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RELATIONSHIP OF URANIUM IN THE ROCKY MOUNTAINS OF SOUTHWESTERN COLORADO TO LOCAL AND REGIONAL METALLOGENESIS

By

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INTRODUCTION

The area under consideration includes the San Juan Mountains, the southern parts of the Sawatch and Mosquito Ranges, and the northern portion of the Sangre de Cristo Range (fig. 1). It does not include the area of stratiform uranium-vanadium deposits of the Colorado Plateau. A review is included of the metallogenetic relationships of the uranium deposits in the Rocky Mountains of Colorado to the deposits elsewhere in the uranium province of the Western United States.

Uranium appears to have been concentrated in veins, in stratiform deposits in sedimentary rocks, or in pegmatites during at least four periods in the geologic history of central and southwestern Colorado as summarized in Table 1. These include the Precambrian, Ordovician, Permian, and Tertiary. Among these, only vein deposits of Tertiary age are economically important.

Other metals were concentrated in magmatic segregations, in pegmatites, in stratiform deposits, and in veins during the Precambrian, Permo-Pennsylvanian, Paleocene, and Miocene periods (table 1). Only the gold, silver, lead, and zinc veins of Tertiary age are of major economic im-

PRECAMBRIAN

Deposits of Precambrian age include the gold-bearing quartz veins of the "Gunnison gold belt" south of Gunnison (fig. 2). A Precambrian age has been assigned (Boyd, 1934) because of the metamorphism of the veins and the truncation of the veins by the Morrison Formation of Jurassic age. The wall rocks are mafic-rich metamorphic rocks of Precambrian age.

Magmatic segregations of copper of presumed Precambrian age are present in basic intrusives and adjacent mafic metamorphic rocks of Precambrian age in the Salida region (Boyd, 1934). Production from each of two of these deposits has exceeded $100,000 in value (fig. 2).

Thorite-bearing veins occur in metamorphic rocks in the Powderhorn district (fig. 2). These veins may be genetically related to the nearby Iron Mountain alkalic igneous intrusive complex of latest Precambrian or earliest Cambrian age. This complex has been explored for niobium and titanium in recent years. The age of this complex is reported to be 550 m.y. (Edwards, 1966, p. 138). Thorite veins in the Wet Mountains, east of the map area, may also be related to an alkalic pluton, which has been dated from 580 to 655 mn.y. (Edwards, 1966, p. 138).

Uranium occurrences in Precambrian granite pegmatites are widespread. Dates on parent batholithic rocks range from about 1.0 to 1.6 b.y. (Edwards, 1966). These pegmatites contain thorium-rare earth-uranium minerals in erratic segregations. Thorium is usually dominant over uranium. A number of the most interesting of these occurrences are in pegmatite dikes in the Crestone pegmatite belt along the lower, western slope of the Sangre de Cristo Range northwestward from Crestone (fig. 2). These northwesterly-trending, near-vertical dikes cut schist, gneiss, and granite in a belt about 25 miles long and 3 miles wide. The

TABLE 1. SUMMARY OF METALLOGENESIS IN CENTRAL AND SOUTHWESTERN COLORADO

	METALLIZATION	TYPES OF DEPOSITS
Precambrian	Cu	Magmatic segregations
	Au, Th	Veins
	Th, U, Li, rare earths	Segregations in pegmatites
	Nb, Ti	Segregations in alkalic igneous complexes
Ordovician	U	Stratiform
Permo-Pennsylvanian	U, Cu, V	Stratiform
Tertiary	Au, Ag, Pb, U, Cu, Zn	Veins

Major
Minor
Uneconomic or unexploited

EXPLANATION

	TQs	Tertiary and Quaternary: sedimentary rocks and alluvium
	Tv	Tertiary volcanic rocks: in the San Juan province, quartz, latite, and rhyolite of Miocene age predominate
	Ti	Miocene: various intrusive rocks related to Silverton and Potosi volcanic series
	Trp	latest stage of intrusive series of Potosi age (predominantly rhyolite porphyry locally enriched in U)
	Tmp	Paleocene: intrusive rocks (predominantly quartz monzonite porphyry)
	PMs	Paleozoic and Mesozoic: sedimentary rocks
	p€	Precambrian rocks
		Faults
		Rim of Silverton and Lake City calderas

FIGURE 1.

