylitization, solutions were introduced that raised the potassium content of the gneiss from 1 to 3 percent. Potassium replaced sodium in the original plagioclase.

The precipitation of uranium followed the potassic alteration and coincided with the beginning of a carbonate phase. This is indicated by the deposition of pitchblende on orthoclase crystals and its intergrowth with ankerite. The reduction of U^{+6} to U^{+4} by the Fe^{+2} ions released by the breakdown of hornblende and chlorite may have caused precipitation of the uranium.

After depletion of the available uranium, several simple copper sulfides, sphalerite, galena and minor molybdenite were

deposited in an intricate fracture network that followed only in part the original pitchblende-bearing veinlets and brecciated zones. Deposition of these sulfides was followed by tennantite. On depletion of arsenic and antimony in the ore fluids, sufficient copper remained so that chalcopyrite formed locally throughout the tennantite and along grain boundaries. In addition cobalt, vanadium, and silver have also been reported by Sheridan et al (1967, pp. 99-100). With deposition of the chalcopyrite, sulfide mineralization ended and a strong carbonate phase began and continued until the close of hypogene activity.

The original ore bodies ranged from a few tons to a thousand tons or more. Mineralization occurs in veinlets or mineralized fault-breccias less than an inch thick to large shoots composed of complexly-branching or coalescing major veins that have minable widths of as much as 35 feet. Material of minable grade occurs across the entire thickness of breccia in some of the mineralized faults, but, in general, the richest concentrations of pitchblende are confined to breccias developed along either the hanging wall or the foot-wall of the faults. Typically, the uraniferous material forms lenses or shoots that are discontinuous along strike and commonly have their longest dimensions down-dip. Young (1978) has compiled metal abundance data on the Schwartzwalder

pitchblende ore. These data are given in Table 9. Photograph M is of a typical high grade breccia ore from the Schwartzwalder mine. Page 133a.

Other Mines of the Foothills Belt

The Mena mine is located on Ralston Creek approximately 1-1/2 miles northwest of the Schwartzwalder; it, too, is located within the Rogers fault zone (Plate 17). The Precambrian host rocks consist of hornblende gneiss with some amphibolite and biotite gneiss. The latter is garnetiferous. Calc-silicate bands also occur in the vicinity of the mine. The foliation trends from N60°W to east-west and dips moderately southwest.

The east branch of the Rogers fault system projects northward from the Schwartzwalder mine, and is situated approximately 1/2 mile east of the Mena mine. The west branch of the system is located approximately 500 feet west of the mine adits (Plate 17). These major boundary faults include zones of shattering, up to 200 feet in width, and locally narrow bands of poorly-cemented breccia. Float of the well-mineralized "breccia reef" material also was noted in a covered area. Within the system are subsidiary faults, locally mineralized by barren carbonate gangue and, in some instances, by uranium-sulfide-bearing fluids which developed orebodies locally along individual faults where permeability

M.

**This photo is found in the
back pocket of this report.**

Schwartzwalder Breccia Ore

This core sample of Schwartzwalder breccia ore is typical of the high grade mineralization found in the fault zones. Note the black bands of uraninite, the red hematite alteration and the late, silica flooded breccia on the left.

Table 9Relative Abundance of Elements in Schwartzwalder Pitch-
blende Ore

<u>Element</u>	<u>No. of Samples</u>	<u>Average Percent</u>	<u>Crustal Abundance* in Percent</u>	<u>Concentration = Average % Crustal Abundance</u>
U	42	17.67	0.00025	70,700
Mo	42	0.53	0.00011	4,800
Sb	41	0.11	0.00005	2,200
W	42	0.15	0.00013	1,150
Pb	42	0.96	0.0016	600
Ag	41	0.0029	0.000007	410
Tl	21	0.04	0.0001	400
Zn	42	0.26	0.0083	30
Cu	42	0.077	0.0047	16
Zr	42	0.135	0.0170	8
Nb	42	0.009	0.0020	5
Be	30	0.0015	0.00038	4
Co	5	0.006	0.0018	3
Y	8	0.0079	0.0029	3
V	42	0.028	0.0090	3
Mn	30	0.22	0.1	2
Ni	41	0.012	0.0058	2
Ca	30	4.32	2.96	1.5
Fe	30	4.84	4.65	1
Sr	30	0.0200	0.0340	0.6
Mg	30	1.12	1.87	0.6
Ti	30	0.2	0.45	0.4
Al	30	3.1	8.05	0.4
Cr	42	0.0030	0.0085	0.4
Ba	30	0.0210	0.0650	0.3

*Vinogradov (1962).

permitted. The Mena vein, which trends N 10-35°E and dips 43-70°NE has been followed for 2,000 feet along the trace of outcrop. It occupies a fault, ranging from 6 inches to 3 1/2 feet in width which contains fault gouge and breccia, with mineralization within and around breccia fragments and in open spaces. Adams, Gude and Beroni (1953, p. 16) report that the shear zone in the Nigger shaft (caved) is 8 feet thick, but that the carbonate-rich, ore-bearing section averages only 2 feet. Sheridan, et al (1967, p. 89) considers this shear zone to be a part of the Mena vein. At stream-level approximately 400 feet east of the Mena vein is a typical breccia-reef fault containing up to 3 1/2 feet of tan to reddish brown, well-cemented breccia. Relatively unaltered hornblende gneiss occurs in the hanging wall; the gneiss is well-shattered and altered in the footwall for at least ten feet below the breccia zone. The cement of the breccia is K feldspar, dolomite and quartz which have flooded and partially replaced the breccia fragments. This fault can be traced for several hundred feet to the northwest where it is cut off by the west Rogers boundary fault. Photos N & O.

As in the case of the Schwartzwalder, mineralization at the Mena is located along easterly-dipping subsidiary faulting within the Rogers system. The mineralization in the Mena vein system formed in breccias cemented by ankerite and potash

N.

**This photo is found in the
back pocket of this report.**

Mena Mine Breccia Reef

The low angle breccia reef mineralized fault is exposed beneath the tree trunk just east of the Mena mine. Note the highly shattered gneiss and amphibolite beneath the trace of the fault on the left.

0.

**This photo is found in the
back pocket of this report.**

Close Up of the Mena Mine Breccia Reef

The 1-foot wide, dense, reddish K feldspar-carbonate flooded zone lies immediately below the log in the upper right. Note the white pen for scale. Shattered, partly replaced Idaho Springs amphibolites lie beneath.

feldspar. There are thin, dark veinlets of pitchblende 12-25 mm wide in the breccia as well as thin films of colloform pitchblende, approximately 0.5 mm thick which coat breccia fragments. Later-formed veinlets of sulfides cut the pitchblende mineralization. The breccia gangue consists of K feldspar, ankerite, quartz and calcite. Minerals of the sulfide veinlets include native bismuth, bismuthinite, galena, chalcopryrite, pyrite, chalcocite, bornite, covellite, niccolite and secondary copper minerals (Sims and Sheridan, 1964). Anomalous trace elements are Ti-0.7%, Cr-0.015% and Zr-0.7%.

The Foothills Mine is located immediately upstream from Idledale which is located about 5 miles west of Morrison in Bear Canyon. (Plate 16). By 1960, 8,500 tons of 0.26% U_3O_8 was produced from the Foothills vein (Sims and Sheridan, 1964, p. 96). The vein occurs in quartz-biotite gneiss and granitic gneisses in which it "curves from N 60°W to N 20°W and dips 50-80°NE" (Sims and Sheridan, 1964, p. 96). It often consists of two curved branches. The vein is composite with a strong breccia development along the hanging wall and uranium-sulfide mineralization along the footwall. Its walls are sharp and often slickensided. Open vugs frequently occur within the vein.

Mineralization formed during two stages. The first consists of ankerite, pyrite, potash feldspar, chlorite, and pitchblende. The second-stage minerals which formed include coarse calcite, purple fluorite, and pyrite with sparse galena, chalcopryrite, marcasite, sphalerite and tetrahedrite-tennantite.

The Grapevine mine is located immediately northeast of Idledale in Sawmill Gulch. According to Sims and Sheridan, seventy-seven tons of uranium ore, averaging 0.29% U_3O_8 , were mined from a shallow shaft in 1955 and 1,691 tons of 0.29% were mined from new workings from 1958-60. The country rock is biotite-quartz gneiss. (Plate 16)

The ore came from splits and branches of the Sawmill Gulch shear zone (Sims and Sheridan, 1964, pp. 100, Fig. 26). They trend northwest and dip 45-60°NE. The strongest mineralization is developed along and outward from the intersection of a shallow dipping "flat" vein and the more steeply dipping East vein. This is a relationship common to the entire Foot-hills Uranium Belt. The ore occurs in a 1-2 foot wide lense of breccia along these mineralized faults; pitchblende coats fractures and altered breccia fragments. Pyrite, quartz, feldspar, and clay minerals also are present in the breccia.

The Critchell center of mineralization, situated about 11 miles south of Idledale, is similar to the productive areas to the north. Mineralization is located along the Billikin and Black Knight faults which are subsidiary structures of nearby "breccia reef" faults. The country rocks are biotite gneiss, amphibolite and migmatite. Uranium mineralization favors a magnetite-bearing, garnet gneiss. The ore minerals are pitchblendewith minor copper and iron sulfides

in a gangue of carbonate minerals. Although considerable core drilling and an exploratory shaft were completed during the 1950's, no uranium ore was found at depth.

The F.M.D. prospect is situated along a northwesterly-trending, copper-bearing breccia reef structure cutting hornblende gneiss, migmatitic quartz diorite and pegmatite (Theobald and Guilinger, 1955). It is located some 3 miles northwest of Idledale. Sparse uranium mineralization occurs with copper. Limonitic staining occurs along the shear zone. However, no anomalous radioactivity is apparent on the dump or outcrops near the mine (Dubyk, pers. commun.).

The Bonzo mine is located approximately one mile upstream from the mouth of the South Platte Canyon, southwest of Denver. Limited, high-grade production occurred in the 1950's. The ore grade was reported to be between 1-2% U_3O_8 .

The following information was acquired from Bradd Watts (pers. commun.) and by personal observation: The property is within a rectangular fault block bounded on the north by the N 70-80°W-trending Cottonwood Canyon fault, and on the east and west by northwest-trending faults. An abrupt change in the foliation trend may indicate that a fault zone may be present in the east-west trending South Platte river drainage to the south. Mineralization is exposed in an adit located approximately 100 feet above the road level. It

precipitated in a northwest-trending "flat" which dips 20-40° northeasterly. The flat appears to have formed by tensional faulting which may dip into the northwest trending boundary fault 100-150 feet to the east and on the east side of the block. If this is the situation, the structural relationships would be similar to those at the Schwartzwalder mine. A second mildly mineralized "flat" occurs about 75 feet below the first in the adit located at the road level. Similar "flats" are present in the adjacent block to the west as well.

Most of the production came from the low-dipping "flat" vein in the upper adit in which the vein was stoped both up-dip and down-dip. The lower stopes are connected to the road-level adit by a raise.

The remnant mineralization on the edges of the stopes consists of 1/2 inch or more of high-grade uraninite ore ranging from 0.6 to 1% U_3O_8 , and locally up to 2%. Pitchblende occurs in the matrix of wider and more brecciated portions of the vein. Towards the portal of the adit, oxidation has given the pitchblende a strong sooty texture and has been effective in the formation of carnotite and other secondary uranium minerals. The primary mineralization is lense-like with uraninite having formed along open "tensional" dilational segments occurring in the plane of shearing. The stoped ore-shoot in the sublevel between the two adits appears to have had a steep rake.

The Aubrey Ladwig mine is located between Clear Creek and Golden canyon approximately 1 1/2 miles northwest of Golden. It was a small producer in the 1950's from an open cut, a 74 foot shaft and some 200 feet of underground drifts and crosscuts (Sims and Sheridan, 1964). In the late 1960's, a 3500 foot adit was driven from a small gulch a mile northwest of Golden, westward at a depth of approximately 500 feet beneath the old workings. (Plates 16 and 17)

The country rocks in the mine area consist of calc-silicate gneiss of the garnetiferous biotite-quartz gneiss. The foliation trend in the gneiss is northeast with near vertical dips. Tight, upright folds have developed within the gneiss. Discordant pegmatite dikes cover about half the area and consist of quartz, feldspar and muscovite.

The mineralization is located in fault-veins within the Hurricane Hill shear system, one of the prominent northwest-trending "breccia reef" structures (Plate 17). Boundary "breccia reef" faults are located one-half mile to the west and to the east. The near-surface workings are developed within an area of minor but complex faults and fractures of small offset. Their predominant trends are northeast and northwest; their dips are steep (Sheridan, et al, 1964). Beneath the early workings, the 3500 foot adit intersects three, steeply-dipping, N40-50°W fault-veins, one of which is

well mineralized, and a strong N80°E fault vein. All are steeply-dipping, and range from a few inches to four feet in width. The ore occurs in bands of breccia and in small lenses within the faults.

The mineralization in the small, open pit near the surface workings occurs largely in northwest-trending fractures which dip at low angles to the northeast. They lie along or close to brecciated contacts between pegmatite and garnetiferous biotite-quartz gneiss and also occur in brecciated gneiss. The pitchblende fills openings in the breccia and coats fragments. In addition to low-grade production, several high-grade lenses and pods, weighing up to 60 pounds were mined in the 1950's (Sheridan and others, 1967, pp. 105). The results of spectrographic analysis of the ore from the easterly-trending vein on the 3500 foot adit level are shown below:

Fe	10%	Ce	100	Pb	5000
Ca	2%	Cr	10	Sb	<500
Mg	0.7%	Cu	700	Sc	<10
Ag	15 ppm	Ga	<10	Sn	10
As	2000	Ge	<20	Sr	100
B	15	La	20	Ti	3000
Ba	50	Mn	3000	V	500
Be	2	Mo	1000	W	<50
Bi	20	Nb	100	Y	20
Cd	<50	Ni	100	Zn	700
				Zr	200

Genesis of Uranium in the Foothills Belt

Lead-uranium isotope ages determined on pitchblende from the veins in the Schwartzwalder mine are approximately 60 m.y. (Marvin, et al, 1974) and correspond with uranium age-dating in the Colorado Mineral Belt (Sheridan, and others, 1967, pp. 45), they consider the uranium mineralization to be hydrothermal with features indicative of epithermal grading to mesothermal. They suggest that the source of the uranium-bearing, hydrothermal fluids was located beneath the Mineral Belt. These moved upward and outward along major faults, such as the northwest-southeast "breccia reef" systems, to supply uranium and base-metals, not only to the Mineral Belt districts, but also to the Foothills Belt. Evidence to support a single uranium source for both include the following:

1. Close proximity of the two belts: 8 miles separates them at the northern end of the Foothills Belt.
2. A complex network of faults connecting them.
3. Petrologic and dating evidence of close uranium relationships in both Belts to late differentiates of Tertiary intrusives.
4. Uranium and trace element content in the "breccia reefs" which extend from the Mineral Belt into the Foothills Belt including Zr, Ba, Mn, Ti, V.

Ed Young of the U.S. Geological Survey, who is a specialist on the geology of the Schwartzwalder mine and immediate area, has proposed a meteoric-hydrothermal origin for the uranium ores. In his 1977 open-file report, he points to three influencing factors:

1. Structures of the northwest-trending Rogers shear zone were present at the time of mineralization, and provided conduits and open spaces for mineralization.
2. Nearby sedimentary rocks provided a source of uranium including overlying and down-faulted late Paleozoic and Mesozoic red beds, sandstones and shales.
3. A magmatic heat source for convective drive supplied by the Ralston mafic monzonite dike, located a short distance to the southeast of the mine. It is mildly radioactive.

He also points to data from the Schwartzwalder mine in support of the meteoric-hydrothermal origin (G.S.A. Abst., Seattle Meetings, 1977, pp. 1237), which includes the following:

- "1. The pitchblende is rich in molybdenum but very poor in thorium and rare earths.
2. Unit cell edges of the pitchblende (uraninite) of about 5.42Å fit sandstone and vein pitchblendes rather than (pegmatitic) magmatic uraninite.
3. Amorphous carbon from sedimentary sources occurs in the veins.
4. Temperatures of ore solutions appear to have been low enough so that muscovite in pitchblende-veined pegmatite host rock retains Precambrian age according to K-Ar age determinations."

He proposes the following model (G.S.A. Abst., Seattle Meetings, 1977, ppg. 1237):

"After tilting of sedimentary strata caused by Laramide tectonism, meteoric water moved down dip along bedding planes, leaching uranium from the rocks and percolating into fractures and the Golden fault zone. Introduction of magmatic heat in and along the Golden fault zone by dike intrusion about 62 m.y. ago instigated convective flow of ground water. A system of flow operated through the Golden fault zone and other deep faults such as the Rogers and Illinois. Parts of the Illinois and hanging wall faults west of the Illinois reopened and brecciated in response to shearing; these served as 'depositional traps' for the pitchblende about 60 m.y. ago."

The writers suggest a composite model combining 1) a magmatic-hydrothermal uranium source; 2) leaching of "stored" uranium from the metamorphic rocks of the Idaho Springs formation in the vicinity of the plumbing system; and 3) meteoric contribution of uranium leached from overlying Paleozoic and Mesozoic sediments. This composite model is shown on Plate 20.

As in the case of Young's model, an igneous heat source is proposed as the mechanism to drive a hydrothermal convection system which delivered metal and sulfide ions to sites favorable for ore deposition in the Foothills Belt. The heat source may have been a magma body related to the Ralston dike which is exposed at the entrance to Ralston Creek canyon, some 3 miles southeast of the Schwartzwalder mine. A dike of similar composition is located just a mile north of the Schwartzwalder in the immediate vicinity of the North Star mine. Two samples

EXPLANATION

PRECAMBRIAN

- S SCHIST
- H HORNBLENDITE
- G GNEISS

MESOZOIC

- Kp PIERRE SHALE
- Kn Niobrara FORMATION
- Kb BENTON FORMATION
- Kd DAKOTA GROUP
- Jm MORRISON FORMATION
- Jrc RALSTON CREEK FORMATION
- LPI LYKINS FORMATION

PALEOZOIC

- Ply LYONS SANDSTONE
- PPF FOUNTAIN FORMATION

HYDROTHERMAL FLUIDS

- MAGMATIC ————
- METAMORPHIC - - - -
- METEORIC ······

CROSS SECTION THROUGH THE SCHWARTZWALDER MINE AREA

LINE OF SECTION N70°E
(SOMewhat GENERALIZED)

of this dike contain over 40 ppm U_3O_8 (S. Johnson. pers. commun.). However, the uranium content of the much larger Ralston dike itself is reported to be only 4 and 5 ppm (Young, 1977). An alternative heat source may have been an early Tertiary monzonitic magma body located under the Mineral Belt which could have served to drive not only the convection system beneath the Foothills Belt, but also that beneath the Mineral Belt. The uranium-bearing bostonite dikes that are present at Central City, Gold Hill, and Jamestown may be late differentiates of such a magma and uranium-bearing veins, their enriched aqueous phase.

Uranium may have been "stored" in sufficient parts per million in the Idaho Springs rocks following metamorphism and may have contributed some of the uranium found in the shear zones of the Foothills Belt and in the veins of the Mineral Belt during early Tertiary time. This contribution may have been particularly significant, especially if hydrothermal circulation in the overall plumbing system continued for a considerable period of time. Uranium is present in small amounts in all of the metamorphic and igneous country rocks both in the Mineral Belt and the Foothills Belt.

Meteoric leaching of uranium from the overlying cover of Paleozoic and Mesozoic sediments should be considered as a distinct possibility, particularly if the hydrothermal

convection system created considerable circulation of meteoric waters through these sediments. The unconformity between the Precambrian and Paleozoic sediments is thought to have been some 1,500 feet above Ralston Creek at the Schwartzwalder mine at the time of mineralization. Some hydrothermal fluids may have circulated upward through the Rogers fault system into the sediments to mix with circulating connate and meteoric waters. An effective trap cover probably existed above the (plumbing) system as the faults of the Rogers system die out into folds where they pass from the Precambrian and Paleozoic rocks into the less competent Mesozoic rocks at the mountain fringe near the Ralston Dike. The Fountain formation which directly overlies the Precambrian erosion surface contains weak uranium concentrations locally. Connate-meteoric mixing with magmatic-hydrothermal waters probably contributed to precipitation of uranium, sulfides and gangue by influencing chemical aspects such as oxidation potential, pH, and oxygen fugacity.

Uranium Occurrences in the Beaverlodge District,
Saskatchewan

The uranium occurrences in the Beaverlodge district of northern Saskatchewan have many similarities to the deposits in the Foothills Uranium Belt and the northern part of the Colorado Mineral Belt. Rich, Holland, and Petersen (1975, pp. 118-129) summarize the geology and uranium deposits as follows:

"The Beaverlodge district is underlain by Precambrian rocks of the Tazin Group (Archean) and Martin Formation (Aphebian). Helikian gabbro dikes cut the rocks of both units. Just to the south of the district the Paleohelikian clastic sediments of the Athabasca basin crop out.

The Tazin group consists of a thick sequence of interbedded graywackes, shales, sandstones, basic tuffs, and carbonates which have been regionally metamorphosed to amphibolite facies quartzites, argillites, amphibolites, impure marbles, garnet-biotite schist, red granites, and quartzofeldspathic gneisses and schists. These rocks have been locally granitized to varying degrees; feldspathic quartzites are most readily and extensively granitized. Tazin rocks in the Beaverlodge area are intensely folded and faulted, extensively brecciated and mylonitized, and are characterized by widespread hydrothermal alteration. All of the granites of the Beaverlodge area are thought to be of metasomatic origin except the granitic dikes and sills which are regarded as mobile fractions of the metasomatic granites. Tazin Group country rocks have slightly anomalous background U contents throughout the Beaverlodge district.

Rocks of the Martin Formation unconformably overlies those of the Tazin Group. The Martin Formation consists of a red bed succession of polymict conglomerates, arkoses, siltstones, shales, and esitic volcanic flows and gabbroic sills. These rocks are unmetamorphosed and only gently folded. Several major post-Martin faults are present in the district. With respect to their spatial relation to U deposits the most notable of these are the ENE-striking St. Louis and NE-trending Black Bay faults.

There exists two types of U occurrences in the Beaverlodge district:

- 1) Syngenetic: monazite, uraninite, cyrtolite, uranothorite, pyrochlore-microlite, and xenotime in pegmatites, in remnants of country rock in a granitized terrane, and in granites. No syngenetic U occurrences are presently of economic interest.

"2) Epigenetic: Fine-grained disseminations of pitchblende near and along fractures, pitchblende fracture fillings and stockworks, pitchblende-mineralized breccias, and vein-type pitchblende occurrences which form locally workable U deposits. Epigenetic U mineralization occurs in all rock types in the Beaverlodge district, but the major U deposits are restricted to altered and granitized portions of the Tazin Group metasediments. Mica schist, epidotic amphibolite, and granitic gneisses are favorable Tazin host rocks. Beaverlodge U deposits show a close spatial relation to major faults, but ore usually occurs in subordinate fault or fracture zones which have been brecciated and hematitized. There appears to exist a distinct relationship between U deposits and intensity of granitization, alteration, and mylonitization of Tazin Group host rocks.

Mineralogy:

Pitchblende is the only important primary U mineral, but more than one generation of pitchblende is usually present in a deposit: e.g., later pitchblende cementing brecciated early pitchblende. Pitchblende is commonly associated with hematite, chlorite, and carbonate. Specular hematite occurs in some pitchblende veins.

Paragenesis:

Notes:

1. Smith (1952) notes that the mineralization at the Martin Lake Mine could be divided into two periods of deposition; the first being characterized by the introduction of pitchblende, carbonate, and hematite, and the second by the introduction of sulfides and selenides of Cu and Pb.
2. Where Hematite + chlorite and + calcite are all found in the wall rock, U is most likely to be present.
3. Pitchblende occurs where pyrite is thickly disseminated.
4. Quartz and pitchblende do not appear to be associated; calcite + chlorite seem to be the gangue minerals associated with the pitchblende.
5. There are exsolved laths of chalcopyrite in bornite which is not associated with the pitchblende.

"6. Reported multiple associations:

Auriferous pyrite + galena + sphalerite +
 chalcoppyrite + gold
 Gold + galena + tiemannite + chalcoppyrite
 Ullmannite + pyrite + chalcoppyrite
 Illmenite + nolanite + hematite + pitchblende +
 feldspar + quartz + chlorite + apatite

7. Marcasite is found where chlorite + carbonate have replaced pitchblende (Robinson, 1955).

Zoning

Increase in V with depth (Robinson, 1955)

Wall Rock Alteration

Hematitization is characteristic of the ore zones. It is often accompanied by the development of calcite, chlorite, and red feldspar (orthoclase or untwinned oligoclase) in the wall rock (Christie, 1953). Other kinds of wall rock alteration recognized in the Beaverlodge deposits include chloritization (chlorite + sericite), epidotization (epidote + albite + chlorite + hematite + quartz), silicification, carbonatization, and albitization. Robinson (1955) observed the occurrence of Ti minerals, principally anatase and rutile, in both wall rocks and veins."

Uranium Exploration in the Foothills Belt

The breccia reef fault zones, such as the Rogers, Hurricane Hill, etc., serve as valuable guides from the aspects of "framing in" favorable target areas within and in the immediate vicinity of the zones in the search for fault-vein type ore bodies. The breccias included within the major faults serve as guide posts in delineating the zones, but

are not continuous along any one structure. In addition, similar breccias, whether carbonate type in the Foothills Uranium Belt or siliceous in the Mineral Belt, also occur along subsidiary faults and fractures and probably represent somewhat later brecciation which formed just prior to the uranium-sulfide mineralization. Thus far there are no diagnostic geochemical criteria established to clearly distinguish between the early breccia reef mineralization and that more specifically related to ore stage.

Exploration guides critical in the search for new Schwartzwalder-type uranium deposits in the Foothills Uranium Belt include the identification of:

1. Subsidiary faults within or in the immediate vicinity of the major northwest-trending "breccia reef" shear systems such as the Rogers, Hurricane Hill, and Black Hawk.
2. Irregularities in trend, including cymoid curvature, branching, and intersections, which create open space available for mineral deposition. The third dimension, horsetail fabric illustrated on Plate 19 created a favorable tensional environment on the hanging wall of the Illinois vein at the Schwartzwalder mine, which probably developed as a result of the plan-view sigmoid curve failure along the Illinois vein.

3. Brittle, readily fractured metamorphics such as calc-silicates, amphibolites gneisses, and quartzites.
4. Faulting along the subsidiary faults at high angles to the foliation of the metamorphic rocks which has contributed to the formation of brecciated, permeable zones favorable for ore deposition.
5. Hematitic and propylitic alteration outward from mineralized faults. The hematite is believed to have formed in part from ferric iron in the hydrothermal fluids and, in part, from oxidation of pyrite and ferrous iron in the country rocks.

Colorado Mineral Belt Vein Systems

Mineralization along the Colorado Mineral Belt (Plate 18) consists largely of precious metal and base-metal vein-type ores and molybdenum porphyry deposits (Lovering and Goddard, 1950; and Wallace, et al, 1978). From the Idaho Springs area northeastward, pitchblende occurs in many of the veins particularly those closely associated in time and space with the Tertiary bostonite dikes and are interpreted as having formed from late-differentiates of monzonitic intrusives. There are numerous reported uranium occurrences in the veins in the Idaho Springs-Lawson-Dumont, Central City, Gold Hill, and Jamestown districts. Uranium also occurs in the Caribou and Fall River districts on the northwestern side of the Mineral Belt, but in those districts, the bostonite dikes are missing.

In almost all occurrences in the Mineral Belt, uranium mineralization is early in the paragenetic sequence and is generally followed by a base-metal sulfide stage. In a few instances there is a later period of uranium mineralization which may represent remobilization. Production of uranium from veins in the Mineral Belt has been minimal as the pitchblende occurs as a minor constituent in narrow bands, lenses, or small pods which generally occur along the walls of the veins.

Fifty-nine uranium occurrences were reported by Sims and others (1963) in the Central City district. More than half of these occur in a one square-mile area on Quartz Hill. Important occurrences in the Idaho Springs and Jamestown districts are shown on Plates 16 and 21.

a. Central City Vein-type Model

The network of early Tertiary veins in the Central City district are a classical example of the composite system typically found in districts of the Colorado Mineral Belt. The country rock in the Central City district is a metasedimentary gneiss which forms a 3,000 foot thick unit along the axis of a broad northeasterly-trending anticline (Sims, Drake, and Tooker, 1963). It is overlain along its flanks by a comparable thickness of biotite gneiss. This structure has been intruded by small bodies of Precambrian Boulder Creek

Geologic sketch map of the Jamestown district, Colorado, showing locations of principal uranium-bearing vein deposits. Geology after E. N. Goddard (1946). (After Sims & others, 1964).

granodiorite and Silver Plume granite. Laramide intrusive rocks, ranging from granodiorite to bostonite in composition, cut all the older rocks. Of these Laramide intrusives, quartz bostonite is the youngest.

Five fracture systems developed in the district (Sims and Sheridan, 1964). The oldest are the northwest-trending "breccia reefs" and the north-northeast-trending faults. These are cut by northeast; east-northeast- and east-trending systems. All are mineralized, but the younger northeast- and east-trending systems are the most heavily mineralized particularly along tensional segments.

The mineralization is mesothermal in character and deposits occur as fault-filling and ore shoots. The district shows clear-cut mineral zoning with higher temperature veins having formed in a central area about a mile in diameter. This core is surrounded by an intermediate transitional zone a half-mile wide, and an outer zone of galena-sphalerite veins. Uranium occurs largely in the intermediate and the outer zones. In this district uranium was deposited during the initial stages of mineralization and was followed by the precious-metal and base-metal sulfide phases (Sims and Sheridan, 1964). Two examples are the Carroll and the Kirk veins; the former contains lead-zinc ore and the latter, gold, pyrite, and quartz.

1. Description

a. Carroll Vein

The Carroll vein occurs in microcline gneiss in the northwestern part of the district and ranges from 2 to 4 feet wide. It trends N70°W and dips 75° to the northeast. The uranium occurs with sulfides in a zone of ore shoots which is 60 feet wide and has a plunge length of 300 feet (Sims and Sheridan, 1964, pp. 75). These shoots occur at the intersection with an eastward-trending vein. Uranium formed in several en echelon ore shoots within the zone, the largest of which is 50 feet high, 50 feet long, and about 6 inches wide. Pitchblende ore occurs as stringers or pods up to a few inches wide along the vein walls. Later sulfides have cut through the uranium mineralization. Twenty eight and a half tons of crude uranium ore containing 349 pounds of U_3O_8 were produced in addition to the base and precious metals.

b. Kirk Vein

The Kirk gold, pyrite-quartz vein, located in the southwestern part of the district on Quartz Hill, also occurs in the microcline gneiss country rock. It trends N 70-75°E, dips 75° SE and ranges from 1-5 feet in width. The mineralization consists of quartz, pyrite, gold, chalcopryrite, tennantite, and minor galena, sphalerite, and pitchblende. The latter occurs along the hanging wall in small high-grade lenses and stringers or bulbous, kidney-shaped bodies, which are distinct from the later sulfide mineralization. Bostonite dikes occur in the immediate vicinity of both the Kirk and Carroll veins (Sims and Sheridan, 1964).

2. Genesis

The uranium in the veins of the northern half of the Mineral Belt appear to have been derived from the aqueous phase developed by late magmatic segregates of the monzonite group of Tertiary intrusives. Some workers have suggested that these hydrothermal fluids were "boiled off" from the monzonite dikes as they were crystallizing. However, the writers favor a deeper, common source within the monzonite magma chamber for both dikes and veins.

3. Economic Potential

The economic potential of uranium occurring in veins in the Central City district and other districts of the Mineral Belt is limited by sparse mineralization, unless it can be recovered as a by-product of precious-metal and base-metal production. Veins in the Caribou district, located north of Central City, are being reopened for their silver, nickel, cobalt and base-metal content. Uranium may prove to be a valuable contributor to the cash flow of these operations.

b. Other Uranium Districts of the Mineral Belt

There are numerous uranium showing in the veins in the mineral districts of Clear Creek County. In twenty-one of these locations, more than 0.1% equivalent uranium has been found (Sims and Sheridan, 1964). Both primary pitchblende and secondary uranium minerals occur in fault-veins with the center of mineralization located at Idaho Springs. Chalcopyrite-tennantite-bearing pyrite-quartz veins occur in an inner zone, whereas silver-bearing lead-zinc sulfide veins form an outer zone extending for some three miles from the center.

The country rocks of the area are Idaho Springs gneisses and schists which are intruded by small stocks and dikes of Precambrian igneous rocks. This Precambrian terrain has been cut by Tertiary porphyries and by faults with predominantly northeast and locally, east and northwest trends. The pertinent features of the Almaden, Golconda, Gold Anchor, Jo Reynolds, and Mary uranium-bearing veins of the Idaho Springs and surrounding districts are given in Appendix A.

There are a number of important occurrence of uranium in the Jamestown district at the northern end of the Mineral Belt. Here Silver Plume granite and gneiss were intruded by early Tertiary granodiorite, dated at 65 m.y. and a later sodic, quartz monzonite stock, dated at 42 m.y. age. It is located immediately north of Jamestown (Plate 21). Two major fault systems developed in the district: 1) a major, northwest-trending "breccia reef" system and related fractures which pre-date the Laramide granodiorite; and 2) a younger, northeast-trending system of minor faults. There is zonal mineralization around the porphyry stock: 1) uranium-bearing lead, silver, fluorite veins of the Burlington, Blue Jay, Emmett, and other mines in an inner zone; 2) pyrite-gold veins in an intermediate zone represented by veins in the Golden Age mine; and 3) gold telluride veins in an outer zone 1 1/2 to 3 miles from the stock. The Fair Day mine, located two miles

west of Jamestown is representative of this outer zone.
(Sims and Sheridan, King et al, 1964).

One period of uranium mineralization, during which gold bismuth, germanium, and uranium were introduced, was related to bostonite dike intrusion. Fluorite occurs in almost all of the veins in the inner zone, but uranium is not always present.

The Caribou "district", part of the larger Grand Island-Caribou mining district, is situated at an elevation of approximately 10,000' in rolling upland topography, 17 miles west of Boulder and 4 miles northwest of Nederland (Plate 16). Metamorphic rocks, occurring generally east and southeast of the Caribou townsite, are primarily quartz-biotite schists with less frequent biotite-sillimanite schists, quartzitic gneiss, hornblende schist and gneiss, and calc-silicates. These metamorphic rocks form the nose of a northeast-trending anticline which, according to Lovering and Goddard (1950), extends to the south-southwest as far as Empire. An extensive Boulder Creek-age intrusive, varying in composition from quartz monzonite to sodic granite, forms the northeastern portion of the district. The Caribou stock, a composite Laramide-age intrusive approximately 2 miles in diameter, has intruded along the axis of the anticline. Its northeast quarter occupies the area west and south of the

Caribou townsite. The intrusive is largely calcic monzonite and quartz monzonite, but it also contains bodies of mafic and ultramafic rocks including gabbro, pyroxenite, hornblendite, biotite amphibolite, biotite pyroxenite, magnetite pyroxenite, magnetite peridotite, and titaniferous magnetite (Lovering and Goddard, 1950, pp. 198). It is believed that these mafic and ultramafic rocks are normally differentiated, filter-pressed or cumulative phases of the monzonite magma. These rocks occur generally within oblong, dike-like bodies several hundred to a thousand feet in length and several tens to several hundreds of feet in width.

Three steeply dipping sets of veins are found in the Caribou area. Most important, in terms of production, are the east-west and northeast-trending uranium-bearing, lead-silver veins which are found primarily in the monzonite. It is thought that the northeast-striking veins, notably the No-Name, represent mineralization along shear zones while the east-west-striking veins represent mineralization along tensional fractures formed in response to shear stresses. Valuable ore shoots have been located at vein intersections and at inflections of dip and strike. Relatively unimportant west-northwest-striking, gold-bearing veins occur in the metamorphic rocks to the east of the Caribou townsite.

Pitchblende-bearing zones occur well beneath the water table. It has been found in ore shoots in the easterly striking Radium and Elmer veins in the Caribou Mine, 900-1140 feet below the surface. In the Radium vein, one pitchblende-bearing shoot is approximately 320 feet in height and 75 feet in diameter; another is approximately 75 feet in height and 35 feet in diameter. Along the Radium vein, pitchblende occurs in the footwall as a thin band up to 6 inches thick or as a braided network of stringers between the fault gouge of the country rock and the adjacent silver-bearing lead-zinc sulfides. The pitchblende is not intermixed with the sulfides and is considered to be a younger, lower temperature phase of mineralization. Quartz and minor pyrite, carbonate, and barite are gangue minerals. (Pitchblende may also occur in the vugs and fractures in the quartz.) Nickel and cobalt are reported to occur with the uranium in the general area (Dubyk, 1978, pers. commun.). However, the implications of this association are not clear.

