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NATIONAL URANIUM RESOURCE EVALUATION
DURANGO QUADRANGLE
COLORADO

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Grand Junction, Colorado 81502

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ABSTRACT

The Durango Quadrangle (2°), Colorado, was evaluated using National Uranium Resource Evaluation criteria to determine environments favorable for uranium deposits. General reconnaissance, geologic and radiometric investigations, was augmented by detailed surface examination and radiometric and geochemical studies in selected areas.

Eight areas favorable for uranium deposits were delineated. Favorable geologic environments include roscoelite-type vanadium-uranium deposits in the Placerville and Barlow Creek-Hermosa Creek districts, sandstone uranium deposits along Hermosa Creek, and vein uranium deposits in the Precambrian rocks of the Needle Mountains area and in the Paleozoic rocks of the Tuckerville and Piedra River Canyon areas. The major portions of the San Juan volcanic field, the San Juan Basin, and the San Luis Basin within the quadrangle were judged unfavorable. Due to lack of information, the roscoelite belt below 1,000 ft (300 m), the Eolus Granite below 0.5 mi (0.8 km), and the Lake City caldera are unevaluated. The Precambrian Y melasyenite of Ute Creek and the Animas Formation within the Southern Ute Indian Reservation are unevaluated due to lack of access.
INTRODUCTION

PURPOSE AND SCOPE

The Durango Quadrangle, southwest Colorado (Fig. 1), was evaluated to identify geologic units and to delineate areas that exhibit characteristics favorable for uranium deposits. Geologic environments were evaluated to a depth of 1500 m based on recognition criteria (Mickle and Mathews, eds., 1978) prepared for the National Uranium Resource Evaluation (NURE) program. A favorable environment, as defined for this program, is an environment that could contain at least 100 tons U₃O₈ in deposits with an average grade no less than 100 ppm U₃O₈. Environments that did not meet the NURE criteria were categorized as unfavorable. Some of the subsurface and several areas of restricted access were categorized as unevaluated because insufficient data exist for proper evaluation.

This study was conducted by Bendix Field Engineering Corporation (BFEC) for the NURE program, managed by the Grand Junction Office of the U.S. Department of Energy (DOE). The evaluation began October 20, 1977, and ended January 21, 1980. About 5 man-years were spent in literature review, field work, data evaluation, and folio preparation.

Figure 1. Location of the Durango Quadrangle.
ACKNOWLEDGMENTS

The authors thank the many mining companies, individual mining claimants, and private landowners for access to their properties. The Public Service Company of Oklahoma is especially thanked. Frank Montonati of Silverton provided useful information regarding uranium occurrences in the Silverton area. The cooperation received from individuals of the U.S. Forest Service is gratefully acknowledged.

D. R. Allen of the BFEC Mineralogy and Petrology Laboratory was the petrologist assigned to the Durango Quadrangle. Results of his work are tabulated in Appendix D.

PROCEDURES

Evaluation of the Durango Quadrangle included both surface geologic investigation and geologic interpretation of subsurface data. Surface geologic investigations consisted of field examination of uranium occurrences, field study and sampling of selected geologic environments, and the followup examination and detailed sampling of anomalous areas defined by the uranium hydrogeochemical and stream-sediment reconnaissance (HSSR) and aerial radiometric reconnaissance (ARR) surveys. Subsurface evaluation involved the study of numerous well logs from wells within the quadrangle.

Literature review greatly aided quadrangle evaluation. Sources of uranium-occurrence information included U.S. Atomic Energy Commission Preliminary Reconnaissance Reports (PRR's), the U.S. Geological Survey Computerized Resources Information Bank (CRIB file), the U.S. Bureau of Mines Mineral Availability System (MAS file), and Bulletin 40 of the Colorado Geological Survey (Nelson-Moore and others, 1978). Other selected geologic literature pertinent to the evaluation was also used. Geologic maps used in the evaluation are indexed on Plate 12.

Field examination of uranium occurrences by BFEC personnel was initiated in 1978 and completed in 1979. Field examinations in remote areas were facilitated by approximately 50 hr of helicopter flight time. Uranium-occurrence reports were completed for 48 uranium occurrences (App. A-1); 64 reported occurrences did not contain uranium in sufficient quantity to indicate that a process of uranium concentration had occurred (App. A-2).

During quadrangle evaluation, approximately 650 rock, sediment, and water samples were taken from various environments. These samples were analyzed using standard analytic techniques. Results of geochemical analyses are reported in Appendix B. Field radiometric measurements were taken using a Mount Sopris SC-132 scintillometer. Petrologic study of 36 selected samples was completed by BFEC personnel in support of field examinations (App. D).

The HSSR program was conducted by Los Alamos Scientific Laboratory (LASL). Results from the western half of the quadrangle were released by Maxwell (1977) as part of the San Juan Mountains reconnaissance, and results from the whole quadrangle were released in January 1979 (Dawson and Weaver). Interpretations were made by BFEC personnel involved in evaluation of the Durango Quadrangle.
Detailed HSSR followup programs were completed by BFEC personnel for the Center area (Pl. 11) and the Sunshine Peak area (Pl. 10a through 10e). A detailed HSSR study in the Needle Mountains is being conducted by LASL.

The ARR survey of the Durango Quadrangle was conducted between September 26 and November 9, 1978, by Western Geophysical Company of America, Aero Service Division. The survey was flown with east-west traverse lines spaced 2 mi (3 km) apart and north-south tie lines spaced 12 mi (20 km) apart. A total of 4,540 line mi of geophysical data was acquired. Because the final report from Western Geophysical was not received within 90 days of the completion of field work, many anomalies reported by Western Geophysical were not field checked. Five areas have been proposed for close-spaced ARR study. These are the Needle Mountains area, the Lake City area, an area near Summitville, the upper Piedra River area, and the La Garita area. Results of ARR detailed studies have not been available.

Subsurface evaluations were restricted mostly to the San Juan Basin within the quadrangle. Well-log data were interpreted from Edwards (1964) and from approximately 75 gamma-ray logs of wells within the quadrangle. Selected well logs (Pl. 8) were used not only for radioactive interpretation but also for lithologic information. Lithologic relationships reported in these well logs to a depth of 5,000 ft (1500 m) were used to construct the generalized cross sections of the San Juan Basin within the quadrangle (Pl. 9).

GEOLOGIC SETTING

The Durango Quadrangle, an area of about 19,600 km² in southwest Colorado (Fig. 1), contains parts of the Colorado Plateau and Southern Rocky Mountains physiographic provinces. The Colorado Plateau, in the western part of the quadrangle, is characterized by gently sloping, dissected plateaus and is represented by parts of the Chama Platform, San Juan Basin, Four Corners Platform, Paradox Basin, and Uncompahgre Uplift (Fig. 2). The Southern Rocky Mountains Province contains the San Juan volcanic field and part of the Rio Grande rift valley. This province is characterized by rugged mountain ranges and irregular river drainages.

The northern part of the San Juan Basin, an elliptical depression within the Colorado Plateau, is in the southwest part of the quadrangle. The San Juan Basin development began during the Laramide orogeny as part of regional uplift of the Colorado Plateau. Post-Eocene subsidence, filling, and erosion produced the present basin features. Rocks exposed in the San Juan Basin consist of marine and continental sandstones and limestones, siltstones, mudstones, and shales. The thickness of sedimentary fill is as much as 12,000 ft (3600 m) near the southern boundary of the quadrangle.

The San Juan volcanic field is a complex interlayering of lava and pyroclastic units derived from many different centers. These units are Tertiary, predominately tuffs, flows, ash flows, and flow breccias, and are basaltic to rhyolitic in composition. The San Juan volcanic field extends diagonally across the northeast half of the quadrangle.
The Rio Grande rift valley is a north-trending structural trough filled with Tertiary alluvial and volcanic deposits. The trough is the northern expression of the Rio Grande Rift. Most of the trough is included in the San Luis Valley, the western part of which is in the Durango Quadrangle.

The stratigraphy of the Durango Quadrangle is shown on Plate 7 and is divided into metamorphic and igneous rocks, sedimentary rocks, igneous rocks, and surficial deposits. Precambrian metamorphic and igneous rocks within the Durango Quadrangle are exposed in areas of uplift and in erosional windows. Precambrian rocks within the San Juan Uplift (Fig. 2) are geographically within the Needle Mountains area. Paleozoic and Mesozoic rocks are predominately sedimentary units: sandstones, shales, siltstones, and conglomerates and some limestones and mudstones. The Paleozoic and Mesozoic strata are exposed in the Paradox Basin, Four Corners Platform, San Juan Basin, and Chama Platform. The Cenozoic sedimentary units, sandstones, grits, shales, and conglomerates, are found above Paleozoic and Mesozoic strata in the San Juan Basin and the Paradox Basin, and as stream deposits throughout the quadrangle.
ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

SUMMARY OF FAVORABLE ENVIRONMENTS

Eight areas within the Durango Quadrangle are favorable for uranium deposits (Pl. 1a). Areas A (Pl. 1c) and B (Pl. 1b) are favorable for roscoelite-type (Class 240 of Jones, 1978a) vanadium-uranium deposits, which occur randomly within empirically defined belts containing a roscoelite layer in the upper part of the Entrada Sandstone. Hermosa Creek, Area C (Pl. 1b), is favorable for non-channel-controlled peneconcordant deposits (Subclass 244 of Austin and D'Andrea, 1978), where reducing environments may be present within the Rico Formation. Area D (Pl. 1b) is favorable for vein uranium deposits in Precambrian metamorphic rocks (Class 720 of Mathews, 1978b) of the Uncompahgre Formation. The Precambrian plutonic rocks of the Needle Mountains, Areas E and F (Pl. 1b), are favorable for magmatic-hydrothermal uranium deposits (Class 330 of Mathews, 1978a). Area E' (Pl. 1d) is also favorable for magmatic-hydrothermal uranium deposits but has a higher probability of occurrence than does Area E. Areas G and H (Pl. 1b) near Tuckerville and the Piedra River Canyon, respectively, are favorable for vein uranium deposits in sedimentary rocks (Class 730 of Mathews, 1978b), where suitable structures exist.

AREAS FAVORABLE FOR ROSCOELITE-TYPE VANADIUM-URANIUM DEPOSITS

Three districts within the Durango Quadrangle have produced vanadium and uranium from roscoelite-type vanadium-uranium deposits. These districts include the Placerville district where it extends into the Durango Quadrangle, the Barlow Creek-Hermosa Creek district, and the Lightner Creek district which is unfavorable for deposits the size and grade defined for NURE. Of the three, the Placerville district has produced the most ore, but uranium was not recovered prior to 1950, and uranium production since 1950 from individual properties (Nelson-Moore and others, 1978) has been insignificant.

Areas A (Pl. 1c) and B (Pl. 1b) are favorable for roscoelite-type vanadium-uranium deposits. Although these deposits are classified as epigenetic uranium deposits in sandstone, Class 240, no specific recognition criteria are available for roscoelite-type uranium deposits. Evaluation of the favorable areas is based on empirical considerations.

