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PROTEROZOIC ORIGINS OF URANIUM MINERALIZATION IN THE COLORADO FRONT RANGE

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Introduction

Over 11 million pounds of uranium have been produced from high-grade vein-type deposits in the Colorado Front Range (Table 1). However, of the 25 occurrences shown in Figure 1, only the Schwartzwalder mine is currently in production.

This paper presents a geologic model for Front Range uranium deposits based on field evaluations and a reinterpretation of published data. Comparisons are drawn to similar deposits in Africa and Australia.

Previous Work

Sims and Sheridan (1964) have divided the uranium occurrences of the Colorado Front Range into three classes: class I deposits, uranium-bearing fluorite veins and breccias; class II deposits, uranium-bearing base metal sulfide veins; and class III deposits, veins in which uranium minerals are dominant. All three types are generally attributed to Tertiary magmas and related hydrothermal activity (Sims et al., 1963; Sims and Sheridan, 1964). Recent models by Young (1977, 1979b) and Phair (1979) have continued to rely on Tertiary magmas as a source of heat but not as a source of uranium. Fisher (1976) and Maslyn (1978) have proposed depositional mechanisms related to a regional unconformity between the Proterozoic and Phanerozoic sections. A recent model for the Schwartzwalder mine proposed a Proterozic origin (DeVoto and Paschis, 1979). This paper reviews evidence for an early Proterozoic uranium accumulation and proposes an intermediate concentration event during middle Proterozoic metamorphism.

Geology

The Schwartzwalder and related deposits of the Foothills uranium belt are hosted by tensional structures developed within northwest-striking shear zones. Ores contain pitchblende and minor jordisite with anomalous base and precious metals. The Schwartzwalder deposit is hosted by garnet-biotite gneiss, quartzite, mica schist, amphibolite, and calc-silicate gneiss of the Idaho Springs Formation. Sheridan et al. (1967) have identified this sequence as a "transition zone" separating thick sequences of hornblende gneiss and mica schist. Rubidium-strontium dating of metasedimentary rocks of the Idaho Springs Formation has provided a minimum age of 1.75 ± 0.3 b.y. (Hedge et al., 1967).

A similar stratigraphic section hosts uranium ore at other Colorado vein-type deposits. The Ascension mine (19, Fig. 1) occurs in a belt of layered calc-silicate gneiss separating thick sections of mica schist and hornblende gneiss. Pitchblende ore occurs in breccias and in subsidiary fractures formed along the northwest-striking Ascension fault. Associated sulfides include chalcopyrite, galena, and pyrite (Sheridan et al., 1967). Pitchblende and coffinite from the Fair Day mine (7, Fig. 1) occur in a breccia ore hosted by Precambrian folds and Laramide faults and fractures. Associated sulfides include pyrite, sphalerite, chalcopyrite, galena, and marcasite (Sims and Sheridan, 1964). The host rock is a graphitic garnet-biotite gneiss which marks the boundary between thick sections of hornblende gneiss and mica schist. Detailed geologic mapping at other Front Range occurrences is needed to establish the lower Proterozoic depositional environment responsible for an initial concentration of uranium and base metals.

Two pre-Laramide episodes of uranium concentration are proposed for the Colorado Front Range: (1) a strata-bound concentration in a lower Proterozoic section of near-shore marine sediments; and (2) a middle Proterozoic metamorphic mobilization of uranium into shears and folds.

Early Proterozoic Strata-Bound Concentration

Support for an early Proterozoic strata-bound concentration of uranium in Front Range deposits comes from several sources. First is the presence of the characteristic transition zone section in all of the major deposits. This lithologic assemblage includes graphitic garnet-biotite gneiss, quartzite, and calc-silicate gneiss. The garnet-biotite gneiss typically contains 5 to 10 percent disseminated pyrite plus pyrrhotite (Sims and Sheridan, 1967). Limited geochemical data indicate background uranium contents of up to 8 ppm (J. A.