The Caribou and Aquarius mines are the only producing mines in the immediate area.

Phair and Jenkins (1975) have evaluated the magmatic and economic uranium potential in the mineral districts in the northern part of the Colorado Mineral Belt. Summaries of their findings are shown on Figure 8.

Bostonite Model

The Upper Cretaceous and Tertiary igneous rocks of the Colorado Front Range comprise one of the most radioactive rock sequences in the world. Uranium values in the phaneritic

URANIUM POTENTIAL OF FRONT RANGE MINING DISTRICTS

Nature of the correlation of areal economic potential based upon number and grade of uranium deposits of Classes 1 and 2 with areal magmatic potential based upon number of CaO-poor late stage differentiates and their average uranium content.

(Reproduced from Phair and Jenkins, 1975, USGS of 75-501, Fig. 1)

nepheline-bearing Empire stock are in the range of 3.8-18.0 ppm (Phair and Jenkins, 1975, p. 6) which represent about one to five times the average uranium content for similar rocks worldwide. Of this Front Range sequence, the most radioactive rocks, by far, are the bostonites and quartz bostonites which form long, narrow dikes and small plugs in the central and northern portions of the Colorado Mineral Belt. These rocks are essentially trachytic leucocratic alkali syenites and quartz-bearing syenites believed to be late stage, CaO-poor differentiates of a monzonitic magma (Phair and Fisher, 1962) or the alkali-calcic, sodic subseries (Phair and Jenkins, 1975 pp. 6).

Phair (1952) and Phair and Jenkins (1975) discuss, in some detail, their petrology, geochemistry, and uranium potential. Some of this material has been summarized by Wells (1960) and by the writers in Chapter 7. Dubyk, formerly of Bendix Field Engineering Corporation, sampled several of the bostonite dikes in the Central City district including an altered dike on Pewabic Mountain (Sec. 25, T3S, R73W). L.M. Fukui and M. L. Dixon of the Bendix Petrology Laboratory in Grand Junction prepared the accompanying Petrographic Reports, Nos. 5 and 6 on the Pewabic Mountain dike. The accompanying photomicrographs illustrate the bostonitic texture and petrographic relationships.

BOSTONITE PORPHYRY
Pewabic Mountain, Central City

PETROGRAPHIC DESCRIPTION NO 5

PROJECT: Denver 12-77-7208

REQUEST: 101096

FIELD NO: MAL-126

AASSN: 24998

ROCK NAME: Altered Porphyry

GENERAL TEXTURE AND FEATURES: Porphyritic, with an aphanitic groundmass.

PETROLOGIST: L. M. Fukui, Bendix Field Engineering Corp.

MINERAL/COMPONENT	%	TEXTURE	CHARACTERISTICS	ALTERATION/REPLACEMENT
Phenocrysts	42			
Altered Feldspar	95	Medium- to coarse-grained, subhedral.	Relict polysynthetic twinning.	Strongly altered to argillite and replaced by calcite and iron oxides.
TOTALS 100%				
Altered Mafic	5	Medium-grained, anhedral to subhedral.		Replaced by chlorite and iron oxides.
Opaque	tr	Medium-grained, subhedral.		
Groundmass	58	Microcrystalline.		
Altered Feldspar*	85	Fine-grained laths.		Argillized.
Opakes	15	Fine-grained.		Could be a replacement product of mafics.
TOTALS 100%				

OTHER COMMENTS: * Feldspar staining may indicate predominantly K-feldspar in the groundmass.

Photomicrographs of sample 24998.

- A.) General texture of rock showing alteration of the groundmass, feldspar and mafic phenocrysts. 16x, plane polarized light.

**These photographs are found in
the back pocket of this report.**

- B.) Same, crossed polarizers.

Electron photomicrograph of sample 24542.

**This photo is found in the
back pocket of this report.**

Thorium-bearing zircon and monazite occurring
as inclusions in K-feldspar.

Z = Zircon

M = Monazite

Secondary and backscattered electron image, 2750x.

TRACHYTE BOSTONITE PORPHYRY
Central City

PETROGRAPHIC DESCRIPTION NO 6

PROJECT: Denver 12-77-7208

REQUEST: 101043

FIELD NO: MAL-105

AASSN: 24542

ROCK NAME: Altered Trachyte Porphyry

GENERAL TEXTURE AND FEATURES: Porphyritic with a trachytic/bostonitic groundmass.

PETROLOGISTS: M. L. Dixon and L. M. Fukui - Bendix Field Engineering Corp.

MINERAL/COMPONENT	%	TEXTURE	CHARACTERISTICS	ALTERATION/REPLACEMENT
Phenocrysts	5			
TOTALS 100% K-feldspar	90	Fine-to medium-grained, sub-hedral to euhedral.	"Hourglass" type of extinction.	Extensively sericitized and argillized; partial replacement by opaques (iron oxides).
Opagues	10	Fine-grained, subhedral.		Grain shapes suggest pseudomorphs after pyroxene or amphibole.
Groundmass	95	Trachytic to bostonitic.		
TOTALS 100% Feldspar/Quartz	99	Trachytic to bostonitic.	Chemical staining suggests that the feldspar is K-feldspar. Albite twins are absent but carlsbadtwins are very common.	
Opagues	tr		Mostly iron oxides.	
Zircon	tr	Subhedral to anhedral.	Thorium bearing (SEM/EDS). Associated with monazite.	
Monazite	tr	Subhedral to euhedral.	Thorium bearing (SEM/EDS).	
Rare earth-thorium mineral	tr	Subhedral to anhedral.	*	

OTHER COMMENTS: *SEM/EDS analysis revealed a cerium-lanthanum-thorium mineral occurring as "etched" or "corroded", somewhat prismatic, grains which are commonly coated by iron oxides. It is possibly an oxide mineral.

Electron photomicrograph of sample 24542.

**This photo is found in the
back pocket of this report.**

Rare earth and thorium-bearing mineral (possibly
an oxide) occurring as inclusions in albite.

R = Rare earth-thorium mineral.

A = Albite

Secondary and backscattered electron image, 700x.

The radioactivity of the bostonite dikes in the Central City district ranges from 15 to 25 times background levels. Phair and Jenkins (p. 6) have analyzed uranium concentration in these dikes in the range of 7.0-138.6 ppm. Bostonite dikes of moderate to high values of U (10 ppm) have also been reported in the Chicago Creek, Idaho Springs, Freeland-Laratine, Lawson, Alice, North Gilpin County, Gold Hill, and Jamestown districts (Phair and Jenkins, 1975, Table 26).

Phair and Jenkins have determined that the uranium content of the bostonites and quartz bostonites increases in approximate proportion to increases in zircon content. Therefore, it is believed that uranium occurs primarily as an ionic substitute in the zircon structure, but that it may also occur as a minor substitute in monazite, allanite, and apatite.

Phair and Jenkins consider the bostonites to be potential uranium targets based on their leachable content, in addition to uranium, of Th, Ce, La, Nd, Zr, and minor Pb, Zn, Cu and Ag. The most promising target in the mineral belt is a highly anomalous, oval-shaped bostonite plug located in the northwest side of Pewabic Mountain along the southern edge of the Central City district in Sec. 23, T3S, R73W. Phair and Jenkins (p. 35) estimate that quarrying and leaching the entire surface outcrop of this body (roughly

2,000 square feet) would yield 15 tons of uranium and 100 tons of thorium for each ten feet of depth mined. The long-term economic significance of such an operation, however, would lie in the extraction, through leaching, of equivalent, or greater quantities of rare earths and lesser quantities of base and precious metals.

CHAPTER L

FRONT RANGE URANIUM POTENTIAL

The discovery potential for uranium in the Front Range igneous and metamorphic terrain cannot be discounted because of a lack of outcropping ore bodies or readily apparent drilling targets. But, new discoveries of economic and paramarginal mineralization will occur, in the opinion of the writers, only after (a) a very specific analysis of the potential uranium environments, and (b) a carefully executed, phased exploration program under the guidance of individuals intimately familiar with hard-rock geology. The following is the writer's analysis of the uranium discovery potential in the Front Range:

Precambrian

Pre-metamorphism Uraniferous Conglomerates

Blind River-Whitewatersrand type uraniferous conglomerates occur in the Medicine Bow and Sierra Madre ranges of southern Wyoming in the marginal basin environment just south of the Archean craton. No conglomerates of this type have been observed in the Idaho Springs rocks of the Front Range thus far and would not be expected to occur in the shallow shelf environment proposed in Chapter B.

Uraniferous biotite gneiss containing well-rounded cobbles up to 3 inches in diameter has been reported in the northern part of the Mineral Belt; but these rocks are interpreted to have been formed in local outwash sites in an environment similar to that illustrated on Plate 8.

Also, graphite-bearing schists similar to the uraniferous chloritic schists of the Jabiluca-Alligator River region of northern Australia, and originally derived from black, carbon-rich shales, have not been found in the Idaho Springs formation. This type of sediment would not be expected in rhyo-dacitic rocks and their outwash equivalents which formed in the vicinity of volcanic centers. However, they may have been uraniferous in part, similar to Late Tertiary rocks in Nevada (see pages 26-28).

Boulder Creek Plutons

Uranium occurrences in the Boulder Creek plutons are sparse. Allanite is reported along the Boulder Creek-Silver Plume contact, but the allanite is believed to have been introduced metasomatically from an aqueous phase generated by the Silver Plume intrusive body.

Silver Plume Plutons

The hood zone of the Silver Plume Pluton, extending from the Fall River drainage, just north of Empire, to the headwaters of South Boulder Creek, south of East Portal, and westward to James Peak area along the Continental Divide, is a general

target area. Wheeler Basin, approximately 5 miles further north (described on pps. 103-107), is even more promising because of deeper erosion into the hood zone. Uraniferous migmatite, pegmatite, alaskite, shear zone and disseminated mineralization may contribute to a buildup of uranium content in specific targets. Supergene enrichment probably would not be significant because of deep glaciation in the drainages. An exception might be the high "platform" formed by a remnant of an old erosion surface located between the Fall River drainage and the South Boulder Creek drainage just east of the Continental Divide.

The crest of the Kenosha pluton described on pps. 111-113 includes migmatite-pegmatite, shear-zone, and disseminated granitic-type mineralization. It may offer large tonnage potential for the long term.

The riebeckite granite center at Georgia Pass is another possible target.

Anomalous, uranium centers in the Sherman granite may be possible targets also, which can be evaluated utilizing the multi-spectral photography, and or imagery, gamma-ray spectrometry and pathfinder-element approach. Low-lying topography would favor supergene enrichment of fractured, anomalous centers in the granite.

Pikes Peak Apophyses

The metal-rich Red Skin granite and its hood zone at Badger Flats is a promising center of anomalous uranium mineralization. Disseminated uranium in fractured centers in the granite is a possibility, particularly if enhanced by supergene enrichment. Again, the topography in the area favors a contribution by supergene enrichment. This target area is discussed on pgs. 114-116.

Because of its exotic mineralogy, the Mt. Rosa center, located between Cripple Creek and Manitou Springs, may include both selective and large-scale target potential. This center is discussed on pgs. 116-117.

Shear Zone Mineralization

The Prairie Divide shear zone is located between the Log Cabin granite on the south and the Sherman granite on the north. It may represent shearing at the time of or soon after the intrusion of the Sherman granite into the Log Cabin. If so, the aqueous phase mineralization from the Sherman may be localized along its trace. Mineralization at the Copper King mine may be an example.

Pegmatite Dikes

The ore-bearing pegmatite dikes of the Front Range are small tonnage deposit with limited potential though they may be locally high grade. As a group, however, they offer a moderate reserve in case of an emergency. In many cases the uranium present is combined with thorium in monazite and

other minerals in addition to uraninite, creating extraction difficulties.

Several pegmatite dikes were mined for their uranium content during the 1950's particularly in the Central City-Idaho Springs area. These are described briefly on pgs. 91-98. Most range up to a few feet in width and several hundred feet in length.

Uraniferous pegmatite dikes are a common occurrence within and in the hood zone of all the Silver Plume age intrusives except the Sherman granite where they are sparse. They also are found in the hood zone and flanks of the Pikes Peak batholith and its satellites.

Migmatites

Migmatites offer a similar limited potential. They are small, often high-grade bands enriched in secondary biotite which serves as host for uraninite, monazite, and xenotime. In many instances they occur as distinct bands or lenses within biotite gneiss generally parallel to the foliation. In other cases they lie adjacent to pegmatite dikes and appear to have formed from fluids generated within the pegmatite-related magmatic system. Usually, they are of insufficient tonnage to be economic, but have been mined with pegmatites and granite in sheared or contact zones. They are important in cauldron centers such as Rossing in south-west Africa.

Uraniferous migmatites occur along the contacts and in the hood zone of all the Silver Plume age intrusives, particularly in the hood zone of the Silver Plume pluton itself in the Fall River-South Boulder Creek area and across the Continental Divide in the James Peak area. Uraniferous migmatites occur in Wheeler Basin as well.

Cauldron Environment

The Cauldron Environment refers to a hood zone "trap" or apophysis in the roof of a batholith or large stock in which aqueous phase exotics, including uranium, may be concentrated. The concentrating sites may be 1) in pegmatite, alaskite, microcline-rich or other late-phase dikes within the intrusive or in the cover rocks, 2) in migmatite replacement zones or lenses in the country rocks, 3) in crestal shear zones, or 4) in centers of widespread cracking and jointing in the upper fringe of the intrusive itself. Wheeler Basin, discussed on pgs. 103-107, exhibits all of these features, but perhaps is only a para-marginal target. It is similar to Rossing in many respects.

The James Peak and other anomalous fringe areas of the Silver Plume pluton should be evaluated for their cauldron potential. The other plutons of Silver Plume age should be considered for their cauldron potential as well. The Pikes Peak satellites, particularly the Red Skin, are promising in this respect.

Unconformities

Unconformities in the Proterozoic in northern Australia have proved to be a guide to the discovery of some of the major uranium ore bodies. Syngenetic uranium has migrated from the host sediments during metamorphism to the lower pressure environment of buried unconformities and has been trapped along or near the erosion surface and its regolith cover. In other instances meteoric water has carried leached uranium downward to unconformities and uranium has deposited where a reductant such as carbon in black shales has been available.

Wahlstrom and Kim (1959), in their study of the Idaho Springs formation in Hall Valley, identified an angular unconformity of some 15 degrees between two units. It is exposed in the cirque at the head of the drainage above the New Whale mine. They also reported graphite beneath the unconformity. The writers observed radioactivity up to 600 cps in calc-silicate rocks along what may be the southerly projection of the unconformity.

Tertiary

Mineralized Shear Zones

The shear zones of the Foothills Uranium Belt offer promising discovery potential not only along the Rogers fault zone near the Schwartzwalder mine, but also along all of the other zones.

Structural fabric is one of the keys to discovery. The ores have formed largely along tensional sections of subsidiary structures of the shear zones particularly where the faults change trend. Minor, low-angle, well-mineralized faults often are associated. New discoveries may result from a detailed analysis of poorly exposed sections along these major shear zones, utilizing key exploration criteria discussed on pps.147-150. Currently there is intensive exploration in progress in the search for additional Schwartzwalder-type deposits.

The northerly-trending hood zone and boundary shear systems located on the crest and along the western side of the Silver Plume pluton should be investigated for their uranium potential. They are located along the Continental Divide in the James Peak area and in the headwaters of the South Boulder Creek and Fall River drainages to the southeast. A uranium-enriched shear zone occurs at a small prospect about two miles above Mammoth Lake in the South Boulder Creek drainage. These shear zones may have been initiated in the Precambrian and reopened in the Tertiary (Braddock, 1969, p. 3).

Uranium-bearing Veins

The uranium-bearing veins of the Idaho Springs, Central City, Caribou and Jamestown districts have not contributed an appreciable volume of uranium in the past. Pitchblende is a minor constituent in the veins, occurring as lenses, pods

and stringers usually as an early phase of the mineralization. Some production of uranium might be anticipated as a by-product of vein mining for precious and base metals as at the reopened Caribou and Aquarius mines of the Caribou district.

Bostonite Breccia Pipes and Dikes

Bostonite breccia-pipes and dikes, although well-mineralized, are not currently economic because of the grade and the cost of extracting the uranium and associated metals. However, these bodies may be an important long term uranium resource for emergency periods. The uranium-bearing bostonites occur in the Central City, Gold Hill, and Jamestown districts, and are discussed on pps. 158-161.

Porphyry Stocks

The porphyry stocks at Henderson and Jamestown are somewhat anomalous. A Radioactive mineral has been reported at Henderson; it may be contributive as a by-product from the very large, daily molybdenite production.

Cripple Creek Volcanic Center

Uranium is anomalous in both the volcanic and granitic rocks of the Cripple Creek district, but only one "ore grade" occurrence has been reported. It is located on Globe Hill about one mile east of the City and has been described by Newcomb (1955). Uranium is anomalous in some of the district's fluorite-bearing veins, and over the long term may compliment precious-metal vein and stockwork production.

Precambrian-Paleozoic Unconformity

The Precambrian-Paleozoic Unconformity should be investigated wherever the major shear zones of the Foothills Uranium Belt cross it. Hydrothermal fluids of a convection system similar to that proposed on pg. 27 may have mineralized the unconformity either at the level of erosion or down-plunge along these structures to the southeast beneath the sedimentary cover of the Denver Basin fringe.

The above occurrences are shown on Plate 22, an idealized cross section sketch.

IGNEOUS URANIUM ENVIRONMENTS

REFERENCES

- Barker, F.; Wones, D.R.; Sharp, W.N.; and Desborough, G.A., 1975, The Pikes Peak batholith, Colorado Front Range, and a model for the origin of the gabbro-anorthosite-syenite and potassic granite suite: Precambrian Research.
- Berning, J., Cooke, R., Hiemstra, S.A. and Hoffman, U., 1976, The Rossing Uranium Deposit, South West Africa, Econ. Geol. v. 71, 351-368.
- Boardman, S.J., 1976, Geology of the Precambrian metamorphic rocks of the Salida area, Chaffee County, Colorado, Mountain Geologis, v. 13, no. 3, p. 89-100.
- Bolicar, S.L., and others, 1978, Uranium Hydrogeochemical and Stream Sediments Reconnaissance of the Denver and Greeley NTMS Quadrangles, Colorado, D.O.E. open file GJBX-60 (78). 138 p.
- Braddock, W.A., 1969, Geology of the Empire Quadrangle, Grand, Gilpin, and Clear Creek Counties, Colorado: U.S. Geol. Survey Prof. Paper 616, 56 pp.
- Bryner, L., 1969, Ore Deposits of the Philippines - An Introduction to Their Geology, Econ. Geol., v. 64, pp. 644-666.
- Camfield, P.A. and Gough, D.J., 1977, A possible Proterozoic plate boundary in North America, Canadian Jour. of Earth Science, v. 14, p. 1229-1238.
- Christie, A.M., 1953, Goldfields-Martin Lake map area: Geol. Survey Canada Mem. 269, 126 pp.
- Crook, K.A.W., 1974, Lithogenesis and geotectonics, the significance of compositional variations in flysch arenites (graywackes), S.E.P.M. Spec. Pub. 19, p. 304-310.
- Dickinson, W.R., 1974, Plate Tectonics and Sedimentation, in Soc. Econ. Paleo. and Min., Spec. Pub. No. 22, pp. 1-27.
- Divis, A., 1976, Geology and Geochemistry of the Sierra Madre Range, Wyoming: Colo. Sch. Mines Quarterly, v. 71, no. 3, 127 pp.

- Downs, G.R. and Bird, A.G., 1965, The Schwartzwalder uranium mine, Jefferson County, Colorado, *The Mountain Geologist*, v. 2, no. 4, p. 183-191.
- Edwards, J., 1966, The petrology and structure of the buried Precambrian basement of Colorado, CSM Ph.D. thesis, 248 p.
- Eggler, D.H. and McCallum, M.E., 1974, Xenoliths in Diatremes of the Western United States: *Carnegie Instit. Wash. Yearbook* 73, pp. 294-300.
- Fisher, J.C., 1976, Remote sensing applied to exploration for vein-type uranium deposits, Front Range, Colorado, CSM Ph.D. thesis, 158 p.
- Gable, D.J., 1969, Geologic Map of the Nederland Quadrangle, Boulder and Gilpin Counties, Colorado: U.S. Geol. Survey Quad. Map GQ-893.
- Gableman, J.W., 1975, Discussion of Paper by H.H. Adler, Geochemical Factors Contributing to Uranium Concentration in Alkaline Igneous Rocks In Recognition and Evaluation of Uraniferous Areas, Proceedings of a Technical Committee Meeting, Vienna, 17-21 November, 1975, p. 45, International Atomic Energy Agency, Vienna, 1977.
- _____, 1977, Migration of Uranium and Thorium--Exploration Significance, A.A.P.G. studies in geology No. 3, 168 p.
- Gallagher, G.L., 1976, Uranium Favorability of Precambrian Rocks in the Badger Flats - Elkhorn Thrust Area, Park and Teller Counties, Colorado, DOE Open File, GHBX-55(76).
- Graff, P., 1978, Stratigraphy of Proterozoic Metasediments in the Sierra Madre, Wyoming and Correlation with a Similar Sequence in the Medicine Bow, Wyoming, in Occurrences of Uranium in Precambrian and Younger Rocks of Wyoming and Adjacent Areas, Lageson, D.R. and Hausel, W.D. eds., *Geol. Survey of Wyoming, Public Info., Circ. 7*, p. 9.
- Gross, E.G. and Heinrich, E.W., 1966A, Petrology and Mineralogy of the Mt. Rosa Area, El Paso and Teller Counties, Colorado: Part II - The Pegmatites *Am. Mineralogist*, v. 51, no. 2.

- Harrison, J.E. and Wells, J.D., 1959, Geology and Ore Deposits of the Chicago Creek Area, Clear Creek County, Colorado: U.S. Geol. Survey Bull. 1032-B, pp. 33-127.
- Hauseux, Marcelle A., 1977, Mode of Uranium Occurrence in a Migmatitic Granite Terrain, Baie Johan Beetz, Quebec.
- Hayashi, S., 1970, Uranium Occurrences in small sedimentary basins in Japan, Uranium exploration geology, I.A.E.A. Proceedings, p. 233-241.
- Hedge, C.E., 1969, A petrogenetic and geochronologic study of migmatites and Precambrian in the central Front Range, Colorado, Colo. Sch. Mines Doctoral thesis, (unpub.) 158 pp.
- Hedge, C.E. and others, 1978, The Precambrian of the Rocky Mountain Region, in Occurrences of Uranium in Precambrian and Younger Rocks of Wyoming and Adjacent Areas, Lageson, D.R. and Hausel, W.D., eds., Geol. Survey of Wyoming, Public Info., Circ. 7, p. 17.
- Hills, F.A. and Houston, R.S., 1978, Early Proterozoic tectonics of southern Wyoming and northern Colorado and the tectonic setting of the radioactive Precambrian conglomerates in Occurrences of uranium in Precambrian and younger rocks of Wyoming and adjacent areas, Geol. Survey of Wyoming, Public Information Circular 7, p. 19.
- Houston, R.S. and Parker, R.B., 1963, Structural Analysis of a Folded Quartzite, Medicine Bow Mountains, Wyoming: Geol. Soc. Amer. Bull., v. 74, pp. 197-202.
- Hunter, M. and Rosebush, H., 1890, Ueber Monchiquit, ein Camptonisches Ganggestein aus Gefolgschaft der Eleolite-Syenite: Tschermak's Min. n. Petrog. Mitth, v. 11, p. 495.
- Hutchinson, R.M., 1976, Precambrian geochronology of western and central Colorado and southern Wyoming, Professional contributions of the Colorado School of Mines, no. 8, p. 73-77.
- Johnson, S.M., 1977, The geology and geochemistry of uranium and thorium in late Cretaceous intrusives and the enclosing Idaho Springs Formation Black Hawk Quadrangle, Gilpin County, Colorado, CSM M.Sc. Thesis, 238 p.

- Karlstrom, K.E., 1978, Stratigraphy of the Deep Lake Group and a Review of the Tectonic History of the Medicine Bow Mountains, in Occurrences of Uranium in Precambrian and Younger Rocks of Wyoming and Adjacent Areas, Lageson, D.R. and Hausel, W.D., eds., Geol. Survey of Wyoming, Public Info., Circ. 7, p. 23.
- Kent, H.C., 1972, Review of Phanerozoic History, in Geologic Atlas of the Rocky Mountain Region, Rocky Mtn. Assoc. Geol., p. 57059.
- Kemp, J.F. and Marsters, V.F., 1893, The Trapdikes of the Lake Champlain Region: U.S.G.S. Bull. 107, pp. 18-22.
- Kober, C.L., and Proctor, Gregg, 1977, Discrimination of Uranium Alteration Zones in Selected Areas by Use of Lands at MSS Imagery, DOE Open File, GJBX-4(77).
- Lanthier, L.R., 1978, Stratigraphy and Structure of the Lower Part of the Precambrian Libby Creek Group, Central Medicine Bow Mountains, Wyoming, in Occurrences of Uranium in Precambrian and Younger Rocks of Wyoming and Adjacent Areas, Lageson, D.R. and Hausel, W.D. eds., Geol. Survey of Wyoming, Public Info., Circ. 7, p. 25.
- Lemoine, A., 1975, Contribution a l'etude du comportement de UO_2 en milieu aqueux a haute temperature et haute pression: doctoral thesis, Universite de Nancy I, France, 111 pp.
- Lipman, P.W., Prostka, H.J., and Christiansen, R.L., 1972, Cenozoic Volcanism and Plate Tectonic Evolution of the Western United States: Phil. Trans. R. Soc. Lond. A. 271, pp. 217-248.
- Lovering, T.S. and Goddard, E.N., 1938, Laramide Igneous Sequence and Differentiation in the Front Range, Colorado: Geol. Soc. America Bull., v. 49, pp. 35-68.
- _____, 1950, Geology and Ore Deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. Paper 223, 319 pp.
- Lovering, T.S., and Tweto, O., 1953, Geology and Ore Deposits of the Boulder County Tungsten District, Colorado: U.S. Geol. Survey, Prof. Paper, no. 245, 199 pp.
- Marvin, R.F. and others, 1974, Summary of Radiometric Age Determinations of Mesozoic and Cenozoic Igneous Rocks and Uranium and Base Metal Deposits in Colorado. Isocron/West, No. 11, 41 pps.

- McBirney, A.R., 1969, Compositional Variations in Cenozoic Calc-Alkaline Suites of Central America. In A.R. McBirney, ed., Proceedings of the Andesite Conference, State of Oregon, Dept. of Geology and Mineral Industries, Bull. 65, pp. 185-189.
- McKelvey, V., 1974, New Mineral Resource, Terminology adopted by U.S. Dept. of Interior, Econ. Geol., Vol. 69, No. 4, p. 599.
- Middleton, G.V., 1972, Albite of secondary origin in the Charney Sandstone, Quebec, Jour. of Sed. Pet., v. 42, no. 2, p. 341-349.
- Moench, R.M. and Drake, A.A., Jr., 1966, Economic Geology of the Idaho Springs District with a Description of Mines and Prospects: U.S. Geol. Survey, Open File Report No. 835.
- Moench, R.H. and others, 1962, Precambrian folding in the Idaho Springs, Central City area, Front Range, Colorado, G.S.A. Bull. v. 73, p. 35-58.
- Moore, F.B., Cavender, W.S. and Kaiser, E.P., 1957, Geology and Ore Deposits of the Caribou Area, Boulder County, Colorado: U.S. Geol. Survey Bull. 1030-N.
- Morton, R.D., 1977, The western and northern Australian uranium deposits--exploration guides or exploration deterrents for Saskatchewan in Uranium in Saskatchewan, Saskatchewan Geol. Soc. Spec. Pub. No. 3, p. 211-254.
- Newcomb, E.L., 1955, Geologic Evaluation of Lady Stith Claim on Stratton Cripple Creek Mining and Development Company Property, Cripple Creek District, Teller County, Colorado (DEB-d-TM-9).
- Peacock, M.A., 1931, Classification of Igneous Rock Series, Journ. Geol., v. 38, pp. 54-67.
- Peterman, Z.E. and others, 1968, Age of Precambrian events in the northeaster Front Range, Colorado, Jour. of Geophys. Research, v. 73, p. 227-2297.
- Phair, G. and Fisher, F.G., 1962, Laramide Comagmatic Series in the Colorado Front Range: The Feldspars. In Engel, James, Leonard, eds. Petrologic Studies: A volume in honor of A.F. Buddington: Geol. Soc. America, pp. 479-522.

- Phair, George, and Gottfried, David, 1964, The Colorado Front Range, Colorado, USA, as a uranium and thorium province: In The Natural Radiation Environment, Chicago, Ill., Univ. Chicago Press (for William Marsh Rice Univ.), pp. 7-38.
- Phair, G. and Jenkins, L.G., 1975, Tabulation of Uranium and Thorium Data on the Mesozoic-Cenozoic Intrusive Rocks of Known Chemical Composition in Colorado: U.S. Geol. Survey, Open File Report 75-501.
- Philippine Bureau of Mines, 1962, Geologic Map Series covering the Philippine Islands.
- Rich, R.A., Holland, H.D., Petersen, Ulrich, 1975, Vein-Type Uranium Deposits: U.S. Energy Research and Development Administration, GHO-1640.
- Robinson, S.C., 1955, Mineralogy of Uranium Deposits, Gold-fields, Saskatchewan: Geol. Survey Canada Bull. 31, 128 pp.
- Sheridan, D.M., Maxwell, C.H., and Albee, A.L., 1967, Geology and uranium deposits of the Ralston Buttes District, Jefferson County- Colorado, USGS Prof. Paper 520, 121 p.
- Sims, P.K., 1963, Geology of Uranium and Associated Ore Deposits of the Central Part of the Front Range Mineral Belt, Colorado: U.S. Geol. Survey Prof. Paper 371, 119 p.
- Sims, P.K., Drake, A.A., Jr., and Tooker, E.W., 1963, Economic Geology of the Central City District, Gilpin County, Colorado: U.S. Geol. Survey Prof. Paper 359.
- Sims, P.K. and Gable, D.J., 1964, Geology of the Precambrian Rocks, Central City District, Colorado: U.S. Geol. Survey Prof. Paper 474-C, pp. C1-C52.
- Sims, P.K. and Gable D.J., 1967, Petrology and Structure of Precambrian Rocks, Central City Quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 554-E.
- Sims, P.K., and others, 1963, Economic Geology of the Central City District, Gilpin County, Colorado, USGS Prof. Paper 359, 231 p.

- Sims, P.K., and Sheridan, D.M., 1963, Geology of Uranium and Associated Ore Deposits of the Central Part of the Front Range Mineral Belt, Colorado, USGS Prof. Paper 371, 119 p.
- _____, 1964, Geology of Uranium Deposits of the Front Range, Colorado, USGS Bull. 1159, 116 p.
- Simmons, E.C. and Hedge, C.E., 1978, Minor Element Geochemistry and Sr-isotopes of Tertiary Stocks, Colorado Mineral Belt: Contributions to Mineralogy and Petrology (accepted for publication).
- Smith, E.E.H., 1974, Review of Current Concepts Regarding Vein Deposits in Uranium, Proc. of IAEA, Symp., Athens, IAEA-SM-183/45, p. 515.
- Spirakis, C.S., and others, 1977, Thermoluminescence of Sand Grains around a South Texas Roll-type Deposit, USGS Open File Report 77-640.
- Spurr, J.E., Garrey, G.H., and Ball, S.H., 1908, Economic geology of the Georgetown Quadrangle (together with the Empire district), Colorado: USGS, Prof. Paper no. 631, 422 pp.
- Steven, T.A., 1975, Middle Tertiary Volcanic Field in the Southern Rocky Mountains: Geol. Soc. Amer. Mem. 144, pp. 75-94.
- Taylor, R.B., 1975, Geology of the Black Hawk Quadrangle, Gilpin, Jefferson and Clear Creek Counties, Colorado, U.S. Geol. Survey, Geol. Quad. Map GQ-1248.
- _____, 1978, U.S. Geol. Survey Pueblo 2° Quadrangle map.
- Theobald, P.K., Jr., and Guilinger, R.R., 1955, A radioactive copper-bearing shear zone in the vicinity of the F.M.D. mine, Jefferson Co., Colorado: U.S. Geol. Survey, Trace Elem. Invest. Rep., No. TEI-590, pp. 202-212.
- Tuttle, O.F. and Bowen, N.K., 1958, Origin of granite in light of experimental studies in the system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-SiO}_2\text{-H}_2\text{O}$, Mem. Geol. Soc. Amer., No. 74. ³

- Tweto, O., 1975, Laramide (Late Cretaceous-Early Tertiary) Orogeny in the Southern Rocky Mountains: Geol. Soc. America Mem. 144, pp. 1-44.
- Tweto, O. and Sims, P.K., 1963, Precambrian ancestry of the Colorado mineral belt, G.S.A. Bull. v. 74, p. 991-1014.
- Wahlstrom, E.E. and Kim, O.J., 1959, Precambrian rocks of the Hall Valley area, Front Range, Colorado, G.S.A. Bull. vol. 70, p. 1217-1244.
- Wallace, S.R.T., Blair, R.G. and Muncaster, N.K., 1978, Geology of the Urad and Henderson Molybdenite Deposits, Clear Creek County, Colorado. Econ. Geol. v. 73, no. 3 p. 325-368.
- Warner, L.A., 1978, The Colorado Lineament: A Middle Precambrian Wrench Fault System: Geol. Soc. Amer. Bull., v. 89, pp. 161-171.
- Wells, J.D., 1960, Petrography of Radioactive Tertiary Igneous Rocks, Front Range Mineral Belt, Colorado: U.S. Geol. Survey Bull. 1032-E, pp. 233-272.
- Wright, H.D., 1954, Mineralogy of a Uraninite Deposit at Caribou, Colorado, Econ. Geol. v. 49, no. 2, p. 129-174.
- Young, E.J., and Sims, P.K., 1961, Petrography and Origin of Xenotime and Monazite Concentrations, Central City District, Colorado: U.S. Geol. Survey Bull. 1032-F.
- Young E.J., and Hauff, P.L., 1975, An Occurrence of Disseminated Uraninite in Wheeler Basin, Grand County, Colorado, Jour. Research U.S. Geol. Survey, vol. 3, no. 3, May-June 1975, pp. 305-311.
- Young, E.J., 1977, Radiometric and Mineralization Maps and Underground Workings of the Schwartzwalder Uranium Mine Area, Jefferson County, Colorado. USGS Open File Report No. 77-725-1977.
- Young, E.J., 1978, Genesis of the Schwartzwalder Uranium Deposit, Jefferson County, Colorado. Uranium II in Contributions to Geology, University of Wyoming - Wyoming Geological Survey.

APPENDIX A

A Summary of Pertinent Features of Selected Mines
in the Central Front Range not discussed in the text.

(see Plate 23)

**LOCATION OF MINES IN THE CENTRAL FRONT RANGE
THAT ARE DISCUSSED IN THE APPENDIX**

1. Sisk	10. Ascension
2. Fair Day	11. Almaden
3. Blue Jay	12. Golconda
4. Black Cloud	13. Mary
5. Caribou	14. Gold Anchor
6. Shirley	15. North Star
7. Wood	16. Union Pacific Prospect
8. Jo Reynolds	17. Grapevine
9. Black Knight and
Billikin Lodes.	18. Buckman

(modified after Sims & Sheridan, 1964)

APPENDIX ABoulder County

A. Black Cloud Mine* (#4 on Plate 23)

1. Country rock:
 - a. Boulder Creek Granite
 - b. Pegmatites are locally present.
2. Structure:
 - a. Principal vein strikes NE, dips steeply northwest.
 - b. Minor veins strike northerly.
 - c. Average width of vein is 2-3 feet.
 - d. The Gold Hill District contains a strong north-westward trending breccia-reef fault system.
3. Mineralogy:
 - a. Veins are composed of fine-grained gray quartz in brecciated and iron-stained rock.
 - b. Disseminated pyrite is in this quartz.
 - c. Galena and sphalerite are locally present in the veins.
 - d. Gold and silver are also present.
 - e. Uranium content ranges from .001% to 0.81%.

B. Blue Jay Mine* (#3, Plate 23)

1. Country rock:
 - a. Altered granodiorite.
 - b. The Eastern area is in Silver Plume granite and pegmatites.
2. Structure:
 - a. The vein strikes N70°W
 - b. The width is from 6"-7'.
3. Mineralogy:
 - a. Radioactive fluorite is present.
 - b. The brecciated coarsely crystalline deep-purple fluorite is cemented by:
 - fluorite
 - quartz
 - ankerite
 - clay minerals
 - pyrite
 - galena
 - uraninite (sparse)
 - uranothorite (sparse)
 - coffinite (sparse)
 - c. Uranium grade: .018%-.084%

* Sims and Sheridan, 1964.