The roscoelite-type deposits are principally vanadium deposits. Uranium occurs only in minor concentrations and may be recovered as a byproduct as it has been from ore mined since about 1950. The roscoelite deposits were discovered in the Placerville area about 1900 and were intensively mined between 1910 and 1920. After 1920, the mines were mostly inactive until 1940. Fischer (1968, p. 100) estimated that 240,000 tons of roscoelite ore had been produced from the Placerville area. Of this, 200,000 tons had been produced through 1920. Fischer and others (1947) detailed much of the early production from the district.

Several authors have described the roscoelite deposits. Notes on the deposits in the Placerville area were published by Hess (1911). The description by Fischer and others (1947) resulted from work conducted during 1942 by a U.S. Geological Survey party. Keith (1945) reported on the deposits in the
Lightner Creek district, and Morehouse and Pursley (1952) described and estimated the ore reserves in part of the Barlow Creek-Hermosa Creek district. Bush and Bryner (1953) reported on the uranium and vanadium resources in all three districts. Fischer (1968) presented a short, synoptic review of the geologic characteristics of the deposits in the Placerville area, and Nelson-Moore and others (1978) compiled pertinent data including production records for the occurrences.

The roscoelite-type vanadium-uranium deposits occur in the Entrada Sandstone in the transitional zone between the Colorado Plateau and the Southern Rocky Mountains Provinces. The Placerville district that extends into the Durango Quadrangle (Pl. 1c) is characterized by horizontal to gently dipping sedimentary rocks that are cut by steeply dipping normal faults and small intrusive bodies. In the Barlow Creek-Hermosa Creek district (Area B), the sedimentary rocks, as a result of intrusive action and uplift, have widely varying attitudes and are cut by numerous faults (Morehouse and Pursley, 1952, p. 3).

The roscoelite deposits are contained in the upper part of the Upper Jurassic Entrada Sandstone. In the Placerville district, the Entrada Sandstone is 40 to 75 ft (12 to 23 m) thick and consists entirely of white to buff sandstone. The formation appears as a single, thick stratum, but actually the upper 5 to 20 ft (1.5 to 6 m) are thinly and evenly bedded and tend to form a ledgy cliff, whereas the lower part is massively cross-bedded and forms a steep slope or rounded cliff (Fischer, 1968, p. 100). Although the Entrada contains a small proportion of coarse, well-rounded sand grains in its lower part, throughout it is typically a uniformly fine-grained, clean quartz sandstone with minor amounts of clay and other minerals.

The Entrada is conformably overlain by the Pony Express Limestone Member of the Wanakah Formation and disconformably overlies the Upper Triassic Dolores Formation. The dark-gray, fine-grained, thin-bedded Pony Express Limestone contrasts sharply with the Entrada, and the contact between them is easily recognized. The Pony Express is about 10 to 12 ft (3 to 4 m) thick in the area of the Bear Creek Mine (occurrence 46) but thins to a depositional edge about 2 mi (3 km) west of the mine. The Pony Express emits a petrolierous odor from freshly broken surfaces and weathers into rubbly appearing, brick-sized and smaller blocks.

The roscoelite-type deposits consist of sandstone impregnated with vanadium and uranium minerals. Roscoelite, a vanadium mica, is the principal vanadium mineral and occurs as minute flakes that coat the sand grains and partly or completely fill the pore spaces between grains (Fischer, 1968, p. 103). Petrographic examination of samples MAE 233 through 235 (App. D) indicated that mineralization occurred in bands or zones. In moderately mineralized zones, roscoelite and other clay minerals replace silica cement, especially along grain boundaries and fractures; in heavily mineralized zones, sand grains may be partially or totally replaced. Clay minerals in the mineralized zones may also be vanadium rich. Fischer (1968, p. 103) reported that minor amounts of montroseite, a hydrous vanadium oxide, occur in high-grade ore. Vanadium minerals impart a greenish gray color to the sandstone. The color darkens as the vanadium content increases and may be almost black in high-grade zones.
No primary uranium mineral has been recognized, but secondary carnotite occurs sparsely in some places on the surface and along fractures near the surface where the roscoelite zones have been oxidized (Fischer, 1968, p. 103). Several samples were collected from the roscoelite zones at various localities, and alpha-track plates were exposed to define radioactive centers for mineral identification. After 21 days, no concentration of alpha tracks was obtained from any of the samples, which suggests that the uranium is evenly dispersed throughout the clayey and micaceous matrix. A more detailed, systematic approach using selected high-grade samples with greater uranium concentration might be successful in identifying a uraniferous phase, but such a study is beyond the purpose and scope of this program. A detailed study might also identify secondary uranium minerals in addition to carnotite.

The genesis of the roscoelite-type deposits is uncertain. The mineralized zone formed after the deposition of the Entrada because the roscoelite crosscuts bedding and corrodes and partially replaces quartz grains. The mineralized zone predate faulting and intrusive activity. After considerable work in the Placerville district, Fischer and others (1947, p. 127) reported that "the ore is displaced by faults and cut by dikes, but neither the distribution of the ore bodies nor variations in the grade of the ore suggest any genetic relationship between the ore and either the faults or the dikes." They suggested that precipitation of uranium occurred at a slightly uneven water table or at the contact between ground waters of two types. Spirakis (1977) commented on the role of semipermeable membranes in the formation of a similar roscoelite-type deposit at Rifle, Colorado. A thin, light-green, chromium-bearing layer is present a few feet below the roscoelite zone in the Placerville area and may have a similar origin.

Genesis is uncertain, but several geologic relationships are apparent. The presence of roscoelite in the Placerville district corresponds closely with the western depositional edge of the overlying Pony Express Limestone. In both favorable districts and in the Lightner Creek district, the vanadium-uranium deposits are restricted to areas where the Pony Express Limestone is at least 2 ft (0.6 m) thick. The roscoelite belts are elongate and occur along a nearly straight line (Fischer, 1955, p. 4).

Area A. The Part of the Placerville District within the Durango Quadrangle

The favorable part of the Placerville district that extends into the Durango Quadrangle is contained in Area A (Pl. 1c). Within the Placerville district a roscoelite zone in the Entrada Sandstone is exposed in two separate belts that have been defined empirically. The mineralized zone, easily recognized by its greenish gray color, is not present outside the belts. Plate 1c shows the projected extent of the two belts, the outcrops of the roscoelite zone, and the occurrences present in the belts within the Durango Quadrangle. Area A consists of 5.6 mi² (14.5 km²) of which 0.2 mi² (0.5 km²) is within the eastern belt and 5.4 mi² (14 km²) are along the Leopard Creek-Big Bear Creek belt. The eastern belt may connect with the Leopard Creek-Big Bear Creek belt northwest of the Durango Quadrangle boundary. The eastern belt does not extend south of the San Miguel River and abuts against a granodiorite porphyry stock on the east. The Leopard Creek-Big Bear Creek belt is projected southeastward to an arbitrary line at which the belt would be about 1,000 ft (300 m) below the surface. The belt is unevaluated below 1,000 ft (300 m) because no information is available.
Within the belts, the mineralized zone forms an essentially continuous, wavy layer in the upper 25 to 30 ft of the Entrada Sandstone (Bush and Bryner, 1953, p. 10). The layer appears to follow the even bedding in the top of the Entrada, but in detail the layer crosses the bedding. The mineralized layer is from a fraction of an inch to as much as 20 ft (0.01 to 6 m) in thickness. In most places, it is only 3 to 6 in. (0.08 to 0.16 m) thick, but it thickens abruptly in places and forms lenticular or tabular masses that have been mined (Fischer, 1968, p. 103).

Individual orebodies have a wide range in size and shape. Small ones are several feet across and a few feet thick and contain only a few tons of ore, whereas the large ones are a few hundred feet across and from 2 to 20 ft thick and contain many thousands of tons of ore. Some orebodies are elongate, display various shapes along sections perpendicular to the long axis, and have well-defined boundaries that crosscut bedding. Other orebodies are roughly circular in plan, thin gradually from a maximum thickness of 3 ft to less than 1 ft, and have indefinite boundaries that are nearly parallel to the bedding. (See Fischer and others, 1947.)

The now inactive Bear Creek Mine (occurrence 46) was the largest mine in the district. It produced about 130,000 tons of vanadium ore between 1910 and 1918 and was also mined during World War II. The early production allegedly averaged between 2.5% and 3%. (See Fischer and others, 1947, p. 133.) Uranium was not recovered from this early production, which probably contained 1 to 2 lb U₃O₈ per ton. Nelson-Moore and others (1978, p. 405) reported that uranium production through 1971 (presumably between about 1950 and 1971) totaled 15,302 lb U₃O₈ from 14,919 tons of ore having an average grade of 0.05% U₃O₈. The same ore contained 600,070 lb of V₂O₅ at an average grade of 2.01% V₂O₅. This ore had a V₂O₅-to-U₃O₈ ratio of about 40. Although the uranium was not recovered from the early production, ore extracted from this mine contained about 100 tons of U₃O₈.

Uranium production from several claims (occurrence 44) along the eastern roscoelite belt totaled about 1,300 lb of U₃O₈. The V₂O₅-to-U₃O₈ ratio for this production was about 30.

Fischer (1968, p. 103) stressed the random distribution of orebodies within the belts. He assumed that if drifts in the Fall Creek Mine "...had been driven along other lines they would have found other orebodies and probably just about as much ore." Inspection of his simplified geologic map of the Fall Creek Mine (Fischer, 1968, p. 102) shows that about 15% of the total length of the drifts cut through the mineralized layer where the layer was 1 ft (0.3 m) or more thick. The Fall Creek Mine is on the Leopard Creek-Big Bear Creek belt and about 1 mi (1.6 km) west of the Durango Quadrangle boundary. A similar relationship between the area of the mineralized belt and the percentage of the area in which the mineralized layer is 1 ft (0.3 m) or more thick is suggested for Area A.

Stream sediments and stream waters sampled in Area A (HSSR) did not contain anomalous concentrations of uranium. However, the ARR survey conducted by Western Geophysical Company (1979) assigned anomaly 1 to a small area in the northwest corner of the quadrangle, which may include part of the eastern roscoelite belt (Pl. 1c). The anomaly was characterized by above-average
values for uranium and uranium-to-thorium ratios and was attributed to the Cutler, Dolores, and Entrada Formations by Western Geophysical Company (1979, p. B1).

The land ownership (Pl. 13) in Area A does not conflict with mine development.

Area B. Favorable Area within the Barlow Creek-Hermosa Creek District

The favorable area within the Barlow Creek-Hermosa Creek district is shown as Area B (Pl. 1b). Within this area, the mineralized layer forms a single northwest-trending belt that extends under the sill-capped mass of Hermosa Mountain (Bush and Bryner, 1953, p. 10). Area B contains 8.2 mi² (21 km²).

The roscoelite deposits in the Barlow Creek-Hermosa Creek district are not as well documented as those of the Placerville district, but Bush and Bryner (1953, p. 9) reported that "similarities between the Placerville deposits and those at Barlow Creek-Hermosa Creek are much greater than the differences." Both districts are cut by numerous faults and dikes that do not have any apparent effect on the mineralized layer that is present near the top of the Entrada in both districts. The distance between the western edge of the mineralized belt and the depositional edge of the Pony Express Limestone is about 0.25 to 0.5 mi (0.4 to 0.8 km) in the Placerville district and is about 0.5 mi (0.8 km) or more in the Barlow Creek-Hermosa Creek district. The chromium-bearing layer is not as well developed in the Barlow Creek-Hermosa Creek district but, where present, has the same relative position beneath the roscoelite layer that it does in Placerville.