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TABLE 1. Production Figures for Vein-Type Deposits of the Colorado Front Range

Deposit	Size (lbs. U_3O_8)	Grade (% U_3O_8)
Schwartzwalder	11,000,000	0.60
Fair Day	200,000	0.57
Foothills	44,300	0.26
Grapevine	23,800	0.32
Ascension	23,400	0.29
Ladwig	9,500	0.25
Mena	6,700	0.26
Copper King	3,800	0.30
Ohman	1,200	0.71

Data from DeVoto and Paschis, 1979; Nelson-Moore et al., 1978; Sims and Sheridan, 1964

Paschis, unpub. rept., 1979; Young, 1979a). Young (1979a) reports a two- to ten-fold enrichment of silver, zinc, lead, and molybdenum in transition zone units near the Schwartzwalder deposit. The garnet-biotite gneiss was a likely source of uranium, molybdenum, silver, and base metals. However, too little data are published on this important rock type to establish firmly its role either as a source of metal or as a source of reductant during later mineralizing events.

The transition zone section characteristic of vein-type uranium deposits in the Colorado Front Range invites comparison with similar sections in Australia's Pine Creek geosyncline and the Zambian Copperbelt. Polymetallic mineralization in the Rum Jungle uranium field occurs in a lower Proterozoic transition zone between shelf sediments of the Batchelor group and trough sediments of the Namoona group. Magnesite and dolomite pseudomorphs after evaporite-derived gypsum and anhydrite are present in Batchelor group Coomalie dolomite (Crick and Muir, 1979). Overlying the dolomite is a chloritic-carbonaceous schist. Similar units are described by Crick and Muir (1979) at the Alligator River uranium field where mineralization is associated with dolomites and secondary magnesite of the evaporite-bearing Cahill Formation.

Vein and disseminated uranium in the South Alligator River uranium field is hosted by the lower Proterozoic Koolpin Formation, a pyritic-carbonaceous siltstone with lenses of stromatolitic carbonate. Carbonate pseudomorphs after gypsum are noted by Crick et al. (1979). The evidence from Australian deposits suggests that uranium was concentrated in a marginal marine environment containing evaporites.

Similar sections (also containing evaporites) are reported from the Zambian Copperbelt (Raybould, 1979; Renfro, 1974). Shinkolobwe is one of several high-grade vein-type uranium deposits hosted by marginal marine sediments of the upper Proterozoic Roan Supergroup (Raybould, 1979). Shinkolobwe ores are enriched in cobalt, nickel, silver, arsenic, thorium, and molybdenum (Byers, 1978; J. A. Paschis, unpub. rept., 1979).

The "transition zone" lithologic assemblage of quartzites, calc-silicates, and graphitic garnet-biotite gneiss indicates a marginal marine environment for initial uranium concentration at Front Range deposits. In addition, there is some evidence for hypersalinity. Young (1979a) reports a two- to ten-fold enrichment of transition zone units in boron and fluorine. Scapolite, an indicator of hypersalinity in amphibolite-facies metasedimentary terranes according to Serdyuchenko (1975), is present in transition zone calc-silicates near the Schwartzwalder mine (Sheridan et al., 1967) and at the Ascension mine. The combination of marginal marine sediments and possible hypersaline conditions suggests an evaporitic environment similar to that proposed for the Rum Jungle and Alligator River uranium fields.

Middle Proterozoic Metamorphic Concentration

An association between uranium mineralization and middle Proterozoic metamorphism is indicated