- a. Alteration zone is from 3'-5' thick.
- b. Zone 4 includes:
 - host rock with minor alteration
 - orthoclase
 - andesine
 - augite
 - hornblende (rare)
 - biotite
 - sphene
 - apatite
 - pyrite
 - chlorite
- c. Zone 3 includes:
 - pyroxene-to-calcite
 - little epidote
 - biotite-to-muscovite and calcite
 - sericite
 - montmorillorite
 - koalinite
 - calcite veinlets

- d. Zone 2 includes:
 - montmorillonite
 - abundant biotite
 - calcite and quartz veinlets
- e. Zone 1 includes:
 - biotite
 - orthoclase
 - muscovite

5. General stages of mineralization

- a. Stage A includes:
 - quartz
 - calcite
 - siderite
 - pyrite
 - chalcopryrite
 - sphalerite
 - galena
- b. Stage B includes:
 - uraninite
 - sphalerite
 - pyrite
 - argentite
 - proustite
 - native silver

D. Fair Day Mine* (#2, Plate 23)

1. Country rock

- a. Main rock in the area is the Silver Plume granite
- b. However, a biotite gneiss containing the following is also present:
 - garnet-bearing gneiss
 - sillimanite-bearing gneiss
 - pyrite-bearing gneiss
- c. Most of the ore is in the biotite gneiss.

2. Structure:

- a. Two faults which are present include:
 - A northward fault.
 - A northeastward fault.
- b. Ore bodies are localized where the north-eastward trending vein intersects the northward trending faults.
- c. A breccia-reef fault system is located about 3,000 feet to the east of the mine.

* Sims and Sheridan, 1964.

3. Mineralogy:

- a. Pitchblende, coffinite.
- b. The quartz gangue contains:
 - pyrite
 - sphalerite
 - chalcopryrite
 - galena
 - marcasite
 - molybdenum

4. Paragenesis:

- a. First -
 - quartz
- b. Second -
 - pitchblende
 - coffinite
 - sphalerite
 - chalcopryrite
 - quartz
 - minor pyrite
- c. Locally third:
 - pyrite
 - sphalerite

5. Trace elements:

Semiquantitative (%)

U	Not tested
Ti	.07
CR	0
CO	.07
Mo	.15
Ni	.15
V	.007
Zr	3.0
Y	.03

E. Shirley Mine* (#6, Plate 23)

1. Country rock:

- a. This area contains a Tertiary monzonite stock that intrudes a biotite gneiss.
- b. Altered monzonite borders the bein.

2. Structure:

- a. The vein has strike of N30°E, dip of 50°SE.
- b. The vein is 6" to 3' wide.

3. Mineralogy:

- a. Uranium: .001%-.034%
- b. Thin veinlets of pyrite are present.
- c. Radioactive material coats quartz vugs.
- d. Quartz is gray or black in color

F. Sisk Mine (#1, Plate 22)

1. Country rock.

- a. Biotite gneiss and schists.
- b. Pink Silver Plume Granite may be present.
- c. The granite is pegmatitic.

2. Structure:

- a. Mine workings are in two fracture zones parallel to the foliation. They are about 10 feet apart.
- b. Foliation strikes northwest and dips 50° to 60° southwest.

3. Mineralogy:

- a. Pitchblende forms thin colloform coatings.

Clear Creek Country

A. Almaden Mine (#11, Plate 23)

1. Country rock:

- a. Folded biotite gneiss that contains:
thin layers of granite gneiss
pegmatite
amphibolite
garnetiferous calc-silicate gneiss
- b. Uranium is found between walls of
barnetiferous calc-silicate gneiss.

2. Structure:

- a. The vein strikes N80°W, dips 60°NE
- b. Width of vein is from 2" to 2'.

3. Mineralogy:

- a. Ore minerals include:
galena
sphalerite
chalcopyrite
tennantite
ruby silver
pitchblende
niccolite
pyrite

- b. Gangue includes:
 - quartz
 - carbonate
 - barite
- c. Pitchblende stringers are separated from the main sulfide ores by a small streak of gangue.
- d. Trace elements

Semiquantitative (%)

U	Not tested
Ti	0
CR	0
Co	.15
Mo	.07
Ni	.7
V	0
Zr	0
Y	.03

B. Golconda Mine* (#12, Plate 23)

1. Country rock

- a. Interlayered biotite gneisses which are locally migmatitic.
- b. Lesser amounts of pegmatite, biotite-muscovite granite, amphibolitic and garnetiferous lime-silicate gneisses are present.

2. Structure:

- a. Possible major east-northeast trending syncline crosses the mine tunnel.
- b. The Virginia vein strikes N42° to 52°W and dips 70° to 75° northeast.
- c. Vein #4 strikes N57°W, dip 50° to 77° northeast. This is the most important vein containing uranium mineralization.

3. Mineralogy of vein #4:

- a. Minerals in increasing order of abundance are:
 - pyrite
 - chalcopryrite
 - tennantite
 - galena
 - sphalerite

- b. Sooty pitchblende is found over a length of 200 feet along the strike of the vein.
- c. Late stage carbonate veins fill fractures.
- d. Paragenesis:
 - pyrite and quartz
 - sphalerite
 - chalcopryrite
 - tennantite
 - galena
 - sphalerite
 - carbonate
- e. Pitchblende is late in the above sequence.
- f. All pitchblende is in lime-silicate gneiss.
- g. Some places sooty pitchblende is up to 1' thick.

* Sims and Sheridan, 1963.

C. Gold Anchor Mine* (#14, Plate 23)

1. Country rock:

- a. Granodiorite.
- b. Biotite gneiss.
- c. Pegmatitic rocks are locally present.

2. Structure:

- a. Two veins present are:
 - The North vein which has a northeasterly strike.
 - The South vein which has a northeasterly strike.
- b. Both veins intersect 43' below the surface.

3. Minerals include:

quartz
pyrite
tennantite
chalcopryrite
pitchblende: .002%-.01%
gold

* Sims and Sheridan, 1964.

D. Jo Reynolds Mine* (#8, Plate 23)

1. Country rock:

- Biotite gneiss.
- b. Granite gneiss.
- c. Pegmatites.
- d. Quartz diorite.
- e. Biotite muscovite granite.
- f. Quartz bostonites cut the above rocks.

2. Structure:
 - a. Large, broad folds plunge northeast.
 - b. The Jo Reynolds #2 vein strikes N65°E and dips 60°-85° northwest.
 - c. Other veins are parallel.
3. Mineralogy:
 - a. Minerals include:
 - galena
 - sphalerite
 - chalcopryrite
 - tetrahedrite - tennantite
 - pyrite
 - polybasite
 - pearceite
 - proustite
 - argentite
 - native silver
 - pitchblende
 - b. Gangue includes:
 - quartz
 - carbonates (siderite)

* Sims and Sheridan, 1963.

E. Mary Mine* (#13, Plate 23)

1. Country rock:
 - a. Hornblende granodiorite porphyry.
 - b. Biotite gneiss.
 - c. Garnetiferous lime-silicate.
2. Structure:
 - a. Vein #1, strike N77°W, dip 65°NE.
 - b. Vein #2, strike N65°W, dip 80° - 90°NE.
 - c. Vein #3, strike N62°E, dip 65°NW.
3. Mineralization:
 - a. Vein #3 is locally mineralized with uranium.
 - b. Vein #3 contains:
 - pyrite
 - quartz
 - pitchblende
 - c. Uranium is late paragenetically.
 - d. Uranium mineralization is in the garnetiferous lime-silicate.

* Sims and Sheridan, 1963.

Gilpin Country

A. Wood Mine* (#7, Plate 23)

1. Country rock:

- a. Principally a microcline-bearing gneiss.

2. Structure:

- a. The Wood vein strikes east-west and steeply dips north or south.
- b. Most uranium occurs within a tapering westward plunging zone of ore-shoots.

3. Mineralogy:

- a. Ore includes:
 - pyrite
 - chalcopryrite
 - tennantite
 - sphalerite
 - sparse galena
 - pitchblende
- b. Gangue is composed of quartz.
- c. Pitchblende is in small, massive, high-grade "pods" and lenses.
- d. Pitchblende ore shoots extend from near surface to level 583.
- e. One lense measured 8'x8'x1" to 8".
- f. Most pyrite cuts the pitchblende.

4. Trace elements:

Semiquantitative (%)

U	13.0 (eU)
Ti	.7
Cr	.0015
Co	0
Mo	0
Ni	0
V	0
Zr	1.5
Y	.15

* Sims and Sheridan, 1963 and 1964.
Sims and others, 1963.

Jefferson County

A. Ascension Mine* (#10, Plate 23)

1. Country rock:
 - a. Located within a belt of layered calc-silicates.
 - b. Units include:
 - amphibolite
 - hornblende gneiss
 - biotite gneiss
 - c. To the north, a mica schist is present.
 - d. To the south, an interlayered hornblende gneiss is present.
 - e. A pegmatite is in the area.
2. Structure:
 - a. Mine is on part of the Hurricane fault system.
 - b. The associated fault breccia is up to 400 feet wide.
 - c. The ascension fault trends N62°W and dips 66°-85° NE.
3. Mineralogy:
 - a. Pitchblende occurs as thin stringers.
 - b. The breccia is cemented by quartz and calcite.
 - c. Base-metal sulfides and sulfosalts are very sparse.
 - d. Chalcopyrite, galena, and pyrite are present in minor amounts.
 - e. Fluorite is present in trace amounts.
4. Trace elements

	Semiquantitative(%)
U	29% (eU)
Ti	1.5
Cr	.01
Co	0
Mo	0
Ni	0
V	0
Zr	1.5
Y	.15

*Sheridan and others, 1967.
Sims and Sheridan, 1964.

B. Black Knight and Billikin Lodes* (#9, Plate 23)

1. Country rock:
 - a. Biolite gneiss
 - b. Amphibolite
 - c. Granite gneiss
 - d. Pegmatite

2. Structure:

- a. The Black Knight fault is related to a breccia-reef fault.
- b. Strike of this fault is N70°W and dips 50°-60°NE.
- c. Billikin fault strikes north-northeastward and dips 50°-70°E.
- d. The two faults are thought to intersect in the mine area.

3. Mineralogy and paragenesis:

- a. First, fracturing.
- b. Second, deposition of pitchblende.
- c. Third, deposition of chalcopyrite and bornite.
- d. The lode was also prospected for copper, gold, and silver.

4. Trace elements for Billikin Lode:

Semiquantitative (%)

U	(high grade)
Ti	.07
Cr	0
Co	.05
Mo	.015
Ni	0
V	0
Zr	1.5
Y	.07

* Sims and Sheridan, 1964.

C. Buckman Mine* (#18, Plate 23)

1. Country rock:

- a. Biotite gneiss
- b. Pegmatite

2. Structure:

- a. Foliation strikes N70°E and dips steeply NW.
- b. The mine structure may be related to Hurricane fault system.

3. Minerals:

- a. Quartz veins contains:
 - quartz
 - pyrite
 - chalcopyrite
 - molybdenite
- b. Pitchblende is in two NE trending shears that cut the quartz vein and dip to SE.
- c. Pitchblende is most abundant where it cuts the quartz vein.

- d. Hematite is abundant in pitchblende-bearing material.
- e. Small amounts of chalcopyrite, pyrite, and covellite may be relics of a Precambrian vein.

4. Trace elements:

Semiquantitative (%)

U	31.0 (eU)
Ti	0.7
Cr	.01
Co	0
Mo	0
Ni	0
V	.07
Zr	.7
Y	.7

- * Sims and Sheridan, 1964.
- Sheridan and others, 1967.

D. Grapevine Mine* (#17, Plate 23)

1. Country rock:
 - a. Mainly mixed gneisses are found in this area.
 - b. However, a biotite-quartz gneiss predominates at the mine locality.
2. Structure:
 - a. The veins strike northwest and dip 20°-60°NE
 - b. Veins are 1-2 feet thick.
 - c. Mine is adjacent to the Sawmill Gulch shear zone.
3. Mineralogy:
 - a. Vein includes:
 - pitchblende
 - pyrite
 - quartz
 - feldspars
 - clay minerals
4. Trace elements:

Semiquantitative (%)

U	-
Ti	.7
Cr	0
Co	.05
Mo	.03
Ni	0
V	0
Zr	.3
Y	.015

- * Sims and Sheridan, 1964.

E. North Star Mine* (#15, Plate 23)

1. Country rock:
 - a. Mine is located in a microcline gneiss.
 - b. Rocks in immediate vicinity are:
 - amphibolite
 - hornblende gneiss
 - biotite gneiss
 - pegmatite
2. Structure:
 - a. Mine is located on a northwest trending breccia-reef fault system.
 - b. The vein at the mine dips 25° - 45° NE.
 - c. Foliation strikes NE and dips 75° - 85° SE.
3. Mineralogy:
 - a. Altered breccia fragments are cemented by:
 1. copper
 2. uranium
 - b. Breccia is not uniformly filled with vein material.
 - c. Ore consists of:
 - bornite
 - chalcocite
 - covellite
 - malachite
 - azurite
 - pitchblende
 - uranophane
 - silver

* Sheridan and others, 1967.

F. Union Pacific Prospect* (#16, Plate 23)

1. Country rock:
 - a. The area contains a northeast trending layer of hornblende gneiss.
 - b. A quartz-biotite gneiss borders on the north and south.
2. Structure:
 - a. The prospect is on a fault zone which strikes $N15^{\circ}$ to 20° W and dips 35° NE.
 - b. Fault zone is 10'-15' wide.
 - c. The prospect is on part of the Hurricane Hill breccia-reef system.
3. Mineralogy:
 - a. Breccia zone is cemented by ankerite and K-feldspar.

- b. The pitchblende, base-metal sulfides and gangue are in a zone which is less than 1/2 foot thick.
- c. Minerals include:
 - pitchblende
 - tennantite
 - hematite
 - chalcopyrite
 - bornite
 - chalcocite
 - covellite
 - sphalerite
 - galena
 - emplectite (?)
 - pyrite
 - ankerite
 - K-feldspar
 - chlorite

* Sheridan and others, 1967.

APPENDIX B

Bibliography of Radioactive Mineral
Occurrences of the Front Range, Colorado

APPENDIX B

BIBLIOGRAPHY OF RADIOACTIVE MINERAL OCCURRENCES OF THE FRONT RANGE, COLORADO*

Adams, J.W., 1953, Uranium in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colorado: Geol. Soc. America Bull., v. 64, p. 1539.

Jefferson County/ ore deposits/ distribution/ gneiss/ relation/ genesis/ wallrock alteration/ Golden Gate Canyon/ Ralston Creek/ igneous-metamorphic/ Colorado/

_____, 1953, Frequency distribution of uranium with relation to enclosing wall rocks (Colorado), in Search for and geology of radioactive deposits, semiannual progress report, December 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 92-93.

Jefferson County/ ore deposits/ occurrence/ distribution/ uranium/ relation/ genesis/ wall rocks/ Golden Gate Canyon/ Ralston Buttes/ Schwartz mine (Schwartzwalder mine)/ igneous-metamorphic/

_____, 1954, Frequency distribution of uranium with relation to enclosing rock type (Colorado), in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1953 to May 31, 1954; U.S. Geol. Survey TEI-440, p. 96-98.

Jefferson County/ ore deposits/ distribution/ relation/ genesis/ wallrock alteration/ uranium/ paragenesis/ Golden Gate Canyon/ Ralston Creek area/ hornblende gneiss/ igneous-metamorphic/ Idaho Springs Formation/ copper/ Union Pacific prospect/ pitchblende/ Schwartzwalder mine/ Nigger Shaft/ North Star property/

Adams, J.W., and Sharp, W.N., 1970, Thalenite in the White Cloud pegmatite, South Platte district, Jefferson County, Colorado, in Geological Association of Canada - Mineralogical Association of Canada, Joint Annual Meetings, Abstracts of Papers (abs.): Winnipeg, Manitoba, Canada, Univ. Manitoba, p. 1.

thalenite/ White Cloud pegmatite/ South Platte district/ Jefferson County/ igneous-metamorphic/ Colorado/ rare earths/ thorium/

*From: Colorado Geological Survey Bull. 40, entitled "Radioactive Mineral Occurrences of Colorado, and Bibliography" J.L. Nelson-Moore, D.B. Collins, and A.L. Hornbaker, 1978.

- Adams, J.W., and Sharp, W.N., 1972, Thalenite and allanite derived from yttrifluorite in the White Cloud pegmatite, South Platte area, Colorado, in Geological Survey Research 1972: U.S. Geol. Survey Prof. Paper 800-C, p. C63.
thalenite/ allanite/ yttrium/ Jefferson County/ Colorado/ rare earths/ thorium/ pegmatite/ White Cloud/ igneous-metamorphic/
- Adams, J.W., and Staats, M.H., 1973, Rare-earth elements, in Brobst, D.A., and Pratt, W.P., United States Mineral Resources: U.S. Geol. Survey Prof. Paper 820, p. 547-556.
rare earths/ thorium/ minerals/ resources/ Colorado/
- Adams, J.W., and Stugard, Frederick, Jr., 1953, Frequency distribution of uranium with relation to enclosing rock type (Colorado), in Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1953: U.S. Geol. Survey TEI-390, p. 96-97, geol. sketch map.
Jefferson County/ ore deposits/ occurrence/ evaluation/ uranium/ igneous-metamorphic/ Golden Gate Canyon/ hornblende gneiss/ paragenesis/
- _____, 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.
wall rock control/ pitchblende/ ore deposits/ Golden Gate Canyon/ Jefferson County/ igneous-metamorphic/
- _____, 1956, Summary of wall-rock control of certain pitchblende deposits in Golden Gate Canyon, Jefferson County, Colorado, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 279-282.
veins/ Jefferson County/ wallrock control/ pitchblende/ uranium/ Colorado/ Golden Gate Canyon/ Union Pacific prospect/ metamorphic/ igneous-metamorphic/
- _____, 1956, Summary of wall-rock control of certain pitchblende deposits in Golden Gate Canyon, Jefferson County, Colorado, in Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955: U.S. Geol. Survey Prof. Paper 300, p. 113-116.
Jefferson County/ wallrock control/ pitchblende/ uranium/ Colorado/ Golden Gate Canyon/ veins/ Union Pacific prospect/ metamorphic/ igneous-metamorphic/

- Adams, J.W., Gude, A.J. 3d, and Beroni, E.P., 1953, Uranium occurrences in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colorado: U.S. Geol. Survey TEM-154, 45 p., maps.
Jefferson County/ Golden Gate Canyon/ Ralston Creek/ pitchblende/ torbernite/ Buckman property/ Hoffmeister prospect/ North Star mine/ Schwartz mine/ Union Pacific prospect/ Ladwig properties/ shear zone/ geology/ ore deposits/ Front Range/ Schwartzwalder mine/ igneous-metamorphic/
- Adams, J.W., Gude, A.J., 3d, and Beroni, E.P., 1953, Uranium occurrences in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colorado: U.S. Geol. Survey Circ. 320, 16 p., 1954.
ore deposits/ Golden Gate Canyon area/ Ralston Creek area/ Jefferson County/ igneous-metamorphic/ uranium/ occurrence/ Front Range/
- Adams, J.W., Hildebrand, F.A., and Havens, R.G., 1962, Thalenite from Teller County, Colorado, in Geological Survey Research 1962: U.S. Geol. Survey Prof. Paper 450-D, p. D6-D8, illus., tables.
thalenite/ thorium/ rare earths/ Teller County/ Colorado/ pegmatite/ igneous-metamorphic/
- Adler, H.H., 1963, Concepts of genesis of sandstone-type uranium ore deposits: Econ. Geology, v. 58, no. 6, p. 839-852.
genesis/ sandstone/ ore deposits/ Jefferson County/ Pueblo County/ Gunnison County/ Moffat County/ Rio Blanco County/ Garfield County/ Mesa County/ Delta County/ Montrose County/ San Miguel County/ Dolores County/ Montezuma County/ La Plata County/ Archuleta County/ Colorado Plateau/ Front Range/
- _____, 1964, The conceptual uranium ore roll and its significance in uranium exploration: Econ. Geology, v. 59, p. 46-53.
uranium/ roll ore/ exploration/ sandstone/ ore deposits/ Jefferson County/ Pueblo County/ Gunnison County/ Moffat County/ Rio Blanco County/ Garfield County/ Mesa County/ Delta County/ Montrose County/ San Miguel County/ Dolores County/ Montezuma County/ La Plata County/ Archuleta County/ Colorado Plateau/

Alsdorf, P.R., 1916, Occurrence, geology and economic value of pitchblende deposits of Gilpin County, Colorado: Econ. Geology, v. 11, p. 266-275.
 Gilpin County/ ore deposits/ pitchblende/ occurrence/ properties/ areal geology/ economics/ veins/ uranium/ igneous-metamorphic/ Colorado/ Clear Creek County/ gneiss/ schist/ pegmatite/

Anonymous, 1973, Occurrence of pitchblende in Gilpin County: Mining Rev., v. 1, no. 6, p. 2.
 Gilpin County/ ore deposits/ occurrence/ pitchblende/ evaluation/ igneous-metamorphic/

_____, 1913, The uranium and radium situation: Eng. and Mining Jour., v. 95, no. 22, 23, p. 1106, 1160.
 carnotite/ pitchblende/ radium/ Gilpin County/ Quartz Hill/ Meeker/ Skull Creek/ Utah/ Colorado/ Moffat County/ Paradox Valley/ Colorado Plateau/ San Miguel County/ sandstone/ igneous-metamorphic/

_____, 1914, Molybdenum, tungsten and uranium ores: Eng. and Mining Jour., v. 97, no. 2, p. 114.
 pitchblende/ Kirk mine/ Gilpin County/ carnotite/ igneous-metamorphic/ Chihuahua/ Mexico/ molybdenum/ tungsten/

_____, 1920, Colorado; Colorado Pitchblende Company: Eng. and Mining Jour., v. 109, no. 12, p. 151.
 regional/ ore deposits/ resources/ pitchblende/ Boulder County/ igneous-metamorphic/

_____, 1950, Colorado. A new discovery of uranium: Eng. and Mining Jour., v. 151, no. 12, p. 132.
 South Park/ Park County/ sandstone/

_____, 1950, Colorado. Consolidated Caribou Silver Mines, Inc.: Eng. and Mining Jour., v. 151, no. 3, p. 115.
 development/ Boulder County/ igneous-metamorphic/ Caribou mine/

_____, 1950, Colorado. Consolidated Caribou Silver Mines, Inc.: Eng. and Mining Jour., v. 151, no. 5, p. 112, 114.
 Boulder County/ igneous-metamorphic/ Caribou mine/ development/

_____, 1950, Colorado. Pitchblende has been rediscovered: Eng. and Mining Jour., v. 151, no. 9, p. 114.
 Clear Creek County/ pitchblende/ igneous-metamorphic/

-
- 1951, Samples of ore taken from the Copper King Mine: Eng. and Mining Jour., v. 152, no. 11, p. 132.
Larimer County/ Copper King mine/ pitchblende/ igneous-metamorphic/
- Antony, J., 1967, Tucker Gulch Area, Jefferson County, Colorado (Geologic map) (Senior Thesis): Colorado School Mines, (Unpubl).
- Armstrong, F.C., 1952, Pitchblende deposits on Quartz Hill, Central City district, Gilpin County, Colorado (abs.): Geol. Soc. Am. Bull., v. 63, no. 12, pt. 2, p. 1232.
pitchblende/ ore deposits/ Quartz Hill/ Central City/ Gilpin County/ Clear Creek County/ Colorado/ igneous-metamorphic/ uranium/ grade/ veins/
-
- 1952, Pitchblende deposits on Quartz Hill, Central City district, Gilpin County, Colorado: Econ. Geology, v. 47, no. 7, p. 767-768, (see also Geol. Soc. America Bull. v. 63, 1952, p. 1232).
pitchblende/ ore deposits/ Quartz Hill/ Central City/ Gilpin County/ Colorado/ Clear Creek County/ igneous-metamorphic/ gneiss/ schist/ pegmatite/
-
- 1953, Pitchblende deposits on Quartz Hill, Central City district, Gilpin County, Colorado (abs.): Am. Mineralogist, v. 38, nos. 3-4, p. 329.
pitchblende/ Quartz Hill/ Central City/ Gilpin County/ igneous-metamorphic/ Colorado/ uranium/ Front Range/ production/ geology/ ore deposits/ gneiss/ schist/ pegmatite/ veins/
- Baillie, W.N., 1962, Feldspar occurrences in Colorado: Colorado School Mines Mineral Industries Bull., v. 5, no. 4, p. 4.
pegmatites/ feldspar/ rare earths/ Boulder County/ Chaffee County/ Clear Creek County/ Douglas County/ El Paso County/ Fremont County/ Gunnison County/ Jefferson County/ Larimer County/ Park County/ igneous-metamorphic/
- Bain, H.F., 1914, Idaho Springs; radium discovery: Mining Sci. Press, v. 108, p. 165.
Idaho Springs, Clear Creek County/ springs/ radium/
- Baker, K.E., 1953, Preliminary report on uranium at the Ralston Creek mine, Jefferson County, Colorado: U.S. Atomic Energy Comm. report, (Unpubl).
uranium/ Ralston Creek mine/ Schwartzwalder mine/ Jefferson County/ igneous-metamorphic/ Front Range/

- Banks, P.O., and Silver, L.T., 1964, Re-examination of isotopic relationships in Colorado Front Range uranium ores: Geol. Soc. America Bull., v. 75, no. 5, p. 469-476, illus., tables.
Front Range/ ore deposits/ isotopes/ age determination/
Colorado/ uranium/ igneous-metamorphic/ Gilpin County/
Larimer County/ pitchblende/ bostonite/ Central City/
- Bastin, E.S., 1915, Geology of the pitchblende ores of Colorado: U.S. Geol. Survey Prof. Paper 90-A, 5 p., illus.
regional/ ore deposits/ pitchblende/ veins/ Colorado/
geology/ uranium/ Gilpin County/ Quartz Hill/ Wood mine/
igneous-metamorphic/
- _____, 1916, Occurrence, geology, and economic value of the pitchblende deposits of Gilpin County, Colorado (Discussion): Econ. Geology, v. 11, p. 681-685.
Gilpin County/ ore deposits/ pitchblende/ uraninite/
resources/ possibilities/ structure/ abundance/ veins/
economic geology/ Colorado/ igneous-metamorphic/ uranium/
- Bastin, E.S., and Hill, J.M., 1915, Preliminary report on the economic geology of Gilpin County, Colorado: U.S. Geol. Survey Bull. 620, p. 295-330.
economic geology/ Gilpin County/ Central City/ Quartz Hill/ uraninite/ pitchblende/ Bostonite porphyry/ igneous metamorphic/
- _____, 1915, Some features of the oredeposits of Gilpin County, Colorado: Washington Acad. of Sci. Jour., v. 5, pp. 160-164.
Gilpin County/ igneous-metamorphic/ Boulder County/
Clear Creek County/ Quartz Hill/ gold/ silver/ uranium/
copper/ tungsten/
- Becke, F., 1909, Uranpecherz von Kirk Mine, Bald Mountain, Gilpin County (Pitchblende from the Kirk Mine, Bald Mountain, Gilpin County): Tschermaks Mineralogy Petrog. Mitt., v. 28, p. 188.
Gilpin County/ Bald Mountain/ ore deposits/ pitchblende/
mineral assemblages/ Kirk mine/ igneous-metamorphic/
- Bell, K.G., 1960, Uranium and other trace elements in petroleum and rock asphalts: U.S. Geol. Survey Prof. Paper 356-B, p. 45-65.
uranium/ trace elements/ petroleum/ asphalts/ distribution/
source/ occurrence/ regional/ Colorado Plateau/ Rocky Mountains/ United States/ general/ Rio Blanco County/
Jefferson County/ Colorado/

- Beroni, E.P., and King, R.U., 1950, The Mike Doyle carnotite deposit, El Paso County, Colorado: U.S. Geol. Survey TEM-133, 8 p., geol. sketch maps.
Front Range/ minerals/ carnotite/ Mike Doyle mine/
continental carbonaceous shale/ Morrison Formation/
El Paso County/ geology/ ore deposits/ sandstone/
- Bertrand, Didier, 1950, Survey of contemporary knowledge of biogeochemistry. 2 - The biogeochemistry of vanadium: Am. Mus. Nat. History Bull., v. 94, p. 405-455.
biogeochemistry/ vanadium/ rocks/ sediments/ waters/
soils/ coals/ Jamestown/ Front Range/ Gilpin County/
Clear Creek County/ igneous-metamorphic/ plants/ animals/
oil/ asphalt/
- Bieniewski, C.L., Persse, F.H., and Brauch, E.F., 1971, Availability of uranium at various prices from resources in the U.S.: U.S. Bur. Mines Inf. Circ. 8501, 92 p.
Colorado Plateau/ Rifle/ Front Range/ Marshall Pass/
Garfield County/ Clear Creek County/ Jefferson County/
Boulder County/ resources/ price/ cost analysis/
- Bird, A.G., 1956, Primary pitchblende deposits at the Ralston Creek mine: Uranium, v. 3, no. 8, p. 8.
Ralston Creek/ pitchblende/ ore deposits/ Jefferson
County/ Schwartzwalder mine/ igneous-metamorphic/
- _____, 1957, Pitchblende occurrences in the Golden Gate Canyon-Ralston Creek areas of Jefferson County, Colorado (abs.): Geol. Soc. America Bull., v. 68, no. 12, pt. 2, p. 1858-1859.
pitchblende/ occurrence/ Golden Gate Canyon/ Ralston
Creek/ Schwartzwalder mine/ Jefferson County/ Front
Range/ igneous-metamorphic/
- _____, 1957, Uranium deposits in the Golden Gate Canyon and Ralston Creek area, Jefferson County; Colorado: Mines Mag., v. 47, no. 3, p. 91-93, illus.
Jefferson County/ igneous-metamorphic/ Ralston Creek/
Golden Gate Canyon/
- _____, 1957, Uranium deposits in the Golden Gate Canyon and Ralston Creek area, Jefferson County, Colorado: Colorado Mining Assoc., 60th Nat. Western Min. Conf., Denver, Colo., Trans., v. 1, Colorado Mining Assoc., p. 148-151.
Golden Gate Canyon/ Ralston Creek/ ore deposits/ Jefferson
County/ igneous-metamorphic/ Idaho Springs Formation/
mineralization/ Schwartzwalder mine/ uranium/

- _____. 1958, Petrology and ore deposits of Schwartzwalder uranium mine, Jefferson County, Colorado (M.S. thesis): Boulder, Colorado, Univ. of Colorado.
Schwartzwalder Mine/ ore deposits/ petrology/ Jefferson County/ metamorphic/ igneous-metamorphic/ uranium/
- _____. 1966, Metamorphic petrology of the Schwartzwalder mine area, Jefferson County, Colorado (abs.): Geol. Soc. America Spec. Paper 87, p. 274.
Jefferson County/ petrology/ Schwartzwalder mine/ metamorphic/ igneous-metamorphic/ uranium/
- Bird, A.G., and Stafford, H.S., 1955, Uranium deposits of the Colorado Front Range foothills region: Mines mag., v. 45, no. 3, p. 81-82.
Front Range/ foothills/ ore deposits/ veins/ Jefferson County/ Schwartzwalder mine/ igneous-metamorphic/ uranium/
- Boos, C.M., and Boos, M.F., 1957, Tectonic of eastern flank and foothills of Front Range, Colorado: Am. Assoc. Petroleum Geologist Bull., v. 41, no. 12, p. 26-30-2676.
tectonics/ Front Range/ Colorado/ igneous-metamorphic/ Larimer County/ Boulder County/ Jefferson County/ Gilpin County/ Clear Creek County/ Park County/ Douglas County/ Teller County/ El Paso County/ Fremont County/ Pueblo County/ granite/ schist/ gneiss/ pegmatite/
- Bozag, H.A., 1943, Precambrian geology of an area near the mouth of Golden Gate Canyon (M.S. Thesis No. 605): Golden, Colorado, Colorado School of Mines, (Unpubl).
Precambrian geology/ Golden Gate Canyon/ Jefferson County/ igneous-metamorphic/
- Braddock, W.A., 1969, Geology of the Empire quadrangle, Grand, Gilpin, and Clear Creek Counties, Colorado: U.S. Geol. Survey Prof. Paper 616, 56 p.
Geology/ ore deposits/ Empire quadrangle/ Grand County/ Gilpin County/ Clear Creek County/ igneous-metamorphic/
- Bray, J.M., 1942, Minor chemical elements in fluorites from Jamestown, Colorado: Am. Mineralogist, v. 27, p. 769-775.
fluorite/ Jamestown district/ Boulder County/ Colorado/ minor elements/ Front Range/ igneous-metamorphic/ veins/

- Breger, I.A., and Deul, Maurice, 1952, Status of investigations on the geochemistry and mineralogy of uraniferous lignites: U.S. Geol. Survey TEI-284 80 p., (see also U.S. Geol. Survey Bull. 1036-H, Econ. Geology, v. 50, no. 2, p. 206-226).
 geochemistry/ mineralogy/ lignites/ uranium/ chemistry/
 South Dakota/ coal/ Leyden mine/ Jefferson County/
 Colorado/ Texas/ extraction/
- Breger, I.A., and Moore, R.T., 1955, Preliminary experiments on the reduction of the uranyl ion to uraninite by carbonaceous substances: U.S. Geol. Survey TEM-942.
 El Paso County/ Montrose County/ Virgin mine/ coal/
 uraninite/ uranyl ion/ reduction/
- Brinkworth, G.L., 1974, Geophysical investigation of the Colorado Front Range mineral belt (Ph.D. Thesis): Boulder, Colorado, Univ. of Colorado, (Unpubl).
 geophysical investigation/ Colorado/ Front Range/ mineral
 belt/ igneous-metamorphic/ Jefferson County/ Boulder County/
 Clear Creek County/ Gilpin County/
- Brown, Andrew, 1961, Geologic investigations of radioactive deposits, a bibliography of U.S. Geological Survey publications on the geology of radioactive deposits: U.S. Geol. Survey TEI-777.
 bibliography/ radioactive deposits/ geology/ uranium/
 thorium/ mineralogy/ geochemistry/ reconnaissance/ United
 States/ Colorado/ Colorado Plateau/ sandstone/ geobotany/
 geophysics/ veins/ igneous-metamorphic/ Front Range/
 Lake County/
- Butler, A.P., Jr., 1947, Memorandum on thorium resources: U.S. Geol. Survey TEM-39.
 thorium/ resources/
- _____, 1952, The Geological Survey's work on the geology of uranium and thorium deposits: U.S. Geol. Survey TEI-207, 26 p.
 Front Range/ thorium/ Colorado Plateau/ Morrison Formation/
 igneous-metamorphic/ Chinle Formation/ Shinarump conglomerate/
 pegmatites/ veins/ sandstone/ placers/ carnotite/
 fresh waters/ gases/ Gilpin County/ Clear Creek County/
 Custer County/ Lake County/ San Miguel County/ Gunnison
 County/

Butler, A.P., Jr., Schnabel, R.W., 1956, Distribution and general features of uranium occurrences in the United States, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, proc., v. 6, p. 224-230.

veins/ occurrences/ United States/ general/ Colorado/ Colorado Plateau/ regional/ distribution/ features/ uranium/ sedimentary rocks/ igneous rock/ water/ igneous-metamorphic/ sandstone/

1956, Distribution and general features of uranium occurrences in the United States, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 27-40.

veins/ distribution/ features/ uranium/ occurrences/ United States/ general/ Colorado/ Colorado Plateau/ regional/ sedimentary rocks/ igneous rock/ water/ igneous-metamorphic/ sandstone/

Butler, A.P., Jr., Finch, W.I., and Twenhofel, W.S., 1962, Epigenetic uranium deposits in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey MR-21, scale 1:3,168,000.

map/ uranium deposits/ Colorado/ United States/ epigenetic/

Butler, A.P., Jr., Killeen, P.L., Page, G.B., and others, 1947, Proposed program for and present status of the Geological Survey's investigation of domestic resources of radioactive raw materials: U.S. Geol. Survey TEI-35, 26 p., maps.

ore deposits/ resources/ reconnaissance/ reserves/ Front Range/ Colorado Plateau/ carnotite/ uranium/ vanadium/ igneous-metamorphic/ uraninite/ Iron Hill/ Gunnison County/ Gilpin County/ Clear Creek County/ radioactive springs/ thorium/ mineralogy/ genesis/

Campbell, R.H., 1953, radiometric reconnaissance of the Gold Hill mining area, Boulder County, Colorado, in Search for and geology of radioactive deposits - Semiannual progress report, Dec. 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 90-92.