The significant difference between the two districts is that the mineralized layer in the Barlow Creek-Hermosa Creek district is thinner. The thickness is less variable and is maximally about 6 ft (2 m). Bush and Bryner (1953, p. 14) reported that, "the part of the layer that is more than 1 foot thick is perhaps one-fifth to one-tenth the equivalent part of the Placerville layer." They concluded that although the districts are comparable in area, the volume of mineralized rock in the Barlow Creek-Hermosa Creek district is less by about an order of magnitude.

Both the Barlow Creek occurrence (occurrence 2) and the Graysill Mine occurrence (occurrence 15) are within Area B. The Graysill Mine produced 51,000 lb of U₃O₈ from ore having an average grade of 0.08% U₃O₈ and 2.4% V₂O₅ (Nelson-Moore and others, 1978, p. 398). The ore had a V₂O₅-to-U₃O₈ ratio of 30. A sill-like intrusive body is present at the Graysill Mine. On the eastern side of Hermosa Creek, the sill-like body is between the top of the mineralized layer and the Pony Express Limestone, and, on the western side of the creek, it is below the mineralized layer. The Barlow Group has produced only 310 lb of U₃O₈, but the grade of the rock was 0.10% U₃O₈ (Nelson-Moore and others, 1978, p. 129).

Neither the HSSR program nor the ARR program detected anomalous concentrations of uranium in Area B. Land ownership (Pl. 13) in Area B does not conflict with mine development.
NON-CHANNEL-CONTROLLED PENECONCORDANT DEPOSITS, AREA C

Area C (Pl. 1b) is favorable for non-channel-controlled peneconcordant sandstone uranium deposits in the Rico Formation along Hermosa Creek.

Peneconcordant uranium deposits are essentially strata-bound and do not show the sharp boundary between altered and unaltered ground commonly present in roll deposits (Austin and D'Andrea, 1978, p. 107). Host rocks are predominately fluvial and represent deposition in stream-channel, braided-stream, and flood-plain environments. Sandstone-to-shale ratios in favorable host rocks of the Uravan mineral belt are approximately 1:1 (Austin and D'Andrea, 1978, p. 111). Favorable characteristics of the host sandstone include lateral continuity, abrupt changes in texture, and the presence of thin, discontinuous claystone lenses (Sears and others, 1974, p. 80). The uranium is epigenetic and may have been derived from overlying tuffaceous sediments or from a feldspathic component of the host.

Uranium is precipitated by reductants. Reductant materials in the Uravan mineral belt are mostly organic material, especially carbonized wood. The organic material may itself be the locus of uranium deposition, or it may have been a nutrient for sulfur-reducing bacteria that caused local reducing environments in otherwise oxidized sandstones. (See Austin and D'Andrea, 1978, p. 113).

The Rico Formation contains the favorable environment within Area C. The Upper Pennsylvanian-Lower Permian Rico Formation is considered transitional between underlying marine sediments of the Hermosa Formation and overlying continental clastics of the Cutler Formation. It consists of red and purple sandstones, arkosic sandstones, conglomerates, shales, and sandy fossiliferous limestones. In the western part of the quadrangle, the Rico is 100 to 300 ft (30 to 90 m) thick.

The Rico sediments were deposited in fluvial-deltaic, paludal, mixed-marine, and marine environments. Many of the fluvial sandstones in the Rico contain carbonized plant debris; the paludal shales frequently contain carbonaceous material.

Permeability of the Rico is variable due to lateral discontinuity of shale and limestone beds. Areas of highest permeability commonly contain thick sandstone units and thin, discontinuous shale lenses.

Favorable Area C also contains a significant uranium occurrence, the Lucky Lepracon (occurrence 19). At this occurrence, uranium is associated with fossil plant fragments in a fluvial sandstone. The light-gray, fine-grained sandstone contains abundant sand-sized organic particles in addition to larger plant fragments. The sandstone is about 20 ft (6 m) thick. A mineralized zone is present in the interval between 3 and 10 ft (1 and 3 m) above the base of the sandstone. Higher grade pods and stringers are scattered throughout the mineralized zone. The mineralized zone has been exposed on both sides of a long narrow ridge by about 1,200 ft (350 m) of stripping. No primary uranium minerals were identified, but secondary carnotite is present on joint surfaces and bedding planes. Boyer and Anderson (1956) estimated that this occurrence contains 1,000 tons of rock at 0.25% \( \text{U}_3\text{O}_8 \) and 1.25% \( \text{V}_2\text{O}_5 \).
Area C was drawn to include the anomalous area as defined by HSSR samples (Pl. 4, no. V), the significant occurrence in the Rico, and contiguous area in the Rico that has similar fluvial environments. Area C contains 8.2 mi$^2$ (21 km$^2$).

Area C is within a Roadless Area Review and Evaluation (RARE II) study area that has been proposed for wilderness-area status.

VEIN URANIUM DEPOSITS IN METAMORPHIC ROCKS, AREA D

Area D is favorable for vein uranium deposits in metamorphic rocks because the area contains suitable host rocks, a possible source of uranium, and a significant uranium occurrence, the presence of which establishes an operable concentration process. Vein uranium deposits in metamorphic rocks are closely associated with brecciated major fault zones similar to those cross-cutting the Uncompahgre Formation in this area.

Mathews (1978d) described vein uranium occurrences in metamorphic rocks as occurrences of uncertain genesis; both the source of the uranium and the nature of the mineralizing solutions are speculative. Several empirical recognition criteria were used in the evaluation of this occurrence type. The location of the veins is structurally controlled. Pitchblende is the principal uranium mineral and, like other uranium minerals, may not necessarily occur in the major fault plane but may be found in related secondary faults, fractures, and breccia zones (Mathews, 1978d, p. 234).

The Uncompahgre Formation is the principal unit in the favorable area. This formation has been isoclinally folded along east to southeast trends and has been regionally metamorphosed in Precambrian time. The Uncompahgre Formation has an aggregate thickness of 8,000 ft (2400 m) and is mapped on the basis of lithology as either slate or quartzite (Steven and others, 1974). The slate units contain gray, green, and black slate, phyllite, and schist. Where the slates are less metamorphosed, they commonly contain abundant organic carbon and pyrite (Steven and others, 1974). Steven and others (1969, p. F50) stated that the black slates and phyllites contain significant quantities of pyrite and organic carbon and are slightly metamorphosed, organic black shales of the type that commonly contains above-background quantities of metals. Organic black shales also commonly have above-average uranium contents and are often cited as possible source rocks for uranium.

The quartzite units of the Uncompahgre Formation are brittle, light gray to pale blue, and from thickly to thinly bedded. The uranium occurrence at Elk Park (occurrence 17) is in these quartzites.

The area of the Elk Park Mine was claimed in 1956 to include radioactivity anomalies discovered in east-trending shear zones in Precambrian metasedimentary rocks. At that time, the claim group consisted of 140 lode claims. Subsequent exploration and development uncovered several lenticular occurrences of pitchblende in one zone. (See Sheridan and Williams, 1969, p. F88.) Through 1971, 33 tons of ore had been produced at an average grade of 0.45% U$_3$O$_8$ (Nelson-Moore and others, 1978, p. 398). The Elk Park area was being actively explored during the 1978 and 1979 field seasons.
Field examination of the Elk Park Mine occurrence found that uranium-bearing minerals are confined to fractures and shears within brittle quartzites, but not all fractures contain uranium. Radiometric traverses detected anomalous but erratic levels of radioactivity. Areas of highest radioactivity typically contain a high fracture density. The highest level of radioactivity measured was from a small surface cut present along strike and about 75 ft (25 m) above and behind the adit entrance. In the side of the cut, a small area containing several closely spaced fractures exceeded 20,000 cps. A chip sample (MFS 063), collected across the fractured area, contained 1.4% U₃O₈. Another chip sample (MFS 062), collected from a veined area on the south side of the adit about 15 ft (5 m) inside the portal, contained 0.48% U₃O₈.

Pitchblende is the dominant uranium mineral. Both sooty and hard varieties are present. Secondary yellow and green uranium oxides are present on some fracture surfaces. In addition to uranium minerals, cobaltite, nickel-in, and native silver are present in small quantities at the occurrence. The analyses, reported in Table 1, indicate that the concentrations of cobalt, nickel, silver, and arsenic are minor but exceed those of other vein deposits sampled. Nelson-Moore and others (1978, p. 398) reported that autunite, metatorbernite, and erythrite are also present at this occurrence.

The Elk Park Mine is classified as a vein uranium occurrence in metamorphic rocks and is assigned to Class 720 of Mathews (1978b). Although the concentrations of cobalt, nickel, arsenic, and silver are minor and not economically significant in samples MFS 062 and 063 (Table 1), cobaltite, nickel-in, and native silver are present and characteristic of polymetallic vein occurrences (Subclass 722, Mathews, 1978b).

Some geologic characteristics of the Elk Park Mine occurrence do not correlate well with the recognition criteria for vein uranium occurrences in metamorphic rocks. One important difference is the alteration pattern; the Elk Park Mine occurrence does not display widespread hematitization and contains only minor chloritization. Another difference is that the rocks in the favorable area do not display the degree of retrogressive metamorphism and are less metamorphosed than rocks in occurrences described by recognition criteria (Mathews and others, 1979, p. 30).

Results of the HSSR programs indicate that some streams draining Area D contain anomalous uranium concentrations. Five stream-sediment samples derived from Precambrian metamorphic and igneous rocks along the Animas River drainage contain uranium concentrations from 17 to 64 ppm (Pl. 4, no. II). One stream-sediment sample from upper Elk Creek is clearly derived from rocks of the Uncompahgre Formation. The source of the anomalously high uranium concentrations in stream sediments from Tenmile Creek is not discernable.