Generalized Geologic Map of the Southwest Portion of Colorado

Aspen
Central
Leadville
Ancestral
Front Range
Smuggler
Colorado
Lady Elk
39°00'
39°00'
39°00'
Crested Butte
North Star
Trough
108°00'
Uncompahgre
Gunnison
Li
Madonna
Salida
Montrose
Quartz Creek
Big Red
Pegmatites
Marshall Pass
Gunnison
Gold Belt
Cochetopa
Whale
Villa Grove
Lightning
Powderhorn
Thorium
Locality
Bonanza
Kerber Cr.
Powderhorn
Fe
Sangre de Cristo Belt
Upper
Uncompahgre
Henson Cr.
Lake City
San Luis
Crestone
Pegmatite
Belt
Ouray
Crestone
38°00'
38°00'
Telluride
Lark
Silverton
Creede
Elk Park
Highland
Rico
Tomahawk
Summitville
Alamosa
Numerous U-V
occurrences of unknown age
ov
ov
ov
Durango

EXPLANATION

Boundary of Miocene metallization: predominately U in Cochetopa, Henson Creek, and Elk Park localities; Au, Ag, Pb, Cu, Zn in other localities.

Boundary of Paleocene metallization: predominately U in Marshall Pass locality; Ag, Pb, Au, Cu, Zn in other localities.

Boundary of Permian metallization: predominately U

Boundary of Ordovician metallization: penesyngenetic U

Boundary of Precambrian metallization: Au and Th south of Gunnison; Cu in the Salida area; U, Th, rare earths in Sangre de Cristo Mts.; Li in Quartz Creek area.

Margin's of late Paleozoic highlands and troughs

Uraniferous localities

U deposits with production and / or reserves

x   U prospects

Th-U prospects

Distribution of base and precious metal deposits (after Fischer, 1946)