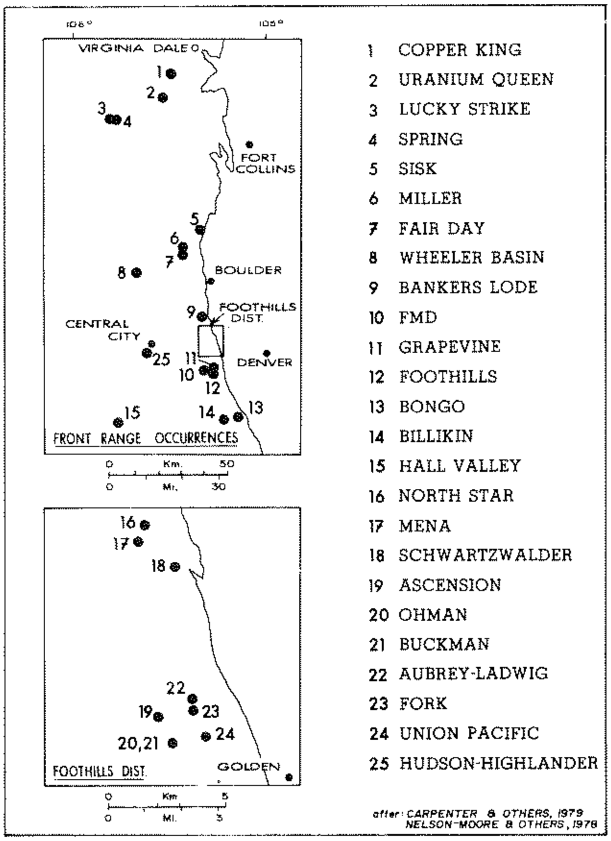

FIG. 1. Vein-type uranium occurrences of the Colorado Front Range.

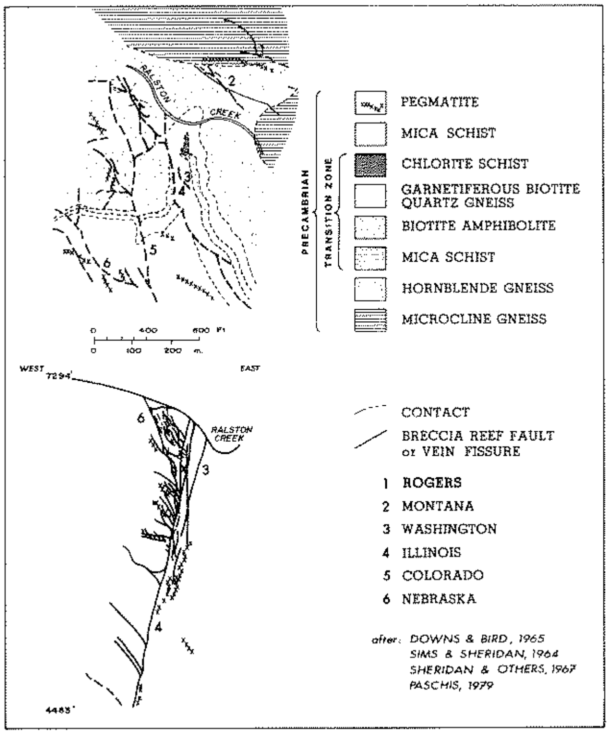

FIG. 2. Geologic map and cross section of the Schwartzwalder mine.

at a number of Front Range deposits. Pegmatites are associated with uranium at the Ladwig mine (22, Fig. 1) (Wallace, 1979), the Ascension mine (Sheridan et al., 1967), and the Fair Day mine (Sims and Sheridan, 1964). Many smaller occurrences, e.g., Hudson-Highlander (25, Fig. 1) and Hall Valley (15, Fig. 1) are also associated with pegmatites.

One of the best examples of metamorphic uranium concentration occurs at Wheeler Basin (8, Fig. 1). Mineralization occurs within a broad zone of migmatization adjacent to Silver Plume Granite. A garnet-biotite gneiss is isoclinically folded and locally recrystallized to coarsely matted segregations of biotite, sillimanite, and quartz with minor pyrite, uraninite, molybdenite, chalcopyrite, and fluorite. Young and Hauff (1975) report grades of 0.02 to 0.70 percent U_3O_8. Mineralization occurs on the axial planes of folds, in subparallel shears, and adjacent to pegmatites.

Metamorphic events in the Colorado Front Range were probably associated with both Silver Plume (1,390–1,450 m.y.) and Boulder Creek (1,700–1,800 m.y.) plutonic activity. Average uranium contents reported by Phair and Gottfried (1964) are 2.2 ppm for Boulder Creek and 7.0 ppm for Silver Plume intrusives. Peterman et al. (1968) considered Silver Plume activity to be post-tectonic relative to Boulder Creek plutonism and regional metamorphism. The Silver Plume at Wheeler Basin, however, is conformable to enclosing metasedimentary units and is surrounded by a broad zone of migmatization. Associated pegmatites are anatectic rather than injected, based on the presence of biotite-rich selvages. Uranium was apparently mobilized during anatexis and locally concentrated in zones of high fluid activity.