Results of the ARR as interpreted by Western Geophysical Company (1979) did not define anomalous areas within Area D. One anomalous area, anomaly 26 (Western Geophysical Company, 1979, p. B2) is on the northeast boundary of Area D, but appears to be mostly within the Irving Formation. This anomaly was not field checked. Many of the data collected by the ARR program in Area D are unreliable because of the large corrections necessary for terrain clearance variations in the rugged mountains.
### TABLE 1. SELECTED ANALYSES OF SAMPLES FROM VEIN URANIUM OCCURRENCES

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Occurrence name</th>
<th>Occurrence no.</th>
<th>U₃O₈ (ppm)</th>
<th>eU (ppm)</th>
<th>K (%)</th>
<th>eTh (ppm)</th>
<th>eTh/eU</th>
<th>Ag* (ppm)</th>
<th>As* (ppm)</th>
<th>Bi* (ppm)</th>
<th>Co* (ppm)</th>
<th>Ni* (ppm)</th>
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<td>MFS 054</td>
<td>Florida Mountain</td>
<td>22</td>
<td>23,000</td>
<td>16,000</td>
<td>1.4</td>
<td>58</td>
<td>0.0036</td>
<td>110</td>
<td>&lt;1</td>
<td>22</td>
<td>nd</td>
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<tr>
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<td>Florida Mountain</td>
<td>22</td>
<td>52</td>
<td>41</td>
<td>3.9</td>
<td>19</td>
<td>0.46</td>
<td>14</td>
<td>&lt;1</td>
<td>12</td>
<td>12</td>
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<tr>
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<td>22</td>
<td>700</td>
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<td>4.5</td>
<td>39</td>
<td>0.003</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>5</td>
<td>18</td>
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</tr>
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<td>22</td>
<td>5,100</td>
<td>7,400</td>
<td>2.4</td>
<td>35</td>
<td>0.0047</td>
<td>76</td>
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<td>MFS 062</td>
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<td>4,800</td>
<td>3,900</td>
<td>0.7</td>
<td>6</td>
<td>0.01</td>
<td>40**</td>
<td>510**</td>
<td>nd</td>
<td>30**</td>
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<tr>
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<td>Elk Park Mine</td>
<td>17</td>
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<td>nd</td>
<td>nd</td>
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<td>---</td>
<td>80**</td>
<td>940**</td>
<td>nd</td>
<td>30**</td>
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<td>30</td>
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<td>48</td>
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<td>33</td>
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<td>48</td>
<td>1.45</td>
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<td>&lt;1</td>
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<td>4</td>
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<td>Golden Fleece</td>
<td>3</td>
<td>6,900</td>
<td>15?</td>
<td>5.4</td>
<td>48</td>
<td>---</td>
<td>&lt;1</td>
<td>36</td>
<td>&lt;1</td>
<td>2</td>
<td>nd</td>
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<td>Tuckerville</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>---</td>
<td>340</td>
<td>77,000**</td>
<td>nd</td>
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<td>4</td>
<td>0.0022</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>620**</td>
</tr>
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* Analyses are quantitative analyses except those analyses indicated as semiquantitative.
Analyses for these elements in Appendix B are semiquantitative.

** Determination made by semiquantitative methods

nd Not determined
Favorable Area D contains about 50 mi$^2$ (130 km$^2$). The boundary of the favorable area was drawn to include the major fault zones contained in the Uncompahgre Formation as shown on the geologic map by Steven and others (1974). The boundary between contiguous Areas D and E was drawn approximately on the surface contact between the Eolus Granite and the Uncompahgre Formation. A small portion of the northwest part of the favorable area is covered by Paleozoic rocks of variable thickness.

The units within Area D are favorable where fractured, faulted, or brecciated. The quartzites are more brittle than the slates and schists, are more easily fractured, and, therefore, may be more favorable.

About half of Area D is within the Weminuche Wilderness and an additional part, about 5%, has been proposed for wilderness-area status. A power-site withdrawal along the Animas River and Elk Creek includes about 20% of Area D. Land status of the remainder of Area D does not conflict with mineral development (see Pl. 13).

MAGMATIC-HYDROTHERMAL URANIUM DEPOSITS, AREAS E, E', AND F

Area E contains a known uranium deposit and is favorable for the occurrence of other uranium deposits. The known deposit (occurrence 22) at Florida Mountain is estimated to be a medium-sized deposit that contains between 200,000 and 2 million lb of U$_3$O$_8$. The deposit is in veins within plutonic rocks and is classified as a magmatic-hydrothermal deposit (Class 330).

Areas E and F (Pl. 1b) are favorable because the areas are geologically similar to the deposit area and meet several specific recognition criteria for magmatic-hydrothermal uranium occurrences as defined by Mathews (1978a) and Mathews and others (1979, p. 18). These characteristics emphasize the importance of the nature and distribution of permeable channelways through which mineralizing solutions might migrate. Magmatic-hydrothermal occurrences are usually found in areas of crustal instability. The veins are commonly brecciated and have a simple mineralogy. Quartz is the dominant vein material. Several elements may be concentrated in the veins, but their presence and concentration are highly variable from one deposit to another. The Cornucopia vein system present on the northeast slope of Florida Mountain displays many of the geologic characteristics of these vein uranium occurrences. In addition, the results of the HSSR indicate that stream sediments derived both from Area E and from Area F contain anomalous concentrations of uranium.

Areas E and F are in the Needle Mountains, which lie within a domal uplift of Precambrian rocks about 25 mi (40 km) in diameter in the southwest part of the San Juan Mountains. The Precambrian geology of the Needle Mountains has been restudied by Barker (1969). Recently, Schmitt and Raymond (1977) published a paper about the geology and mineral deposits of the Needle Mountains district that emphasizes the base-metal potential of the district and details the geology of the Chicago Basin stock. A study of mineral resources of the San Juan Primitive Area was published by Steven and others (1969). The above studies preceded the discovery of the Cornucopia vein and did not include comment on the uranium potential of plutonic rocks of the Needle Mountains. Little has been published regarding the geology of the Cornucopia vein and the uranium potential of the surrounding area.
The central part of the Needle Mountains consists of Precambrian Y plutonic rocks. The Eolus Granite is a composite batholith consisting mainly of biotite-hornblende quartz monzonite and biotite quartz monzonite. Typically, the Eolus Granite contains 0.5- to 1.5-in. grains of pink, blocky, Carlsbad-twinned microcline microperthite set in a medium- to coarse-grained matrix of andesine, quartz, biotite, and hornblende (Barker, 1969, p. A25). The Eolus Granite batholiths were emplaced about 1,460 m.y. ago (Barker, 1969, p. A27). The western batholith is in Area E, and the eastern batholith is in Area F.

Within Area E, a stocklike mass of Trimble Granite intrudes the central part of the western body of Eolus Granite. The contacts are sharp, but on the southwest side of the Trimble stock numerous apophyses project into the Eolus (Schmitt and Raymond, 1977, p. 7). The Trimble Granite is predominately a pale-red, porphyritic, fine- to medium-grained biotite granite. The finer grain size of the Trimble Granite readily distinguishes it from the Eolus Granite.

Both the Eolus Granite and the Trimble Granite are regionally highly fractured (Schmitt and Raymond, 1977, p. 13). Most fractures trend nearly north or east and are steeply dipping to vertical, but Schmitt and Raymond (1977) described, as well, a set of nearly horizontal fractures similar to those found in exfoliation domes. Many of the fractures are filled with quartz-pyrite veins that locally have ore shoots of sphalerite, galena, chalcopyrite, gold, and silver similar to those mined at the Pittsburg Mine occurrence 21) and the Republic Tunnel (occurrence 20). Pitchblende is associated with vein-filled fractures in the Trimble and Eolus Granites in the Florida Mountain-Thunder Mountain area.

Public Service Company of Oklahoma (PSO) conducted uranium exploration in the Needle Mountains, particularly in the Thunder Mountain-Florida Mountain area, in 1975 through 1978. In July 1978, PSO provided Durango Quadrangle evaluators with a tour of the area including the surface exposure of the Cornucopia vein. The following discussion of the Cornucopia vein and adjacent area is based on information provided by PSO geologists while discussing the geology of the area and incorporates observations made by quadrangle evaluators. Several PSO personnel were present, including Paul Jones, Fuel Division Manager; Bill Carlson, Exploration Manager; Chris Metzger, Project Manager; and Jeff Milligan, geologist.

Florida Mountain (Pl. 1d) is on a block of Trimble Granite that is in the angle formed by the intersection of the Bullion Fault on the north and the Trimble Fault on the south. Schmitt and Raymond (1977) showed these structures as unnamed faults on their geologic map, but stated (p. 33) that the faults dip nearly vertically and have localized, surficially barren quartz veins as much as 20 to 30 ft wide.

PSO geologists have identified three structural fracture types. The Bullion and Trimble Faults are examples of steeply dipping faults with large major offsets. Simple fractures and fissures are examples of another type. These fractures are commonly steeply dipping and trend either north or east. As these fractures do not transect Paleozoic sedimentary outliers, they were probably caused by Precambrian deformation (Schmitt and Raymond, 1977, p. 13). The Cornucopia vein exemplifies the third type, uranium-bearing veins emplaced
in shallow-dipping fracture zones. The Johnson vein system is commonly parallel to the Cornucopia vein but is separated from the Cornucopia by about 400 ft (120 m) of barren rock.

The Cornucopia vein system crops out on the northeast slope of Florida Mountain. The vein system strikes northwest and dips southwest under Florida Mountain toward the Trimble Fault at an average dip of about 35°. Dip of the Cornucopia vein ranges from 10° to 45°. The vein system pinches and swells and ranges in thickness from less than 1 ft to more than 20 ft (0.3 m to more than 6 m) in places. The uranium content of the vein system is from a few hundredths of a percent to as much as 4% over short intervals.

Where examined on the northeast slope of Florida Mountain, the Cornucopia vein system consisted of a major vein and two minor veins, one above and one below the major vein. These two minor splays pinch out 150 to 200 ft (45 to 60 m) along the outcrop. The maximum thickness of the vein system where exposed was about 25 ft (8 m) from the top of the upper minor splay to the bottom of the lower splay. The lower 5 ft (2 m) of the vein system, which include the main vein and the lower splay, are well mineralized, but the upper 20-ft (6-m) section between the major vein and the upper splay is not. The reading for the most radioactive section of the major vein was off the scale of our scintillometer (exceeded 20,000 cps) and contained 2.3% U3O8 (sample MFS 054). A sample from the lower contact of the vein system (MFS 057) contained 0.5% U3O8. Six feet above the upper splay, the scintillometer reading was about 2 times background at 600 cps, but a grab sample (MFS 055) contained 52 ppm U3O8. At this exposure, the lower contact of the vein system appears to be sharp and the upper contact gradational.

At the outcrop, the major vein contains abundant brecciated material. All three veins are silicified and are contained in argillic alteration envelopes. The thickness of the envelopes is roughly proportional to the thickness and prominence of the vein. A zone of propylitic alteration encloses the argillic alteration, and a zone of chloritic alteration extends beyond the propylitic zone.

Pitchblende is the principal uranium mineral present in the Cornucopia vein system, but gummite and other brightly colored secondary uranium minerals are present where the vein is oxidized. Quartz is the most important gangue mineral and occurs as vein quartz, as cockscomb quartz, and as a red jasperoid material in some of the veins. A black manganese mineral, possibly psilomelane, occurs in the veins. Fluorite is present in a variety of colors, but dark and purple varieties are the best indicators of pitchblende. Dense, fine-grained, green barite is also present. Calcite is a minor gangue mineral and, in most places, has a leached appearance. Pyrite and sphalerite are the most common sulfides in the Cornucopia vein system.

PSO geologists reported that radiometrically determined equivalent uranium is in equilibrium with, or within about 10% of, chemically determined U3O8. Table 1 lists the equivalent uranium and U3O8 values determined for the samples collected from the Cornucopia vein where it crops out on the northeast side of Florida Mountain. These results are more variable. The analyses reported in Table 1 also indicate that the thorium-to-uranium ratio is much less than unity, in agreement with recognition criteria of Mathews (1978c) for magmatic-hydrothermal deposits. The arsenic contents of the samples from Florida Mountain indicate minor concentration, but silver, cobalt,
nickel, and bismuth contents are about normal. Schmitt and Raymond (1977, p. 36) reported anomalously high bismuth contents in the Vallecito Basin north of the Cornucopia vein.