Gold Hill mining district/ Boulder County/ zoning/ igneous-metamorphic/ Black Cloud mine/ pitchblende/

1955, Reconnaissance for radioactivity in the Gold Hill mining area, Boulder County, Colorado: U.S. Geol. Survey TEM-563, 28 p., figures. (See U.S. Geol. Survey TEM-563.)

Boulder County/ Gold Hill area/ mineralogy/ petrology/ geochemistry/ breccia reefs/ zoning/ Front Range/ pitchblende/ schroekingerite/ torbernite/ Black Cloud mine/ Goldsmith Maid vein/ Snowbound mine/ reconnaissance/ igneous-metamorphic/

- Campbell, R.H., and Schafer, M., 1953, A systematic radio-activity reconnaissance of part of the North Gilpin County mining district, Colorado: U.S. Geol. Survey TEM-512. Gilpin County/ mineralogy/ petrology/ geochemistry/ zoning/ Front Range mineral belt/ uraninite/ Elliott mine/ reconnaissance/ radioactive materials/ metal-mining districts/ igneous-metamorphic/
- Cannon, R.S., Jr., 1952, Geological Survey's work on isotope geology of uranium and thorium and their decay products: U.S. Geol. Survey TEI-209, 12 p. isotope geology/ uranium/ thorium/ decay products/ plans/ Colorado Plateau/ Front Range/ Morrison Formation/ sandstone/ igneous-metamorphic/
- Chapman, J.J., 1948, The geology of the eastern Clear Creek-Golden Gate Canyon area, Jefferson County, Colorado (M.S. Thesis): Golden, Colorado, Colorado School of Mines, (Unpubl). geology, Clear Creek area/ Golden Gate Canyon area/ Jefferson County/ igneous-metamorphic/ Front Range/
- Collins, G.E., 1909, Vanadium and uranium in Colorado: England Mining Jour., v. 87, p. 106. regional/ ore deposits/ occurrence/ evaluation/ milling/ Gilpin County/ Belcher Mine/ Quartz Hill/ pitchblende/ Wood vein/ Kirk vein/ German vein/ igneous-metamorphic/
- _____, 1914, Metal mining in Colorado in 1913: Eng. and Mining Jour., v. 97, no. 2, p. 116-118. carnotite/ sandstone/ San Miguel County/ Montrose County/ pitchblende/ igneous-metamorphic/ Gilpin County/
- Colorado Geological Survey, 1976, Bibliography and index of Colorado geology 1875-1975: Colorado Geol. Survey Bull. 37, 488 p. bibliography/ geology/ uranium/ Colorado/ Colorado Plateau
- Cooper, Margaret, 1953, Selected bibliography on uranium exploration and the geology of uranium deposits: U.S. Atomic Energy Comm. RME-4007. Colorado/uranium/ exploration/ geology/ deposits/ general/ bibliography/ geobotany/ geochemistry/ geophysics/ United States/ prospecting/ occurrence/ world/ thorium/

-
- 1953, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States, Part 3, Colorado and Utah: U.S. Atomic Energy Comm. RME-4003, (see Geol. Soc. America Bull., 1954, v. 65, p. 467-590).
Colorado/ Utah/ bibliography/ uranium/ thorium/ radioactive occurrences/ general/ ore deposits/
-
- 1954, Bibliography and index of literature of uranium and thorium and radioactive occurrences in the United States - Part 3, Colorado and Utah: Geol. Soc. America Bull., v. 65, no. 6, p. 467-590.
Colorado/ Utah/ bibliography/ uranium/ thorium/ general/ occurrences/ radioactive occurrences/
- Curran, T.F., 1913, Carnotite: Eng. and Mining Jour., v. 96, no.s 25, 26, p. 1165-67, 1223-25.
Regional/ ore deposits/ carnotite/ abundance/ possibilities/ history/ Gilpin County/ Wood mine/ Montrose County/ sandstone/ igneous-metamorphic/ pitchblende/ San Miguel County/ Mesa County/ Dolores County/ Routt County/ Rio Blanco County/ Paradox Valley/ Utah/ Australia/ recovery/
- Curtis, Diane, 1956, Selected annotated bibliography of the uranium geology of igneous and metamorphic rocks in the United States and territories: U.S. Geol. Survey TEI-534 (see U.S. Geol. Survey Bull. 1059-E, p. 205-262).
bibliography/ annotated/ uranium/ geology/ United States/ igneous-metamorphic/
- Del Rio, S.M., Comp., 1960, Mineral Resources of Colorado, First Sequel: Colorado Geol. Survey. Colorado Mineral Resources Board, 764 p., 73 figures, 9 pls., 106 tables, maps.
minerals/ resources/ Colorado/
- Denson, M.E., Jr., 1956, Geophysical-geochemical prospecting for uranium, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 687-703.
Colorado/ Front Range/ geophysics/ geochemistry/ South Dakota/ Wyoming/ prospecting/ exploration/ uranium/ methods/ thorium/ Jefferson County/ igneous-metamorphic/

- Derzay, R.C., 1953, Uranium occurrence at the Cherokee Mine, Queen Mineral Ranch, Gilpin County, Colorado: U.S. Atomic Energy Comm. RME-4041, 8 p., illus.
Cherokee mine/ ore deposits/ occurrence/ Queen Mineral Ranch/ Gilpin County/ veins/ igneous-metamorphic/ pitchblende/ Precambrian/ quartz-biotite schist/ schistose gneiss/ pegmatite/ drilling/ Front Range/
- Derzay, R.C., and Baker, K.E., 1953, Results of exploration at the Copper King mine, Larimer County, Colorado: U.S. Atomic Energy Comm. RME-4018, 16 p., illus. (incl. sketch map).
Copper King mine/ ore deposits/ exploration/ Larimer County/ igneous-metamorphic/ veins/ pitchblende/ Precambrian/ granite/ schist/ pegmatite/ copper/ zinc/
- Derzay, R.C., and Bird, A.G., 1976, Economic geology of uranium deposits in the Ralston Creek area, Jefferson County, Colorado: U.S. Energy Research Devel. Adm. RME-1077.
economic geology/ ore deposits/ uranium/ Ralston Creek area/ Jefferson County/ igneous-metamorphic/ Front Range/
- Downs, G.R., and Bird, A.G., 1965, The Schwartzwalder uranium mine, Jefferson County, Colorado: Mtn. Geologist, v. 2, no. 4, p. 183-191, illus.
Jefferson County/ Schwartzwalder mine/ ore deposits/ genesis/ production/ reserves/ occurrence/ pitchblende/ veins/ igneous-metamorphic/
- Drake, A.A., Jr., 1955, Geology of the Wood and East Calhoun mines, central City district, Gilpin County, Colorado: U.S. Geol. Survey TEI-175, (see U.S. Geol. Survey Bull. 1032, Part I open-filed).
Front Range/ igneous-metamorphic/ Central City/ Gilpin County/ geology/ mineralogy/ petrology/ geochemistry/ pitchblende/ ore deposits/ Calhoun (east and west) mines/ Wood mine/ production/ veins/ Precambrian/ Quartz Mill vein/ Wood vein/ Willowdale vein/ paragenesis/ alteration/ bostonite porphyry/ Clear Creek County/
-
- 1955, Occurrence of pitchblende at the Wood mine, Central City district, Gilpin County, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1673.
ore deposits/ Wood mine/ Central City/ pitchblende/ occurrence/ Gilpin County/ uranium/ veins/ Colorado/ igneous-metamorphic/ Clear Creek County/

- 1957, Geology of the Wood and East Calhoun mines, Central City district, Gilpin County, Colorado, in Geology and ore deposits of Clear Creek, Gilpin, and Larimer Counties, Colorado: U.S. Geol. Survey Bull. 1032-C, p. 129-170, illus., incl. geol. sketch maps, (see U.S. Geol. Survey TEI-175).
veins/ Precambrian/ bostonite porphyry/ pitchblende/ production/ Central City/ Gilpin County/ structure/ geology/ Wood-East Calhoun area/ igneous-metamorphic/ Wood mine/ East Calhoun mine/ Clear Creek County/ veins/ mineralogy/
- Duncan, D.C., compiler, 1953, Reconnaissance investigations for uranium in black shale deposits of the Western States during 1951 and 1952: U.S. Geol. Survey TEI-381, 89 p., illus. (incl. sketch map).
ore deposits/ black shale/ Weber Formation/ exploration/ shale/ reconnaissance/ Belden Shale/ Paradox Formation/ Eagle County/ Garfield County/ Gunnison County/ Hermosa Formation/ San Juan County/ La Plata County/ Lake County/ Pony Express Limestone/ Ouray County/ Dakota Sandstone/ Archuleta County/ Pierre Shale/ Las Animas County/ Huerfano County/ Vermejo Formation/
- Eckel, E.B., 1961, Minerals of Colorado -- A 100-year record: U.S. Geol. Survey Bull. 1114, 339 p., illus.
summary/ description/ minerals/ Colorado/ general/ uranium/ occurrence/ vanadium/ thorium/
- Everhart, D.L., 1956, Uranium-bearing vein deposits in the United States, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and U.S. Atomic Energy Comm. for U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 97-103.
United States/ veins/ Colorado Plateau/ structural tension/ Tertiary/ Front Range/ Copper King mine/ Larimer County/ Los Ochos mine/ Saguache County/ Caribou mine/ Boulder County/ Placerville district/ San Miguel County/ sandstone/ granite/ pitchblende/ Colorado/ igneous-metamorphic/ ore deposits/

-
- 1956, Uranium-bearing vein deposits in the United States, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 257-264.
 veins/ sandstone/ Colorado Plateau/ Front Range/ Copper King mine/ Larimer County/ Los Ochos mine/ Saguache County/ Caribou mine/ Boulder County/ Schwartzwalder mine/ Jefferson County/ Carroll mine/ Placerville district/ San Miguel County/ alteration/ pitchblende/ igneous-metamorphic/
- Everhart, D.L., and Wright R.J., 1953, The geologic character of typical pitchblende veins: Econ. Geology, v. 48, no. 2, p. 77-96.
 geology/ pitchblende/ veins/ igneous-metamorphic/
- Ferris, C.S., and Bennett, N., 1977, Geochemical prospecting at the Ladwig uranium mine, near Golden, Colorado, in Short papers of the U.S. Geol. Survey uranium-thorium symposium, 1977: U.S. Geol. Survey Circ. 753, p. 66-67.
 geochemistry/ exploration/ Ladwig mine/ Jefferson County/ Front Range/
- Finch, W.I., 1967, Geology of epigenetic uranium deposits in sandstone in the United States: U.S. Geol. Survey Prof. Paper 538, 121 p.
 regional/ ore deposits/ occurrence/ sandstone/ genesis/
- Fix, P.F., 1954, Uranium in natural waters, hydrogeochemical exploration for uranium, in Geologic investigations of radioactive deposits - semiannual progress report, classified data, June 1 to Nov. 30, 1954: U.S. Geol. Survey TEI-491, p. 23.
 natural waters/ hydrogeochemical exploration/ streams/ stream sediments/ ore deposits/ ground water/ mine waters/ Sevier River/ Utah/ Ralston Creek/ Colorado/ Jefferson County/ Montana/ Schwartzwalder mine/ Front Range/
-
- 1954, Uranium in natural waters, in Geologic investigations of radioactive deposits - Semiannual progress report, classified data, Dec. 1, 1953, to May 31, 1954: U.S. Geol. Survey TEI-441, p. 24.
 Colorado Plateau/ natural waters/ streams/ snow/ surface water/ ground water/ San Juan Mountains/ San Juan County/ Ouray County/ acid tuff/ igneous-metamorphic/ Front Range/

-
- 1956, Hydrogeochemical exploration for uranium, in
 Geology of uranium and thorium: U.N. Internat. Conf. on
 Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6,
 p. 788-791.
 hydrochemistry/ surface water/ ground water/ uranium/
 general/ exploration/ prospecting/ Front Range/ Colorado
 Plateau/ Central City/ Gilpin County/ Clear Creek County/
 background/ uranium/
-
- 1956, Hydrogeochemical exploration for uranium, in
 Contributions to the geology of uranium and thorium by
 the United States Geological Survey and Atomic Energy
 Commission for the United Nations International Conference
 on Peaceful Uses of Atomic Energy, Geneva, Switzerland,
 1955: U.S. Geol. Survey Prof. Paper 300, p. 667-671.
 hydrochemistry/ surface water/ ground water/ uranium/
 general/ exploration/ prospecting/ background/ uranium/
- Fleck, Herman, 1908, A brief statement of the rising impor-
 tance of rare elements: Am. Min. Congr., Ann. Rept.
 Proc., no. 11, p. 204-211.
 rare elements/
-
- 1908, Welfare of Colorado's rare metal industry
 (pitchblende deposits of Gilpin County and vanadium deposits
 of Placerville, Colorado): Colorado School Mines Quart.,
 v. 3?, p. 34-35.
 pitchblende/ Gilpin County/ igneous-metamorphic/ uranium/
 vanadium/ ore deposits/ Placerville/ Entrada Formation/
 sandstone/ San Miguel County/
-
- 1909, Welfare of Colorado's rare metal industry
 (pitchblende deposits of Gilpin Co. and vanadium deposits
 of Placerville, Colo.): Colorado School of Mines Quart.,
 v. 4, p. 234-242.
 Gilpin County/ ore deposits/ pitchblende/ production/
 possibilities/ vanadium/ Placerville/ San Miguel County/
 rare metals/ uranium/ Entrada Formation/ sandstone/
 igneous-metamorphic/
-
- 1916, A series of treatises on the rare metals;
 tungsten, molybdenum, vanadium, uranium: Colorado Sci.
 Soc., Proc., v. 11, p. 103-176.
 regional/ ore deposits/ occurrence/ production/ rare
 metals/ tungsten/ molybdenum/ vanadium/ uranium/

McKelvey, V.E., 1953, Search for uranium in western United States: U.S. Geol. Survey TEI-199, 29 p.
 Colorado Plateau/ Dolores County/ Mesa County/ exploration/ veins/ sandstone/ igneous-metamorphic/ pegmatites/ geobotany/ Front Range/ Gilpin County/ Clear Creek County/ coal/ Montrose County/ San Miguel County/ ore deposits/ phosphates/ shale/ placers/

____ 1953, Search for uranium in the western United States (abs.): Am. Assoc. Petroleum Geologists Bull., v. 37, no. 11, p. 2614.
 Dolores County/ Mesa County/ exploration/ veins/ sandstone/ igneous-metamorphic/ Front Range/ pegmatites/ geobotany/ Gilpin County/ Clear Creek County/ coal/ Montrose County/ San Miguel County/ ore deposits/ Colorado Plateau/ phosphates/ shale/ placers/

____ 1954, search for uranium in the United States: U.S. Geol. Survey TEI-476, 68 p., (see U.S. Geol. Survey Bull. 1030-A).
 Dolores County/ Mesa County/ exploration/ carnotite/ veins/ sandstone/ igneous-metamorphic/ pegmatites/ geobotany/ Front Range/ Gilpin County/ Clear Creek County/ coal/ Montrose County/ San Miguel County/ ore deposits/ veins/ Colorado Plateau/ phosphates/ shale/ placers/

____ 1955, Search for uranium in the United States: U.S. Geol. Survey Bull. 1030-A, p. 1-64 (see U.S. Geol. Survey TEI-476).
 regional/ ore deposits/ exploration/ veins/ bituminous substances/ coal/ sandstone/ phosphates/ United States/

McKelvey, V.E., Everhard, D.L., and Garrels, R.M., 1955, Origin of uranium deposits: U.S. Geol. Survey TEI-504, 102 p. (see Econ. Geology 50th Anniv. Vol., pt. 1, p. 464-533).
 origin/ uranium/ ore deposits/ occurrence/ veins/ igneous-metamorphic/ bituminous substances/ sandstone/ limestone/ coal/ shale/ pitchblende/ geochemistry/ age/ Colorado/ general/ Earth/ Front Range/ Colorado Plateau/ Gilpin County/ Clear Creek County/

____ 1955, Origin of uranium deposits: Econ. Geology 50th Anniv. Vol., pt. 1, p. 464-533 (see U.S. Geol. Survey TEI-504).
 veins/ bituminous substances/ genesis/ origin/ uranium/ ore deposits/ occurrence/ igneous-metamorphic/ sandstone/ limestone/ coal/ shale/ pitchblende/ geochemistry/ age/ Colorado/ general/ Earth/ Front Range/ Colorado Plateau/ Gilpin County/ Clear Creek County/

- Franz, G.A., Jr., 1960, The minerals of Colorado and area locations: Colorado Bur. Mines Circ., no. 1, 26 p.
Colorado/ minerals/ locations/
- _____, 1963, The minerals of Colorado and area locations: Colorado Bur. Mines Circ., no. 2.
Colorado/ minerals/ locations/
- Fraser, G.D., 1948, Coal Creek Quartzite, Jefferson and Boulder Counties, Colorado (abs.): Geol. Soc. America Bull., v. 60, no. 12, pt. 2, p. 1960.
Coal Creek Quartzite/ igneous-metamorphic/ Jefferson County/ Boulder County/ Front Range/
- Gabelman, J.W., 1948, The geology of the Golden Gate-Van Bibber Creek area, Jefferson County, Colorado (M.S. thesis): Colorado School of Mines M.S. Thesis No. 638, Golden, Colorado, Colorado School of Mines, (Unpubl).
geology/ Golden Gate area/ Van Bibber Creek area/ Jefferson County/ Front Range/ igneous-metamorphic/
- Gabelman, J.W., and Boyer, W.H., 1974, Status of uranium exploration, in Colorado Mining Assoc. Mining Yearbook: Colorado Mining Assoc., p. 72-81.
exploration/ status/ uranium/ technology/ history/ pitch-blende/ radium boom/ vanadium/ Colorado Plateau/ Front Range/ Montrose County/ Mesa County/ San Miguel County/ Dolores County/ Moffat County/ Jefferson County/ sandstone/ igneous-metamorphic shale/
- Gable, D.J., 1968, Geology of the crystalline rocks in the western part of the Morrison quadrangle, Jefferson County, Colo.: U.S. Geol. Survey Prof. Paper 1251-E, p. E1-E45.
geology/ crystalline rocks/ Morrison quadrangle/ Jefferson County/ igneous-metamorphic/
- _____, 1969, Geologic map of the Nederland quadrangle, Boulder and Gilpin Counties, Colorado: U.S. Geol. Survey GQ-833, scale 1:24,000 (1970).
geology/ Nederland quadrangle/ Boulder County/ Gilpin County/ igneous-metamorphic/ ore deposits/

- Gallagher, G.L., 1976, Uranium favorability of Precambrian rocks in the Badger Flats - Elkhorn Thrust area, Park and Teller Counties, Colorado: U.S. Energy Research Devel. Adm. GJBX-55(76).
Badger Flats area/ Elkhorn Thrust area/ Park County/ Teller County/ Precambrian rocks/ igneous-metamorphic/ Front Range/ uranium favorability/
- George, D'Arcy, 1949, Mineralogy of uranium- and thorium-bearing minerals: U.S. Atomic Energy Comm. RMO-563, 198 p.
uranium/ thorium/ mineralogy/ hypogene/ supergene/ rare earth minerals/ chemistry/ pegmatites/ igneous-metamorphic/ sandstone/ placers/ black shales/ Colorado/
- George, R.D., 1917, Common minerals and rocks - their occurrence and uses: Colorado Geol. Survey Bull. 12, 463 p., 55 figs., 1 pl., 5 tables. Rerelease of Bulletin 6.
minerals/ rocks/ Colorado/ occurrence/ uses/
- George, R.D., Curtis, H.A., Lester, O.C., and others, 1920, mineral waters of Colorado: Colorado Geol. Survey Bull. 11, 474 p., 40 figs., 2 pls.; map (scale 1:1,000,000).
Colorado, mineralized waters/ springs/
- Gilbert, R.E., 1972, Schwartzwalder area geology (map): Cotter Corporation, unpublished map prepared for publisher.
Jefferson County/ Schwartzwalder mine/ igneous-metamorphic/ Front Range/ geology/ map/
- Gill, J.R., 1953, Uranium in carbonaceous rocks; parts of Colorado, Wyoming and Montana, in Search for and geology of radioactive deposits - Semiannual progress report, Dec. 1, 1952, to May 31, 1953: U.S. Geol. Survey TEI-330, p. 118-119.
Colorado/ Montana/ Wyoming/ ore deposits/ carbonaceous rocks/ coal/ Park County/ Gunnison County/ Delta County/ Las Animas County/ El Paso County/ Teller County/ La Plata County/ Montezuma County/ Denver Basin/ Larimer County/ shale/ Crested Butte/ Laramie Formation/
- Goddard, E.N., 1946, Fluorspar deposits of the Jamestown district, Boulder County, Colorado: Colorado Sci. Soc. Proc., v. 15, no. 1, 47 p., illus.
Boulder County/ veins/ igneous-metamorphic/ fluorite/ Tertiary intrusions/ ore/ grades/ Jamestown district/

- Goddard, E.N., and Glass, J.J., 1940, Deposits of radioactive cerite near Jamestown, Colorado: Am. Mineralogist, v. 25, no. 6, p. 381-404, illus. (incl. geol. map).
cerite/ Jamestown/ Colorado/ deposits/ igneous-metamorphic/ uranium/ Boulder County/ Precambrian/ geology/ occurrence/ mineralogy/ chemistry/
- Gott, G.B., 1948, Investigation of radioactive springs near Jamestown, Colorado: U.S. Geol. Survey TEM-1, 4 p.
Boulder County/ water/ nonsealine/ springs/ Jamestown/ radioactivity/
- _____, 1948, Radioactive springs near Jamestown, Colorado: U.S. Geol. Survey TEM-1A, 8p.
Boulder County/ water/ nonsaline/ Jamestown/ springs/ radioactivity/
- _____, 1950, The Leyden uranium prospect, Jefferson County, Colorado: U.S. Geol. Survey Tem-132.
Leyden Ridge/ Jefferson County/ Leyden uranium prospect/ Old Leyden coal mine/ coal/ ore deposits/ geology/ origin/
- Gott, G.B., Wyant, D.G., and Beroni, E.P., 1952, Uranium in black shales, lignites, and limestones in the United States: U.S. Geol. Survey Circ. 220, p. 31-35 (maps).
Front Range/ ore deposits/ occurrence/ shale/ black shale/ lignite/ limestone/ organics/ United States/ Colorado/ general/ coal/ Leyden coal mine/ Jefferson County/ uranium/
- Gottfried, David, 1956, Distribution of uranium in igneous complexes; Precambrian granites of the Front Range of Colorado, in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1956: U.S. Geol. Survey TEI-640, p. 292-297.
Front Range/ ore deposits/ distribution/ exploration/ Precambrian/ igneous complexes/ distribution/ granite/ igneous-metamorphic/ uranium/ Jefferson County/ Boulder County/ Clear Creek County/ Gilpin County/ Pikes Peak batholith/ Log Cabin batholith/ Boulder Creek batholith/
- Gow, T.T., 1914, Radioactivity of the basalt of Table Mountain at Golden (Jefferson County), Colorado, and igneous rocks in the region northwest of Gilmore, Conejos County (and Rio Grand County), Colorado (M.S. thesis): Golden, Colorado, Colorado School of Mines.
basalt/ Table Mountain/ igneous-metamorphic/ Jefferson County/ Conejos County/ Rio Grande County/ igneous/

- Granger, H.C., and Beroni, E.P., 1950, Cook property, Jefferson County: U.S. Geol. Survey TEM-20.
Jefferson County/ Cook property/ igneous-metamorphic/ reconnaissance/
- Granger, H.C., and King, R.U., 1950, Report of factual data obtained during examination of Copper King shaft, Black Hawk claim No. 1, Larimer County, Colorado: U.S. Geol. Survey TEM-128, 1 p., figures.
Larimer County/ Copper King uranium mine/ Copper King shaft/ Black Hawk Claim No. 1/ pitchblende/ analysis/ igneous-metamorphic/
- _____, 1951, Uranium in the Copper King mine, Black Hawk No. 1 claim, Larimer County, Colorado: U.S. Geol. Survey TEM-128A.
Larimer County/ pitchblende/ Copper King uranium mine/ Black Hawk No. 1/ igneous-metamorphic/ pitchblende/ geology/ analysis/
- Grossman, E.L., 1957, Uranium deposits of the Colorado Front Range: Western Min. Conf., 60th Natl., Denver, Colorado, Trans., v. 1, p. 47-51.
Front Range/ ore deposits/ Colorado/ uranium/ Gilpin County/ Clear Creek County/ Jefferson County/ Schwartzwalder/ pitchblende/ igneous-metamorphic/ Ladwig mine/ Leyden mine/ Boulder County/ coal/ sandstone/ Morrison Formation/ Park County/ Gem Dandy/
- Grossman, E.L., and Smith, B.C., 1956, Results of airborne radiometric survey of the Dakota Hogbacks of north central Colorado: U.S. Atomic Energy Comm. RME-1079, 13 p.
Colorado/ lithology/ uranium/ ore deposits/ aerial prospecting/ aerial monitorin/ sandstone/ Dakota Hogback/ Dakota Sandstone/ Cretaceous/ Boulder County/ Larimer County/ asphaltite/ Rose Mary No. 1/ Wahketa Lease/ Horsetooth Reservoir site/ Carter Lake/ Bonnell Lease/
- Gruner, J.W., and Smith, D.K., Jr., 1955, Mineral determinations in uranium deposits and prospects in Wyoming and Northern Colorado, in Annual report for April 1, 1954, to March 31, 1955: U.S. Atomic Energy Comm. RME-3020, p. 25-33.
Colorado/ Wyoming/ ore deposits/ mineralogy/ Moffat County/ Miocene/ Browns Park Formation/ sandstone/ Maybell district/ Weber Formation/

- 1955, Progress report no. 10 for period April 1 to October 1, 1955: U.S. Atomic Energy Comm. RME-3125, 19 p.
Wyoming/ South Dakota/ North Dakota/ Colorado/ Moffat County/ sandstone/ Browns Park Formation/ Colorado Plateau/ Morrison Formation/ Chinle Formation/ Mesa County/ Montrose County/ San Miguel County/ peat/ lignite/
- Gude, A.J., 3d, and McKeown, F.A., 1952, Results of exploration at the Old Leyden coal mine, Jefferson County, Colorado: U.S. Geol. Survey TEM-292, 18 p., figures, maps.
Jefferson County/ ore deposits/ Front Range/ coal/ exploration/ drilling/ Old Leyden coal mine/ minerals/ carnotite/ Laramie Formation/
- 1953, Results of exploration at the Old Leyden coal mine, Jefferson County, Colorado: U.S. Geol. Survey TEM-292, 14 p.
drilling/ core/ reserves/ sandstone/ coal/ shale/ veins/ exploration/ Jefferson County/ Old Leyden coal mine/
- Guillotte, G.B., 1944, Report of preliminary field reconnaissance of reported SOM uranium mineral occurrences in Eastern Colorado: U.S. Atomic Energy Comm. RMO-49, 4 p.
reconnaissance/ uranium/ ore deposits/ eastern Colorado/
- 1944, SOM deposits of Gilpin County, Colorado: U.S. Atomic Energy Comm. RMO-48, 38 p.
reconnaissance/ uranium/ ore deposits/ Gilpin County/ igneous-metamorphic/ Kirk mine/ Wood mine/ Belcher mine/
- 1944, S-37 uranium occurrences in the Grover Pegmatite Mine on North Beaver Brook, Clear Creek County, Colorado: U.S. Atomic Energy Comm. RMO-46, 11 p.
uranium/ ore deposits/ Grover Pegmatite/ mine/ North Beaver Brook/ igneous-metamorphic/ Clear Creek County/
- Gustafson, J.K., 1949, Uranium resources: Nucleonics, v. 4, no. 5, p. 23-28.
uranium/ resources/ occurrence/ veins/ Gilpin County/ Boulder County/ Igneous-metamorphic/ pitchblende/ Colorado Plateau/ vanadium/ Morrison Formation/ sandstone/ Montrose County/ Mesa County/ San Miguel County/

- Hall, C.R., 1976, Selected references on alkalic igneous rocks of the United States: U.S. Energy Research and Devel. Adm. GJBX-4 (76).
alkalic/ igneous rocks/ igneous-metamorphic/ Front Range/ bibliography/
- Hanley, E.S., 1948, Golden Cycle tailings dump, Colorado Springs, Colorado: U.S. Geol. Survey TEM-6, 10 p., tables, maps.
El Paso County/ Golden Cycle mill dump/ tailings/ Cripple Creek ore/ Teller County/
- Hanley, J.B., Heinrich, E.W., and Page, L.R., 1950, Pegmatite investigations in Colorado, Wyoming, and Utah, 1942-44: U.S. Geol. Survey Prof. Paper 227, 125 p.
pegmatites/ geology/ mineralogy/ Chaffee County/ Boulder County/ Clear Creek County/ Douglas County/ El Paso County/ Fremont County/ Gunnison County/ Jefferson County/ Larimer County/ Montrose County/ Park County/ Summit County/ monazite/ thorium/ production/ Front Range/ igneous-metamorphic/
- Harder, J.O., and Stead, F.W., 1945, Reconnaissance for radioactive ore deposits in the United States, summary of progress: U.S. Geol. Survey Tei-21 (see U.S. Geol. Survey Prof. Papers 300, 356-C, D, 357, 455-A-F, and 538).
Boulder County/ Gilpin County/ Gunnison County/ Jefferson County/ Mesa County/ Teller County/ ore deposits/ sandstone/ igneous-metamorphic/
- Harder, J.O., and Wyant, D.G., 1944, Preliminary report on a trace elements reconnaissance in western states: U.S. Geol. Survey TEI-4, 47 p.
Central City/ Cripple Creek/ Jamestown Nederland district/ Boulder County/ Gilpin County/ Gunnison County/ Teller County/ Clear Creek County/ ore deposits/ igneous-metamorphic/ reconnaissance/ Precambrian/ granite/ veins/ Brown Derby Pegmatite/ Calhoun mine/ Belcher mine/ trace elements/
- Harrison, J.E., 1952, The uranium occurrences in the Martha E prospect, Lawson-Dumont district, Clear Creek County, Colorado: U.S. Geol. Survey TEM-291, 12 p., figures.
Clear Creek County/ ore deposits/ Front Range/ Idaho Springs area/ Spring gulch/ Lawson-Dumont district/ pegmatite/ granite/ schist/ minerals/ autonite/ metatorbernite/ pitchblende/ Martha E prospect/ igneous-metamorphic/

-
- 1953, Relation between fracture pattern and hypogene zoning in the Freeland-Lamartine district, Clear Creek County, Colorado (abs.): Geol. Soc. America Bull., v. 64, no. 12, pt. 2, p. 1431 (see U.S. Geol. Survey TEI-295).
fracture pattern/ zoning/ Freeland-Lamartine district/ Colorado/ Clear Creek County/ igneous-metamorphic/ vein/ Gilpin County/ thorium/
-
- 1953, Freeland-Lamartine district: U.S. Geol. Survey TEI-330, p. 96-97.
Freeland/Lamartine district/ Clear Creek County/ vein/ igneous-metamorphic/ Gilpin County/
-
- 1955, Relation between fracture pattern and hypogene zoning in the Freeland-Lamartine district, Colorado: Econ. Geology, v. 50, no. 3, p. 311-320, illus.
fracture pattern/ zoning/ Freeland-Lamartine district/ Colorado/ Clear Creek County/ igneous-metamorphic/ Gilpin County/ vein/ thorium/
- Harrison, J.E., and Leonard, B.F., 1952, Preliminary report on the Jo Reynolds area, Lawson-Dumont district, Clear Creek County, Colorado: U.S. Geol. Survey Circ. 213, 9 p. (1953).
Front Range/ Clear Creek County/ Lawson-Dumont district/ pitchblende/ Jo Reynolds mine/ veins/ stratigraphy/ Idaho Springs Formation/ Precambrian rocks/ igneous-metamorphic/ structure/ ore deposits/ geology/ metamorphic rock/ bostonite porphyry/ economic geology/
-
- 1952, Preliminary report on the Jo Reynolds area. Lawson-Dumont district, Clear Creek County, Colorado: U.S. Geol. Survey TEM-153, (see U.S. Geol. Survey Circ. 213).
Front Range/ Clear Creek County/ Lawson-Dumont district/ pitchblende/ Jo Reynolds mine/ veins/ stratigraphy/ Idaho Springs Formation/ Precambrian rocks/ igneous-metamorphic/ structure/ ore deposits/ geology/ metamorphic rocks/ bostonite porphyry/ economic geology/
- Harrison, J.E., and Wells, J.D., 1953, Area south and west of Freeland: U.S. Geol. Survey TEI-390, p. 105-106.
igneous-metamorphic/ Clear Creek County/ Freeland district/ Chicago Creek/ structure/ pitchblende/

- 1954, Geology and ore deposits of Freeland-Lamartine district, Clear Creek County, Colorado: U.S. Geol. Survey TEI-295, 127 p., (see U.S. Geol. Survey Bull. 1032-B).
Freeland-Lamartine district/ Front Range/ Clear Creek County/ autonite/ dumontite(?)/ Ariadne mine/ Belle of the West (mine) tunnel/ Belle Creole mine/ Invincible mine/ veins/ stratigraphy/ Idaho Springs Formation/ igneous-metamorphic/
- 1956, Geology and ore deposits of the Chicaco Creek area, Clear Creek County, Colorado: U.S. Geol. Survey TEI-432, (see U.S. Geol. Survey Prof. Paper 319).
Clear Creek County/ Chicago Creek area/ Front Range/ mineralogy/ petrology/ geochemistry/ breccia reefs/ pitchblende/ intrusive igneous rocks/ igneous-metamorphic/ uranium/ pegmatites/ veins/ Colorado/ geology/ genesis/ production/ ore deposits/
- 1956, Geology and ore deposits of the Freeland-Lamartine district, Clear Creek County, Colorado: U.S. Geol. Survey Bull. 1032-B, p. 33-127 (see U.S. Geol. Survey TEI-295), illus. (incl. maps).
veins/ ore deposits/ production/ geology/ bostonite/ alaskite/ migmatite/ metamorphic/ Freeland-Lamartine district/ Clear Cree County/ igneous-metamorphic/
- 1959, Geology and ore deposits of the Chicaco Creek area, Clear Creek County, Colorado: U.S. Geol. Survey Prof. Paper 319, v. V, 92 p., illus (incl. geol. maps).
Clear Creek County/ Chicago Creek Area/ Front Range/ mineralogy/ petrology/ geochemistry/ breccia reefs/ minerals/ pitchblende/ intrusive igneous rocks/ metalliferous pegmatites/ veins/ uranium/ Colorado/ geology/ genesis/ production/ ore deposits/ igneous-metamorphic/
- Hart, S.R., 1964, The petrology and isotopic mineral age relations of a contact zone in the Front Range, Colorado: Jour. Geology, v. 72, p. 493-525.
petrology/ isotopes/ age dating/ minerals/ contact zone/ Front Range/
- Hawley, C.C., and Moore, F.B., 1955, Control of uranium deposition by garnet-quartz rocks in the Fall River area, Clear Creek County, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1675.
Fall River/ ore deposits/ genesis/ controls/ rocks/ garnet/ quartz/ Clear Creek County/ veins/ Colorado/ uranium/ ore control/ igneous-metamorphic/ pitchblende/

- _____. 1967, Geology and ore deposits of the Lawson-Dumont-Fall River district, Clear Creek County, Colorado: U.S. Geol. Survey Bull. 1231, 92 p., illus., tables, geol. map. Clear Creek County/ ore deposits/ resources/ occurrences/ areal geology/ genesis/ Lawson-Dumont-Fall River district/ vein deposits/ Idaho Springs Formation/ Precambrian/ Front Range/ metamorphic/ igneous-metamorphic/
- Heyse, J.V., 1971, Mineralogy and paragenesis of the Schwartzwalder mine uranium ore, Jefferson County, Colorado: U.S. Atomic Energy Comm. GHO-910-1, 91 p. Colorado/ uranium deposits/ uranium ores/ mineralogy/ petrology/ Schwartzwalder mine/ Jefferson County/ age estimation/ emission spectroscopy/ mines/ quantitative chemical analysis/ uraninite/ ore deposits/ Front Range/ igneous-metamorphic/ paragenesis/ pitchblende/
- Hickling, N.L., 1965, The mineralogy of allanite from the Boulder Creek batholith (M.S. thesis): Washington, D.C., American Univ. Boulder Creek batholith/ allanite/ mineralogy/ epidote/ igneous-metamorphic/ Precambrian/ Boulder County/ analysis/ geochemistry/
- _____. 1965, Allanites from the Boulder Creek batholith, Colorado: U.S. Geol. Survey open-file report. Boulder Creek batholith/ allanite/ mineralogy/ epidote/ igneous-metamorphic/ Precambrian/ Boulder County/ analysis/ geochemistry/
- Hickling, N.L., Phair, G., Moore, R., and others, 1970, Boulder Creek batholith, Colorado; Part I, Allanite and its bearing upon age patterns: Geol. Soc. America Bull., v. 81, no. 7, p. 1973-1993, illus. (incl. sketch maps). Boulder Creek batholith/ Colorado/ uranium/ thorium/ age/ allanite/ mineralogy/ origin/ paragenesis/ Silver Plume batholith/ igneous-metamorphic/ Jefferson County/ Clear Creek County/ Gilpin County/ Boulder County/ Larimer County/ Summit County/ Grand County/
- Hill, J.M., 1945, Unwatering and sampling of the Kirk mine, Gilpin County, Colorado, Part I. Geology of the Kirk Mine, Gilpin County, Colorado, Part II.: U.S. Atomic Energy Comm. RMO-47, 28 p. Gilpin County/ Kirk mine/ geology/ sampling/ igneous-metamorphic/