Mine or cluster of mines; each mine has produced more than $100,000

Mine or cluster of mines; each mine has produced less than $100,000
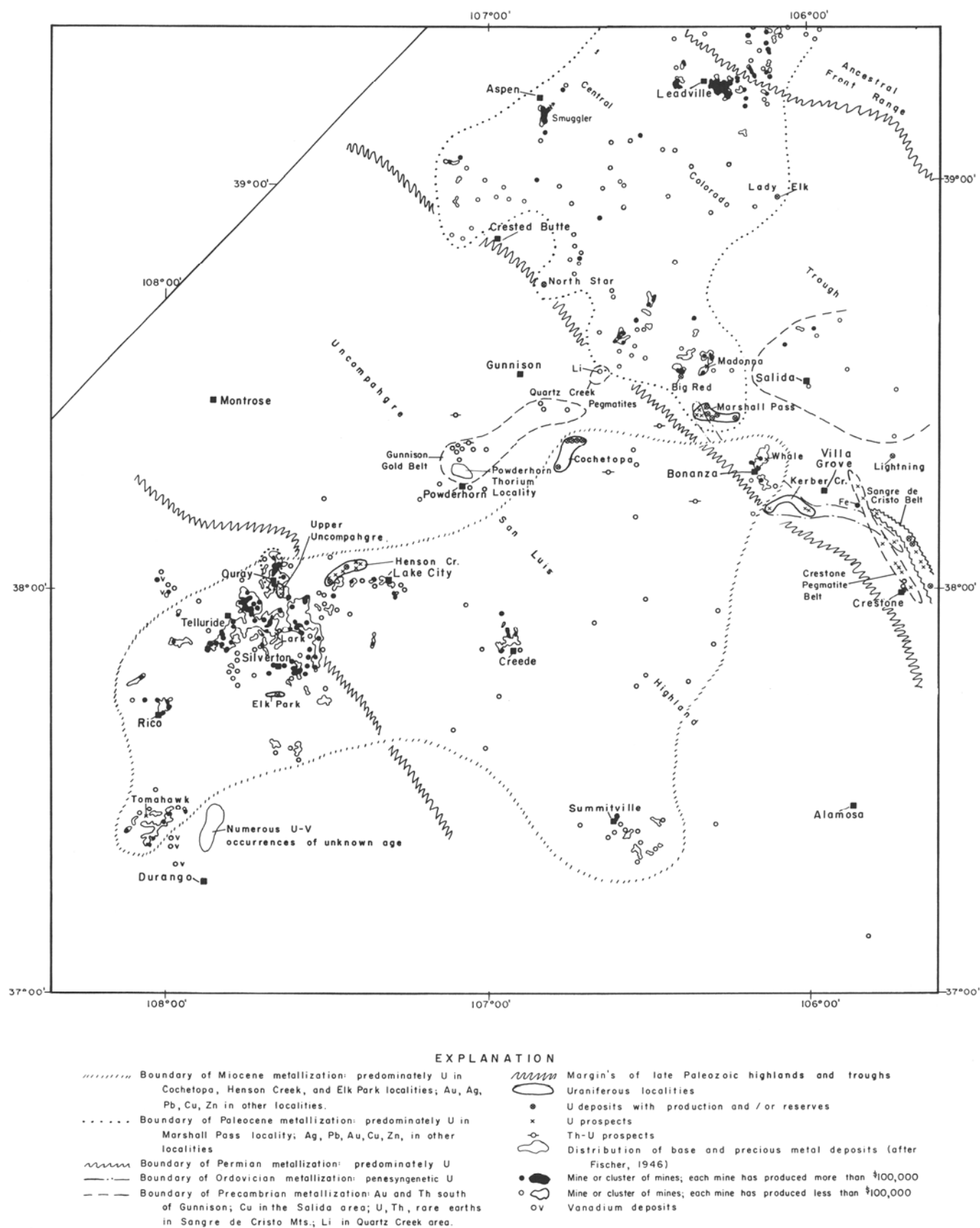
ov   Vanadium deposits

FIGURE 2.
Distribution, Type, and Age of Metallization in Southwestern Colorado.

dikes range from a few feet to 80 feet thick. Vein-like segregations of xenotime, garnet, monazite, cyrtolite (?), and samarskite in the dikes are 1 to 10 feet thick; all exceed 40 feet in length. Spectrographic analyses indicate that cerium and yttrium are the most abundant rare-earth elements.

Unsuccessful attempts have been made to exploit lithium in lepidolite-bearing Precambrian pegmatites of the Quartz Creek pegmatite district (fig. 2) (Staatz, 1955).

ORDOVICIAN

Ordovician metallization is believed to be represented by uneconomic, stratiform, penesyngenetic (?) concentrations of uranium in the Harding Quartzite of Ordovician age in the Marshall Pass and Kerber Creek localities (fig. 2). The Harding was deposited as a shoreline sandstone in a regressive Middle Ordovician sea. In the Marshall Pass and Kerber Creek localities nearly all drill hole intercepts and outcrop exposures of a pyritic, permeable sandstone bed, four to five feet thick, in the upper part of the Harding, are weakly to moderately mineralized with uranium. At rim exposures, the mineralized bed contains autunite, limonite, casts of fish scales, and asphaltic pellets. Its brown to orange color contrasts sharply with the typical gray quartzite of superjacent and subjacent strata of the Harding. This mineralized bed also has been recognized about seven miles northwest of Crestone on the east side of the San Luis Valley. Originally, it may have formed a belt about 35 miles long extending from near Crestone northwesterly to the Marshall Pass locality (fig. 2). Only segments of this inferred belt are now observable because of either volcanic cover or removal by erosion. This bed has not been recognized in other parts of Colorado nor is the Harding known to be mineralized with uranium elsewhere.