The age and the source of the mineralizing fluids are in question. Schmitt and Raymond (1977, p. 8) reported that the Chicago Basin stock is between 9 and 10 m.y. old. Nelson-Moore and others (1978, p. 205) reported that the age of uranium mineralization (reported to them by PSO?) is not Tertiary but 1.34 b.y. This age is approximately that of the Trimble Granite, but pegmatitic phases of the Trimble Granite observed by PSO geologists are not apparently related to the mineralization. Another factor is that the areas of anomalous stream-sediment samples (Pl. 4) collected during the HSSR (Maxwell, 1977; Dawson and Weaver, 1979) are much more widespread than either the Chicago Basin stock or the Trimble Granite. Most streams draining Precambrian plutonic rocks have anomalously high uranium contents.

The results of the HSSR (Maxwell, 1977; Dawson and Weaver, 1979) indicate that stream sediments collected from streams draining the plutonic rocks of the Needle Mountains contain anomalous concentrations of uranium (Pl. 4). In fact, the only drainage lacking anomalous concentration of uranium is the Los Pinos River drainage. Seven samples collected from this drainage all contained between 3.0 and 3.6 ppm uranium (Maxwell, 1977, p. 13), and such remarkable homogeneity in this drainage area is suspect. The interpretation of the anomalous areas is difficult on the basis of uranium analyses alone. The high uranium values could be attributed to uranium-bearing refractory minerals derived from the granites and concentrated in the stream sediments. Many of these drainages are at high elevations and have relatively steep gradients. Chemically unstable minerals, such as uraninite, may be dispersed further downstream before they are completely oxidized and leached.

Independent studies conducted by an unidentified mining company and referred to by Dawson and Weaver (1979, p. 16) have delineated a large anomalous area that complements the HSSR results. Nelson-Moore and others (1978, p. 205) reported that several anomalies (presumably from detailed geochemical or aerial radiometric surveys) were found over a 10-mi² area.

Western Geophysical Company (1979, p. B3) assigned anomaly 38 to the Eolus in the southwest part of Area E. They characterized this anomaly as "strong U, moderate Th, U/Th and U/K."

Several factors may explain the failure of the ARR to identify the Needle Mountains as an anomalous area. First, corrections for terrain clearance variations in areas of rugged topography are large and render many of the data collected unreliable. Almost half the ARR data (Western Geophysical Company, 1979) collected in Area E showed excessive terrain clearance; unreliable data are usually not interpreted. Second, small outcrops like that of the Cornucopia vein are point sources and may not fall under a flight line. Third, although the area may have a higher regional background than do other areas, anomalous areas were defined by counting rates at a selected level above the average for each individual rock type. This may have resulted in a high background but no exceptionally anomalous areas. Quadrangle evaluators did succeed in detecting the outcrop of the Cornucopia vein from a helicopter with a small portable scintillometer.
Results of a detailed aerial radiometric survey of part of the Needle Mountains are pending. Perhaps this survey will better define the radiometric response in this area.

In an attempt to better define the anomalous areas, a detailed geochemical survey is being conducted by LASL over the area shown on Plate 4. When the results of the detailed study are available, the boundaries of the favorable areas may be refined. The present boundaries are based on the HSSR results.

Area E (Pl. 1b) contains about 115 mi$^2$ (300 km$^2$), excluding 14.6 mi$^2$ (38 km$^2$) in Area E', and includes the western part of the composite Eolus batholith, the Trimble Granite, and the Temmle Granite. The Temmle Granite is included in Area E because of its similar geologic environment and the anomalous concentrations of uranium found in stream sediments collected in that area (Pl. 4, no. II). The boundary of Area E on the east is placed on the Eolus-Vallecito Conglomerate contact and along Vallecito Creek. Maxwell (1977, p. 13) reported that samples from streams on the eastern side of Vallecito Creek contain only normal amounts of uranium.

Area E' (Pl. 1d), an area of 14.6 mi$^2$ (38 km$^2$), should be assigned a probability of occurrence higher than that for Area E. This opinion is based on the observation of Schmitt and Raymond (1977, p. 33) that more regional fractures are vein-filled in the Vallecito Basin than in other areas. In their overview, Schmitt and Raymond (1977, p. 34) suggested that a north-northwest-trending belt of discontinuous vein-filled regional fractures is crossed by several east-trending fractures between Johnson Creek and Grizzly Gulch. Area E' contains much of the area described by Schmitt and Raymond and also includes major fractures to the south and east. The Cornucopia vein deposit is within Area E'.

Area F (Pl. 1c), about 68 mi$^2$ (176 km$^2$), contains the eastern Eolus batholith. This area has a geologic setting similar to that of Area E. Area F does lack intrusive Trimble Granite. The quartz diorite of Pine River is older than the Eolus Granite and is included in Area F. Five stream-sediment samples from creeks draining Area F contain uranium concentrations from 10 to 29 ppm (Pl. 4, no. IV).

Currently, about 65% of Area E is within the Weminuche Wilderness, and another 20% is proposed for wilderness-area status. The Weminuche Wilderness includes about 85% of Area E' and about 80% of Area F. Land ownership in the remaining parts of all three areas does not conflict with mineral development.

Areas E, E', and F are unevaluated at depths greater than 0.5 mi (0.8 km) because of lack of information.

**VEIN URANIUM DEPOSITS IN SEDIMENTARY ROCKS**

Areas G and H (Pl. 1b) are favorable for uranium deposits in sedimentary rocks. This occurrence type, Class 730, is mainly controlled by structure. Vein systems that host the epigenetic uranium deposits may be related to regional fractures, shear systems, and growth faults; occurrences of Class 730 are characterized by brecciated, cataclastic textures. Pitchblende is the
principal uranium mineral and is commonly associated with calcite and quartz. Vein uranium deposits in sedimentary rocks have no specific rock association, a low thorium-to-uranium ratio, and various types of alteration patterns. These deposits have two general forms, pipelike and tabular. (See Mathews, 1978d, p. 241-244.)

**Area G. Tuckerville**

Area G is favorable for vein uranium deposits in sedimentary rocks because it contains a sequence of brittle rocks that has been cut by a regional pattern of east-trending faults. Two uranium occurrences in the area are of this class and provide credence for a concentration mechanism.

Area G contains a relatively thin sequence of favorable Paleozoic sedimentary rocks that overlies metamorphosed Precambrian Vallecito Conglomerate. The Lower Mississippian Leadville Limestone crops out over much of the area although exposures are limited because of vegetation and cover. The upper part of the Leadville is distinctly karstic and contains terra rosa that has filtered down from the Molas Formation. Other parts of the Leadville are not distinct and are difficult to place in the stratigraphic section.

The Leadville Limestone varies lithologically from one outcrop to another. At some outcrops, the Leadville is a rather thick-bedded, dense crystalline limestone and contains abundant fossils, including brachiopods and crinoids. At other places, it is hematitic and sandy.

The total thickness of the Leadville in the favorable area is about 150 ft (45 m), and the unit is separated from the Precambrian Vallecito Conglomerate by about 100 ft (30 m) of lower Paleozoic sediments including the Ouray Limestone, the Elbert Formation, and the Ignacio Formation. In the central part of Area G, the favorable Leadville is overlain by a variable thickness of Lower Permian and Pennsylvanian sedimentary rocks of the Rico, Hermosa, and Molas Formations. These cover rocks have a maximum thickness of 1,300 ft (400 m).

The Tuckerville occurrence (6) is present on the north flank of Runlett Peak in an area that contains several parallel to subparallel brecciated shear zones. The shear zones are nearly vertical and cut nearly horizontal beds. The shear zones are probably genetically related to the major fault that crosses Runlett Peak about 0.5 mi (0.8 km) to the south and drops lower Paleozoic strata against Precambrian Vallecito Conglomerate. Both the shear zones and the fault trend east.

A radiometric survey of the occurrence area found that the more radioactive zones are more brecciated and contain green copper oxides. Radioactivity is more closely related to the brecciated shear zones than to collapse features within the beds of the Leadville. Spots on the dump and some areas along the main shear zone are 35 times more radioactive than the regional background of 100 cps. Radioactivity is strongly correlated with the presence of green copper oxides. Sample MFS 024 (App. B-1), selected on the basis of its anomalous level of radioactivity, contained 77,000 ppm arsenic, 17,000 ppm antimony, 45,000 ppm copper, 24,000 ppm zinc, and had a uranium content of 2,300 ppm U₃O₈.
Samples of highly radioactive material from dumps at the occurrence were submitted for mineral identification. Small black pods scattered through the samples have a somewhat concentric structure and were identified as digenite, a copper-sulfide mineral of the chalcocite group. Thin green crusts filling fractures in the digenite were found to be mixtures of malachite and metazeunerite, a hydrated secondary mineral containing copper, uranium, and arsenic. No other uranium minerals were identified, but the samples also contained azurite and quartz (see samples MFS 024 and 630, App. D).

This occurrence in the Leadville has been reported as a peneconcordant deposit (Dawson and Weaver, 1979, p. 10), but our observations indicate that the uranium is more closely related to the brecciated zones than to bedding features. Some solution entry may have occurred along bedding planes, but was less important than that along zones of brecciation.

Although the North Tuckerville occurrence (5) is in a geologic setting similar to that of the Tuckerville occurrence, it differs in many aspects. The host rock is Leadville Limestone, but the lithology of the unit is almost a limy sandstone. Above-background levels of radioactivity are associated with shears and fractures, but the highest level of radioactivity measured was only about 10 times background. The maximum uranium content determined from samples collected at this occurrence was 130 ppm $U_3O_8$. Unlike the Tuckerville occurrence, no copper minerals are apparent.

Neither the HSSR nor the ARR identified Area G as anomalous. Area G (Pl. 1b) is defined by the extent of the lower Paleozoic units within the general area north and slightly east of Vallecito Lake. This area is cut by major east-trending faults. Uranium deposits within this 15.7-mi$^2$ (40.7-km$^2$) area would be mainly controlled by structure. Dolomitized limestone within the Leadville is the most favorable host rock because of its brittleness. In the central part of the area, the Leadville is overlain by Pennsylvanian and Permian sedimentary rocks that may be as much as 1,300 ft (400 m) thick.

About a third of Area G is within the Weminuche Wilderness, and about 10% is within a wildlife withdrawal. Land ownership of the remainder does not conflict with mineral development (see Pl. 13).

**Area H. Piedra River Canyon**

Area H, an area of 17 mi$^2$ (44 km$^2$) along the Piedra River drainage, is also favorable for vein uranium deposits in sedimentary rocks. This area displays a favorable geologic environment analogous to that at Tuckerville. Leadville Limestone is exposed throughout much of the area, but in places is covered by Pennsylvanian and Permian rocks. Several faults crosscut the area (Steven and others, 1974).

A small cluster of HSSR samples within Area H was slightly above the regional background. Four samples of stream water contained between 2.0 and 2.7 ppb uranium (Pl. 4, no. VI).

Anomaly 56, identified by the ARR program (Western Geophysical Company, 1979) is within this favorable area. The anomaly is "fairly prominent"
(Western Geophysical Company, 1979, p. 39) and is characterized by anomalous uranium and by both anomalous uranium-to-thorium and uranium-to-potassium ratios. The values for uranium and uranium-to-thorium are more than three standard deviations greater than their respective mean values as determined for the quadrangle. Western Geophysical Company (1979) defined the anomaly area as one of possible enrichment because the value of the uranium-to-thorium and uranium-to-potassium ratios remained higher than at least one standard deviation above the mean for a distance of more than 1 mi (1.6 km).