Hillebrand, W.F., 1890, On the occurrence of nitrogen in uraninite and on the composition of uraninite in general: U.S. Geol. Survey Bull. 78, p. 43-79.
 regional/ ore deposits/ geochemistry/ nitrogen/ properties/ Black Hawk/ analysis/ Gilpin County/ nitrogen/ igneous-metamorphic/

1890, On the occurrence of nitrogen in uraninite and on the composition of uraninite in general: Am. Jour. Sci., ser. 3, v. 40, p. 384-394.
 regional/ ore deposits/ uraninite/ geochemistry/ nitrogen/ properties/ Black Hawk/ Gilpin County/ igneous-metamorphic/ nitrogen/

Hirschi, H., 1923, Radioaktivitaet zweier Eruptivgesteine and ihre genetische Beziehung zur Pechblende von Central City, Colorado (Radioactivity of volcanic rocks and its genetic relationship to pitchblende at Center City, Colorado): Schweizer Mineralog. U. Petrogr. Mitt., v. 3, nos. 3-4, p. 240-252.
 igneous-metamorphic/ Clear Creek County/ volcanic rocks/ pitchblende/ Central City/ genesis/ volcanics/

Hurley, P.M., and Fairbairn, H.W., 1957, Abundance and distribution of uranium and thorium in zircon, sphene, apatite, epidote, and monazite in granitic rocks: U.S. Geol. Survey TEI-636, 20 p., (see Am. Geophys. Union Trans. 38, no. 6: 939-944, 1957).
 Uranium/ thorium/ abundance/ distribution/ zircon/ analyses/ sphere/ apatite/ epidote/ monazite/ granite/ minerals/ igneous-metamorphic/ pegmatites/ mineralogy/ Climax/ Colorado/ Massachusetts/ Nova Scotia/ Canada/ Germany/ El Paso County/ Eagle County/ Lake County/ Summit County/

Jenkins, E.D., 1961, Records and logs of selected wells and test holes, and chemical and radiometric analysis of ground water in the Boulder area, Colorado: Colorado Water Conserv. Board Ground-Water Ser. Basic Data Rept. 5, 30 p., illus., tables.
 records/ logs/ wells/ test holes/ chemical analysis/ radiometric analysis/ ground water/ Boulder area/ Boulder County/ ground water data/ logs/ analyses/

- Kaiser, E.P., and Page, L.R., 1952, Distribution of uranium deposits in United States: U.S. Geol. Surv. Circ. 220, p. 1-7, (maps).
regional/ ore deposits/ distribution/
- Kaiser, E.P., King, R.U., Wilmarth, V.R., and others, 1952, Selected papers on uranium deposits in the United States: U.S. Geol. Survey Circ. 220, 35 p., maps (see U.S. Geol. Survey TEI-168).
Front Range/ pitchblende/ sandstone/ igneous-metamorphic/ coal/ shale/ Archuleta County/ Routt County/ Eagle County/ Pitkin County/ Gunnison County/ San Juan County/ Park County/ Fremont County/ Huerfano County/ Ouray County/ Colorado Plateau/ ore deposits/
- Kehn, T.M., 1955, Selected annotated bibliography of the geology of uranium-bearing coal and carbonaceous shale in the United States: U.S. Geol. Survey TEI-533 (see U.S. Geol. Survey Bull. 1059-A, p. 1-28).
bibliography/ geology/ shale/ uranium/ coal/ lignite/ Great Plains/ Leyden Coal mine/ Jefferson County/ carnotite/ Moffat County/ gilsonite/ Jackson County/
- _____, 1957, Selected annotated bibliography of the geology of uranium-bearing coal and carbonaceous shale in the United States: U.S. Geol. Survey Bull. 1059-A.
regional/ ore deposits/ occurrence/ coal/ shale/ carbonaceous/ bibliography/ uranium/ geology/
- Keller, G.V., 1953, Progress report on petrophysical studies of the Morrison formation: U.S. Geol. Survey TEM-608, 10 p.
Colorado Plateau/ electric well logs/ Morrison Formation/ Spud Patch area/ Montrose County/ San Miguel County/ geophysical investigations/ petrophysical studies/ sandstone/
- Kelly, F.N., 1962, Technological economic problems of rare-earth and thorium resources in Colorado, New Mexico and Wyoming: U.S. Bur. Mines IC-8124, 38 p.
thorium/ Wet Mountains/ Custer County/ El Paso County/ Fremont County/ Gunnison County/ Jefferson County/ Gilpin County/ Park County/ mineralogy/ Powderhorn district/ rare earths/ resources/ igneous-metamorphic/ Colorado/

Kerr, P.F., 1950, Mineralogical studies of uraninite and uraninite-bearing deposits, July 1, 1949-June 30, 1950: U.S. Atomic Energy Comm. RMO-715, 56 p.
 uraninite/ Canada/ Idaho/ eastern Colorado/ Lake Superior/ Wood's Hole/ Colorado/ Caribou/ Radium vein/ Boulder County/ igneous-metamorphic/ Front Range/ mineralogy/

1956, Rock alteration criteria is the search for uranium, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 633-639.
 veins/ rock alteration/ prospecting/ exploration/ uranium/ Colorado Plateau/ Colorado/ general/ sandstone/

1956, The natural occurrence of uranium and thorium, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 5-59.
 uranium/ thorium/ occurrences/ veins/ sediments/ worldwide/

1956, Rock alteration criteria in the search for uranium, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 679-685.
 veins/ rock alteration/ prospecting/ exploration/ uranium/ Colorado Plateau/ Colorado/ general/ sandstone/

Kerr, P.F., Anderson, T.P., and Hamilton, Peggy-Kay, 1951, Bellevue-Rochester mine, in Annual report for July 1, 1950 to June 30, 1951: U.S. Atomic Energy Comm. RMO-797, p. 44-57.
 veins/ Bellevue-Rochester mine/ igneous-metamorphic/ Clear Creek County/ alteration/ Front Range/

King, R.U., 1950, Vein deposits of uranium at the Caribou mine, Boulder County, Colorado: U.S. Geol. Survey TEM-13, 23 p., maps, tables.
 Boulder County/ pitchblende/ base and precious metals/ metalliferous deposits/ veins/ igneous-metamorphic/ Caribou mine/ geology/ ore deposits/ No Name vein/ Radium vein/ Precambrian/ silver/ uranium/ lead/ zinc/ analyses/ Front Range/

1950, A radiometric traverse at the Apex claims
(Bates Creek), Gilpin County, Colorado: U.S. Geol.
Survey TEM-22, 4 p.
Gilpin County/ Apex claims/ Bates Creek/ Front Range/
ore deposits/ igneous-metamorphic/

1950, Investigations in the Wood mine, Colorado:
U.S. Geol. Survey TEM-102, 3 p.
Central City district/ Gilpin County/ pitchblende/ Wood
mine/ igneous-metamorphic/ Front Range/ ore deposits/

1951, Reconnaissance investigations for uranium in
the Colorado Front Range, 1947-1951: U.S. Geol. Survey
TEI-58, 260 p., (see U.S. Geol. Survey Circ. 215, U.S.
Geol. Survey Prof. Paper 300, U.S. Geol. Survey Bull.
1159).
reconnaissance/ Front Range/ geology/ mineralogy/ ore
deposits/ pitchblende/ Boulder County/ Clear Creek County/
Gilpin County/ Chaffee County/ Custer County/ Douglas
County/ El Paso County/ Fremont County/ Huerfano County/
Jefferson County/ Larimer County/ Teller County/ veins/
igneous-metamorphic/ stream sediments/ spring deposits/
shear zones/ pegmatites/ sandstone/ coal/

1951, Radioactivity in the Jo Reynolds mine, Clear
Creek County, Colorado: U.S. Geol. Survey Tem-5, 11 p.,
tables, maps.
Lawson area/ Clear Creek County/ Jo Reynolds mine/
minerals/ pitchblende/ metalliferous deposits/ base
and precious metals/ veins/ igneous-metamorphic/ ore
deposits/ geology/ schist/ granite/ Precambrian/ Elida
tunnel/ Front Range/

1951, Investigations in the Wood mine, Colorado:
U.S. Geol. Survey TEM-102-A, 1 p.
Central City/ Wood mine/ ore deposits/ pitchblende/
investigations/ Gilpin County/ igneous-metamorphic/
Front Range/

1952, Vein deposits of uranium at the Caribou mine,
Boulder County, Colorado: U.S. Geol. Survey TEM-13A,
18 p., geol. map.
ore deposits/ Boulder County/ Caribou mine/ vein deposits/
No Name vein/ Radium vein/ uranium/ igneous-metamorphic/
Front Range/ pitchblende/

- 1952, Vein deposits of uranium at the Caribou mine (abs.): Nuclear Sci., v. 6, no. 1, p. 28.
uranium/ veins/ Caribou mine/ Boulder County/ Front Range/ igneous-metamorphic/ pitchblende/ ore deposits/
- 1953, Reconnaissance for uranium in the United States; Colorado-Wyoming district, in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1953: U.S. Geol. Survey TEI-390, p. 205-209 (sketch map).
reconnaissance/ Front Range/ igneous-metamorphic/ Boulder County/ Clear Creek County/ Park County/ Summit County/ summary/ 1953/ ore deposits/
- 1954, Reconnaissance for uranium in the United States, Colorado district, in Geologic investigations of radioactive deposits - Semiannual progress report, Dec. 1, 1953, to May 31, 1954: U.S. Geol. Survey TEI-440, p. 173-175.
regional/ ore deposits/ exploration/ veins/ Ralston Creek/ Jefferson County/ Coperdale/ Lake George/ Park County/ summary/ 1954/ igneous-metamorphic/ Front Range/
- King, R.U. and Beroni, E.P., 1953, Regional reconnaissance for uranium and thorium in the United States; Colorado - Wyoming district, in Search for and geology of radioactive deposits - Semiannual progress report, Dec. 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 208-213, (sketch maps).
igneous-metamorphic/ reconnaissance/ Jefferson County/ Park County/ El Paso County/ Clear Creek County/ prospects/ summary/ 1953/ Front Range/ ore deposits/
- King, R.U., and Granger, H.C., 1952, Torbernite occurrence at the Robineau Claims, Clear Creek County, Colorado: U.S. Geol. Survey TEM-24A, 7 p., (geol. sketch map).
Clear Creek County/ torbernite/ George Peabody claim/ Little Mac claim/ MacGregor claim/ Robineau claims/ Front Range/ granite/ pegmatites/ veins/ igneous-metamorphic/ ore deposits/
- King, R.U., and Moore, F.B., 1951, Pitchblende deposits in the United States (abs.): Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1537, (see U.S. Geol. Survey TEI-1681).
distribution/ pitchblende/ ore deposits/ United States/ Colorado/ general/ occurrence/ Front Range/ sandstone/ igneous-metamorphic/ sedimentary rock/
- King, R.U. and Theobald, P.K., Jr., 1955, Colorado, in Geologic investigations of radioactive deposits - Semiannual progress report, December 1, 1954, to May 31, 1955: U.S. Geol. Survey TEI-540, p. 208-209.
Canon City/ Idledale/ ore deposits/ exploration/ Fremont County/ Jefferson County/ veins/ FMD mine/ Front Range/ Summary/ 1955/ igneous-metamorphic/

- 1955, Blackhawk district, Gilpin County, in Geologic investigations of radioactive deposits - Semiannual progress report, Dec. 1, 1954, to May 31, 1955: U.S. Geol. Survey TEI-540, p. 141-142.
veins/ Gilpin County/ Blackhawk district/ Silver Hill/ igneous-metamorphic/ summary/ 1955/ Front Range/ ore deposits/
- King, R.U., Leonard, B.F., Moore, F.B., and others, 1952, Uranium in the metal-mining districts of Colorado: U.S. Geol. Survey TEI-173 (see U.S. Geol. Survey Circ. 215, GSA Bull. v. 63, no. 12, pt. 2, p. 1335).
Front Range/ Boulder County/ Clear Creek County/ Eagle County/ Garfield County/ Gilpin County/ Jefferson County/ Larimer County/ Moffat County/ Pitkin County/ pitchblende/ hydrocarbons/ hot spring deposits/ limestone/ pegmatites/ sandstone/ veins/ breccia pipes/ igneous-metamorphic/ Park County/ Lake County/ geology/ mineralogy/ San Miguel County/ ore deposits/ metal-mining districts/
- 1953, Uranium in the metal-mining districts of Colorado: U.S. Geol. Survey Circ. 215, 10 p., (see U.S. Geol. Survey TEI-173).
Front Range/ Boulder County/ Clear Creek County/ Eagle County/ Garfield County/ Gilpin County/ Jefferson County/ Larimer County/ Moffat County/ Pitkin County/ pitchblende/ hydrocarbons/ hot springs deposits/ limestone/ sandstone/ veins/ breccia pipes/ igneous-metamorphic/ Park County/ Lake County/ geology/ mineralogy/ San Miguel County/ ore deposits/ metal-mining districts/
- King, R.U., Moore, F.B., and Leonard, B.F., 1952, Uranium in metal-mining districts of Colorado (abs.): Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1335 (see U.S. Geol. Survey TEI-173).
Front Range/ Boulder County/ Clear Creek County/ Eagle County/ Garfield County/ Gilpin County/ Jefferson County/ Kiowa County/ Larimer County/ Moffat County/ Pitkin County/ Rio Blanco County/ Routt County/ ore guides/ pitchblende/ theories of origin/ hydrocarbons/ hot spring deposits/ limestone/ sandstone/ veins/ breccia pipes/ ore deposits/ igneous-metamorphic/ metal-mining districts/ fluorite/

-
- 1952, Pitchblende deposits in the United States, in Selected papers on uranium deposits in the United States: U.S. Geol. Survey Circ. 220, p. 8-12.
 veins/ occurrence/ United States/ Colorado/ uranium/
 Front Range/ San Miguel County/ pitchblende/ ore deposits/
 distribution/ Larimer County/ Jefferson County/ Gilpin
 County/ Clear Creek County/ Central City/ Ralston Creek/
 Jamestown/ Caribou/ Lawson/ igneous-metamorphic/
- Klepper, M.R., and Wyant, D.G., 1956, Uranium provinces, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 17-25.
 uranium/ United States/ general/ Colorado/ geochemistry/
 origin/ prospecting/ provinces/
-
- 1956, Uranium provinces, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 217-223.
 uranium/provinces/ United States/ general/ Colorado/
 geochemistry/ origin/ prospecting/
- Knox-Bergman-Shearer Corp., 1970, Areal geologic and structural interpretation map of Front Range, Colorado: U.S. Atomic Energy Comm. Prelim. Map No. 14.
 geology/ structure/ Front Range/ map/
- Kober, C.L., and Procter-Gregg, H.D., 1977, Discrimination of uranium alteration zones on selected areas by use of LANDSAT MSS imagery: U.S. Energy Research and Devel. Adm. GJBX-4(77).
 uranium/ alteration zones/ LANDSAT MSS imagery/
- Krusiewski, S.V., 1970, Selected bibliography on radioactive occurrences in the United States: U.S. Atomic Energy Comm. RME-4110 136 p.
 USA/ uranium deposits/ bibliographies/ geology/ geochem-
 istry/ uranium ores/ geologic deposits/ natural radio-
 activity/ mineralogy/ rocks/ occurrences/ ore deposits/
- Lahr, M., 1974, Map of Schwartzwalder Mine area, Ralston Buttes Quadrangle, Jefferson County, Colorado: Lakewood, Colorado, Cotter Corporation, Unpub. company map.
 Front Range/ map/ Schwartzwalder Mine/ Ralston Buttes
 quadrangle/ Jefferson County/ igneous-metamorphic/ ore
 deposits/

- Langford, F.F., 1974, A supergene origin for vein-type uranium ores in the light of the western Australian calcrete-carnotite deposits: *Econ. Geology*, v. 69, no. 4, p. 516-526.
uranium deposits/ western Australia/ supergene/ origin/ veins/ uranium/ calcrete/ carnotite/ ore deposits/ Colorado/ general/ igneous-metamorphic/ sandstone/
-
- 1977, Surficial origin of North American pitchblende and related uranium deposits: *Am. Assoc. Petroleum Geologists Bull.*, v. 61, no. 1, p. 28-42.
origin/ genesis/ surficial origin/ pitchblende/ ore deposits/ uranium/ igneous-metamorphic/ surface waters/ sandstone/ Colorado Plateau/ Front Range/
- Larsen, E.S., 3d, 1957, Distribution of uranium in igneous complexes: U.S. Geol. Survey TEI-700, p. 249-253, prepared by U.S. Geol. Survey.
analysis/ Colorado/ Wyoming/ Montana/ igneous-metamorphic/ quartz monzonite/ granite/ Log Cabin batholith/ Sherman batholith/ solubility/ uranium/ thorium/ Front Range/ Gilpin County/ Clear Creek County/ Boulder County/
- Larsen, E.S., and Berman, Harry, 1926, The identity of gilpinite and johannite: *Am. Mineralogist*, v. 11, no. 1, p. 1-5, illus.
gilpinite/ geochemistry/ properties/ Gilpin County/ Colorado/ igneous-metamorphic/ johannite/ mineralogy/
- Larsen, E.S., and Brown, G.V., 1917, Gilpinite, a new uranium mineral from Colorado: *Am. Mineralogist*, v. 2, p. 75-79.
Gilpinite/ uranium/ Colorado/ Gilpin County/ igneous-metamorphic/
- Larsen, E.S., and Phair, George, 1957, the distribution of uranium and thorium in igneous rocks: *Nuclear geology - A symposium on nuclear phenomena in the earth sciences*, p. 75-89.
- Lee, H.A., 1901, Uranium in Colorado: *Eng. and Mining Jour.*, v. 71, p. 564.
regional/ ore deposits/ uranium/ Colorado/
-
- 1901, Mining in Colorado: *Mines Miner.*, v. 21, p. 415-416.
Colorado/ mining/

Leonard, B.F., 3d, 1952, Relation of pitchblende deposits to hypogene zoning in the Front Range mineral belt, Colorado (abs.): Econ. Geology, v. 47, no. 7, p. 773.
Front Range/ ore deposits/ pitchblende/ zoning/ hypogene/ veins/ uranium/ Colorado/ Larimer County/ Boulder County/ Jefferson County/ Gilpin County/ Clear Creek County/ igneous-metamorphic/

1952, Relation of pitchblende deposits to hypogene zoning in the Front Range mineral belt, Colorado (abs.): Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1274-1275 (see Econ. Geology, v. 47, p. 773).
veins/ Front Range area/ mineralogy/ petrology/ hypogene zoning/ pitchblende/ geochemistry/ Colorado/ ore deposits/ igneous-metamorphic/ Central City/ uranium/ bostonite/ Gilpin County/ Clear Creek County/ Larimer County/ Boulder County/ Jefferson County/

1952, Preliminary summary on zonal relations of uranium deposits in metalliferous districts: U.S. Geol. Survey TEM-521, 10 p.
Central City/ Front Range/ pitchblende/ metalliferous deposits/ base metals/ precious metals/ Clear Creek County/ igneous-metamorphic/ Gilpin County/ zoning/ ore deposits/

1953, Relation of pitchblende deposits to hypogene zoning in the Front Range mineral belt, Colorado (abstr.): Am. Mineralogist, v. 38, nos. 3-4, p. 348-349.
regional/ ore deposits/ zoning/ pitchblende/ hypogene zoning/ Front Range/ Colorado/ igneous-metamorphic/ Central City/ Gilpin County/ Clear Creek County/

1953, Zonal relations of uranium deposits in metalliferous districts, Colorado: U.S. Geol. Survey TEI-270, pt. 1, p. 19-21.
pitchblende/ ore deposits/ zoning/ metalliferous districts/ Front Range/ Gilpin County/ Clear Creek County/ Lake County/ igneous-metamorphic/ Pitkin County/ Teller County/ San Juan County/ Couer d'Alene/ Idaho/

LeRoy, L.W., 1969, Precambrian stratigraphy northwest of Golden, Jefferson and Gilpin Counties, Colorado - a summary: Golden, Colorado, Colorado School of Mines, unpublished notes for students and faculty.
Precambrian/ stratigraphy/ Golden, Jefferson County/ Gilpin County/ Front Range/ igneous-metamorphic/

- Lickus, R.J., and LeRoy, L.W., 1968, Precambrian structure and stratigraphy along the mountain front west of Golden, Jefferson County, Colorado - a reconnaissance study: Colorado School of Mines Quart., v. 63, no. 1, p. 129-165.
Precambrian/ structure/ stratigraphy/ Front Range/ reconnaissance/ Golden/ Jefferson County/ igneous-metamorphic/
- Lindgren, Waldemar, 1933, Ores of copper, lead, vanadium, and uranium in sandstone and shale, in Mineral deposits (4th ed): New York, McGraw-Hill Book Co., p. 403-415.
copper/ lead/ vanadium/ uranium/ sandstone/ shale/ carnotite/ roscoelite/ Colorado Plateau/ San Miguel County/ Mesa County/ Montrose County/ Dolores County/ Entrada Sandstone/ La Plata Sandstone/ McElmo Formation/ genesis/ Gilpin County/ igneous-metamorphic/ ore deposits/
- Lovering, T.G., and Beroni, E.P., 1956, Preliminary study of radioactive limonite localities in Colorado, Utah and Wyoming: U.S. Geol. Survey TEI-427 (see U.S. Geol. Survey Bull. 1046-N).
Diamond J Ranch/ Golden Gate Canyon/ Haputa Ranch area/ Ouray hot springs/ Chaffee County/ Custer County/ El Paso County/ Gunnison County/ Jefferson County/ Ouray County/ limonite/ Lucky Break Iron mine/ thorium/ uranium/ sandstone/ conglomerate/ limestone/ tufa/ analysis/ igneous-metamorphic/ ore deposits/
- _____, 1959, Preliminary study of radioactive limonite in Colorado, Utah, and Wyoming: U.S. Geol. Survey Prof. Paper 1046-N, p. 339-384.
Diamond J Ranch/ Golden Gate Canyon/ Haputa Ranch area/ Ouray hot springs/ Chaffee County/ Custer County/ El Paso County/ Gunnison County/ Jefferson County/ Ouray County/ limonite/ Lucky Break Iron mine/ thorium/ uranium/ sandstone/ conglomerate/ limestone/ tufa/ igneous-metamorphic/ ore deposits/
- Lovering, T.S., 1942, The mineral belt of the Colorado Front Range, in Newhouse, W.H., ed., Ore deposits as related to structural features: Princeton, N.J., Princeton Univ. Press, p. 79-93. (prepared under the direction of the committee on processes of ore deposition of the Div. of Geol. and Geog. on the National Research Council.)
Colorado/ Front Range/ mineral belt/ ore deposits/ structural features/ igneous-metamorphic/

Lovering, T.S., and Goddard, E.N., 1938, Laramide igneous sequence and differentiation in the Front Range, Colorado: Beol. Soc. America Bull., f. 49, p. 35-68.
Laramide/ tectonics/ differentiation/ igneous rock/ correlations/ geochemistry/ petrology/ Boulder County/ Grand County/ Summit County/ Gilpin County/ Clear Creek county/ Park County/ Larimer County/ Teller County/ Jefferson County/ Front Range/ igneous-metamorphic/

1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. Paper 223, 319 p., illus (incl. geol. map).
veins/ Front Range/ Colorado/ economic geology/ production/ uranium/ Quartz Hill/ Clear Creek County/ geology/ ore deposits/ Gilpin County/ Central City/ igneous/ bostonite porphyry/ igneous-metamorphic/

Lovering, T.S., Lakin, H.W. Ward, F.N., and others, 1956, The use of geochemical techniques and methods in prospecting for uranium, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 659-665.
geochemical techniques/ methods/ prospecting/ uranium/ analysis/ regional/ generation/ Colorado/ geochemistry/

1956, The use of geochemical techniques and methods in prospecting: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 782-787/
geochemical techniques/ methods/ prospecting/ uranium/ analysis/ general/ Colorado/ geochemistry/

Malan, R.C., 1972, Summary report: Distribution of uranium and thorium in the Precambrian of the western United States: U.S. Atomic Energy Comm. RD-12, 64 p., (for abstract see NSA 29:20849).
Arizona/ California/ Colorado/ Nevada/ Wyoming/ geologic deposits/ uranium/ throrium/ abundance/ quantitative chemical analysis/ distribution/ sedimentary rocks/ chemical composition/ natural occurrence/ Precambrian/ igneous-metamorphic/

- Malan, R.C., and Sterling, D.A., 1969, A geologic study of uranium resources in Precambrian rocks of the western United States. 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 54 p., (for abstract see NSA 31:22596).
California/ Nevada/ New Mexico/ Arizona/ uranium reserves/ uranium deposits/ geology/ thorium minerals/ uranium minerals/ distribution/ ore composition/ Precambrian/ Colorado Plateau/ Colorado/ igneous-metamorphic/ resources/
-
- _____, 1970, Distribution of uranium and thorium in the Precambrian of the West-Central and Northwest United States: U.S. Atomic Energy Comm. AEC-RD-11 64 p., (for abstract see NSA 31:22598).
Colorado/ Utah/ Wyoming/ South Dakota/ Montana/ Idaho/ Washington/ natural occurrence/ ore composition/ potassium/ uranium reserves/ Precambrian/ Colorado/ igneous-metamorphic/ resources/
- Mallory, N.S., and Bird, A.G., 1953, Final report: Airborne radiation detection survey, Jefferson County, Colorado and adjacent areas: U.S. Atomic Energy Comm. RME-1041, 10 p. (for abstract see NSA 32:00688).
Colorado/ aerial prospecting/ geology/ Jefferson County/ Ralston Creek area/ Dawson Arkose/ James Peak area/ Boulder County/ Adams County/ Larimer County/ Gilpin County/ igneous-metamorphic/ Idaho Springs Formation/ sandstone/ Dakota Formation/ Morrison Formation/ Front Range/
- Marvin, R.F., Young, E.J., Mehnert, H.H., and others, 1974, Summary of radiometric age determinations on Mesozoic and Cenozoic igneous rocks and uranium and base metal deposits in Colorado: Isochron West, no. 11, p. 1-41.
radiometric ages/ Mesozoic/ Cenozoic/ igneous-metamorphic/ uranium/ base metals/ ore deposits/
- Maxwell, C.H., 1955, Bedrock geology of area west of Denver, in Geology of Front Range Foothills, west of Denver: Rocky Mtn. Assoc. of Geologist Guidebook, 98 p.
bedrock geology/ Front Range/ igneous-metamorphic/
- McCarn, D.W., and Freeman, R.W., 1976, Chemical analysis of ground and surface water samples from parts of the United States, 1956-1975: U.S. Energy Research Devel. Adm. GJBX-51(76).
ground water/ surface water/ United States/ uranium/ chemical analysis/

-
- 1956, Summary of hypotheses of genesis of uranium deposits, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 41-53.
 veins/ bituminous substances/ regional/ Colorado/ general/ summary/ hypotheses of genesis/ genesis/ uranium/ ore deposits/ igneous rocks/ pegmatites/ migmatites/ coal/ replacement/ sandstone/ shale/ phosphorites/ origin/ igneous-metamorphic/
-
- 1956, Summary of hypothesis of genesis of uranium deposits, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 5, p. 551-561.
 veins/ bituminous substances/ summary/ hypotheses of genesis/ regional/ Colorado/ general/ genesis/ uranium/ ore deposits/ igneous rock/ pegmatites/ migmatites/ replacement/ sandstone/ coal/ shale/ phosphorites/ origin/ igneous-metamorphic/
- McKelvey, V.E., Page, L.R., Fischer, R.P., 1951, Domestic resources of uranium and thorium -- a summary based upon investigations by the U.S. Geological Survey: U.S. Geol. Survey TEI-150, 108 p.
 geochemistry/ mineralogy/ geophysics/ geobotany/ veins/ pitchblende/ thorium/ uranium/ resources/ exploration/ igneous-metamorphic/ Front Range/ Gilpin County/ Clear Creek County/ pegmatites/ sandstone/ limestone/ Colorado Plateau/ Custer County/ Gunnison County/ Boulder County/ Larimer County/ Jefferson County/ coal/
-
- 1952, Uranium deposits in the United States (abs.): Econ. Geology, v. 47, no. 1, p. 125.
 uranium/ ore deposits/ United States, distribution/ occurrence/ igneous-metamorphic/ sandstone/ shale/ phosphorites/ Colorado Plateau/ Colorado/ general/
- McKeown, F.A., and Gude, A.J., 3d, 1951, Preliminary report on the carnotite deposits of the Old Leyden coal mine, Jefferson County, Colorado: U.S. Geol. Survey TEM-308, 9 p., figures.
 minerals/ carnotite/ clay/ coal/ lignite/ sandstone/ Laramie Formation/ Front Range/ Jefferson County/ ore deposits/ Old Leyden Coal mine/ reserves/ geology/ structure/

Merewether, E.A., 1960, Geologic map of the igneous and metamorphic rocks of Colorado showing location of uranium deposits: U.S. Geol. Survey I-309, scale 1:500,000.
regional/ ore deposits/ occurrence/ resources/ maps/
igneous rocks/ metamorphic rocks/

Merritt, P.L., 1950, Uranium exploration in the United States: Rocks and Minerals, v. 25, nos. 7-8, p. 363-370.
uranium/ Colorado Plateau/ Front Range/ Colorado/ exploration/ programs/ Morrison Formation/ phosphates/ shale/ sandstone/ igneous-metamorphic/ Mesa County/ Montrose County/ San Miguel County/ Montezuma County/ Dolores County/ Gilpin County/ Clear Creek County/ Garfield County/

1950, Uranium exploration in the United States: Canadian Mining and Metall. Bull., v. 43, no. 460, p. 438-443.
uranium/ exploration/ Colorado Plateau/ sandstone/ Morrison Formation/ Entrada Sandstone/ Mesa County/ Montrose County/ San Miguel County/ Dolores County/ Montezuma County/ Front Range/ Boulder County/ Gilpin County/ Clear Creek County/ Caribou district/ igneous-metamorphic/

1950, Uranium exploration in the United States: Mines Mag., v. 40, no. 6, p. 36, 51-52.
uranium/ Colorado Plateau/ Morrison Formation/ Entrada Sandstone/ sandstone/ Mesa County/ Montrose County/ San Miguel County/ Dolores County/ Montezuma County/ Front Range/ Boulder County/ Gilpin County/ Clear Creek County/ Caribou district/ igneous-metamorphic/

Merritt, R.C., and Pings, W.B., 1969, Processing of uranium ores: Colorado School Mines Mineral Industries Bull., v. 12, no. 6, 20 p.
uranium ore treatment/ processing/ history/ mining/

Merwin, S.S., 1956, Colorado Front Range uranium districts: Uranium, v. 3, no. 6, 24 p., illus.
Front Range/ ore deposits/ occurrence/ uranium/ Colorado/ districts/ igneous-metamorphic/

1956, Uranium occurrences, control, and potential of Colorado's Front Range: Uranium, v. 3, no. 3, 86 p. illus.
Front Range/ ore deposits/ occurrence/ possibilities/ controls/ Colorado/

-
- 1956, Uranium ore deposition, theory of control by thrust faults (Colorado): Uranium, v. 3, no. 5, p. 30-31, 34-36, illus. (incl. geol. map).
Regional/ ore deposits/ genesis/ structural controls/ faults/ thrust/ theoretical studies/ Colorado/
- Moench, R.H., 1953, Idaho Springs district, in Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1953: U.S. Geol. Survey TEI-390, p. 104-105.
mapping/ Idaho Springs district/ Precambrian/ veins/ igneous-metamorphic/ mineralogy/ Stanley mines/ Lawrence L claim/ P.J. claim (?)/ radioactivity/ Clear Creek County/ Gilpin County/ Front Range/
-
- 1964, Geology of Precambrian rocks, Idaho Springs district, Colorado: U.S. Geol. Survey Bull. 1182-A, p. A1-A70, illus. (incl. tables, geol. map).
geology/ Precambrian/ metamorphic/ Idaho Springs/ Front Range/ petrography/ Clear Creek County/ Gilpin County/ igneous-metamorphic/
- Moench, R.H., and Drake, A.A., Jr., 1966, Economic geology of the Idaho Springs district, Clear Creek and Gilpin Counties, Colorado: U.S. Geol. Survey Bull. 1208, 91 p.
economic geology/ pitchblende/ coffinite/ uranophane/ Idaho Springs/ Clear Creek County/ Gilpin County/ mineralogy/ metamorphic/ ore deposits/ Front Range/ production/ igneous-metamorphic/
- Moench, R.H., Harrison, J.E., and Sims, P.K., 1954, Precambrian structures in the vicinity of Idaho Springs, Front Range, Colorado (abs.): Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1383-1384.
Precambrian/ structure/ Idaho Springs/ Front Range/ Colorado/ geology/ Gilpin County/ Clear Creek County/ Jefferson County/ Colorado/ igneous-metamorphic/
-
- 1962, Precambrian folding in the Idaho Springs-Central City area, Front Range, Colorado: Geol. Soc. America Bull., v. 73, p. 35-58.
Precambrian/ structure/ Idaho Springs/ Central City/ Front Range/ Colorado/ Gilpin County/ Clear Creek County/ igneous-metamorphic/

Moore, F.B., 1953, Dumont-Fall River area, in Search for and geology of radioactive deposits, semiannual progress report, December 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 96.
Dumont-Fall River area/ Clear Creek County/ radioactivity/ vein/ Golden Calf mine/ igneous-metamorphic/ Front Range/

Moore, F.B., and Butler, C.R., 1950, Pitchblende deposits at the Wood and Calhoun mines, Central City mining district, Gilpin County, Colorado: U.S. Geol. Survey TEM-198, 22 p., (see U.S. geol. Survey Circ. 186) maps. ore deposits/ Gilpin County/ Central City district/ pitchblende/ Calhoun (east and west) mines/ Wood mine/ metalliferous deposits/ base and precious metals/ veins/ igneous-metamorphic/ Front Range/ geology/ reserves/ metamorphic rock/ bostonite porphyry/ Front Range/

1952, Pitchblende deposits at the Wood and Calhoun mines, Central City mining district, Gilpin County, Colorado: U.S. Geol. Survey Circ. 186, 8 p., illus. (incl. geol. sketch maps) see U.S. Geol. Survey TEM-198. Gilpin County/ Central City/ ore deposits/ pitchblende/ Wood mine/ Calhoun mine/ veins/ igneous-metamorphic/ Front Range/ metamorphic rock/ bostonite porphyry/ Front Range/

Moore, F.B., and Cavender, W.S., 1952, The pitchblende deposit at the Caribou mine, Boulder County, Colorado (abs.): Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1281 (see U.S. Geol. Survey TEI-228).
pitchblende/ Caribou mine/ Boulder County/ Colorado/ uranium/ igneous-metamorphic/ veins/ ore deposits/ Front Range/

1952, Pitchblende deposit at the Caribou Mine, Boulder County, Colorado: Econ. Geology, v. 47, p. 775. veins/ Caribou mine/ Boulder County/ Colorado/ pitchblende/ igneous-metamorphic/ monzonite/ uranium/

1953, Pitchblende deposits at the Caribou mine, Boulder County, Colorado (abs.): Am. Mineralogist, v. 38, p. 352.
pitchblende/ Caribou mine/ Boulder county/ Colorado/ veins/ monzonite/ igneous-metamorphic/ ore deposits/

Moore, F.B., and Hawley, C.C., 1952, Geology and ore deposits of the Lawson-Dumont-Fall River district, Clear Creek County, Colorado: U.S. Geol. Survey TEI-358.
geology/ ore deposits/ Larson-Dumont-Fall River district/ Clear Creek County/ igneous-metamorphic/ Front Range/

1953, Dumont-Fall River region, in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1953: U.S. Geol. Survey TEI-390, p. 106.