PERMIAN

Permian metallization is believed to be represented by the trend of uranium, copper, and vanadium deposits in the Lower Member of the Permian Sangre de Cristo Formation in the Sangre de Cristo Range. This trend extends from near Villa Grove 100 miles southward to the New Mexico state line and beyond. Only the northern portion of the trend is within the map area (fig. 2). All the deposits are localized in carbonaceous, siltstone, and feldspathic sandstone but they differ in the relative abundance of copper, uranium, and vanadium. Uranium is dominant in the northern portion of the belt; whereas, copper or vanadium is dominant elsewhere in the belt.

During the Pennsylvanian and Permian, from 10,000 to 13,000 feet of predominantly continental sediments were deposited in a narrow portion of the late Paleozoic eugeosyncline, the Central Colorado trough (fig. 2), between elements of the Uncompahgre-San Luis and the Ancestral Front Range highlands (Karig, 1964). As much as 8,000 feet of fluvial strata in this section is included in the Sangre de Cristo Formation. The trough was uplifted during the Tertiary, forming the Sangre de Cristo Range. Flood-plain deposits of siltstone, sandstone, and conglomerate characterize the undifferentiated Sangre de Cristo Formation in the southern portion of the range; in the northern portion, this formation includes piedmont cyclothems and flood-plain deposits in the Lower Member which are overlain by coalesced alluvial fanglomerates in the Crestone Conglomerate Member (Bolyard, 1959). These fanglomerates presumably formed at the eastern margin of a rapidly rising segment of the Uncompahgre-San Luis highland where Precambrian rocks were exposed (Karig, 1964). Portions of the Precambrian Crestone uraniferous pegmatite belt and the belt of the mineralized Ordovician Harding Quartzite probably were exposed to Permian erosion in this area. During erosion, uranium in the Harding Quartzite and in the pegmatites would have been oxidized, solubilized and transported by ground water into the detrital sediments of the Sangre de Cristo Formation. As a result of this process new deposits could be formed in the fine- to medium-grained sandstone peripheral to the fanglomerate facies of the Crestone Conglomerate.

EARLY TERTIARY

In Colorado, the first post-Precambrian plutonism occurred during the Laramide orogeny of the latest Cretaceous and early Tertiary periods. Nearly all economic metal deposits are related to this early Tertiary plutonism or to a subsequent igneous event during the Miocene (Lovering and Goddard, 1950, Tweto and Sims, 1964). The uranium-vanadium deposits of the Uravan mineral belt, in Jurassic rocks, are an important exception. Early Tertiary metallization also predominates in numerous districts in the other western states (Damon and Manger, 1966).

Mining districts in Colorado are concentrated from near Durango to near Boulder along a narrow belt, the Colorado mineral belt (Tweto and Sims, 1964). The total value of metals mined from this belt is about $3 billion. Nearly all of the deposits in the Colorado mineral belt between the northeast margin of the late Paleozoic Uncompahgre-San Luis highland (fig. 2) and the northeastern termination of the belt near Boulder are spatially and genetically related to porphyry intrusives of early Tertiary age. The clustering of districts near the margin of the late Paleozoic highland is striking (fig. 2). The abrupt southwestern termination of this belt coincides with the margin of this highland. Similar but more important clustering of districts in the area around Leadville appears to be spatially related to the southwestern margin of the late Paleozoic Front Range highland (fig. 2).

During the Laramide, recurrent movement on northwest-trending late Paleozoic faults that are marginal to the late Paleozoic ranges may have created unusually favorable conduits for ascending, mineralizing solutions. These faults are transverse to the northeast trend of the Colorado mineral belt. The northeast trend of the mineral belt and the coincident distribution of porphyry intrusives may be controlled by a Precambrian tectonic lineament (Tweto and Sims, 1964). Thus the intersections of Precambrian and late Paleozoic-early Tertiary tectonic lineaments may be important basic elements determining the distribution of deposits within the Colorado mineral belt.