About 40% of Area H is within a U.S. Forest Service Rare II study area and has been recommended for wilderness-area status. The remaining 60% has not been withdrawn from mineral development.

ENVIROMENTS UNFAVORABLE FOR URANIUM DEPOSITS

SUMMARY OF UNFAVORABLE ENVIRONMENTS

A geologic environment is considered unfavorable if it does not display characteristics of environments where uranium deposits have been found (recognition criteria), if it displays characteristics that are judged to be incompatible with uranium concentration, if it exhibits some characteristics similar to those of environments where uranium deposits have been found but lacks other important recognition criteria, or if it contains uranium deposits of insufficient size or grade as defined for this program.

Geologic environments unfavorable for uranium deposits within the Durango Quadrangle are the Precambrian metamorphic and igneous rocks except for part of the Uncompahgre Formation (Area D, Pl. 1a) and the plutonic rocks in the Needle Mountains (Areas E, E', and F), all Paleozoic sedimentary rocks except for the Rico Formation along Hermosa Creek (Area C) and the lower Paleozoic sedimentary rocks near Tuckerville (Area G) and along the Piedra River Canyon (Area H), all Mesozoic sedimentary rocks except for parts of the Entrada Sandstone in the Placerville district and in the Barlow Creek-Hermosa Creek district (Areas A and B, respectively), and most Tertiary volcanic and sedimentary rocks. These host-rock environments lack specific recognition criteria and include areas where postulated deposits would not contain 100 tons U₃O₈.

PRECAMBRIAN METAMORPHIC AND IGNEOUS ROCKS

Precambrian metamorphic and igneous rocks within the Durango Quadrangle are exposed in areas of uplift and in erosional windows. Precambrian rocks within the San Juan Uplift (Fig. 2) are geographically within the Needle Mountains area. These Precambrian X and Precambrian Y rocks are less than about 2 b.y. old. Lithologically similar Precambrian rocks are exposed in the San Juan volcanic field. Windows are present where erosion has cut through volcanic rocks outside of the caldera structures. The Uncompahgre Formation is present along the northern boundary of the quadrangle near the edge of the San Juan volcanic field.
Vallecito Conglomerate

The Vallecito Conglomerate is most similar to environments that host quartz-pebble conglomerate uranium deposits (Class 120). The base of the Vallecito Conglomerate is not exposed, but the formation is at least 2,400 ft (750 m) thick and may be as much as 5,000 ft (1500 m) thick (Barker, 1969, p. A1). It is a quartzose polymictic conglomerate and contains clasts of quartzite, quartz, chert, red and black jasper, banded iron formation, and minor quantities of other rock types. The matrix contains quartz, sericite, hematite, and some magnetite. Channels, small scours, and trough cross-bedding are common sedimentary structures. Barker (1968 and 1969) considered the Vallecito to be the oldest rock unit in the Needle Mountains area, but recent studies suggest it is younger than the Irving Formation (L. K. Burns, Colorado State University, oral comm., 1979).

Several characteristics of the Vallecito Conglomerate are incompatible with recognition criteria for quartz-pebble conglomerate uranium deposits (Jones, 1978b). The Vallecito is not oligomictic, does not contain pyrite, and is younger than 2.2 b.y., which is the postulated time of the Earth's oxygenation. The presence of hematite, magnetite, and banded iron formation and the lack of pyrite indicate that the Vallecito was deposited under oxidizing conditions. Oxidizing conditions are incompatible with the mechanical transport and concentration of uraninite, required for the development of quartz-pebble conglomerate deposits. The Vallecito is unfavorable.

Irving Formation

The Precambrian X Irving Formation is a collection of interlayered metavolcanic and metasedimentary rocks. The metavolcanic rocks are of basaltic to intermediate composition and have been metamorphosed to amphibolites and plagioclase-bearing gneisses. The Irving Formation also contains quartzite, minor iron formation, and biotite and muscovite schist (Steven and others, 1974). The various rock types within the Irving are under a major unconformity and commonly exhibit effects of retrograde metamorphism (Barker, 1969, p. A5). The Irving lacks specific recognition criteria and is considered unfavorable for uranium deposits.

Twilight Gneiss

The Twilight Gneiss is a fine- to medium-grained quartzofeldspathic gneiss. Its composition ranges from quartz diorite to quartz monzonite. It is well foliated and homogeneous in outcrop except for variable amounts of ubiquitous slabby interlayers of amphibolite. These interlayers are metamorphosed tholeiitic basalt. (See Barker, 1969, p. A16-A22.)

Amphibolite-facies metamorphism has destroyed much of the original fabric of the rock. Barker (1969, p. A21) suggested that the Twilight Gneiss is the metamorphic product of either a pile of basalt that was intruded by sills of intermediate composition or a closely interlayered volcanic sequence of basalt and silicic extrusives.
The rather mafic composition of the Twilight Gneiss precludes significant uranium concentration. The Twilight Gneiss is unfavorable for uranium deposits.

**Bakers Bridge Granite**

A small mass of Bakers Bridge Granite is present near Rockwood. This granite is pale red, massive, and medium to coarse grained. We have found no reason to consider this granite favorable for uranium occurrences; therefore, it is unfavorable.

**Uncompahgre Formation**

The Uncompahgre Formation has been discussed under Area D. Parts of the Uncompahgre Formation, in areas on the northern boundary of the quadrangle and east of Area D, are unfavorable. These areas lack the major regional structures as shown on the geologic map by Steven and others (1974).

**Granite of Cataract Gulch**

Precambrian Y granite is exposed in Cataract Gulch southwest of the Lake City caldera and in adjacent areas where overlying volcanic rocks have been removed by erosion. The granite of Cataract Gulch is massive, coarse grained, and weakly foliated in places. Lithologically it varies between a two-feldspar granite and quartz monzonite.

Although the granite of Cataract Gulch contains an occurrence, this unit is considered unfavorable. Only two samples of the six collected at the occurrence contained more than 100 ppm $U_3O_8$. Although disequilibrium conditions favored radiometrically determined uranium 2:1 over chemically determined uranium, the projected volume of mineralized rock was much less than the required size and grade as defined for this program. Furthermore, results of a detailed stream-sediment survey (Pl. 10b and 10c) clearly indicate that anomalous concentrations of uranium in stream sediments are associated with the ring-fracture system of the Lake City caldera and not with this granite. Samples derived from the granite had lower uranium concentrations.

**Electra Lake Gabbro**

The Electra Lake Gabbro is a heterogeneous intrusive mass. It consists of a variety of medium- to coarse-grained gabbroic rocks including gabbro, augite-hornblende gabbro, biotite-augite-quartz diorite, and granodiorite. The Electra Lake Gabbro sharply crosscuts its wall rocks, but the component rock types have gradational contacts with one another (Barker, 1969, p. A27).

No recognition criteria exist for gabbroic rocks; the unit is unfavorable for uranium deposits.
PALEOZOIC SEDIMENTARY ROCKS

Paleozoic sedimentary rocks crop out on the flanks of uplifted areas in the western part of the Durango Quadrangle and dip south into the San Juan Basin. These rocks consist of marine limestones, shales, and sandstones, as well as continental clastics. Evaluation of the Ignacio and Elbert Formations, the Ouray and Leadville Limestones, and the Molas, Hermosa, Rico, and Cutler Formations is based on surface examination and on interpretation of petroleum-test-well logs.

Ignacio Formation

The Upper Cambrian Ignacio Formation is a thinly to massively bedded, light-tan to yellowish brown, arenaceous quartzose sandstone that is locally quartzitic. Quartzite outcrops of the Ignacio Formation were examined in the Cave Basin, Coal Bank Pass, and Bakers Bridge areas. The Ignacio was deposited on an irregular Precambrian surface and has been partly removed by pre-Elbert erosion. Thickness of the Ignacio Formation ranges from 0 to 140 ft (0 to 40 m) in the quadrangle. The thickest sections are preserved in the Bakers Bridge and Rockwood Quarry areas. The Ignacio Formation represents several types of nearshore marine environments and contains beach, littoral, and tidal-flat deposits.

The Ignacio Formation is unfavorable for uranium deposits. It has low permeability and lacks organic debris. No uranium occurrences are reported in the Ignacio, and no evidence of uranium concentration processes was found.

Elbert Formation

The Upper Devonian Elbert Formation consists of thin-bedded, red to purple calcareous shales, limestones, calcareous sandstones, quartzitic sandstones, and siltstones. The lower McCracken Sandstone Member of the Elbert Formation rests disconformably on the Ignacio Formation. The upper part of the Elbert Formation is dolomitic and grades conformably into the overlying Ouray Limestone. Thickness of the formation within the quadrangle ranges from 0 to a maximum of about 130 ft (40 m) at Endlich Mesa. The formation is 600 ft thick in the subsurface in the Four Corners area (Ward, 1966, p. 38).

The Vay Claim (occurrence 16), a minor occurrence in the Elbert Formation, contains uranium associated with small pea-sized pods of carbonaceous material. All of the known pods represent less than 10 tons of rock. Extensive development work has failed to discover additional mineralized rock (Boyer and others, 1956).

The Elbert Formation is unfavorable for the occurrence of uranium deposits because it commonly lacks reductants.

Ouray and Leadville Limestones

The Upper Devonian Ouray Limestone and the Lower Mississippian Leadville Limestone consist of light-tan to buff, thin-bedded fossiliferous crystalline
limestones, dolomites, and sandy limestones. The contact of the Ouray with the underlying Elbert Formation is disconformable. The Ouray is gradational into and conformable with the overlying Leadville. The Leadville is disconformably overlain by the Molas Formation.

The Ouray and Leadville crop out along the northern edge of the San Juan Basin, at Cave Basin, and at Molas Lake. The maximum thickness of the Ouray is 150 ft (45 m); the Leadville is commonly 40 to 60 ft (12 to 18 m) thick but attains as much as 180 ft (55 m) in the quadrangle. Regionally, both limestones thicken to the west.

The depositional environment of the Ouray Limestone includes intertidal algal mats, channels, and shoals; the Leadville Limestone was deposited in a deeper marine environment (Ward, 1966, p. 72-73).

Uranium precipitation in carbonate depositional environments is unlikely because carbonate and bicarbonate ions provide high uranium solubility. Uranium concentration in limestone could be the result of impurities or epigenesis. (See Jones, 1978b, p. 75.)

The Ouray and Leadville Limestones do not contain reductants, are highly impermeable, and do not exhibit evidence of uranium concentration. The Ouray and Leadville Limestones are not favorable for uranium deposits with the exception of vein deposits in Areas G and H (Pl. 1b).

Molas Formation

The Pennsylvanian Molas Formation consists of thin-bedded, red, calcareous shale, sandy shale, and siltstone. The lower part of the formation contains some chert nodules; the upper part is arenaceous.

The Molas Formation includes regolith derived from underlying Leadville Limestone and represents continental deposition transitional into the conformably overlying Hermosa Formation.

Outcrops of the Molas Formation are poor and scattered. The better exposures are at the type locality near Molas Lake where the formation is 116 ft (35 m) thick. Thickness of the Molas is variable and commonly ranges from 40 to 120 ft. (See Wengerd, 1957, p. 134.) The formation exists in the subsurface in the San Juan Basin.