Dumont-Fall River/ Clear Creek County/ igneous-metamorphic/ mapping/ veins/ radioactivity/ Front Range/

Moore, F.B., Cavender, W.S., and Kaiser, E.P., 1954, Geology and uranium deposits of the Caribou area, Boulder County, Colorado: U.S. Geol. Survey TEI-228, (see U.S. Geol. Survey Bull. 1030-N; Geol. Soc. America Bull. v. 63, no. 12, pt. 2, p. 1281).
Boulder County/ Caribou area/ pitchblende/ ore deposits/ geology/ igneous-metamorphic/ Belcher mine/ Caribou mines/ Comstock mine/ Cross mine/ Great Northern mine/ Idaho mine/ No Name mine/ Poorman mine/ Potosi mine/ Radium vein/ St. Louis mine/ Seven-thirty mine/ Sherman mine/ Silver Point mine/ Socorro mine/ Spencer mine/ Wigwam mine/

1957, Geology and uranium deposits of the Caribou area, Boulder County, Colorado: U.S. Geol. Survey Bull. 1030-N, p. 517-552, illus. (1957, incl. geol. maps).
ore deposits/ Boulder County/ Caribou mine/ No Name Vein/ Radium Vein/ (1958)/

Moore, F.B., King, R.U., and Hinrichs, E.N., 1951, Proposed exploration for uranium in the Front Range mineral belt, Colorado: U.S. Geol. Survey TEM-215, 22 p., figures.
Caribou district/ Central City district/ Front Range/ Clear Creek County/ Gilpin County/ Boulder County/ ore deposits/ Grand Island district/ Jamestown district/ Lawson area/ Quartz Hill/ fluorite deposits/ Calhoun mines/ Caribou mines/ Jo Reynolds mine/ Kirk mine/ Wood mine/ pitchblende/ breccia deposits/ igneous-metamorphic/

Moore, R.B., 1913, A preliminary report on uranium, radium, and vanadium: U.S. Bur. Mines. Bull. 70, 101 p.
Regional/ ore deposits/ carnotite/ Colorado/ Utah/ mining/ uranium/ radium/ vanadium/ North Carolina/ marketing/ uranium belt/ San Miguel County/ Montrose County/ Mesa County/ Gilpin County/ pitchblende/ Huerfano County/ Colorado Plateau/ Front Range/ sandstone/ igneous-metamorphic/

- Moya, E.A., 1969, Structural and stratigraphic analyses of Precambrian rocks, North Clear Creek Area, Jefferson and Gilpin Counties, Colorado (M.S. thesis): Golden, Colorado, Colorado School of Mines.
structure/ stratigraphic/ analyses/ Precambrian/ North Clear Creek area/ Jefferson County/ Gilpin County/ igneous-metamorphic/ Front Range/
- Muench, O.B., 1940, Lead-uranium ratio of pitchblende from one of the youngest pegmatites; Colorado (abs.): Pan-American Geol., v. 73, no. 4, p. 376-377.
Colorado/ pitchblende/ ratio/ lead-uranium/pegmatites/ igneous-metamorphic/
- Murray, D.K., 1976, Energy resource development map of Colorado (map): Colorado Geol. Survey Map Series 6, scale 1:500,000
energy resources/ map/ uranium/ coal oil/ gas/ geothermal/ Colorado/
- Narten, P.F., Crawford, E., and Butler, A.P., Jr., 1951, Summary review of analytical data pertaining to the uranium content or radioactivity of domestic shales: U.S. Geol. Survey TEM-240.
Clear Creek County/ Garfield County/ Jefferson County/ Mesa County/ Montrose County/ Rio Blanco County/ Dakota Sandstone/ Fountain Formation/ Green River Formation/ Laramie Formation/ Hermosa Formation/ Paradox member/ shales/ sandstone/ Front Range/ Colorado Plateau/
- Nash, A.L., and Brown, L.J., 1954, Results of an airborne radiometric survey in the Canon City embayment area, Colorado (rev.): U.S. Atomic Energy Comm. RME-1050, 11 p., (sketch maps).
Canon City embayment/ airborne radiometrics/ surveying/ Pueblo County/ shale/ clay/ George Avery Ranch/ carnotite/ assay/s Hoyt Adkins Ranch/ Burgess prospect/ El Paso County/ Dawson arkose/ sandstone/ Fremont County/ geology/ Morrison Formation/ Dakota Formation/
- Neuerburg, G.J., Antweiler, J.C., and Bieler, B.H., 1955, Uranium content and leachability of some igneous rocks and their geochemical significance: U.S. Geol. Survey TEI-626.
uranium/ leachability/ igneous-metamorphic/ geochemistry/ leaching studies/ analytical techniques/ Montana/ Arizona/ Front Range/ Colorado/ Wyoming/

Nishimori, R.K., Ragland, P.C., Rogers, J.J., and others,
1977, Uranium deposits in granitic rocks: U.S. Energy
Research Devel. Adm. GJBX-13 (77).
uranium/ ore deposits/ granite / igneous-metamorphic/

Osterwald, F.W., 1967, Relation of tectonic elements in Pre-
cambrian rocks to uranium deposits in the Cordilleran
Foreland of the western United States, in Geology of
uranium and thorium: U.N. Internat. Conf. on Peaceful
Uses of Atomic Energy, Geneva, 1955, Proc., v. 6,
p. 293-298.

veins/ Precambrian rocks/ uranium/ ore deposits/ Cor-
dilleran Foreland/ structures/ tectonics/ origin/ Routt
County/ Jackson County/ Larimer County/ Grand County/
Front Range/ Eagle County/ Summit County/Lake County/
Chaffee County/ Park County/ Douglas County/ Teller
County/ El Paso County/ Fremont County/ Pueblo County/
Custer County/ Saguache County/

1956, Relation of tectonic elements in Precambrian
rocks to uranium deposits in the Cordilleran Foreland
of the western United States, in Contributions to the
geology of uranium and thorium by the U.S. Geol. Survey
and Atomic Energy Comm. for the U.N. Internat. Conf. on
Peaceful Uses of Atomic Energy, Geneva, Switzerland,
1955: U.S. Geol. Survey Prof. Paper 300, p. 329-335.
veins/

1965, Structural control of uranium-bearing vein
deposits and districts in the conterminous United States:
U.S. Geol. Survey Prof. Paper 455-G, p. 121-145.
ore deposits/ genesis/ veins/ mining districts/
structural controls/ pitchblende/ conglomerate/ Front
Range/ igneous-metamorphic/ sandstone/ Jefferson County/
Moffat County/ Boulder County/ Montrose County/ Clear
Creek County/ Gilpin County/ Saguache County/ Fremont
County/

Osterwald, F.W., and Dean, B.S., 1956, Tectonic map of northern
Colorado and northeastern Utah showing the distribution
of uranium deposits (map): U.S. Geol. Survey TEM-949
(see U.S. Geol. Survey MF-130).
bibliography/ structural geology/ Larimer County/ Boulder
County/ Jefferson County/ Gilpin County/ Clear Creek County/
igneous-metamorphic/ sandstone/ Front Range/ Grand
County/ Jackson County/ Summit County/ Eagle County/ Rio
Blanco County/ Garfield County/ Routt County/ Moffat
County/ ore deposits/

1958, Preliminary tectonic map of northern Colorado and northeastern Utah, showing the distribution of uranium deposits (map): U.S. Geol. Survey Map MF-130, 2 sheets, scale 1:500,000.

ore deposits/ tectonics/ structural geology/ Larimer county/ Boulder County/ Jefferson County/ Gilpin County/ Clear Creek County/ igneous-metamorphic/ sandstone/ Front Range/ Grand County/ Jackson County/ Summit County/ Eagle County/ Rio Blanco County/ Garfield county/ Routt County/ Moffat County/

1961, Relation of uranium deposits to tectonic pattern of the central Cordilleran foreland: U.S. Geol. Survey Bull. 1087-I, p. 337-390.

Cordilleran Foreland/ ore deposits/ genesis/ controls/ structural controls/ tectonic pattern/ general/ deposits/ Front Range/ Denver Basin/ regional/ uranium/ igneous-metamorphic/

Page, L.R., 1950, Beryllium in Colorado: U.S. Geol. Survey TEI-88, 9 p., (see 1950 Mining Handbook, Colorado Mining Assoc., Denver, p. 37-39).

Mount Antero region/ Crystal Mountain district/ San Juan Mountains/ Chaffee County/ Larimer County/ helvite/ pegmatites/ beryllium/ beryl/ Colorado Plateau/ igneous-metamorphic/ Devils Hole mine/ Fremont County/ Gunnison County/ Jefferson County/ San Juan County/

1950, Beryllium in Colorado, in The 1950 Mining Yearbook: Denver, Colorado Mining Assoc., p. 37-39, (see U.S. Geol. Survey TEI-88).

beryllium/ beryl/ Colorado Plateau/ permatites/ Crystal Mountain district/ Larimer County/ igneous-metamorphic/ Devils Hole mine/ Fremont County/ Gunnison County/ Jefferson County/ Mounta Antero/ Chaffee County/ San Juan County/

1950, Uranium in pegmatites: Econ. Geology, v. 45, p. 12-34.

pegmatite/ geochemistry/ igneous rocks/ igneous-metamorphic/ uranium/ general/ mineralogy/ Gunnison County/ Larimer County/ Chaffee County/ Fremont County/ Colorado/ United States/

Page, L.R., Stocking, H.E., and Smith, H.B., compilers, 1956, Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, 739 p., (various U.S. papers on uranium geochemistry and isotope geology).

contributions/ geology/ uranium/ thorium/ United States/ regional/ Colorado/ general/ economics/ prospecting/ extraction/ chemistry/ mineralogy/ igneous-metamorphic/ sandstone/ conglomerate/ arkose/ limestone/ coal/ shale/ distribution/ stratigraphy/ petrology/ tectonics/

Pearce, Richard, 1898, Uraninite in Colorado: Mining Sci. Press, v. 113, p. 43-44.

uraninite/ Colorado/ veins/ igneous-metamorphic/ Gilpin County/ Front Range/

____ 1896, Some note on the occurrence of uraninite in Colorado: Colorado Sci. Soc., Proc., v. 5, p. 156-158.

ore deposits/ uraninite/ occurrence/ evaluation/ Gilpin County/ igneous-metamorphic/ veins/ Front Range/ Colorado/

____ 1898, Some notes on the occurrence of uraninite in Colorado: Mines Miner., v. 19, p. 108.

uraninite/ Colorado/ veins/ igneous-metamorphic/ Gilpin County/ Front Range/

____ 1916, Some notes on the occurrence of uraninite in Colorado: Mining and Scientific Press, v. 113, p. 44.

veins/ uraninite/ Colorado/ igneous-metamorphic/ Gilpin County/ Front Range/ occurrence/

Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colorado, and their bearing upon pitchblende deposition: U.S. Geol. Survey TEI-247, 53 p., illus. (incl. geol. sketch map).

ore deposits/ porphyry/ radioactive/ Gilpin County/ Central City district/ pitchblende/ Tertiary/ deposition/ Front Range/ mineralogy/ petrology/ geochemistry/ zircon/ veins/ igneous-metamorphic/ uranium/ thorium/ analyses/ Front Range/ Quartz Hill/ Nigger Hill dike/ Clear Creek County/

1952, The Colorado Front Range project in Summary of the research work of the Trace Elements section, Geochemistry and Petrology Branch, for the period October 1 - December 31, 1951: U.S. Geol. Survey TEI-218, p. 10-12.

Front Range/ Central City/ ore deposits/ Clear Creek County/ Gilpin County/ analyses/ quartz monzonite/ igneous-metamorphic/ Wood mine/ Kirk mine/ Quartz Hill/ pitchblende/ Copper King mine/ Larimer County/ paragenesis/

1953, Colorado Front Range mineralogic, geochemical and petrologic studies in Trace elements research, quarterly progress report--January 1 to March 31, 1952: U.S. Geol. Survey TEI-270, pt. 1, p. 21-22.

Front Range/ Central City/ ore deposits/ geochemistry/ petrology/ mineralogy; bostonite pitchblende/ Wood mine/ Kirk mine/ igneous-metamorphic/ Quartz Hill/ Copper King mine/ Larimer County/ Jamestown/ Boulder County/ Chalk Mountain rhyolite/ Climax/ beta-uranophane/ uraninite/ Lake County/ Eagle County/ Summit County/

1953, Mineralogy and geochemistry (Colorado) in Geologic investigations of radioactive deposits, semi-annual progress report, June 1 to November 30, 1953: U.S. Geol. Survey TEI-390, p. 114-115.

mineralogy/ geochemistry/ Copper King mine/ Larimer County/ pitchblende/ uraninite/ igneous-metamorphic/ coffinite/ Front Range/

1954, Occurrence of uranium in veins and igneous rocks (Colorado) in Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1954: U.S. Geol. Survey TEI-490, p. 146.

uranium/ veins/ igneous-metamorphic/ Front Range/ pitchblende/ porphyries/ thorium/

1955, Distribution of uranium in igneous complexes (Colorado) in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI-540, p. 237-244.

regional/ ore deposits/ mineralization/ distribution/ igneous rocks/ igneous-metamorphic/ thorium/ analyses/ granite/ Front Range/ Boulder Creek batholith/ Sherman granite/ Pikes Peak granite/ New Hampshire/

-
- 1956, Distribution of uranium in igneous complexes (Colorado, New Hampshire) in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1955 to May 31, 1956: U.S. Geol. Survey TEI-620, p. 310-319, illus.
Colorado/ New Hampshire/ ore deposits/ geochemistry/ distribution/ igneous rocks/ igneous-metamorphic/ Precambrian/ granite/ Boulder Creek batholith/ Silver Plume granite/ Front Range/
-
- 1958, Uranium and thorium in the Laramide intrusives of the Colorado Front Range in Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1958: U.S. Geol. Survey TEI-750, p. 103-108.
uranium/ thorium/ intrusives/ Laramide/ igneous-metamorphic/ mineralogy/ geochemistry/ Caribou Complex/ Boulder County/ Central City/ Clear Creek County/ Gilpin County/ Jamestown-Gold Hill/
- Phair, George, and Antweiler, J.C., 1954, Mineralogy and geochemistry (Colorado) in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1953 to May 31, 1954: U.S. Geol. Survey TEI-440, p. 93-95.
Larimer County/ Copper King Mine/ ore deposits/ absolute age/ geochemistry/ mineralogy/ uraninite/ coffinite/ pitchblende/ Front Range/ Central City/ Clear Creek county/ Gilpin County/ igneous-metamorphic/
- Phair, George, Bottfried, David, 1955, Uranium in the Precambrian "granites" of the Colorado Front Range in Geologic investigation of radioactive deposits, semiannual progress report, June 1 to November 30, 1955: U.S. Geol. Survey TEI-590, p. 310-313.
Front Range/ Boulder Creek batholith/ Silver Plume/ ore deposits/ uranium/ Precambrian/granite/ igneous-metamorphic/ thorium/
-
- 1958, Fractionation of uranium in the rocks and accessory minerals of the Boulder Creek batholith, Colorado in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1957 to May 31, 1958: U.S. Geol. Survey TEI-740, p. 286-290.
fractionation/ uranium/ rocks/ minerals/ Boulder Creek batholith/ igneous-metamorphic/ Front Range/

- ____ 1958, Study of the geological causes of the variation in Pb/alpha age shown by zircon from the Boulder Creek batholith, Colorado in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1957 to May 31, 1958: U.S. Geol. Survey TEI-740, p. 290-293.
zircon/ Boulder Creek batholite/ Front Range/ igneous-metamorphic/ granite/ uranium/ Precambrian/ age dates/
- ____ 1964, The Colorado Front Range, Colorado, USA, as a uranium and thorium province, in The Natural Radiation Environment: Chicago, Univ. Chicago Press, p. 7-38, illus. tables (for William Marsh Rice Univ.).
Colorado/ Front Range/ province/ thorium/ uranium/ igneous-metamorphic/
- Phair, George, and Herz, Norman, 1953, Mineralogic, geochemical and petrologic studies (Colorado) in Search for and geology of radioactive deposits, semiannual progress report, December 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 98-99.
ore deposits/ pitchblende/ coffinite/ geochemistry/ Front Range/ igneous-metamorphic/ quartz bostonite dikes/ Central City/ Clear Creek County/ Gilpin County/ mineralogy/ petrology/
- Phair, George, Jenkins, L.B., 1975, Tabulation of uranium and thorium data on the Mesozoic-Cenozoic intrusion rocks of known chemical composition in Colorado: U.S. Geol. Survey open-file report 75-501.
- Phair, George, and Levine, Harry, 1952, Notes on the differential leaching of uranium, radium and lead from pitchblende in H₂SO₄ solutions: U.S. Geol. Survey TEI-262, 23 p., (see Geol. Soc. America Bull. v. 63, no. 12, pt. 2, p. 1290; Econ. Geology v. 48, no. 5, p. 358-369).
Central City district/ Wood mine/ geochemistry/ leaching/ uranium/ radium/ lead/ pitchblende/ solutions/ Katanga/ Great Bear Lake/ Russel Gulch/ Clear Creek County/ Gilpin County/ igneous-metamorphic/ Front Range/

-
- 1952, Notes on the differential leaching of uranium, radium, and lead from pitchblende in H₂SO₄ solutions (abs): Geol. Soc. America Bull, v. 63, no. 12, pt. 2, p. 1290, (see U.S. Geol. Survey TEI-262).
leaching/ uranium/ radium /lead/ pitchblende/ Wood mine/ Central City/ Colorado/ Gilpin County/ analyses/ exploration/ igneous-metamorphic/ general / Clear Creek County/ Front Range/
-
- 1953, Notes on the differential leaching of uranium, radium, and lead from pitchblende in H₂SO₄ solutions: Econ. Geology, v. 48, no. 5, p. 358-369, (see U.S. Geol. Survey TEI-262).
uranium/ radium/ lead/ leaching/ pitchblende/ Central City/ Gilpin County/ Colorado/ United States/ general/ igneous metamorphic/ Front Range/
- Phair, George, and Mela, Henry, Jr., 1955, The isotopic variation of common lead in galena from the Front Range and its geological significance: U.S. Geol. Survey TEI-506, 20 p.
Bergen Park/ Breckenridge/ Caribou/ age determination/ Front Range/ Cotopaxi/ Gold Hill/ Guffy/ Laramide/ isotopes/ Lawson-Dumont/ Silver Plume/ El Paso County/ mineralogy/ petrology/ geochemistry/ galena/ Summit County/ igneous-metamorphic/ Boulder County/ Clear Creek County/ Gilpin County/ Fremont County/ Chaffee County/
- Phair, George, and Onoda, Kiyoko, 1950, Verification of uraninite in fluorite breccias from the Blue Jay mine, Jamestown, Colorado: U.S. Geol. Survey TEM-173.
Boulder County/ Jamestown district/ ore deposits/ mineralogy/ petrology/ geochemistry/ uraninite/ Blue Jay mine/ breccias/ igneous-metamorphic/ Front Range/ fluorite veins/ fluorite breccias/
-
- 1951, Hydrothermal uranothorite in fluorite breccias from the Blue Jay Mine, Jamestown, Boulder County, Colorado: U.S. Geol. Survey TEI-144, 16 p. (see Am. Mineralogist, v. 37, nos. 7-8, p. 659-666).
Jamestown district/ Boulder County/ ore deposits/ hydrothermal uranothorite/ fluorite breccias/ mineralogy/ petrology/ geochemistry/ thorium haloes/ Blue Jay mine/ igneous-metamorphic/ Front Range/

Phair, George, and Shimamoto, K.O., 1952, Hydrothermal uranothorite in fluorite breccias from the Blue Jay mine, Jamestown, Boulder County, Colorado: *Am. Mineralogist*, v. 37, nos. 7-8, p. 659-666, (see U.S. Geol. Survey TEI-144).

veins/ uranothorite/ hydrothermal minerals/ Blue Jay mine/ Jamestown district/ Boulder County/ igneous-metamorphic/ thin sections/ heavy minerals/ New Zealand/ Alaska/ comparisons/ fluorite breccias/ mineralogy/ petrology/ geochemistry/ haloes/ Front Range/

1953, Colorado Front Range mineralogic, geochemical and petrologic studies in Trace elements research quarterly progress report, April 1 to June 30, 1952: U.S. Geol. Survey TEI-280, p. 33-34.

Front Range/ ore deposits/ mineralization/ mineralogy/ petrology/ geochemistry/ porphyries/ pitchblende/ Central City district/ igneous-metamorphic/ Clear Creek County/ Gilpin County/

Phair, George and Sims, P.K., 1954, Paragenesis and age of the uranium minerals in the Copper King, Larimer County, Colorado (abs.): *Geol. Soc. America Bull.*, v. 65, no. 12, pt. 2, p. 1385.

Larimer County/ Copper King Mine/ ore deposits/ paragenesis/ mineralization/ age/ uranium/ igneous-metamorphic/ Front Range/ Colorado/

Pliler, Richard, and Adams, J.A.S., 1959, Distribution of thorium and uranium in a Pennsylvanian weathering profile; Colorado (abs.): *Geol. Soc. America Bull.*, v. 70, no. 12, pt. 2, p. 1657.

Regional/ ore deposits/ occurrence/ distribution/ resources/ Pennsylvanian/ thorium/ weathering profile/ uranium/ Boulder County/ Colorado/ igneous-metamorphic/ analyses/ Front Range/ geochemistry/

1962, The distribution of thorium and uranium in a Pennsylvanian weathering profile: *Geochim. et Cosmochim. Acta*, v. 26, p. 1137-1146, illus., tables.

Weathering/ profiles/ pre-Pennsylvanian/ Pennsylvanian/ thorium/ distribution/ Boulder County/ geochemistry/ igneous-metamorphic/ analysis/ Front Range/

Popenoe, Peter, 1965, Aeroradioactivity survey and areal geology of the Denver area, Colorado (ARMS-I): U.S. Atomic Energy Comm. CEX-59.4.26, 26 p., illus., tables. arkose/ shale/ sandstone/ conglomerate/ Denver basin/ Larimer County/ Boulder County/ Jefferson County/ Douglas County/ Elbert County/ Arapahoe County/ Denver County/ Adams County/ Weld County/ Morgan County/ areal geology/ aero radioactivity survey/ conglomerate/

1965, Natural gamma aeroradioactivity map of the Denver area, Colorado (map): U.S. Geol. Survey GP-505, scale 1:250,000, text. Laramie Formation/ Dawson arkose/ Pierre Shale/ Fox Hills Sandstone/ Castle Rock Conglomerate/ Denver basin/ Larimer County/ Boulder County/ Jefferson County/ Douglas County/ Elbert County/ Arapahoe County/ Denver County/ Adams County/ Weld County/ Morgan County/ gamma-ray/ airborne/ radioactivity/

Rabbitt, J.C., 1950, Numerical summary of the analytical work of the Trace Elements Section, Geochemistry and Petrology Branch, for the fiscal year 1950: U.S. Geol. Survey TEM-174. summary of work/

1950, The first annual report of the Trace Elements Section for the fiscal year 1949: U.S. Geol. Survey TEI-101. summary/ trace elements section/ 1949/ annual report/

1951, Summary of the research work of the Trace Elements Section, Geochemistry and Petrology Branch, for the period January 1/June 30, 1951: U.S. Geol. Survey TEI-167, 43 p. Central City/ Jamestown district/ ore deposits/ pitchblende/ Blue Jay mine/ bostonite/ fluorite/ veins/ breccia/ Colorado Plateau/ research carnotite project/ sandstone/ igneous-metamorphic/ Boulder County/ Gilpin County/ Clear Creek County/ Front Range/

1951, Summary of the research work of the Trace Elements Section, Geochemistry and Petrology Branch, for the period April 1, 1948 to December 31, 1950: U.S. Geol. Survey TEI-148A, open-file report, 96 p. Blue Jay mine/ Jamestown/ Colorado Plateau/ bostonite dikes/ Colorado/ Front Range/ Central City/ mineralogy/ petrology/ geochemistry/ radioactivity/ fluorite/ Clear Creek County/ pitchblende/ ore deposits/ minerals/ Gilpin County/ veins/ breccia/ sandstone/ Boulder County/ igneous-metamorphic/

-
- 1951, Summary of the research work of the Trace Element Section, Geochemistry and Petrology Branch, for the period January 1 to March 31, 1951: U.S. Geol. Survey TEI-151, 44 p.
Front Range/ Central City/ ore deposits/ ore guides/ exploration/ Clear Creek County/ Gilpin County/ Colorado Plateau/ Jamestown district/ mineralogy/ petrology/ geochemistry/ pitchblende/ Blue Jay mine/ bostonite/ fluorite/ veins/ breccia/ sandstone/ igneous-metamorphic/ Boulder County/
-
- 1952, Summary of the research work of the Trace Elements Section, Geochemistry and Petrology Branch, for the period October 1-December 31, 1951: U.S. Geol. Survey TEI-218, 39 p.
Colorado Plateau/ results of carnotite project/ Gilpin County/ Larimer County/ sandstone/ igneous-metamorphic/ Front Range/
-
- 1952, Summary of the research work of the Trace Elements Section, Geochemistry and Petrology Branch, for the period July 1 to September 30, 1951: U.S. Geol. Survey TEI-182, 33 p.
Colorado Plateau/ Front Range/ Central City/ ore deposits/ exploration/ trace elements/ sandstone/ igneous-metamorphic/ Gilpin County/ Clear Creek County/
- Ray, E.D., 1975, Metal mining activity in district 1, in Colorado Mining Assoc. Mining Yearbook: p. 23.
mining/ Jefferson County/ Schwartzwalder mine/ Ladwig mine/ igneous-metamorphic/ district 1/
- Rich, R.A., and Barabas, A., 1976, Mineralogy, paragenesis, fluid inclusions, and origin of the Schwartzwalder uranium deposit, Jefferson County, Colorado (abs): Geol. Soc. America Abs. with Programs, v. 8, no. 6, p. 1068.
mineralogy/ paragenesis/ fluid inclusions/ origin/ Schwartzwalder mine/ ore deposits/ Jefferson County/ Front Range/ igneous-metamorphic/

Rich, R.A., Holland, H.D., and Peterson, U., 1975, Vein-type uranium deposits: U.S. Energy Research and Devel. Adm. GJO-1640, Cambridge, Massachusetts, Dept. of Geological Sciences, Harvard University.
veins/ uranium/ ore deposits/ igneous-metamorphic/ mineralogy/ fluid inclusions/ paragenesis/ hydrothermal/ pitchblende/ ground waters/ references/ Front Range/ Jefferson County/ Clear Creek County/ Gilpin County/ Gunnison County/ Saguache County/ Marshall Pass district/ Schwartzwalder mine/

1977, Hydrothermal Uranium Deposits: New York, N.Y., Elsevier Scientific Publishing Co., 264 p.
geology/ mineralogy/ geochemistry/ genetic models/ hydrothermal uranium deposits/ ore deposits/ igneous-metamorphic/

Rickard, Forbes, 1913, Pitchblende from Quartz Hill, Gilpin County, Colorado: Mining Sci. Press, v. 106, no. 23, p. 851-856.
veins/ Quartz Hill/ Gilpin County/ pitchblende/ Front Range/ igneous-metamorphic/

Ridland, G.C., 1949, Development and geology at the Caribou mine, Consolidated Caribou Silver Mines, Inc., in Mining Assoc. Yearbook: p. 35, illus.
Caribou mine/ silver/ uranium/ pitchblende/ Boulder County/ geology/ igneous-metamorphic/ Idaho Springs biotite schist/ Precambrian/ quartz monzonite porphyry/ No Name vein/ Front Range/

1950, Radioactivity at the Caribou Silver Mine, Boulder County, Colorado: Mining Eng., v. 2, p. 98-101, illus.
veins/ ore deposits/ pitchblende/ Boulder County/ Caribou silver mine/ radioactivity/ No Name vein/ Radium vein/ igneous-metamorphic/ Front Range/

1951, Radioactivity at the Caribou silver mine, Boulder County, Colorado: Am. Inst. Mining Metall. Eng. Trans., v. 187, p. 98-100.
ore deposits/ pitchblende/ Boulder County/ Caribou silver mine/ radioactivity/ No Name vein/ Radium vein/ veins/ igneous-metamorphic/ Front Range/

Schlottmann, J.D., 1961, Geology of the Schwartzwalder uranium deposit, Jefferson County, Colorado: Unpublished.
geology/ Schwartzwalder mine/ ore deposits/ Jefferson County/ igneous-metamorphic/ Front Range/

----- 1961, Foothills mine, Idledale district, Jefferson County, Colorado: U.S. Atomic Energy Comm., RME-138, 10 p.
Colorado/ uranium deposits/ exploration/ mineralogy/ uranium ores/ Foothills Mine/ Idledale district/ Jefferson County/ veins/ igneous-metamorphic/ paragenesis/ Wright lease/ quartz monzonite breccia/

Scott, B.C., 1957, Geology of the uranium occurrences in the Dakota Hogback Ridge, near Morrison, Jefferson County, Colorado: U.S. Atomic Energy Comm. DAO-3-TM-41 10 p., (for abstract see NSA 32:00664).
Colorado/ uranium/ ore deposits/ uranium ores/ geology/ asphaltite/ sandstone/ geologic faults/ thermal waters/ ground water/ mineralization/ Dakota Hogback/ structure/ Morrison/ Jefferson County/ Front Range/

Scott, R.C., and Barker, F.B., 1962, Data on uranium and radium in ground water in the United States 1954 to 1957: U.S. Geol. Survey Prof. Paper 426, 115 p.
data/ uranium/ radium/ groundwater/ distribution/ analysis/ United States/ regional/ Colorado/ Logan County/ Phillips County/ Yuma County/ Jefferson County/ Garfield County/ Kit Carson County/ Pitkin County/ Mesa County/ Prowers County/ Huerfano County/ Baca County/ Montezuma County/

Shedd, J.C., 1912, Radioactivity of the mineral springs of Manitou, Colorado: Colorado Sci. Soc. Proc., v. 10, p. 233-263.
El Paso County/ springs/ radioactivity/ Manitou/ Front Range/

Sheridan, D.M., 1953, Ralston Buttes district, Colorado: U.S. Geol. Survey TEI-330, p. 99-100.
Jefferson County/ veins/ pitchblende/ Ralston Buttes district/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Mena mine/ Ladwig Lease/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ Copper faults/

-
- 1955, Ralston Buttes district, Colorado: U.S. Geol. Survey TEI-590, p. 212-217, sketch map.
 Jefferson County/ veins/ pitchblende/ Ralston Buttes district/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Mesa mine/ Ladwig lease/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ copper/ faults/
-
- 1956, Ralston Buttes, Colorado: U.S. Geol. Survey TEI-640, p. 125-137, illus. (incl. geol. sketch maps).
 Jefferson County/ pitchblende/ Ralston Buttes district/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Mesa mine/ Ladwig lease/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ faults/ copper/ paragenesis/ structure/
-
- 1956, Ralston Buttes, Colorado: U.S. Geol. Survey TEI-620, p. 222.
 Jefferson County/ veins/ pitchblende/ Ralston Buttes district/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Mesa mine/ Ladwig lease/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ faults/ copper/
- Sheridan, D.M., and Maxwell, C.H., 1953, Ralston Buttes district, Colorado: U.S. Geol. Survey TEI-390, p. 107-110, sketch map.
 Ralston Buttes/ ore deposits/ occurrence/ exploration/ Jefferson County/ veins/ pitchblende/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Mesa mine/ Ascension mine/ Ladwig lease/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ copper/ faults/
-
- 1954, Uranium in veins, igneous rock, and related deposits, Ralston Buttes district, Colorado, in Geologic investigations of radioactive deposits, semiannual progress report, Classified data, June 1 to November 30, 1954: U.S. Geol. Survey TEI-491, p. 20.
 Front Range/ igneous-metamorphic/ Ralston Buttes/ Jefferson County/ pitchblende/ Schwartzwalder mine/ Golden Gate Canyon/
-
- 1954, Ralston Buttes district, Jefferson County, Colorado: U.S. Geol. Survey TEI-440, p. 88-89, sketch map.
 Ralston Buttes/ ore deposits/ exploration/ veins/ Jefferson County/ pitchblende/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Ladwig lease/ Mesa mine/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ copper/ faults/

- ____ 1954, Ralston Buttes district, Colorado: U.S. Geol. Survey TEI-490, p. 139-141, sketch map.
Jefferson County/ veins/ pitchblende/ Ralston Buttes district/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Mesa mine/ Ladwig lease/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ copper/ faults/
- Sheridan, D.M., Maxwell, C.H., Albee, A.L., and others, 1958, Preliminary map of bedrock geology of the Ralston Buttes quadrangle, Jefferson County, Colorado: U.S. Geol. Survey MF-179, scale 1:24,000, text.
Jefferson County/ veins/ pitchblende/ Ralston Buttes district/ bedrock/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Ladwig lease/ Mesa mine/ Ascension mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ copper/ faults/
- ____ 1967, Geology and uranium deposits of the Ralston Buttes district, Jefferson County, Colorado, with sections on Paleozoic and younger sedimentary rocks, by Richard Van Horn, U.S. Geol. Survey Prof. Paper 520, 121 p., (illus., tables, geol. maps).
Ralston Buttes/ ore deposits/ genesis/ areal geology/ maps/ Jefferson County/ Schwartzwalder mine/ Mesa mine/ Ascension mine/ Ladwig lease/ structure/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ copper/ faults/ Colorado/ uranium/ economic geology/ production/ Front Range/ vein/ breccias/ pitchblende/ gneiss/ pegmatite/
- ____ n.d., Geology of the Ralston Buttes district, Jefferson County, Colorado - a preliminary report: U.S. Geol. Survey TEM-901.
Jefferson County/ Juanita Arch quadrangle/ veins/ pitchblende/ Ralston Buttes district/ Front Range/ uranium/ igneous-metamorphic/ Schwartzwalder mine/ Ascension mine/ Ladwig lease/ Mesa mine/ Golden Gate Canyon/ Ralston Creek/ mineralogy/ paragenesis/ structure/ copper/ faults/
- Sims, P.K., 1953, Colorado Front Range, Georgetown-Central City area, Colorado in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1953: U.S. Geol. Survey TEI-390, p. 100-102, (sketch map).
ore deposits/ Central City/ Georgetown/ Front Range/ summary/ Clear Creek County/ Gilpin County/ igneous-metamorphic/

-
- 1953, Colorado Front Range in Search for and geology of radioactive deposits - Semiannual progress report, Dec. 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 93-94, 97-98.
Front Range/ ore deposits/ exploration/ summary/ Clear Creek County/ Gilpin County/ igneous-metamorphic/
-
- 1954, Colorado Front Range in Geologic investigations of radioactive deposits - Semiannual progress report, Dec. 1 to May 31, 1954: U.S. Geol. Survey TEI-440, p. 75-87, illus (incl. sketch map).
Front Range/ ore deposits/ mineralogy/ petrology/ summary/ igneous-metamorphic/ Gilpin County/ Clear Creek County/
-
- 1954, Colorado Front Range, in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1954: U.S. Geol. Survey TEI-490, p. 135-139 (sketch map).
veins/ summary/ igneous-metamorphic/ Clear Creek County/ Gilpin County/ Front Range/
-
- 1955, Colorado Front Range in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1955: U.S. Geol. Survey TEI-590, p. 200-202.
Front Range/ ore deposits/ trace elements/ Clear Creek County/ Gilpin County/ summary/ igneous-metamorphic/
-
- 1955, Precambrian pegmatites in Geologic investigations of radioactive deposits - Semiannual progress report, Dec. 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI-540, p. 140.
Regional/ ore deposits/ veins/ igneous-metamorphic/ Front Range/ summary/ Precambrian/ pegmatites/
-
- 1955, Tertiary vein deposits in Geologic investigations of radioactive deposits - Semiannual progress report, Dec. 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI-540, p. 140-141.
veins/ Tertiary/ igneous/ Front Range/ summary/
-
- 1955, Paragenesis and structure of pitchblende-bearing veins, Central City district, Gilpin County, Colorado (abs): Econ. Geology, v. 50, no. 7, p. 792-793.
paragenesis/ structure/ pitchblende/ veins/ Central City/ igneous-metamorphic/ Gilpin County/ Clear Creek County/ uranium/ Colorado/ mineralogy/