Small uranium vein type deposits such as the North Star, Big Red, and Lady Elk, and the major veins in the Marshall Pass locality are near the margins of the area of early Tertiary base and precious metal deposits (fig. 2). A similar pattern exists in the Front Range where epithermal uranium veins are marginal to somewhat higher temperature base and precious metal veins of the Colorado mineral belt (Sims and Sheridan, 1964).

A small area near Ouray contains base and precious metal veins in Paleozoic rocks. These veins are truncated by Miocene volcanic flows; they are believed to be genetically related to nearby intrusives of early Tertiary age. Possibly, other early Tertiary intrusive centers with important related metallization may be covered by the extensive Miocene and early Pliocene flows of the San Juan volcanic field.

The Marshall Pass area, near the crest of the southern part of the Sawatch Range (fig. 2), contains the most important of the early Tertiary uranium veins in Colorado, exclusive of the Front Range (Malan, 1959). Paleozoic strata in this portion of the range have been reduced to erosional remnants along a north- to northwest-trending system of reverse faults. At Marshall Pass, one of these remnants of about 10 square miles is bounded on the east by the steeply-dipping Chester reverse fault. The area surrounding the remnant is underlain by Miocene volcanic flows and by Precambrian rocks. At the Pitch mine, the largest in the area, five high-grade ore shoots as much as 100,000 tons in size occur in the Pennsylvanian Belden Formation along the foot wall side of the Chester fault. The ore shoots are in brecciated, steeply-dipping beds of limestone which arc interbedded with lignite, shale, and sandstone. Precambrian pegmatite and metamorphic rocks form the hanging wall of the fault. The ore shoots in the limestone breccia are commonly adjacent to steeply-dipping elongated fault slices of Precambrian rock that were displaced from the hanging wall of the main fault to the foot wall. The ore mineral, uraninite, is associated with trace amounts of copper, iron, and lead sulfides.

MIOCENE

In Colorado, Miocene metallization, genetically related to plutonism and widespread volcanism, predominates in the area between the northeast margin of the late Paleozoic Uncompahgre-San Luis highland and Durango (fig. 2). The gold-silver-lead-copper-zinc vein deposits are usually grouped in the vicinities of widely scattered Miocene intrusive centers in the San Juan volcanic field (figs. 1 and 2). The greatest density of deposits and the largest deposits are in the Telluride, Ouray, and Silverton areas in the western part of the volcanic field. The marked clustering of deposits in these intensely mineralized areas appears to be structurally related to the faulted margins of calderas. These clusters of deposits are at the southwest margin of the late Paleozoic Uncompahgre-San Luis highland (fig. 2) where reactivated late Paleozoic faults may have provided unusually favorable conduits for invading magmas and related mineralizing solutions.

The most important uranium deposits of probable Miocene age are in the Cochetopa district near Gunnison (fig.

2). This district is near the northeast margin of the late Paleozoic Uncompahgre-San Luis highland. The Upper Jurassic Morrison Formation overlies peneplaned Precambrian rocks in the Cochetopa district and in the surrounding area. The Cretaceous Dakota Sandstone and Mancos Shale overlie the Morrison. The late Miocene was a time of faulting, volcanism, and intrusion related to the San Juan volcanic episode. Uranium deposits formed in fracture zones and breccia adjacent to normal faults. The most important deposits, which have total production of about 500,000 tons of ore, are in silicified Morrison sandstone and mudstone along the west-trending, high-angle, Los Ochos normal fault (Malan and Ranspot, 1959). The ore mineral, uraninite, is associated with trace amounts of marcasite in a gangue of quartz and clays. These deposits may be genetically related to nearby late Miocene rhyolite porphyry intrusives. Rhyolite porphyry intrusives of similar age in the Henson Creek locality west of Late City (fig. 2) contain greater than average amounts of uranium, but there are no known uranium deposits in the surrounding rocks.

Uranium is present in uneconomic amounts in base and precious-metal veins in Miocene volcanic rocks in several districts in the San Juan volcanic field (Pierson, et al., 1958). The age of vein prospects in the Precambrian Uncompahgre Quartzite at Elk Park south of Silverton (fig. 2) is believed to be Miocene because of their proximity to a large area of metallization of that age.