Documentation of uranium mobility during progressive metamorphism is provided by Yermoleyev (1971, 1973) and by Yermoleyev and Zhidikova (1966). Most of the uranium liberated would be dispersed by metamorphic fluids or absorbed into anatectic magmas such as the Silver Plume Granite. Coincidence of a source rock and an appropriate chemical environment for precipitation would, however, lead to uranium concentration. Zones of local high fluid concentration provide a favorable host environment. These include the axial planes of isoclinal folds, associated shears, and zones of cataclasis.

Several arguments favor an episode of metamorphic mobilization and uranium mineralization at the Schwartzwalder mine. The Rogers breccia reef and associated ore-bearing tensional structures developed along a Laramide-reactivated Precambrian shear zone (Tweto and Sims, 1963). Tourmaline-bearing pegmatites occur in the shear zone (Fig. 2) and "foreshadow" the orientation of pitchblende veins (J. A. Paschis, unpub. rept., 1979). Ore occurs where the shear intersects an isoclinally folded section of transition zone metasedimentary rocks. Massive chlorite (Fig. 2) occurs in the nose of this fold (Downs and Bird, 1965) and is associated with ore in the subsurface.

DeVoto and Paschis (1979) suggest a Silver Plume age for tourmaline-bearing pegmatites at the Schwartzwalder mine. Wheeler Basin, however, is the only Front Range uranium occurrence where a Silver Plume age is well documented. Additional dating on both pegmatites and uranium mineralization at Front Range deposits is needed. Scattered age dates, tourmaline-bearing pegmatites, and associated Silver Plume intrusion suggest a Silver Plume (1,390–1,450 m.y.) age for uranium concentration.

The association of uranium with hydrous mineral assemblages and pegmatites is also reported from amphibolite facies metamorphic terranes of northern Australia. Massive chlorite hosts uranium ore at Jabiluka (Hegge and Rowntree, 1978; Ewers and Fergusen, 1979) and may reflect local high fluid concentration during an 1,800-m.y. episode of prograde metamorphism. Rubidium-strontium chronology by Riley et al. (1979) and lead isotope studies by Gulson (1979) are consistent with an interpretation calling for contemporaneous amphibolite facies metamorphism, pegmatite emplacement, and local chlorite mineralization.

Conclusions

Recent models for uranium mineralization in the Colorado Front Range recognize an early Proterozoic origin for vein-type deposits such as the Schwartzwalder. A near-shore marine environment is suggested by evidence for strata-bound uranium and base metals in a near-shore section of terriginous clastics, carbonates, and evaporites.

Significant mobilization of uranium probably occurred during both Boulder Creek (1,700–1,800 m.y.) and Silver Plume (1,390–1,450 m.y.) orogenesis. By far the bulk of uranium was dispersed during Boulder Creek metamorphism but was effectively concentrated during Silver Plume anatexis. Uranium accumulated in anatectic melts and in structurally prepared zones of high fluid activity.

Laramide tectonism resulted in reactivation of Proterozoic structures and remobilization of Proterozoic uranium. Local transport and precipitation was critical to orebody development. Successive mineralizing events span a period of approximately two billion years but are superimposed in space to form a deposit such as the Schwartzwalder.

Proterozoic origins emphasized in this paper suggest consideration of Proterozoic as well as Tertiary ore controls and expansion of exploration efforts to the entire Front Range province. Deposits are likely to be hosted by a characteristic transition zone section of calc-silicate gneiss, quartzite, and garnet-biotite gneiss. Host structures are likely to include isoclinal folds, shears, and zones of Precambrian cataclasis. Ore may be associated with pegmatites and massive biotite or chlorite indicating local high fluid concentration during Silver Plume metamorphism and anatexis.

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