-
- 1955, Paragenesis and structure of pitchblende-bearing veins, Central City, district, Colorado (abs.): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1617. Gilpin County/ Central City district/ mineralogy/ petrology/ geochemistry/ pitchblende/ deposits/ veins/
-
- 1956, Paragenesis and structure of pitchblende-bearing veins, Central City district, Gilpin County, Colorado: U.S. Geol. Survey TEI-433, 32 p. (see Econ. Geology, 1956, v. 51, p. 739-756). Front Range/ Gilpin County/ Central City district/ mineralogy/ petrology/ geochemistry/ pitchblende/ ore deposits/ vein deposits/ zoning in Front Range mineral belt/ tennantite/ Calhoun (East and West) mines/ Carroll mine/ J.P. Whitney mine/ theories of origin of uraniferous host intrusive igneous structure/ veins/ stratigraphy of Precambrian rocks/ s./ metalliferous Colorado/ uranium/ igneous-metamorphic/ pitchblende-bearing veins/
-
- 1956, Uranium deposits in the Front Range, Colorado: Mines Mag., v. 46, no. 3, p. 77-79, illus (incl. geol. sketch map). Front Range/ ore deposits/ uranium/ Larimer County/ Boulder County/ Gilpin County/ Clear Creek County/ Jefferson County/ Fremont County/ igneous-metamorphic/
-
- 1956, Colorado Front Range, in Geologic investigations of radioactive deposits - Semiannual progress report for Dec. 1, 1955 to May 31, 1956: U.S. Geol. Survey TEI-620, p. 217-221, illus. veins/ Front Range/ igneous-metamorphic/ summary/
-
- 1957, Colorado Front Range in Geologic investigations of radioactive deposits - Semiannual progress report, Dec. 1, 1956 to May 31, 1957: U.S. Geol. Survey TEI-690, p. 291-298. Front Range/ igneous-metamorphic/ summary/
-
- 1960, Geology of the Central City - Idaho Springs area, Front Range, Colorado, in Guide to the geology of Colorado: Rocky Mtn. Assoc. Geologists, Denver, Colo., p. 279-285, illus. (incl. geol. sketch map). Clear Creek County/ Gilpin County/ geology/ igneous-metamorphic/ Central City area/ Front Range/ Idaho Springs area/

-
- 1960, Hypogene mineral zoning, Central City district, Colorado (abs.): Geol. Soc. America Bull., v. 71, no. 12, pt. 2, p. 1974.
hypogene/ zoning/ mineralogy/ Gilpin County/ Clear Creek county/ Colorado/ Central City district/ Front Range/ igneous-metamorphic/
-
- 1963, Geology of uranium and associated ore deposits, central part of the Front Range mineral belt, Colorado: U.S. Geol. Survey Prof. Paper 371, 119 p., illus. geol. maps. geology/ uranium/ ore deposits/ Front Range/ Colorado/ production/ Summit County/ Clear Creek County/ Gilpin County/ Boulder County/ Grand County/ Central City/ Idaho Springs/ Lawson-Dumont-Fall River/ Freeland-Lamartine/ Chicago Creek/ gneiss/ pegmatite/ bostonite/ alaskite/ thorium/ monizite/ igneous-metamorphic/
-
- 1964, Geology of the Central City quadrangle, Colorado (map): U.S. Geol. Survey GQ-267, scale 1:24,000, sections. Gilpin County/ Clear Creek County/ igneous-metamorphic/ Central City quadrangle/ Russell Gulch/ geology/ Front Range/
- Sims, P.K., and Barton, P.G., Jr., 1962, Hypogene zoning and ore genesis, Central City district, Colorado, in Engel, A.E.J., and others, Petrologic Studies (Buddington volume): Geol. Soc. America Bull., p. 373-396, illus., table. Gilpin County/ Central City/ zoning/ genesis/ ore deposits/ igneous-metamorphic/ Front Range/
- Sims, P.K., and Drake, A.A., Jr., 1953, Colorado Front Range, Central City district: U.S. Geol. Survey TEI-390, p. 102-104.
Front Range/ Central City/ Gilpin County/ Clear Creek County/ igneous-metamorphic/ Jefferson County/
- Sims, P.K., and Gable, D.J., 1963, Cordierite-bearing mineral assemblages in Precambrian rocks, Central City quadrangle, Colorado, in Geological Survey research 1963: U.S. Geol. Survey Prof. Paper 475-B, p. B35-B37, tables.
cordierite/ Precambrian/ gneiss/ igneous-metamorphic/ Colorado/ Central City/ Gilpin County/ Clear Creek County/ Front Range/

-
- 1964, Geology of Precambrian rocks, Central City district, Colorado: U.S. Geol. Survey Prof. Paper 474-C, p. C1-C52 (1965), illus., tables, geol. map.
geology/ Precambrian rocks/ Central City district/ Colorado/ Gilpin County/ Clear Creek County/ uranium/ thorium/ monazite/ igneous-metamorphic/ pegmatite/ gneiss/ granite/ Front Range/
-
- 1967, Petrology and structure of Precambrian rocks, Central City quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 554-E, p. E1-E56, illus., tables, geol. map.
petrology/ structure/ Precambrian Rocks/ Central City/ Colorado/ Gilpin County/ Clear Creek County/ igneous-metamorphic/ pegmatite/ gneiss/ granite/ uranium/ thorium/ Front Range/
- Sims, P.K., and others, 1959, Geology of uranium and associated ore deposits, central part of the Front Range mineral belt, Colorado: U.S. Geol. Survey TEI-601, 10 p., (see U.S. Geol. Survey Prof. Paper 371).
abstract of PP 371/ Front Range/ igneous-metamorphic/ uranium/ ore deposits/ geology/
- Sims, P.K., and Phair, George, 1952, Geology of the Copper King Mine area, Prairie Divide, Larimer County, Colorado: U.S. Geol. Survey TEI-311, pt. 1, 46 p., illus (incl. sketch maps).
age determination/ Front Range/ Larimer County/ mineralogy, petrology and geochemistry/ mines/ minerals/ pitchblende/ Copper King uranium mine/ fault breccia/ shear zone materials/ veins/ stratigraphy/ Precambrian rocks/ veins/ geology/
-
- 1953, Some features of the pitchblende deposit at the Copper King mine, Larimer County, Colorado (abs): Geol. Soc. America Bull., v. 64, no. 12, pt. 2, p. 1555-1556 (see U.S. Geol. Survey TEI-311).
pitchblende/ ore deposits/ Copper King mine/ Larimer County/ Colorado/ uranium/ igneous-metamorphic/ Front Range/
- Sims, P.K., and Sheridan, D.M., 1964, Geology of uranium deposits in the Front Range, Colorado, with sections by R.U. King, F.B. Moore, D.H. Richter, and J.D. Schlottmann: U.S. Geol. Survey Bull. 1159, 116 p.
geology/ ore deposits/ Front Range/

Sims, P.K., and Tooker, E.W., 1954, Geologic maps of the Eureka Gulch area, Central City district, Gilpin County, Colorado: U.S. Geol. Survey open-file rept. Eureka Gulch/ Central City district/ Gilpin County/ igneous-metamorphic/ maps/ Front Range/

1955, Localization of metatorbernite in altered wall rocks, Central City district, Gilpin County, Colorado (abs): Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1680. matatorbernite/ alteration/ wall rock/ Central City/ Gilpin County/ Colorado/ uranium/ igneous-metamorphic/ veins/ Front Range/

1956, Pitchblende deposits in the Central City district and adjoining areas, Gilpin and Clear Creek counties, Colorado, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955: U.S. Geol. Survey Prof. Paper 300, p. 105-111. Clear Creek County/ Gilpin County/ ore deposits/ pitchblende/ Central City district/ veins/ Colorado/ uranium/ igneous-metamorphic/ bostonite/ production/ pegmatite/ gneiss/ origin/ distribution/ Front Range/

1956, Pitchblende deposits in the Central City district and adjoining areas, Gilpin and Clear Creek Counties, Colorado, in Geology of Uranium and Thorium: U.N. Internat. Conf. on Peaceful Uses Atomic Energy, Geneva, 1955, Proc., v. 6, p. 265-269 (revised in Page, L.R., Contributions to the geology of uranium and thorium, U.S. Geol. Survey Prof. Paper 300, p. 105-111, 1967). Clear Creek County/ Gilpin County/ ore deposits/ pitchblende/ Central City district/ veins/ Colorado/ uranium/ igneous-metamorphic/ bostonite/ production/ pegmatite/ gneiss/ origin/ distribution/ Front Range/

Sims, P.K., and Toulmin, Priestley, 3rd, 1961, Temperature of formation of a Precambrian massive sulfide deposit, Copper King mine, Front Range, Colorado, in Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-B, p. B1-B2. temperature of formation/ Precambrian/ massive sulfide deposits/ Copper King mine/ Front Range/ Colorado/ Larimer County/ igneous-metamorphic/ uranium/ granite/

Sims, P.K., Drake, A.A., Jr., and Moench, R.H., 1953, Preliminary geologic and vein maps of part of the Central City district, Gilpin and Clear Creek counties, Colorado: U.S. Geol. Survey TEI-304, 8 p., maps, tables.
 Gilpin County/ Clear Creek County/ Central City district/ preliminary geologic maps/ vein maps/ ore deposits/ igneous-metamorphic/ veins/ Russell Gulch/ Quartz Hill/ Nevada Gulch/ pitchblende/ Wood mine/ Calhoun mine/ Gold King claim/ Kirk mine/ Koss Shaft/ Belcher claims/ German claims/ Pewabic mine/ Iron mine/ Front Range/

1953, Central City district, Gilpin County, in Search for and geology of radioactive deposits, semiannual progress report, December 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, p. 94-96.
 Gilpin County/ Clear Creek County/ igneous-metamorphic/ Central City district/ Front Range/

1954, Preliminary geologic and vein maps of part of the Central City district, Gilpin and Clear Creek Counties, Colorado: U.S. Geol. Survey open-file rept., 8 p.
 veins/ maps/ Central City district/ Gilpin County/ Clear Creek County/ igneous-metamorphic/ Front Range/

1963, Economic geology of the Central City district, Gilpin County, Colorado: U.S. Geol. Survey Prof. Paper 359, 231 p., illus., geol. maps.
 economic geology/ Central City/ Gilpin County/ Colorado/ igneous-metamorphic/ production/ geology/ ore deposits/ mineralogy/ uranium/ pitchblende/ veins/ Front Range/ granite/ gneiss/ pegmatite/

Sims, P.K., Harrison, J.E., and Moore, F.B., 1952, Preliminary report on 1952 investigations in the Colorado Front Range: U.S. Geol. Survey TEM-520.
 Central City/ Dumont/ Fall River/ Eureka Gulch/ Freeland-Lamartine/ Front Range/ Georgetown/ Clear Creek County/ pitchblende/ Diamond Mountain (Lanagan) mine/ Golden Calf mine/ Golden Glen mine/ Gomer mine/ Martha E. mine/ Old Town mine/ Spread Eagle mine/ reconnaissance for radioactive materials in metal mining districts/ Gilpin County/ metalliferous deposits/ base metals/ precious metals/ veins/ igneous-metamorphic/ Clear Creek County/

Sims, P.K., Moench, R.H., Drake, A.A., Jr., and others, 1963, uranium deposits of the Central City-Idaho Springs mining district, Gilpin and Clear Creek Counties, Colorado: U.S. Geol. Survey TEI-359.

uranium/ ore deposits/ Central City district/ Idaho Springs district/ mining/ Gilpin County/ Clear Creek County/ Front Range/ igneous-metamorphic/

Sims, P.K., Osterwald, F.W., and Tooker, E.W., 1954, Uranium deposits in the Eureka Gulch area, Central City district, Gilpin County, Colorado: U.S. Geol. Survey TEI-125, 52 p., (see U.S. Geol. Survey Bull. 1032-A; TEI-125, part 1 open filed).

Gilpin County/ igneous-metamorphic/ Wood mine/ Eureka Gulch/ Nigger Hill/ Uinta Mountains/ Central City district/ mineralogy/ petrology/ geochemistry/ pitchblende/ ore deposits/ veins/ minerals/ kasolite/ metatorbernite/ Buckley mine/ Bullion mine/ Carroll mine/ Clair Marie mine/ Rara Avis mine/ R.H.D. mine/ Two Sisters mine/ theories of origin of uraniferous vein deposits/ stratigraphy/ Precambrian rocks/

1955, Uranium deposits in the Eureka Gulch area, Central City district, Gilpin County, Colorado, in Geology and ore deposits of Clear Creek, Gilpin, and Larimer Counties, Colorado: U.S. Geol. Survey Bull 1032-A, p. 1-31, illus. (incl. geol. map).

Gilpin City/ metamorphic/ veins/ pitchblende/ metatorbernite/ igneous-metamorphic/ Colorado/ uranium/ Front Range/

Sims, P.K., Phair, George, and Moench, R.H., 1955, Geology of the Copper King uranium mine, Larimer County, Colorado: U.S. Geol. Survey TEI-424, (see U.S. Geol. Survey Bull. 1032-D).

age determination/ Front Range/ Larimer County/ mineralogy/ petrology/ geochemistry/ pitchblende deposits/ vein deposits/ wall rock influence/ Colorado/ geology/ minerals/ coffinite/ uraninite/ Copper King uranium mine/ theories of origin/ uraniferous vein deposits/ uranium/ metalliferous deposits/ igneous-metamorphic/ base and precious metals/ metamorphic rocks, veins/ stratigraphy of Precambrian rocks/

1958, Geology of the Copper King uranium mine, Larimer County, Colorado: U.S. Geol. Survey Bull. 1032-D, p. 171-221, illus (incl. geol. sketch maps).

Larimer County/ Copper King Mine/ ore deposits/ petrology/

Sims, P.K., Tooker, E.W., and Osterwald, F.W., 1954, Uranium deposits in Eureka Gulch area, Central City district, Gilpin County, Colorado (maps): U.S. Geol. Survey TEI-125, 52 p., Open-file Rept. (3 geologic maps only).
Central City district/ Gilpin County/ Eureka Gulch/ geology/ igneous-metamorphic/ uranium deposits/ ore deposits/ Front Range/

Sims, P.K., Young, E.J., and Sharp, W.N., 1961, Coffinite in uranium vein deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. paper 424-B, art. 1, p. B3-B5, illus.
coffinite/ uranium/ veins/ occurrences/ Front Range/ Colorado/ Boulder County/ Larimer County/ Jefferson County/ Clear Creek County/ igneous-metamorphic/ ore deposits/

Slaughter, A.L., and Clabaugh, S.E., 1945, Preliminary report on trace elements reconnaissance in central and southwestern states: U.S. Geol. Survey TEI-9, 59 p., (see U.S.G.S. Bull. 1107-E, 1147-B).
Jefferson County/ trace elements/ igneous-metamorphic/ coal/ carnotite/

Soister, P.E., Conklin, D.R., and Bowman, M.D., 1956, Bibliography and index of U.S. Geological Survey Trace elements and related reports through June 1956: U.S. Geol. Survey TEI-600, 533 p., (expanded version, see U.S. Geol. Survey Bull. 1107-A).
Colorado/ New Mexico/ Utah/ Arizona/ United States/ bibliography/ trace element reports/ uranium/ vanadium/ thorium/ TEI/TEM/

Soule, J.H., 1960, Mining methods and costs, Schwartzwalder uranium mine, Jefferson County, Colorado: U.S. Bur. Mines Inf. Circ. 7963, 24 p.
Jefferson County/ ore deposits/ resources/ production/ mining/ methods/ economics/ costs/ Schwartzwalder mine/ uranium/ igneous-metamorphic/ Front Range/ development/ Ralston Creek/ geology/ history/

Staatz, M.H., 1975, Thorium deposits in the United States, in Craig, L.C., Brooks, R.A., and Patton, P.C., ed., Abstracts of the 1975 Uranium and Thorium Research and Resources Conferences (abs.): U.S. Geol. Survey Open-file Rept. 75-595, p. 48.
thorium/ ore deposits/ igneous-metamorphic/ United States/ Colorado/

-
- 1976, Thorium resources, 1974: U.S. Geol. Survey Open-file Rept. 76-690, 5 p.
 thorium/ resources/ igneous-metamorphic/ United States/ Colorado/
-
- 1976, Thorium in the United States: U.S. Geol. Survey Open-file Rept. 76-192, 6 p.
 thorium/ igneous-metamorphic/ United States/ Colorado/
- Staatz, M.H., Adams, J.W., and Wahlberg, J.S., 1976, Brown, Yellow, orange, and greenish-black thorites from the Seerie pegmatite, Colorado: U.S. Geol. Survey Jour. research, v. 4, no. 5, p. 575-582.
 thorite/ Seerie pegmatite/ igneous-metamorphic/ fluorite/ mineralogy/ geochemistry/ uraninite/ Jefferson County/ Front Range/ thorium/
- Staatz, M.H., and Trites, A.F., Jr., 1952, Geology of the Quartz Creek pegmatite district, Gunnison County, Colorado: U.S. Geol. Survey TEI-138, 272 p., maps (see USGS Prof. Paper 265, open-filed).
 Front Range, granite/ pegmatite/ igneous-metamorphic/ geology/ structure/ mineralogy/ Gunnison County/ Wood Gulch/ Beryllium/ petrology/ geochemistry/ minerals/ allanite/ monzaite/ pyrochlore-microlite/ Beryl and Rare Minerals Lode claim/ Black Wonder claim/ Brown Derby claim/ Buckhorn mica mine/ Bucky claim/ Opportunity no. 1 claim/ Trio claims/ White Spar claim/ Quartz Creek district/ uranium/ thorium/ beryllium/ reserves/ resources/
-
- 1955, Geology of the Quartz Creek pegmatite district, Gunnison County, Colorado: U.S. Geol. Survey Prof. Paper 265 (see U.S. Geol. Survey TEI-138).
 geology/ Quartz Creek district/ pegmatite/ Gunnison County/ Colorado/ igneous-metamorphic/ thorium/ monazite/ mineralogy/ granite/ gneiss/ origin/
- Stahl, R.L., 1974, Detection and delineation of faults by surface resistivity measurements, Schwartzwalder mine, Jefferson County, Colorado: U.S. Bur. Mines Rept. Inv. 7975, 27 p.
 Schwartzwalder mine/ Jefferson County/ Front Range/ igneous-metamorphic/ surface resistivity/ faults/ fault detection/ fault delineation/

Stern, T.W., and Stieff, L.R., 1953, Preliminary description of coffinite - a new uranium mineral: U.S. Geol. Survey TEM-647, see Geol. Soc. America Bull. v. 66, no. 12, pt. 2, p. 1621.
 coffinite/ Colorado Plateau/ Larimer County/ Mesa County/ minerals/ coffinite/ Copper King uranium mine/ La Sal No. 2 mine/ sandstone/ Front Range/ igneous-metamorphic/

Stieff, L.R., and Stern, T.W., 1951, The identification and lead-uranium ratio ages of massive uraninite from the Shinarump conglomerate, Utah: U.S. Geol. Survey TEM-317 (see Chem. Abs., v. 46, no. 17, p. 7943, 1952; Science, v. 115, p. 706-708, 1952).
 age determination/ Colorado Plateau/ origin/ sandstone/ ore deposits/ uranium/ Front Range mineral belt/ conglomerate/ lead-uranium ratio/ ages/ uraninite/ Shinarump conglomerate/ Shinarump conglomerate/

1952, The identification and lead-uranium ratio ages of massive uraninites from the Shinarump conglomerate, Utah (abs.): Chem. Abs., v. 46, no. 17, col. 7943, (see U.S. Geol. Survey TEM-317).
 age determination/ Colorado Plateau/ origin/ sandstone/ ore deposits/ uranium/ Front Range mineral belt/ conglomerate/ lead-uranium ratio/ ages/ uraninite/ Shinarump conglomerate/

Stieff, L.R., Stern, T.W., and Milkey, R.G., 1952, A preliminary determination of the age of some Colorado Plateau uranium ores by the lead-uranium and lead-lead-ratio method (abs): Econ. Geology, v. 47, no. 1, p. 123.
 Colorado Plateau/ age dating/ uranium ores/ ore deposits/ ratios/ Pb/U/ Pb/Pb/ sandstone/ uranium/ origin/ Front Range/ Colorado/ general/

1955, Coffinite, a uranous silicate with hydroxyl substitution: a new mineral: U.S. Geol. Survey TEI-538, (see Am. Mineralogist, 1956, v. 41, p. 675-688).
 Uravan/ Jefferson County/ Larimer County/ Mesa County/ Montrose County/ San Miguel County/ minerals: coffinite/ Arrowhead mines/ Black Mama mine/ Copper King uranium mine/ J.J. mine/ LaSal No. 2 mine/ Little Muriel mine/ Matchless mine/ Old Leyden coal mine/ Oversight mine/ Peanut mine/ Robinson property (uraniferous pyrobitumen deposits)/ Shattuck Denn Shaft/ Small Spot mine/ Virgin No. 2 mine/ Weatherly property (uraniferous pyrobitumen deposits)/ Wild Steer mine/ host rocks and materials: veins, sandstone/ Cutler formation/ Dolores formation/ Laramie formation/ Morrison formation/ Salt Wash member of Morrison formation/

-
- 1955, Coffinite, a uranous silicate with hydroxyl substitution; a new mineral (sum.): Science, v. 121, no. 3147, p. 608-609.
 coffinite/ Mesa County/ La Sal No. 2 mine/ mineralogy/ sandstone/ Colorado Plateau/
-
- 1956, Coffinite, A uranous silicate with hydroxyl substitution; a new mineral: Am. Mineralogist, v. 41, no. 9-10, p. 675-688, illus.
 Front Range/ coffinite/ uranium/ silicate/ Colorado Plateau/ Copper King mine/ Larimer County/ Arrowhead mine/ Mesa County/ Colorado/ occurrence/ Jefferson County/ Montrose County/ San Miguel County/ properties/ geochemistry/ x-ray analysis/
- Stocking, H.E., and Page, L.R., 1956, Natural occurrence of uranium in the United States- a summary, in Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 5-12.
 veins/ Front Range/ coffinite/ uranium/ silicate/ Colorado Plateau/ Copper King mine/ Larimer County/ Arrowhead mine/ Mesa County/ Colorado/ occurrence/ Jefferson County/ Montrose County/ San Miguel County/ properties/ x-ray analysis/ geochemistry/
-
- 1956, Natural occurrence of uranium in the United States - a summary, in Geology of Uranium and Thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 5, p. 211-216.
 veins/
- Stugard, Frederick Jr., Wyant, D.G., and Gude, A.J., 3d, 1951, Secondary uranium deposits in the United States (abs): Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1512 (see U.S. Geol. Survey TEI-168).
 uranium/ ore deposits/ United States/ Colorado Plateau/ Front Range/
-
- 1952, Secondary uranium deposits in the United States: U.S. Geol. Survey Cir. 220, p. 19-25, (maps).
 veins/ uranium/ secondary/ United States/ regional/ Central City/ Colorado Plateau/ Gilpin County/ metamorphic/ ore deposits/ Colorado/ igneous-metamorphic/ sandstone/ Front Range/

- Taylor, R.B., 1975, Geologic map of the Black Hawk quadrangle, Gilpin, Jefferson and Clear Creek Counties, Colorado (map): U.S. Geol. Survey Map GQ-1248.
geology/ map/ Black Hawk quadrangle/ Gilpin County/ Jefferson County/ Clear Creek County/ Front Range/ igneous-metamorphic/
- Theobald, P.K., and Guilinger, R.R., 1955, A radioactive copper-bearing shear zone in the vicinity of the F.M.D. mine, Jefferson County, Colorado, in Geologic investigations of radioactive deposits - Semiannual progress report for June 1 to Nov. 30, 1955: U.S. Geol. Survey TEI-590, p. 202-212.
veins/ FMD mine/ Jefferson County/ shear zone/ copper/ radioactivity/ igneous-metamorphic/ geology/ Front Range/
- Thurston, W.R., 1950, Exploration of the Big Boulder prospect, Larimer County, Colorado: U.S. Geol. Survey TEM-106, (see U.S. Geol. Survey Bull. 1011).
beryllium/ pegmatite/ Larimer County/ Big Boulder beryl prospect/ igneous-metamorphic/ exploration/ Front Range/
- _____, 1950, Exploration of the Hyatt pegmatite, Larimer County, Colorado: U.S. Geol. Survey TEM-105, (see U.S. Geol. Survey Bull. 1011).
beryllium/ pegmatites/ Larimer County/ Hyatt mica mine/ pegmatite/ beryl/ igneous-metamorphic/ exploration/ Front Range/
- _____, 1950, Exploration of the Buckhorn mica mine, Larimer County, Colorado: U.S. Geol. Survey TEM-104, (see U.S. Geol. Survey Bull. 1011).
beryllium/ pegmatite/ Larimer County/ Buckhorn Mica mine/ drill section/ igneous-metamorphic/ Front Range/
- _____, 1952, Pegmatites of the Crystal Mountain district, Larimer County, Colorado: U.S. Geol. Survey TEI-139, 167 p., maps, tables, (see U.S. Geol. Survey Bull. 1011, open-filed).
igneous-metamorphic/ Buckhorn mica mine/ schists/ Larimer County/ Hyatt area/ Front Range/ beryllium/ pegmatite/ Crystal Mountain district/ mineralogy/ petrology/ geochemistry/ minerals/ autunite/ gunnite/ metatorbernite/ uraninite/ Big Boulder Beryl prospects/ Hyatt Mica-beryl pegmatite/ reserves/ resources/ uranium/ thorium/ beryllium/

- 1955, Pegmatites of the Crystal Mountain district, Larimer County, Colorado: U.S. Geol. Survey Bull. 1011, 185 p., (see U.S. Geol. Survey TEI-139, TEM-104, 105, 106).
Front Range/ Larimer County/ igneous-metamorphic/ schist/ granite/ diorite/ pegmatite/ Crystal Mountain district/ uraninite/ structure/ alteration/ Hyatt Pegmatite/ Big Boulder prospect/ Buckhorn Mica mine/ Idaho Springs Formation/
- 1955, Investigation of wall-rock alteration, Central City and Idaho Springs district, Gilpin and Clear Creek Counties, Colorado: Geol. Soc. America Bull., v. 66, no. 12, pt. 2, p. 1682.
Gilpin County/ Clear Creek County/ Central City district/ Idaho Springs district/ mineralogy/ petrology/ alteration/ geochemistry/ wall rock/ Colorado/ igneous-metamorphic/ uranium/ veins/ Front Range/
- 1956, Altered wall rocks along vein deposits in the Central City-Idaho Springs region, Colorado: Natl. Research Council Pub. 456, p. 348-361.
Central City/ Idaho Springs/ Gilpin County/ Clear Creek County/ igneous-metamorphic/ alteration/ veins/ wall rock/ sulfides/ structures/ ore deposits/ Front Range/
- 1963, Altered wallrocks in the central part of the Front Range mineral belt, Gilpin and Clear Creek Counties, Colo.: U.S. Geol. Survey Prof. Paper 439, 102 p., (1964).
alteration/ wall rocks/ Front Range mineral belt/ Gilpin County/ Clear Creek County/ igneous-metamorphic/
- Tovote, W.L., 1906, Das Pechblende-Vorkommen in Gilpin County, Colorado (The pitchblende occurrence in Gilpin County, Colorado): Austria, Z. Bergwirtsch. Huettenwes., v. 54, p. 223-224.
Gilpin County/ pitchblende/ igneous-metamorphic/ Front Range/
- 1906, Ein Ausflug durch Boulder County, Colorado (an expedition through Boulder County, Colorado): Austria, Z. Bergwirtsch. Huettenwes., v. 54, p. 281-283.
Boulder County/ igneous-metamorphic/ Front Range/

- Trautwein, C.M., 1975, Detailed Precambrian stratigraphic, structural and metamorphic petrology of the Eldorado Springs and Ralston Buttes Quadrangle, Jefferson and Boulder Counties, Colorado (Ph.D. thesis): Colorado School of Mines, (unpublished, in progress).
Precambrian/ stratigraphy/ structure/ igneous-metamorphic/ metamorphic petrology/ Eldorado Springs quadrangle/ Ralston Buttes quadrangle/ Jefferson County/ Boulder County/ Front Range/
- Tripp, R.M., 1944, Radon survey of the Fort Collins anticline (Colorado) (abs.): Dallas Dig., Dallas, Texas, p. 67.
radon/ survey/ Fort Collins Anticline/ Weld County/ Larimer County/ sandstone/
- U.S. Atomic Energy Commission, 1959, Guidebook of uranium deposits of western United States: U.S. Atomic Energy Comm. RME-141, (for abstract see NSA 31:33009).
manuals/ uranium deposits/ geology/ exploration/ United States/ mining/ uranium mines/ mineralogy/ prospecting/ bibliographies/ guidebook/ sandstone/ Colorado/ ore deposits/ igneous-metamorphic/
-
- 1966, Preliminary reco-naissance reports on reported occurrences of uranium deposits, Colorado, Arapahoe County: U.S. Atomic Energy Comm. PB-172, 524, 2 p.
geology/ uranium/ geophysical prospectin/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Arapahoe County/ reconnaissance/ ore deposits/ sandstone/
-
- 1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Archuleta county: U.S. Atomic Energy Comm. PB-172 525, 3 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Archuleta County/ reconnaissance/ ore deposits/
-
- 1966, Preliminary reconnaissance report on reported occurrences of uranium deposits, Colorado, Boulder County: U.S. Atomic Energy Comm. PB-172 528, 72 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Boulder County/ Front Range/ ore deposits/ reconnaissance/ igneous-metamorphic/

1966, Preliminary reconnaissance report on reported occurrences of uranium deposits, Colorado, Chaffee County: U.S. Atomic Energy Comm. PB-172 529, 47 p. geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Chaffee County/ reconnaissance/ ore deposits/ sandstone/ igneous-metamorphic/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Clear Creek County: U.S. Atomic Energy Comm. PB-172 530, 131 p. geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Clear Creek County/ igneous-metamorphic/ veins/ Front Range/ reconnaissance/ ore deposits/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Costilla County: U.S. Atomic Energy Comm. PB-172 532, 8 p. geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Costilla County/ reconnaissance/ ore deposits/ Front Range/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Custer County: U.S. Atomic Energy Comm. PB-172 533, 32 p. geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Custer County/ reconnaissance/ ore deposits/ Front Range/ sandstone/ igneous-metamorphic/

1966, Preliminary reconnaissance reports on reported occurrences on uranium deposits, Colorado, Denver County: U.S. Atomic Energy Comm. PB-172 534, 3 p. geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Denver County/ reconnaissance/ ore deposits/ Front Range/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Douglas County: U.S. Atomic Energy Comm. PB-172 536, 10 p. geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Douglas County/ reconnaissance/ ore deposits/ Front Range/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, El Paso County: U.S. Atomic Energy Comm. PB-172 539, 18 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ El Paso County/ reconnaissance/ ore deposits/ Front Range/ sandstone/ igneous-metamorphic/

1966, Preliminary reconnaissance reports of reported occurrences of uranium deposits, Colorado, Fremont county: U.S. Atomic Energy Comm. PB-172 540, 44 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Fremont County/ reconnaissance/ ore deposits/ Front Range/ sandstone/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Gilpin County: U.S. Atomic Energy Comm. PB-172 542, 47 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Gilpin County/ reconnaissance/ ore deposits/ Front Range/ igneous-metamorphic/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Grand County: U.S. Atomic Energy Comm. PB-172 543, 36 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Grand County/ reconnaissance/ ore deposits/

1966, Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Jefferson County: U.S. Atomic Energy Comm. PB-173 548, 66 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Jefferson County/ reconnaissance/ ore deposits/ Front Page, sandstone/ igneous-metamorphic/

1966 Preliminary reconnaissance reports on reported occurrences of uranium deposits, Colorado, Moffat County: U.S. Atomic Energy Comm. PB-172 555, 95 p.
geology/ uranium/ geophysical prospecting/ economic geology/ mining engineering/ petrology/ minerals/ radioactivity/ Moffat County/ reconnaissance/ ore deposits/ sandstone/ Colorado Plateau/

-
- 1969, Availability of U.S. Atomic Energy Comm. geology--
mineralogy Reports: U.S. Atomic Energy Comm. PB-187559,
117 p.
geology/ mineralogy/ geologic deposits/ availability/
uranium deposits/ documents types/ uranium ores/ information
retrieval/ bibliography/
- U.S. Energy Research and Development Administration, 1976,
National uranium resource evaluation, preliminary report,
June 1976: U.S. Energy Research Devel. Adm. GJO-111(76),
132 p.
resources/ United States/ uranium areas/ sandstone/ vein/
igneous-metamorphic/ Colorado Plateau/ geology/ Great
Palins/ Front Range/ Rocky Mountains/ NURE/
- U.S. Geological Survey, 1950, Characteristics of radioactive
carbonaceous and bituminous shales: U.S. Geol. Survey
TEI-78.
shales/ radioactivity/ carbonaceous rocks/ bituminous
shales/ characteristics/ Jefferson County/ Rio Blanco
county/ oil shale/ United States/ Front Range/ Colorado
Plateau/
-
- 1950, Colorado Front Range area, progress report:
U.S. Geol. Survey TEM-97.
Front Range/ igneous-metamorphic/ sandstone/
-
- 1953, Uranium in veins, igneous rocks and related
deposits, Colorado Front Range, in Geologic investigations
of radioactive deposits, semiannual progress report,
classified data, June 1 to November 30, 1953: U.S.
Geol. Survey TEI-391, p. 17.
Front Range/ veins/ igneous-metamorphic/ ore deposits/
Central City/ Idaho Springs/ Gilpin County/ Clear Creek
County/ reserves/ Wood mine/ Kirk mine/ Bonanza mine/
German mine/ pitchblende/ Martha E. mine/
-
- 1953, Geologic investigations of radioactive
deposits, semiannual progress report, classified data,
June 1 to November 30, 1953: U.S. Geol. Survey TEI-391,
49 p., (see U.S. Geol. Survey TEI-390).
sandstone/ Colorado Plateau/ Front Range/ veins/ igneous-
metamorphic/ thorium/ Powderhorn/ Gunnison County/
natural waters/ Morrison Formation/ Mesa County/ Montrose
County/ San Miguel County/ Dolores County/ San Juan
Mountains/ San Juan County/ La Plata County/ Ouray County/

1953, Search for and geology of radioactive deposits, semi-annual progress report for December 1, 1952 to May 31, 1953: U.S. Geol. Survey TEI-330, 302 p. geologic mapping/ Colorado Plateau/ Front Range/ Carbonaceous rocks/ geochemistry/ reconnaissance/ black shales/ summaries/ 1953/ sandstone/ igneous-metamorphic/

1953, Geologic investigations of radioactive deposits, semi-annual progress report, June 1 to November 30, 1953: U.S. Geol. Survey TEI-390, 281 p. Colorado Plateau/ Front Range/ sandstone/ coal/ springs/ igneous-metamorphic/ shale/ Gilpin County/ Clear Creek County/ Jefferson County/ Boulder County/ Custer County/ thorium/ Gunnison County/ La Plata County/ San Juan County/ Ouray County/ summaries/ 1953/

1953, Trace elements research quarterly progress report, January 1 to March 31, 1952: U.S. Geol. Survey TEI-270, 61 p. Colorado Plateau/ veins/ Front Range/ Morrison studies/ Triassic studies/ mineralogy/ petrology/ analysis/ summaries/ 1952/ sandstone/ igneous-metamorphic/

1954, Geologic investigations of radioactive deposits, semiannual progress report, classified data, June 1 to November 30, 1954: U.S. Geol. Survey TEI-491, 29 p. Clear Creek County/ Gilpin County/ ore deposits/ reserves/ Colorado Plateau/ exploration/ sandstone/ Mesa County/ Montrose County/ San Miguel County/ Garfield County/ Moffat County/ Dolores County/ Rio Blanco County/ Front Range/ igneous-metamorphic/ Jefferson County/ pitch-blende/ hydrogeochemical exploration/ stream sediments/ ground water/ mine waters/

1954, Geologic investigations of radioactive deposits, semi-annual progress report, December 1, 1953 to May 31, 1954: U.S. Geol. Survey TEI-440, 229 p. summaries/ Colorado Plateau/ geophysics/ Front Range/ igneous rocks/ sandstone/ mineralogy/ coal/ shales/ reconnaissance/ petrology/ stratigraphy/ 1954/ sandstone/ igneous-metamorphic/

1954, Geologic investigations of radioactive deposits, semi-annual progress report, classified data, December 1, 1953 to May 31, 1954: U.S. Geol. Survey TEI-441, 24 p. (see U.S. Geol. Survey TEI-440).

Colorado Plateau/ sandstone/ Mesa County/ Montrose County/ San Miguel County/ Dolores County/ ore deposits/ Morrison Formation/ geology/ Chinle Formation/ Shinarump conglomerate/ reserves/ snow/ surface water/ ground water/ San Juan Mountains/ Ouray County/ San Juan County/ igneous-metamorphic/ Front Range/

1954, Geologic investigations of radioactive deposits, semi-annual progress report, June 1 to November 30, 1954: U.S. Geol. Survey TEI-490, 299 p.

summaries/ Front Range/ Colorado Plateau/ stratigraphic studies/ botanical prospecting/ mineralogy/ Ralston Buttes district/ black shale/ reconnaissance/ analysis/ 1954/ Jefferson County/ sandstone/ igneous-metamorphic/

1955, Geologic investigations of radioactive deposits, semi-annual progress report, classified data, December 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI-541.