REGIONAL METALLOGENETIC CONSIDERATIONS

GENERAL DISTRIBUTION OF URANIUM DEPOSITS IN TIME AND SPACE

Most of the known uranium in Precambrian rocks of the Western United States is in small concentrations of multiple oxide minerals in pegmatites. None of the widely-scattered occurrences is economic.

No metal deposits were formed from Precambrian to the late Triassic except for a few minor copper-uranium-vanadium deposits in early and late Paleozoic strata. Precambrian granitic and metamorphic rocks were extensively exposed to erosion along the Transcontinental Arch during the early Paleozoic (fig. 3) and in the Colorado highland systems (fig. 4) during the late Paleozoic (Sloss, Dapples, and Krumbein, 1960), but no important uranium deposits were emplaced in the detrital outwash.

Two-thirds of the uranium reserves plus production in the Western United States are in stratiform deposits in coarse elastic continental sediments of Late Triassic and Late Jurassic age. Nearly all of these deposits are in the Colorado Plateau (fig. 5); all are believed to have formed soon after the deposition of the host rocks. The absence of economic uranium deposits of these ages in the Colorado Rockies may be because facies favorable for uranium are not present.

About one-fourth of the uranium reserves plus production in the Western United States are in stratiform de-

posits in coarse clastic sediments of Tertiary age. Most of these deposits are in intracratonic basins in Wyoming (fig. 5).

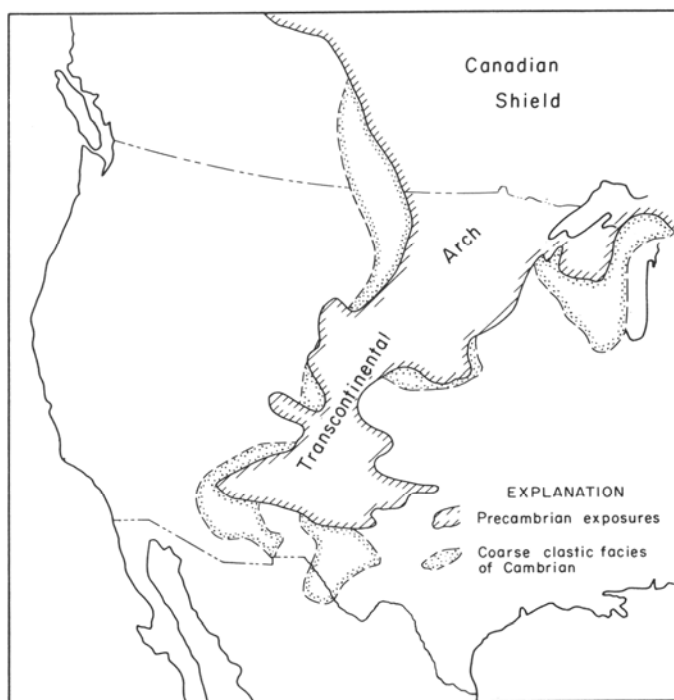Numerous Tertiary uranium occurrences that are simi-lar to the Wyoming deposits are present in intermontane basins in Colorado; however, they are economic only in the Tallahassee Creek basin just east of the map area in figure 2. In the Colorado Rockies, the most important concentrations of metals are in veins of Tertiary age. The most important uranium veins are in the Cochetopa and Marshall Pass areas (fig. 2) and in the Front Range. The base and precious metal veins in the Colorado mineral belt are of far greater importance than the uranium veins. The gross value of uranium production from veins is only about one and one-half percent of the gross value of pro-duction of other metals from veins in the Colorado Rock-ies.

SOURCE OF THE URANIUM

The most probable source of the uranium in the vein deposits in Colorado is magmatic hydrothermal solutions of early and middle Tertiary age (Sims and Sheridan, 1964) (Malan and Ranspot, 1959).