The Molas Formation is not favorable for uranium deposits. It is commonly oxidized throughout and does not contain reductants.

Hermosa Formation

The Pennsylvanian Hermosa Formation consists mostly of marine limestones, sandstones, and shales. Wengerd and Matheny (1958) proposed raising the Hermosa to group status and dividing it into the Pinkerton Trail, Paradox, and Honaker Trail Formations. This terminology has not been fully accepted. (See Ridgley and others, 1978, p. 12.)
The lower part of the Hermosa Formation (Pinkerton Trail) contains thin sandstones and shales and increasing numbers of thin, sandy and shaly limestone beds near the top. The middle part (Paradox) contains massive, light- to dark-gray fossiliferous limestone beds with interbedded dark-gray to black sandy shales. The upper part (Honaker Trail) contains alternating black and gray shales, thin-bedded green grits, and thin-bedded light-gray fossiliferous limestone, and becomes more sandy near the top.

The Hermosa Formation crops out near the western margin of the San Juan Uplift and forms prominent cliffs at the type locality near Hermosa, Colorado. Thickness of the Hermosa Formation is about 2,500 ft (800 m) in the Hermosa area. The formation is present in the subsurface in the San Juan Basin.

The Hermosa sediments represent a variety of depositional environments. Lower Hermosa sediments were deposited in a shallow-water marine-transgressive environment; middle Hermosa sediments were deposited in a shallow- to moderate-depth marine environment, and upper Hermosa sediments were deposited in a littoral to intertidal regressive-marine environment.

The Hermosa Formation is unfavorable for uranium deposits. Two minor occurrences are known in the Hermosa Formation. The Mary Ann (occurrence 18) and the Phantom No. 3 (occurrence 26) contain small amounts of uranium associated with carbonaceous materials in gray to black sandy shales. At both occurrences, the shales are thin and of limited lateral extent. Uranium content of these occurrences does not meet size and grade requirements. In other localities, Hermosa sediments lack reductants and do not exhibit evidence of uranium concentration.

Rico Formation

The geology of the Rico Formation has been discussed in this report in the favorable-areas section (Area C). The Rico is exposed in the west-central part of the quadrangle and exists in the subsurface in the San Juan Basin. Thickness of the Rico is commonly from 100 to 200 ft in the western San Juan Mountains (Wengerd, 1957, p. 136). The thickness varies locally and, at the type locality in the Rico Mountains, ranges from 237 to 328 ft (McKnight, 1974, p. 28).

Several minor uranium occurrences of various types are present in the Rico Formation. All of these occurrences are in the Trimble and Hermosa Park areas. Both the Lem Snow Ranch occurrence (29) and the Silver Peak occurrence (24) exhibit some characteristics similar to the sandstone uranium deposits of Austin and D'Andrea (1978). Uranium at the Lem Snow Ranch occurrence is associated with a carbonaceous sandstone, and at the Silver Peak occurrence with a carbonaceous shaly zone in a sandstone. Uranium at both the Tripp Gulch Occurrence (27) and the Big Spring Gulch Property (23) is associated with carbonaceous reductants in limestone similar to the Todilto-type (Class 230) uraniumiferous limestone occurrences of Jones (1978b). None of these occurrences contain large quantities of reductants. All host rocks are thin, and all are laterally discontinuous.

At the Irish Lady #1 and 2 occurrence (25), a uraniferous hornfelsic black shale is in contact with an intrusive sill. This occurrence is similar
to the contact-metasomatic occurrences of Mathews (1978c). The hornfelsic host rocks contain only minor amounts of uranium, are thin, and are in only a small area.

Except for favorable Area C (Pl. 1b), the Rico Formation is unfavorable for uranium deposits. The host rocks are thin and laterally discontinuous and do not contain abundant reductants.

**Cutler Formation**

The Permian Cutler Formation is a sequence of continental red shales, sandstones, grits, and conglomerates deposited in a fluvial environment. The formation is exposed from Bear Mountain, west of Silverton, southward to Trimble and westward to the border of the quadrangle. The Cutler also crops out along the San Miguel River Valley near Telluride and is present in the subsurface in the San Juan Basin. Thickness of the Cutler Formation ranges from 1,500 to 2,200 ft (450 to 670 m).

Only one minor occurrence is known in the Cutler. The Silver Chief occurrence (47), a magmatic-hydrothermal occurrence, contains a small amount of uranium along a vein selvage that is unrelated to the sedimentary features of the formation.

The Cutler lacks reductants and is red and oxidized throughout. The unit is unfavorable for uranium deposits.

**MESOZOIC SEDIMENTARY ROCKS**

**Dolores Formation**

The Upper Triassic Dolores Formation is well exposed in the Hermosa area where it is about 300 ft (90 m) thick. The thickness is variable due to pre-Entrada erosion and may be as much as 600 ft thick in some areas (Steven and others, 1974) in the western part of the quadrangle. Both the upper and lower contacts are disconformable, and reworked Dolores material is common in the lower part of the Entrada Sandstone in many places.

The Dolores Formation contains mostly nonmarine shale, siltstone, sandstone, and minor amounts of limestone-pebble conglomerate. All units are a characteristic brick red, and most were deposited in a fluvial continental environment. This formation is oxidized, lacks reductant materials, and is, therefore, unfavorable for uranium deposits.

**Entrada Sandstone**

The Upper Jurassic Entrada Sandstone is a friable, fine- to medium-grained, light-tan to cream sandstone. The sandstone is well sorted, massively cross-bedded near the base, and thin bedded and finer grained in the upper part.
The Entrada is exposed in the northwest part of the quadrangle, in the Barlow Creek-Hermosa Creek district, and around the northern edge of the San Juan Basin. The Entrada is present in the subsurface between the northwest part of the quadrangle and the Barlow Creek-Hermosa Creek district and in the San Juan Basin. Thickness of the Entrada commonly ranges from about 50 to 100 ft but may be as much as 250 ft (Steven and others, 1974).

The Entrada Sandstone was deposited in eolian and coastal dune environments. The Entrada is permeable because it is poorly cemented, contains only minor amounts of interstitial clays, and lacks paludal or fluvially deposited organic material.

Roscoelite-type vanadium-uranium deposits have been found in the Entrada. Area A (Pl. 1c) in the Placerville district and Area B (Pl. 1b) in the Barlow Creek-Hermosa Creek district are discussed in the section on favorable environments. A similar environment exists in the Lightner Creek district northwest of Durango. This district was investigated by Keith (1945) and was subsequently included in a resource estimation for roscobelite-type deposits by Bush and Bryner (1953, p. 5). A chip sample, MFS 076, of the mineralized zone at the Good Hope-Nevada occurrence (30) contained 38 ppm U$_3$O$_8$. Estimated resources do not indicate sufficient quantities of uranium to meet the requirements defined for this study.

In other areas, the Entrada lacks evidence of uranium concentration processes and lacks reductants. With the exception of Areas A and B, the Entrada Sandstone is unfavorable for uranium deposits.

Wanakah Formation

The Upper Jurassic Wanakah Formation consists of three members in both the Placerville district and the San Juan Basin, but the character of the upper members varies from place to place. In the San Juan Basin, the Junction Creek Sandstone Member (upper) is light-gray cross-bedded sandstone. In the northwest part of the quadrangle, an upper marl member consists of calcareous claystone, siltstone, and sandstone (Steven and others, 1974). Near Durango, the middle member includes limy shale, siltstone, and sandstone, whereas, in the Placerville district, the fine-grained thin-bedded Bilk Creek Sandstone Member is the median member. In both places, the basal Pony Express Limestone Member is dark-gray bituminous limestone. The Pony Express Limestone Member has undulatory shale partings and is frequently fractured into small rubbly blocks. The Pony Express Limestone is equivalent to the Todilto Limestone in New Mexico.

The Wanakah Formation is present along the western boundary of the Durango Quadrangle from the Sawpit area southward to the Durango area, except where it has been removed by erosion. The Wanakah is traceable along or near the Hogback Monocline of the San Juan Basin and exists in the subsurface within the basin. The thickness of the Wanakah ranges from 100 to 300 ft (30 to 90 m) and both its upper and lower contacts are conformable.

Depositional environments of the formation are varied. The Pony Express Limestone and the middle member present near Durango appear to be sabkha-related (Rawson, 1979), whereas the upper Junction Creek Sandstone Member is eolian and interdunal.
Characteristics of the Pony Express Limestone Member were compared with recognition criteria for Todilto-type uraniferous limestone occurrences (Class 230, Jones, 1978b). All of the important orebodies in the Todilto are within the crests of anticlinal folds (Jones, 1978b, p. 82). Although the general geologic settings are the same, pressure recrystallization and tensional fracturing along anticlinal axes have not been recognized in the Pony Express. The Pony Express Limestone Member is, therefore, not favorable for the occurrence of uranium deposits. All of the other members of the Wanakah Formation are also unfavorable for uranium deposits because they either lack reductants or are relatively impermeable.

Morrison Formation

Two members of the Upper Jurassic Morrison Formation are present within the Durango Quadrangle. The Brushy Basin Shale Member, in the upper part of the formation, consists of varicolored, silty, bentonitic claystones with interbedded buff to tan sandstones. The Salt Wash Sandstone Member consists of interbedded reddish brown and greenish gray sandstones, claystones, and siltstones. Morrison sediments were deposited in medium- to high-energy fluvial, as well as paludal and lacustrine, environments.

The Morrison Formation crops out in the western part of the quadrangle in the Barlow Creek area and along the Hogback Monocline near Durango. In the Lightner Creek district, the thickness of the Brushy Basin Member is about 230 ft (Keith, 1945, p. 6). The total formational thickness may reach 800 ft within the quadrangle (Steven and others, 1974). The Morrison Formation is conformable with the underlying Wanakah Formation and is disconformably overlain by the Cretaceous Burro Canyon Formation.

The Morrison Formation within the quadrangle displays some characteristics similar to those of environments where uranium deposits have been found. Sandstone-to-shale ratios of the Salt Wash Member may approach the favorable 1:1 ratio reported for the Uravan mineral belt (Austin and D'Andrea, 1978, p. 111), but in the quadrangle the member does not contain abundant reductants. Sandstone lenses in the Brushy Basin Member are thin, slightly permeable, and do not contain abundant reductants. Sears and others (1974, p. 96) stated that the Brushy Basin of the Grants mineral belt contains radioactivity anomalies of low intensity, the majority of which are in clay zones. The claystones in the Brushy Basin within the Durango Quadrangle do not contain anomalous levels of radioactivity.

Two uranium occurrences exist in the Morrison Formation within the quadrangle. The Ridgeview No. 6 occurrence (33) contains uranium associated with asphaltic material in shale. The Sunetha Claim Group (occurrence 1) contains uranium associated with a carbonaceous sandstone.

Although the Morrison contains two minor uranium occurrences, it is unfavorable for uranium deposits. As discussed above, the Morrison Formation within the Durango Quadrangle lacks several specific recognition criteria.
Burro Canyon Formation

The Lower Cretaceous Burro Canyon Formation is composed of white, tan, and orange conglomerates, conglomeratic sandstones, and sandstones, as well as green mudstones and shales. Basal Burro Canyon beds contain calcareous and siliceous nodules and an abundance of gastroliths (Kottlowski, 1957, p. 143). The contact with the underlying Brushy Basin Member of the Morrison Formation is sharp and disconformable. Sediments of the Burro Canyon were deposited by braided to meandering streams in a fluvial environment (Ridgley and others, 1978, p. 41).