Beaver Mesa/ Disappointment Valley or syncline/ Front Range/ Jo Dandy area/ La Sal Creek area/ Monogram Mesa/ Ralston Buttes district/ Uravan/ exploratory drilling/

1955, Geologic investigations of radioactive deposits, semi-annual progress report, classified data, June 1 to November 30, 1955: U.S. Geol. Survey TEI-591, 17 p.

Front Range/ Golden Gate Canyon/ Ralston Buttes district/ Uravan/ exploratory drilling/ Colorado Plateau/ summaries/ 1955/ Jefferson County/ San Miguel County/ Montrose County/ Mesa County/ Dolores County/ sandstone/ igneous-metamorphic/

1955, Geologic investigations of radioactive deposits, semi-annual progress report, December 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI-540, 284 p.

Colorado Plateau/ Front Range/ sandstone/ geologic mapping/ veins/ carbonaceous rocks/ geochemistry/ reconnaissance/ analysis/ summaries/ 1955/ igneous-metamorphic/

1956, Geologic investigations of radioactive deposits, semi-annual progress report, June 1 to November 30, 1955: U.S. Geol. Survey TEI-590, 347 p.

summaries/ Colorado Plateau/ Front Range/ veins/ geologic mapping/ mineralogy/ petrology/ geophysics/ carbonaceous rocks/ analysis/ 1955/ sandstone/ igneous-metamorphic/

-
- 1956, Geologic investigations of radioactive deposits, semi-annual progress report, December 1, 1955 to May 31, 1956: U.S. Geol. Survey TEI-620, 361 p.
Colorado Plateau/ mapping/ geology/ geophysics/ mineralogy/ vanadium/ igneous rocks/ carbonaceous rocks/ petrology/ summaries/ 1956/ sandstone/ igneous-metamorphic/
-
- 1956, Geologic investigations of radioactive deposits, semi-annual progress report, June 1 to November 30, 1956: U.S. Geol. Survey TEI-640, 327 p.
Colorado Plateau/ Front Range/ geology/ geophysics/ mineralogy/ research/ summaries/ 1956/ sandstone/ igneous-metamorphic/
-
- 1957, Geologic investigations of radioactive deposits, semi-annual progress report for June 1 to November 30, 1957: U.S. Geol. Survey TEI-700, 288 p.
Colorado Plateau/ Front Range/ geology/ geophysics/ topical studies/ geochemistry/ geophysics/ thorium/ summaries/ 1957/ sandstone/ igneous-metamorphic/
-
- 1957, Geologic investigations of radioactive deposits, semi-annual progress report for December 1, 1956 to May 31, 1957: U.S. Geol. Survey TEI-690, 571 p.
Colorado Plateau/ Front Range/ geology/ geophysics/ topical studies/ geophysics/ mineralogy/ research/ summaries/ 1957/ sandstone/ igneous-metamorphic/
-
- 1958, Geologic investigations of radioactive deposits, semi-annual progress report for December 1, 1957 to May 31, 1958: U.S. Geol. Survey TEI-740, 320 p.
summaries/ Colorado Plateau/ mapping/ geophysics/ topical studies/ geochemistry/ Maybell-Lay area/ Front Range/ research/ thorium/ 1958/ Moffat County/ sandstone/ igneous-metamorphic/
-
- 1958, Geologic investigations of radioactive deposits, semi-annual progress report for June 1 to November 30, 1958: U.S. Geol. Survey TEI-750, 149 p.
summaries/ Colorado Plateau/ geophysics/ geochemistry/ research/ Front Range/ thorium/ reconnaissance/ 1958/ sandstone/ igneous-metamorphic/
-
- United Nations, 1956, Geology of uranium and thorium: Internat. Conf. on the Peaceful Uses of Atomic Energy, 1st, Geneva, 1955, Proc., v. 6, 825 p., (various U.S. and foreign papers on uranium geochemistry and isotope geology - see U.S. Geol. Survey Prof. Paper 300).
uranium/ thorium/ geology/ ore deposits/ geochemistry/ isotope geology/

- Vanderpool, J.S., 1957, Discussion of paragenesis and structure of pitchblende-bearing veins, Central City district, Gilpin County, Colorado: Econ. Geology, v. 52, p. 713.
paragenesis/ structure/ pitchblende/ veins/ Central City district/ igneous-metamorphic/ Gilpin County/ Front Range/
- Vanderwilt, J.W., 1947, Mineral resources of Colorado: Colorado Geol. Survey Colorado Mineral Resources Board, 547 p., 10 figs., 34 pls., 150 tables.
minerals/ resources/ Colorado/ uranium/ thorium/
- Vickers, R.C. (compiler), 1951, Bibliography of U.S. Geological Survey Trace Element Reports: U.S. Geol. Survey TEI-200.
bibliography/ trace element reports/ uranium/ vanadium/ thorium/ beryllium/ Colorado Plateau/ Colorado/
- Vine, J.E., 1956, Uranium-bearing coal in the United States, in Contributions to the geology of uranium and thorium by the U.S. Geol. Survey and Atomic Energy Comm. for the U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Procl: U.S. Geol. Survey Prof. Paper 300, p. 405-411.
uranium/ coal/ Old Leyden Coal Mine/ Jefferson County/ Cretaceous/ Laramie formation/ United States/ regional/ occurrence/ distribution/ shale/ Front Range/
- _____, 1956, Uranium-bearing coal in the United States, in Geology of uranium and thorium: U.N. Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, Proc., v. 6, p. 452-457.
uranium/ coal/ Old Leyden Coal mine/ Jefferson County/ Cretaceous/ Laramie Formation/ United States/ regional/ occurrence/ distribution/ shale/ Front Range/
- Walker, G.W., 1956, Host rocks and their alterations as related to uranium-bearing veins in the United States: U.S. Geol. Survey TEI-638, 59 p., (see U.S. Geol. Survey Prof. Paper 455-C, p. 37-53).
ore deposits/ host rocks/ alteration/ veins/ sandstone/ igneous-metamorphic/ limestone/ Boulder County/ Park County/ Front Range/ Gilpin County/ Clear Creek County/ Jefferson County/ Saguache County/ coal/ dolomite/ Pitkin County/ Larimer County/

1963, Host rocks and their alterations as related to uranium-bearing veins in the conterminous United States, in Geology of uranium-bearing veins in the conterminous United States: U.S. Geol. Survey Prof. Paper 455-C, p. 37-53.

alteration/ veins/ igneous-metamorphic/ sandstone/ limestone/ Boulder County/ Park County/ Front Range/ Gilpin County/ Clear Creek County/ Jefferson County/ Saguache County/ coal/ Cochetopa district/ Central City district/ Placerville/ San Miguel County/ Larimer County/

Walker, G.W., and Osterwald, F.W., 1963, Introduction to the geology of uranium-bearing veins in the conterminous United States, including sections on geographic distribution and classification of veins, in Geology of uranium-bearing veins in the conterminous United States: U.S. Geol. Survey Prof. Paper 455-A, p. 1-28.
ore deposits/ veins/ classification/geology/ Front Range/ Gilpin County/ Jefferson County/ Clear County/ sandstone/ Boulder County/ San Miguel County/ igneous-metamorphic/ Colorado Plateau/ Saguache County/ Custer County/ Chaffee County/

Walker, G.W., 1957, Supergene alteration of uranium-bearing veins in the United State: U.S. Geol. Survey TEI-693, 39 p., (see U.S. Geol. Survey Prof. Paper 455-E, p. 91-103).

Maryvale/ leaching/ enrichment/ uranium/ ore deposits/ alteration/ supergene/ veins/ Marshall Pass/ Colorado/ Utah/ Saguache County/ Nigger Shaft/ North Star mine/ Jefferson County/ Gilpin County/ Front Range/ sandstone/ igneous-metamorphic/ zoning/ Madonna mine/ Chaffee County/

1963, Supergene alteration of uranium-bearing veins in the conterminous United States in Geology of uranium-bearing veins in the conterminous United States: U.S. Geol. Survey Prof. Paper 455-E, p. 91-103.

Maryvale/ leaching/ enrichment/ uranium/ ore deposits/ alteration/ supergene/ veins/ Marshall Pass/ Colorado/ Utah/ Saguache County/ Nigger Shaft/ North Star mine/ Jefferson County/ Gilpin County/ Front Range/ sandstone/ igneous-metamorphic/ zongin/ Madonna mine/ Chaffee County/

- Wallace, S.R., and Laub, D.C., 1954, Zonal relations of uranium deposits in metalliferous districts, in Geologic investigations of radioactive deposits - Semiannual progress report, June 1 to Nov. 30, 1954: U.S. Geol. Survey TEI-490, p. 146-148.
veins/ Colorado/ Arizona/ ore deposits/ exploration/ zoning/ metalliferous deposits/ Gold Hill/ Boulder County/ igneous-metamorphic/ summary/ Front Range/
- Wallace, S.R., Leonard, B.F., 3d, and Campbell, R.H., 1955, Relation of uranium to hypogene mineral zoning in the Front Range mineral belt, Colorado: U.S. Geol. TEI-357, 43 p. (with maps).
Breckenridge/ Caribou/ Central City Summit County/ Freeland-Lamartine/ Front Range/ Georgetown/ Silver Plume/ Gold Hill/ Idaho Springs/ Lawson-Dumont/ igneous-metamorphic/ Gilpin County/ Ward district/ Boulder County/ Clear Creek County/ Gilpin County/ hypogene mineral zoning/
- Waring, C.L., and Ansell, C.S., 1952, A semi-quantitative spectrographic method for the analysis of minerals, rocks and ores (II): U.S. Geol. Survey TEI-215, 32 p., (see Anal. Chemistry, v. 25, no. 8, p. 1174-1179).
Larimer County/ Hyatt mica-beryl/ pegmatite/ chemical analysis/ spectrographic analysis/ pegmatite samples/ Front Range/ igneous-metamorphic/
- Wells, J.D., 1955, Structure and petrology of the granodiorite along Ute Creek, Clear Creek County, Colorado (abs.): Geol. Soc. America Bull., v. 66, p. 1683.
structure/ petrology/ granodiorite/ Ute Creek/ Clear Creek County/ Colorado/ Front Range/ igneous-metamorphic/
- _____, 1960, Petrography of radioactive Tertiary rocks, Front Range mineral belt, Colorado: U.S. Geol. Survey Bull. 1032-E, p. 223-272 (1961).
petrology/ Tertiary rocks/ igneous-metamorphic/ thorium/ Front Range/ Colorado/ radioactivity/ distribution/ Gilpin County/ Clear Creek County/ volcanic/ bostonite porphyry/ uranium/
- _____, 1967, Geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geol. Survey Bull. 1221-D, 85 p.
geology/ Eldorado Springs quadrangle/ Boulder County/ Jefferson County/ igneous-metamorphic/ Front Range/

- _____. n.d., Geology of the Tertiary igneous rocks, central part of the Front Range mineral belt, Gilpin and Clear Creek Counties: U.S. Geol. Survey TEI-597. geology/ Tertiary/ igneous-metamorphic/ Front Range/ Gilpin County/ Clear Creek County/
- Wells, J.D., and Harrison, J.E., 1953, Radioactivity reconnaissance of part of north-central Clear Creek County, Front Range, Colorado: U.S. Geol. Survey TEI-305, 21 p. (see U.S. Geol. Survey Circ. 345). Clear Creek County/ reconnaissance/ radioactivity/ igneous-metamorphic/ Front Range/
- _____. 1954, Radioactivity reconnaissance of part of north-central Clear Creek County, Colorado: U.S. Geol. Survey Circ. 345, 9 p., illus. Clear Creek County/ north-central/ ore deposits/ exploration/ veins/ radioactivity/ igneous-metamorphic/ reconnaissance/ methods/ Colorado/ Front Range/
- Wells, J.D., Sheridan, P.M., and Albee, A.L., 1951, Metamorphism and structural history of the Coal Creek area, Front Range, Colorado: in short papers in the geologic and hydrologic sciences: U.S. Geol. Surv. Prof. Paper 424-C, p. C127-C131. metamorphism/ structure/ geologic history/ Coal Creek area/ Front Range/ igneous-metamorphic/ Jefferson County/ Clear Creek County/
- _____. 1964, Relationship of Precambrian quartzite-schist sequence along Coal Creek to Idaho Springs Formation, Front Range, Colorado: U.S. Geol. Surv. Prof. Paper 454-0, 25 p. Precambrian/ quartzite/ schist/ Coal Creek/ Idaho Springs Formation/ Front Range/ igneous-metamorphic/ Jefferson County/ Clear Creek County/
- Wilmarth, V.R., Bauer, H.L., Jr., Staatz, M.H., and Wyant, D.G., 1951, Uranium in fluorite deposits (abs.): Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1543 (see U.S. Geol. Surve. TEI-168). uranium/ fluorite/ ore deposits/ Colorado/ general/ regional/ occurrence/ classification/
- _____. 1952, Uranium in fluorite deposits, in Selected paper on uranium deposits in the United States: U.S. Geol. Survey Circ. 220, p. 13-18. veins/ fluorite/ uranium/ Colorado/ general/ grouping/ mineral association/ ore deposits/

- Wilson, J.H., 1923, An occurrence of carnotite near Denver:
Eng. Mining Jour., v. 116, no. 6, p. 239-240.
Denver/ ore deposits/ occurrence/ carnotite/ Laramie
Formation/ sandstone/ Jefferson County/ Leyden coal mine/
Front Range/
- Wood, H.E., 1913, Concentration of pitchblende: Eng. and Mining
Jour., v. 95, no. 23, p. 1164-1165.
radium/ pitchblende/ Gilpin County/ chemical separation/
igneous-metamorphic/
- Wood, H.B., 1956, Relations of the origins of host rocks to
uranium deposits and ore production in western United
States, in Contributions to the geology of uranium and
thorium by the U.S. Geol. Survey and Atomic Energy Comm.
for the U.N. Internat. Conf. on Peaceful Uses of Atomic
Energy, Geneva, 1955, Procl: U.S. Geol. Survey Prof.
Paper 300, p. 533-541.
Colorado Plateau/ origins/ host rocks/ uranium/ United
States/ ore deposits/ regional/ Colorado/ Jefferson County/
Saguache County/ Park County/ Boulder County/ San Miguel
County/ Montrose County/ Moffat County/ sandstone/ Front
Range/ coal/ igneous-metamorphic/
-
- 1956, Relations of the origin of host rocks to
uranium deposits and ore production in western United
States, in Geology of uranium and thorium: U.N. Internat.
Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955,
Proc., v. 6.
Colorado Plateau/ origins/ host rocks/ uranium/ United
States/ ore deposits/ regional/ Colorado/ sandstone/
Jefferson County/ Saguache County/ Park County/ Boulder
County/ Montrose County/ San Miguel County/ Moffat County/
coal/ igneous-metamorphic/ Front Range/
- Wood, J.R., 1912, New vanadium fields in Boulder County,
Colorado: Mining Sci., v. 65, p. 74-75.
vanadium/ Boulder County/ igneous-metamorphic/ Front
Range/
- Wright, H.D., 1950, Mineralogy of the Radium Vein, Caribou,
in Kerr, P.F., Mineralogical studies of uraninite and
uraninite-bearing deposits: U.S. Atomic Energy Comm.
RMO-715, 3 p.
Caribou Mine/ ore deposits/ radium/ mineralogy/ Boulder
County/ Radium Vein/ igneous-metamorphic/ uraninite/
sampling/ analysis/ paragenesis/ Front Range/

-
- 1950, Wall rock of the Radium Vein, Caribou Mine (a preliminary account), in Kerr, P.F., Mineralogical studies of uraninite and uraninite-bearing deposits: U.S. Atomic Energy Comm. RMO-715, 6 p.
ore deposits/ radium/ veins/ wallrock alteration/ Boulder County/ Caribou Mine/ Radium Vein/ igneous-metamorphic/ uraninite/ Front Range/
-
- 1951, Paragenesis of a uranium-bearing vein at Caribou, Colorado: Denison Univ., Sci. Lab Jour., v. 42, art. 8, p. 75-82, illus.
ore deposits/ paragenesis/ Boulder County/ Caribou/ veins/ Radium Vein/ igneous-metamorphic/ uraninite/ silver/ Caribou mine/ Front Range/
-
- 1951, Memorandum on the study of certain Colorado and Ontario uraninite deposits, in Annual report for July 1, 1950 to June 30, 1951: U.S. Atomic Energy Comm. RMO-797, p. 69-86, illus.
Canada/ Ontario/ ore deposits/ uraninite/ Caribou mine/ alteration/ Boulder County/ paragenesis/ Front Range/ igneous-metamorphic/ Colorado/
-
- 1954, Mineralogy of a uraninite deposit at Caribou, Colorado: Econ. Geology, v. 49, no. 2, p. 129-174, illus.
ore deposits/ uraninite/ mineralogy/ Boulder County/ silver/ Caribou/ Radium vein/ uranium/ vein/ wallrock/ igneous-metamorphic/ geochemistry/ Caribou mine/ Front Range/
-
- Wright, H.D., and Shulhof, W.P., 1957, An investigation of the amount and distribution of uranium in sulfide minerals in vein ore deposits - annual report for July 1, 1955, to March 31, 1956: U.S. Atomic Energy Comm. RME-3142, 29 p.
veins/ distribution/ quantities/ sulfide minerals/
-
- Wright, H.D., Hutta, J.J., Shulhof, W.P., and Smith, C.M., 1957, An investigation of the amount and distribution of uranium in base metal sulfide minerals in vein ore deposits, Annual report for April 1956, to April 30, 1957: U.S. Atomic Energy Comm. RME-3154, 24 p.
veins/ igneous-metamorphic/ distribution/ quantities/ sulfide minerals/ base metals/ mineral associations/ analysis/ paragenesis/ trace elements/ Idaho/ Arizona/ Clear Creek County/ Central City district/ Carroll mine/ Colorado/ pitchblende/ solid solution/ ore deposits/ Front Range/

- Wyant, D.G., 1949, Treasure Hill area, Larimer County, Colorado:
U.S. Geol. Survey TEM-9, 6 p., figures.
Larimer County/ Treasure Hill area/ schist/ granite/ igneous-
metamorphic/ Precambrian/ reconnaissance/ Front Range/
-
- 1949, The Wheelman Tunnel, Boulder County, Colorado:
U.S. Geol. Survey TEM-8, 6 p., tables, maps.
Boulder County/ Wheelman (mine)tunnel/ pegmatites/ igneous-
metamorphic/ Precambrian/ granite/ gold/ wolframite/
veins/ Front Range/ analyses/
-
- 1949, Spaulding-Woodhams scheelite prospects,
Larimer County, Colorado: U.S. Geol. Survey TEM-9A.
Larimer County/ Spaulding-Woodhams prospects/ scheelite/
igneous-metamorphic/
-
- 1951, Treasure Hill area, Larimer County, Colorado:
U.S. Geol. Survey Tem-9B, 3 p.
Larimer County/ igneous-metamorphic/ Treasurer Hill area/
Front Range/
- Young, E.J., 1972, Laramide-Tertiary intrusive rocks of Colorado:
U.S. Geol. Survey Open-File Rept. 1796, 206 p.
Laramide/ Tertiary/ intrusives/ Colorado/ igneous-metamorphic/
-
- 1977, Geologic, radiometric, and mineralogic maps
and underground workings of the Schwartzwalder uranium
mine and area, Jefferson County, Colorado: U.S. Geol.
Survey open-file Report 77-725.
geology/ maps/ radiometric maps/ mineralogic maps/ under-
ground workings/ Schwartzwalder mine/ Jefferson County/
igneous-metamorphic/ Front Range/ uranium/
- Young, E.J., and Hauff, P.L., 1975, An occurrence of dissem-
inated uraninite in Wheeler Basin, Grand County, Colorado:
U.S. Geol. Survey Jour. Research, v. 3, no. 3, p. 305-311.
uranium deposits/ Colorado/ isotopes/ radioactivity/ age
dating/ uranium/ lead/ uraninite/ pegmatite/ gneiss/
Wheeler Basin/ Grand County/ Fossing uranium deposit/
Precambrian/ igneous-metamorphic/ ore deposits/
- Young, E.J., and Lahr, M., 1975, The Schwartzwalder uranium
mine (abs.): Geol. Soc. America Abs. with Programs, v.7,
no. 5, p. 653.
Schwartzwalder mine/ Jefferson County/ Front Range/ igneous-
metamorphic/ uranium/

Young, E.J., and Sims, P.K., 1958, Occurrence of xenotime and monazite in Precambrian biotite gneiss and migmatite, Gilpin County, Colorado (abs.): Geol. Soc. America Gull., v. 69, no. 12, pt. 2, p. 1750.

Front Range/ occurrence/ xenotime/ monazite/ biotite gneiss/ Precambrian/ migmatite/ igneous-metamorphic/ Gilpin County/ Colorado/ thorium/ Central City/

1961, Petrography and origin of xenotime and monazite concentrations, Central City district, Colorado:

U.S. Geol. Survey Bull. 1032-F, p. 273-299.

Central City district/ Gilpin County/ petrography/ monazite/ xenotime/ Precambrian/ gneiss/ metamorphic/ origin/ Colorado/ igneous-metamorphic/ Front Range/

Young, Patti, and Micle, D.G., 1976, Uranium favorability of Tertiary rocks in the Badger Flats - Elkhorn Thrust area, Park and Teller Counties, Colorado: U.S. Energy Research Devel. Adm. GJBX-54 (76).

uranium/ favorability/ Tertiary/ Badger Flats/ Elkhorn Thrust area/ Park County/ Teller County/ igneous-metamorphic/

APPENDIX C

Breccia Reef Discussions

by

Lovering and Tweto, P.P. 245, pp. 30.

"The so-called breccia reefs of the Front Range area--or dikes as they were known to the early miners--are silicified fault zones. In general they mark the major faults of the early, north-west-trending fracture system; numerous minor faults and fractures of the same system are unsilicified and inconspicuous. The major faults, or reefs, were recognized and named by the earliest miners in Boulder County because ore on many of the northeastward-trending veins is localized near the intersections of the veins with the reefs. In the Tungsten district the reefs are spaced 2 to 3 miles apart across the entire length of the district, as shown in Plate 3. From east to west they are known as the Hoosier reef, which marks the east end of the tungsten district, the Livingston reef; the Rogers reef; the Hurricane Hill reef; and the Maine-Cross reef, which marks the west end of the district."

"Displacement on the breccia-reef faults is best seen at the mountainfront, where the faults displace the sedimentary rocks as much as several hundred feet, with the southwest side downthrown. The total displacement cannot be determined with certainty in the crystalline rocks of the Tungsten district, but various types of movement and directions of displacement recorded by individual fractures within the reefs attest to a long and complex fault history. Nearly all the reefs contain fractures that show a minor, nearly horizontal movement, in which the northeast walls moved southeast and rose slightly, and a major movement in which these same walls dropped and moved southeast at an angle of 20° - 50° , but numerous other, less readily correlated movements occurred. The first movement on the breccia-reef faults took place before the Paleocene Iron dike gabbro was intruded in the eastern part of the district, and movement was repeated intermittently at various times during the Laramide revolution."

"The northwestward-trending fractures of the breccia-reef system are the oldest Laramide fractures recognized in the Tungsten district and surrounding region. They are followed by the earliest dikes, such as the Iron dike, and they are cut and displaced by the northeastward-trending veins. Many of the fractures were mineralized with quartz and hematite before the tungsten vein fissures were formed. The minor fractures between the main reefs are marked only by a little hematite, either specular or earthy, or are merely slips marked by gouge, but the major faults or reefs are characterized at most places by dike-like masses of silicified fault breccia or silicified sheared rock as much as 50 feet wide. These masses are colored purplish by disseminated hematite and are seamed by veins of quartz and hematite. The hematite in the veins or veinlets is nearly all fine-grained, but the quartz with which it is associated is in part coarse-grained, white and glassy and in part

fine-grained and horny. In places hematite is absent, and there the fissures may be filled with a nearly solid vein of coarse-grained quartz 2 to 15 feet wide, or the outcrop may be marked by a wall of silicified granite standing in strong relief above the surrounding rock. Although the northwest-trending faults are conspicuous where they cut across the pre-Cambrian structure and contain a breccia cemented by quartz and hematite, they are commonly much less prominent where they follow northwestward-trending aplite dikes as do the Hoosier and Hurricane Hill reefs at Arkansas Mountain and Hurricane Hill, or where favorable structure in the granite allows them to widen out into broad, sheeted zones. At some places the reefs are broad, chloritized shear zones, and at other they are simply wide gougy zones."

"Both the Hoosier reef and the Livingston reef are strongly silicified throughout their course in the Tungsten district, and they contain less hematite than the breccia reef to the west. The Rogers reef, where it crosses the ridge between North and Middle Boulder Creeks, carries abundant hematite and quartz in a zone 20 to 30 feet wide. It contains as much as 0.03 oz. of gold to the ton, and a little lead-silver ore is said to have been found on it in several prospect pits on the crest of the ridge. A polished slab from this reef is shown in Fig. 23. The Hurricane Hill reef, which crosses the tungsten district near the west margin of the Boulder Creek batholith, ranges from a wide, gougy, unmineralized fault zone to a strongly silicified shear zone with or without hematite. A little late sphalerite and galena have been found in it near Sherwood Gulch. It is relatively obscure at the surface between Tungsten and North Boulder Creek, where it follows the gneissic structure of the aplite that borders the granite; but it is well exposed in the workings of the Clark tunnel. As the reef is essentially parallel to the foliation, the fault movement was largely interlaminal and thus diffused, and in a few places the resulting shear zone was sufficiently permeable to carry the quartz-hematite solutions that mineralized the reef elsewhere. In the Clark tunnel, however, a small body of hematite was mined from it (p. 129)."

"Numerous minor breccia reefs have been found in the Beaver Creek district, south of Nederland, and a strong, but relatively narrow quartz-hematite reef that cuts diagonally through the Cross and Maine claims marks the western limit of the tungsten ore in this part of the district. The Maine-Cross reef can be traced for only about a mile northwest of the Main claim. It probably continues to the northwest, and it may connect with a zone of hematite-bearing, northward-trending shear planes in the Illinois mine, about a mile northwest of Nederland, but it is parallel to the schistosity of the Idaho Springs formation in most of the intervening area and thus is inconspicuous."

"In a few places eastward-trending breccia reefs branch from, or cross the northwestward-trending faults. Of these the Poorman reef, which extends from the Maxwell to the Hoosier reef, is the most conspicuous in the Tungsten district, though it barely extends into the northeast corner of the area shown in plate 1, near the Logan mine. The Copeland reef, which is about 5 1/2 miles farther south, near South Boulder Creek, extends westward from the Livingston reef to the Rogers reef; it contains tungsten at the Copeland mine and at places is slightly mineralized with gold. Many of the veins with an easterly strike in the eastern part of the district show characteristics of the breccia reefs and are believed to be reef fractures that were partly reopened and mineralized during tungsten deposition. The zone of eastward-trending veins that crosses Black Tiger Gulch is an example of this group. The Black Prince vein, on the southwest side of the gulch, comprises narrow, discontinuous streaks of late horn quartz and ferberite in a wide shear zone that contains veins of horn quartz of the breccia reef type and many strong gougy slips. The granite in and along the shear zones is stained red by hematite through widths of as much as 100 feet, but along the tungsten veins within the shear zone the iron-stained granite is bleached and chloritized. Where the Black Prince and other east-west veins of Black Tiger Gulch intersect the Iron dike, the width of the dike changes abruptly, indicating that the veins were in existence at the time that the dike was intruded."

"Although many important bodies of ore have been found in north-eastward-striking veins near their intersection with the reefs, the breccia reefs themselves in general are barren, except that at a few places, particularly near the margins of the district, the reefs were reopened at the time of vein formation and were mineralized with tungsten and gold (pp. 55-57). At a few places, also, breccia reefs served as the loci of intrusion for biotite latite porphyry and latitic intrusion breccia and there is some suggestion that the intrusions were the cause of the late movement on the reefs and thus a factor in the subsequent mineralization. In the Yellow Pine and Logan mines, at the northeast edge of the district, the Hoosier reef is a wide, silicified shear zone whose middle portion has risen in a horst-like movement. The reef is locally bounded and cut by dikes of biotite latite porphyry and intrusion breccia (p. 27), and it seems possible that the horst-like movement of the reef and some of the brecciation along the reef walls were caused by the upward push of an underlying biotite latite magma and that the reef was silicified partly by the solutions from the biotite latite magma. Somewhat similar relations were observed in one of the group of short adits that comprise the Rogers No. 17 mine (fig. 24B), where intrusion breccia bordering a small dike

of biotite latite porphyry grades almost imperceptibly into the silicified breccia of a minor breccia reef and a narrow streak of the breccia is partly filled with later ferberite. Thus it appears that at some places the breccia reefs were loci of later intrusion and that attendant fracturing allowed the mineralizing solutions that followed to gain access to the reefs."

Mineralization in Breccia Reefs - Tungsten District

P.P. 245 - Lovering and Tweto, 1953, pg. 55

"Sometime after the breccia-reef fracture zones were formed, and after the Iron dike was intruded but before any of the veins described were formed, the breccia reefs were mineralized with quartz and hematite as described on p. 30. This mineralization was essentially barren of precious or base metals, but most of the reef quartz assays a trace of gold, and the Rogers reef assays as high as 0.03 oz of gold per ton in places. The quartz-hematite mineralization appears to have sealed the reef-fracture zones, for in general these remained unaffected during the later periods of mineralization. They were remineralized in a few isolated localities, however, and the several types of mineralization found in such deposits testify to the early age of the reefs. In the Yellow Pine mine early silver ore is closely associated with the Hoosier breccia reef (see description of the Yellow Pine mine). The Hurricane Hill breccia reef contains sulfides of iron, copper, lead and zinc with some silver, and similar ore is found at places in the Rogers reef. These occurrences are probably related to the early silver veins. Breccia reefs in the area adjoining the northeast end of the district have been mineralized at places by pyritic gold ore and by gold telluride ore and the Copeland reef south of Magnolia contains gold telluride."

"The breccia reefs contain tungsten at several localities, particularly near the margins of the district and in outlying areas. On the Great Sphinx claim on the east slope of Arkansas Mountain tungsten occurs in several closely spaced seams of sheared and silicified rock in the footwall fracture zone of the main Poorman breccia reef. Finely crystalline ferberite and black, tungsten-bearing horn quartz cements a breccia of silicified rock and occur as small pockets and veinlets in moderately persistent minor veins of gray horn quartz within the crushed and silicified rock. The nearby Little Wallace K mine on the northeast branch of the Hoosier breccia reef at the foot of the Yellow Pine dump, is said to have produced tungsten ore valued at \$60,000 during World War I."

"The Ohio mine on the ridge south of Bummers Gulch about 3,500 feet east of Millionaire Gulch, is on a wide east-west breccia-reef fracture zone that branches from the main Hoosier reef a short distance east of the mine. Crushed or sheared rock, some of it hematite stained, occurs in several streaks, each several feet wide, in a zone 50-75 feet wide. Veinlets of late ferberite and scheelite ramify through these streaks and the intervening shattered pegmatite, making a large body of fairly low grade ore that was mined chiefly by glory-holing."

"The Copeland breccia reef is tungsten bearing at the Copeland mine, near South Boulder Creek about 2 1/2 miles south of Magnolia. This occurrence is described in connection with the Copeland mine."

"A northwestward-trending breccia reef that is part of the Rogers breccia reef system is mineralized with tungsten on the Walker ranch about half a mile west of Crescent station on the D&RG RR and about 5 miles south of the main Tungsten district. Small veins of high grade, coarsely crystalline ferberite occupy late fractures within or alongside the reef; finely crystalline ferberite occurs in places on joint faces and in small spots of bunches in reef breccia, mostly in close association with reef hematite; and tungsten-bearing black horn quartz of low grade seams the sheared reef rock or cements a breccia of sheared and silicified rock in places, particularly near the intersection of the northwestward-trending reef with one that trends N 80° E. The granite along the east-northeastward-trending veins that branch from the northeast side of the reef is intensely altered and shows both the argillic and the sericitic alteration characteristics of the veins in the main tungsten district. These veins contain a little gray and greenish-gray horn quartz, but no ferberite has been found in them."

"Fairly high grade ferberite ore occurs in northwestward-trending fractures of the Hurricane Hill breccia reef and in intersecting northeastward-trending fractures about 1 1/2 miles east-southeast of Tungsten Mountain."

APPENDIX D

BIOGEOCHEMISTRY

The use of biogeochemistry in uranium exploration along the Front Range has received very little attention. However, a survey conducted by Fisher (1976) in the Ralston Buttes district indicates that such methods may be useful. Two separate traverses over the Schwartzwalder mine established an uranium and molybdenum anomaly above the deposit. Samples of current-year and one-year old ponderosa pine needles were ashed and analyzed for the two metals. Values ranged from 0.5 ppm to 160 ppm and 2 ppm to 36 ppm for uranium and molybdenum respectively. Ranges of 1 ppm to 5 ppm for uranium and 2 ppm to 8 ppm for molybdenum were reported to be background values for the pine needle ash. Figure D-1 illustrates the relationship between the metal content of the ash and the structural setting of the Schwartzwalder mine. The sampling for this survey consisted of collecting needles at shoulder height all around the trees. Ponderosa pine was selected for this study because it was believed that its root system would extend to the greatest depths. The samples were taken on 80 meter centers over known veins and at localities of

intense surface leaching. Presumably the root systems tested the potential beneath these leached areas.

The results of this study clearly indicate that biogeochemistry might be an additional exploration tool for the testing of the uranium potential along the Front Range.

The concentration of molybdenum with uranium in the vegetation shows its usefulness as a path-finder element. Ginzburg (1960) reports that certain trees can concentrate molybdenum in amounts related to the nitrogen contained in the plant. The amount of uptake of molybdenum seems to show a positive effect with the presence of phosphates and a negative effect with the sulfates. Concentration of uranium also appears to be greater in plants that absorb large quantities of sodium, selenium, sulfur, and calcium along with lesser amounts of potassium. It is reported that rapid reconnaissance at the district level can be conducted with sample spacing at about 75 meters. The writers believe that the best use of biogeochemistry along the Front Range is at the prospect level.

Figure D-1
 Conifer Needle Biogeochemical
 Transects-Schwartzwalder Mine

(Fisher, 1976)

APPENDIX E
Spirakis, C.S. and others (1977)
Theory of Thermoluminescence

"Thermoluminescence is the emission of energy in the form of light as a crystal is heated. When a crystal is heated, the energy of the electrons trapped in crystal defects increases and their escape rate accelerates. As the electrons escape and return to a more stable position in the lattice, thermoluminescence is produced (Levy, 1968). Both the number of traps and the flux of trappable electrons affect the thermoluminescence of a sample. The flux of electrons is a function of radiation in that irradiation of a sample generates free electrons, which may be captured in the traps. Even at low temperatures, electrons eventually escape from the traps; thus, if the flux of trappable electrons is terminated or reduced, thermoluminescence will decay with time. Electrons in low escape-energy traps are emitted more readily with heating or with time than electrons in high escape-energy traps. Thus, light observed as thermoluminescence at high temperatures is related to the emission of electrons from the high escape-energy traps. The residence of electrons in these high escape-energy traps may have a half-life of up to a million years (Renault and Hayslip, 1976)."

"After a sample has received a dose of high radiation, its thermoluminescence decays until a background level is reached. This level is determined by the number of traps (susceptibility) of each sample and by the background level of radiation. The background radiation varies slightly among samples used in this study, but this variation is minimal compared to the difference between the background radiation and the radiation in the mineralized front. Thus, background radiation should be equal or nearly so for all samples to either side of the ore. Because high-temperature thermoluminescence (from the high escape-energy traps) decays at a slower rate than the low-temperature thermoluminescence (from the low escape-energy traps), the effect of a dose of high radiation, as from the passage of a mineralized front or a mineralizing solution, will exist for a longer time as high-temperature thermoluminescence than as low-temperature thermoluminescence. Thus during a certain span of time after a sample receives a dose of radiation, the low-temperature thermoluminescence is dependent only on the susceptibility on the sample and the background radiation, whereas the high-

"temperature thermoluminescence is dependent only on the susceptibility of the sample and the background radiation, whereas the high-temperature thermoluminescence is dependent on the susceptibility, background radiation, and the radiation from the mineralizing process. This suggests that ratios of the low-temperature thermoluminescence to the high-temperature thermoluminescence might normalize the effects of susceptibility of the samples. Normalizing the variation in susceptibility should yield results that are better indicators of radiation-induced thermoluminescence."