The source of the uranium in the Mesozoic and Tertiary stratiform deposits in the Colorado Plateau and in Wy-oming is unresolved. Three theories for the origin of these deposits have been proposed by numerous investigators during the past two decades. These are:

1. Low-order amounts of uranium dispersed in granitic rocks were concentrated into economic epigenetic de-

Adapted from Sloss, Dapples and Krumbein, 1960

FIGURE 3.
Paleogeologic Map Showing Clastic Facies of
Cambrian Strata.

After Mallory, 1960
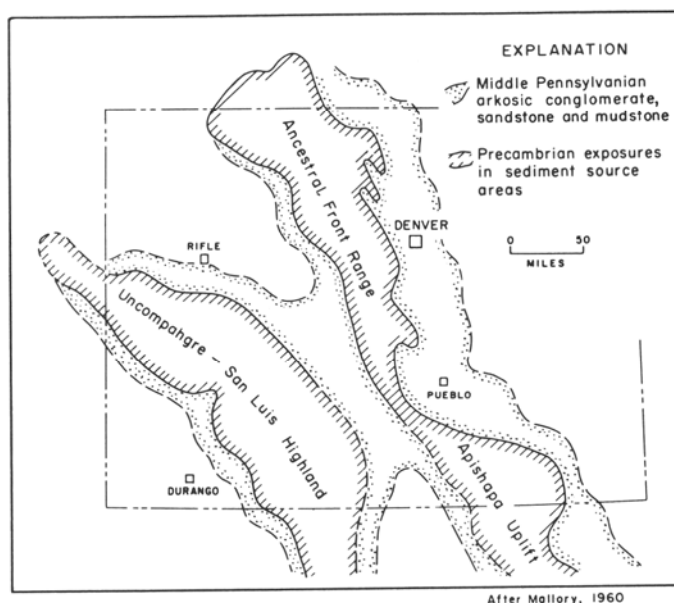
FIGURE 4.
Paleogeologic Map Showing Coarse Clastic Facies of
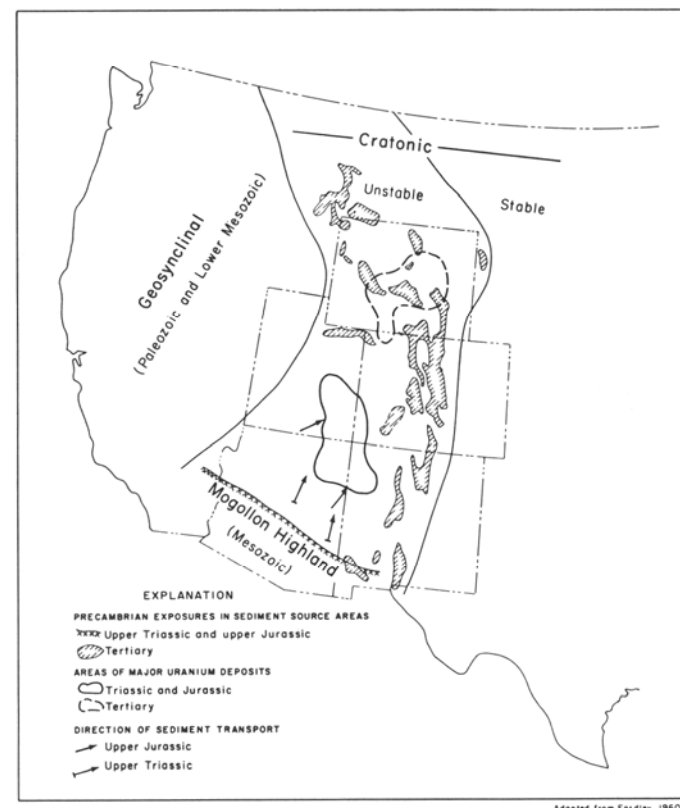Pennsylvanian Strata in Colorado.

Adapted from Eardley, 1960

FIGURE 5.
Relationship of Western U. S. Uranium Province
to Regional Tectonism.

posits in detrital outwash through solution, ground water transport, and reprecipitation.

2. Low-order amounts of uranium dispersed in tuffaceous rocks were dissolved and transported by ground water to favorable sites where the epigenetic deposits formed.

3. Uranium-bearing, magmatic, hydrothermal solutions, perhaps comingled with ground water, migrated from parent plutons to favorable sites in sedimentary rocks where the deposits formed.

The writer favors tuffaceous rocks as a source for the uranium because of the following factors:

1. The earliest-formed important uranium deposits in the United States, those of probable upper Triassic age in the Colorado Plateau (Wood, 1968) (Malan, 1968), were emplaced almost contemporaneously with the earliest Phanerozoic (post-Precambrian) plutonism and pyroclastic volcanism (Gilluly, 1963) (table 2). The site of this initial plutonic and volcanic activity and also the source area for the Upper Triassic and the Upper Jurassic uranium host sediments of the Colorado Plateau was the ancestral Mogollon highland (fig. 5), an early-stage positive element of the Mesozoic Nevadan orogenic system (McKee, Oriel, and Ketner, 1959) (McKee, et al., 1956) (Eardlcy, 1962). The widespread, thick, tuffaceous sediments overlying both the Upper Triassic and the Upper Jurassic uranium host rocks in the Colorado Plateau are indicators of this volcanism in the ancestral Mogollon highland. The deposits are a few hundred miles from the sites of igneous activity in this highland. The plutons in the ancient highland are not known to be enriched in uranium and there are no genetically-related uranium deposits nearby. Wind-borne tuffs and pyroclastic debris in fluviatile sediments are the more probable sources of the uranium in the Colorado Plateau deposits.

2. In the Tertiary basins of Wyoming and Colorado, tuffs either overlie the uranium host rocks or pyroclastic debris is admixed within the elastic host sediments. Most of the tuffs in Wyoming originated from volcanic centers in the northwest part of that state. Tertiary plutonic activity was minor in Wyoming.

3. Granitic rocks were extensively exposed to erosion during six periods in the Phanerozoic history of the Western United States (table 2). Favorable coarse elastic host rocks were deposited during the Cambrian, the Permo-Pennsylvanian, and the Cretaceous but no pyroclastic volcanism accompanied or closely followed these periods of sedimentation and no major uranium deposits were formed. The average uranium content of the tuffs and the granites in the Western United States uranium province has not been established; however, the amount of uranium in present-day ground and surface waters draining tuffaceous sedimentary environments is nearly eight times greater than the amount of uranium in waters draining granitic or arkosic environments (AEC unpublished data) (Denson, et al., 1955).

4. No important stratiform uranium deposits seem to have formed in response to plutonism unaccompanied by pyroclastic volcanism (table 2). For example, there are no important stratiform deposits that are genetically related to Cretaceous granitic plutonism, by far the most pronounced in the Phanerozoic history of the Western United States (Gilluly, 1963).

5. The event common and unique to each of the three major periods of uranium accretion was pyroclastic volcanism (table 2). The importance of tuffaceous rocks as uranium source rocks is thus emphasized.

These tuffs that are so closely related to the Upper Triassic, Upper Jurassic and Tertiary uranium host rocks originated in volcanic centers east of the geosynclinal belt in the unstable portion of the craton where the Precambrian is relatively shallow (fig. 5). The source of the major resources of uranium in these rocks thus appears to have been Precambrian rocks that were subjected to syntexis. The Precambrian is equally important as an initial source of the uranium whether the most important process in the formation of the deposits was erosion, plutonism nr vninanicm

TABLE 2. PHANEROZOIC ENVIRONMENTS IN THE WESTERN UNITED STATES

CONDITIONS IN SOURCE AREA OF URANIUM HOST ROCKS	CAMBRIAN	PERMO-PENN.	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY
Granitic highlands extensively exposed; widespread coarse clastic sedimentation	X	X	X	X	X	X
Extensive plutonism			X	X	X	
Extensive pyroclastic volcanism			X	X		X*
Important uranium deposits formed			X	X		X

* in source area of superjacent sediments

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