The Burro Canyon Formation in the Durango Quadrangle is not well exposed. The thickness of the formation along the southeast edge of the La Plata Mountains ranges from 0 to about 60 ft (about 20 m).

The Burro Canyon Formation does not contain reductants nor does it demonstrate evidence of uranium concentration. The formation is judged to be unfavorable for uranium deposits.

Dakota Sandstone

The Upper Cretaceous Dakota Sandstone in the Durango Quadrangle has variable lithology. The lower part characteristically contains coal seams, carbonaceous shales, and conglomeratic sandstone interbedded with poorly sorted, cross-bedded, medium- and coarse-grained sandstones. The upper part consists of tan to yellow, medium-grained, cross-bedded sandstone.

The best exposures of the Dakota Sandstone are in the southwest portion of the quadrangle near Durango. Thickness is fairly uniform from 150 ft in the Lightner Creek district (Keith, 1945, p. 6) to 200 ft in the Ignacio area (Barnes, 1953).

The lower Dakota Sandstone was deposited in a medium- to high-energy fluvial environment; the upper part was deposited in a transgressive-marine environment. The fluvial distributary sandstones of the lower part contain minor amounts of reductants and few claystone or mudstone lenses. Tuffaceous components were not observed.

Most of the uranium deposits in the Gallup and Ambrosia Lake mining districts of New Mexico are in distributary sandstones of the lower Dakota that may contain interbedded carbonaceous shales. In some places the presence of underlying Brushy Basin claystone may have prevented the entry of uranium-bearing solutions into the Dakota. (See Pierson and Green, 1977, p. 19 and 39.)

Dakota Sandstone within the quadrangle disconformably overlies the Brushy Basin Member of the Morrison Formation and the Burro Canyon Formation where present. The Mancos Shale conformably overlies and intertongues with the Dakota.

Two uranium occurrences are known in the Dakota within the quadrangle. The Bill Group (occurrence 31) contains uranium associated with organic material in a coaly shale. The shale contains an estimated 0.005% U₃O₈, but
the Dakota commonly lacks radioactivity and abundant carbon 1 mi south (Boyer and Anderson, 1956). The Schafer Ranch occurrence (32) contains uranium associated with asphaltic material in sandstone. The concentration of uranium at this occurrence may also be associated with placer processes (Houston and Murphy, 1970, p. C141-C143). The uranium-bearing zone at the Schafer Ranch is thin and laterally discontinuous.

The Dakota Sandstone is unfavorable for uranium deposits because the formation lacks abundant reductants and through-going permeability.

**Upper Cretaceous Marine Sandstones**

Several Upper Cretaceous formations of predominately marine sandstone are present within the San Juan Basin portion of the Durango Quadrangle. The marine sandstones include the Point Lookout Sandstone, the Cliff House Sandstone, and the Pictured Cliffs Sandstone (see Pl. 7). Upper Cretaceous marine sandstones are either nearshore marine-transgressive or coastal-barrier depositional types.

The Upper Cretaceous marine sandstones are unfavorable for uranium deposits. Field examinations showed that these sandstones lack reductant materials, have high permeability, and do not exhibit evidence of uranium concentration.

**Upper Cretaceous Marine Shales**

Marine shales account for most of the thickness of Upper Cretaceous sedimentary rocks in the San Juan Basin. The Mancos Shale has a thickness of about 2,200 ft near the southern boundary of the quadrangle (Dane, 1948), and the Lewis Shale has a thickness of 2,350 ft in the Los Pinos River Valley (Barnes, 1953). Both the Mancos and Lewis Shales were deposited in benthonic-marine environments.

In benthonic-marine environments, minor concentrations of uranium are syngenetically precipitated by organic material (Jones, 1978b). Western Geophysical Company (1979) identified several radioactivity anomalies associated with the Mancos Shale. The HSSR (Maxwell, 1977; Dawson and Weaver, 1979) also found anomalous concentrations of uranium in stream waters draining the Mancos Shale. The anomalous concentrations of uranium in stream water are probably related to release of minor concentrations of syngenetic uranium by oxidation and weathering of the shale.

The Mancos and Lewis Shales are unfavorable for uranium deposits. Field examination has shown that syngenetic concentrations of uranium in these shales are insignificant. After lithification, the low permeability and reduced nature of these shales preclude uranium mobility.

**Upper Cretaceous Nonmarine Sandstones and Shales**

Nonmarine Upper Cretaceous sandstones and shales in the San Juan Basin within the Durango Quadrangle include the Menefee and Fruitland Formations,
the lower part (McDermott Member) of the Animas Formation, and the Kirtland Shale (see Pl. 7). These units contain a variety of fluvial and paludal deposits.

ARR anomalies were reported by Western Geophysical Company (1979) for the Animas Formation but not for the Kirtland Shale and Menefee and Fruitland Formations. The anomalies are commonly weak. Many are in the Southern Ute Reservation and have not been field checked. Our field examinations did not find evidence of a uranium concentration process.

The Menefee Formation, Fruitland Formation, Kirtland Shale, and McDermott Member of the Animas Formation are unfavorable for uranium deposits because the sandstones are highly permeable, do not contain abundant reductants, and do not exhibit anomalous levels of radioactivity. Lignite, coals, and carbonaceous shales are known to be among the least uraniferous sedimentary rocks (Jones, 1978b, p. 49-50).

CENOZOIC SEDIMENTARY UNITS

Cenozoic sedimentary units within the Durango Quadrangle consist of conglomerates, sandstones, siltstones, and shales of predominately continental-fluvial origin. The Tertiary formations include the upper part of the Animas Formation and the Nacimiento Formation (both Paleocene), the Eocene San Jose and Blanco Basin Formations, the Eocene-Oligocene (?) Telluride Conglomerate, the Miocene-Pliocene Santa Fe Formation, and the lower part of the Alamosa Formation (Pliocene). The Quaternary sediments include the upper part of the Alamosa Formation and Recent surficial deposits. All of the Cenozoic sedimentary units are unfavorable for uranium deposits.

Animas Formation

The Animas Formation consists of olive-brown, olive-green, and gray-green tuffs interbedded with coarse-grained sandstones and siltstones. Andesitic debris in the Animas near Durango may have been derived from the north. Maximum thickness of the formation is about 2,670 ft near the La Plata-Archuleta County boundary. (See Fasset and Hinds, 1971, p. 33.) The Animas commonly has high permeability and lacks reductants.

Nacimiento Formation

The Nacimiento Formation consists of black, gray, and olive-green clayey shales and sandy shales with interstratified coal beds and fine- to coarse-grained arkosic sandstones. The formation thickens from about 150 m near the southern quadrangle boundary to 670 m in the San Juan Basin of New Mexico (Ridgley and others, 1978, p. 50). In the Durango Quadrangle the formation lacks abundant reductants.

San Jose Formation

The San Jose Formation consists of conglomeratic sandstones interbedded with fine- to coarse-grained argillaceous and arkosic sandstones. The San Jose
is the youngest consolidated sediment in the San Juan Basin and is the present erosion surface. It has a maximum thickness of 2,400 ft in the southwest part of the quadrangle (Steven and others, 1974). Field examination did not find abundant reductants or evidence of uranium concentration.

**Blanco Basin Formation**

The Blanco Basin Formation consists of red to brown arkoses, arkosic mudstones, sandstones, and conglomerates as well as red, yellow, and white claystones. Thickness of the formation is reported to be about 400 to 600 ft (Larsen and Cross, 1956, p. 61). No uranium occurrences exist in the Blanco Basin Formation, and no reductants were observed during field examination. ARR and HSSR did not detect anomalous uranium concentrations in the formation.

**Telluride Conglomerate**

The Telluride Conglomerate consists of rounded clasts of red and gray sandstone, gray limestone, bluish gray and gray quartzite, gray granite, and green and dark-gray schist enclosed in a reddish-stained arkosic sandy matrix. The Telluride Conglomerate is well exposed in the northwest part of the quadrangle in the Telluride and Mount Wilson areas. Thickness ranges from 300 to 400 ft near Telluride and up to 1,000 ft near Mount Wilson (Larsen and Cross, 1956, p. 60). The Telluride Conglomerate lies with angular unconformity on Mesozoic sedimentary rocks, and is disconformably overlain by Oligocene volcanic tuffs. The conglomerate does not exhibit evidence of uranium concentration, nor does it display characteristics of environments where uranium deposits have been found.

**Sediments in the San Luis Basin**

Sediments in the San Luis Basin include the Santa Fe Formation and the Alamosa Formation. The Santa Fe Formation comprises most of the 16,500 ft of post-Paleocene basin fill (C. Goodknight, BFEC, written comm., 1979). The Santa Fe consists of clastic sediments that were derived from the Sangre de Cristo Mountains and the San Juan Mountains. The sediments are oxidized, commonly orange brown in color, and have a clayey matrix.

The Alamosa Formation consists of a series of Pliocene and Pleistocene lake clays interbedded with thin gravels and sands. In the western part of the basin, the Alamosa consists of clastic sediments of the Rio Grande fan (Powell, 1958, p. 11) and a lower clay layer that hydrologically confines the underlying Santa Fe Formation. The clay layer is a drab gray-blue color. Above the clay, the Alamosa is coarser grained, permeable, and grades upward into Recent basin fill. The formation is reported to be 382 ft (116 m) thick near Monta Vista and 885 ft (270 m) thick near Center. The Alamosa thins rapidly to the west and thickens to the east. (See Powell, 1958, p. 22-24.)

Analytic data from Dawson and Weaver (1979) indicate anomalous concentrations of uranium in well waters from the Center area (Pl. 4, area VII). Results of a detailed followup study do not show a meaningful pattern for the anomalous uranium concentration in well waters (Pl. 11).
Recent Surficial Deposits

Pleistocene and Recent deposits are represented by the upper part of the Alamosa Formation (Pleistocene) and a variety of unconsolidated surficial sediments including glacial drift, landslide debris, and alluvium. Surficial sediments are not favorable host rocks for uranium deposits within the recognition criteria.

VOLCANIC ROCKS OF THE SAN JUAN VOLCANIC FIELD

The San Juan volcanic field comprises a complex intertonguing of lava and pyroclastic units derived from many different centers. Some of these centers can be identified by intrusive cores, but many others are covered by their own or younger volcanic accumulations or are obscured by calderas. The calderas are volcano-tectonic subsidence structures that formed when the roof of a magma chamber collapsed in response to removal of material by eruption. Figure 3 shows the locations of calderas within the San Juan volcanic field, and Table 2 shows ash-flow stratigraphy and estimated volume, dominant composition, age, and related caldera for the ash-flow units. The distribution of individual ash-flow units is shown on the geologic map by Steven and others (1974). Few of the calderas demonstrate all the stages of caldera development described by Smith and Bailey (1968), but every stage is exceptionally well developed in one or more of the calderas (Steven and Lipman, 1976, p. 1).

Pilcher (1978a and 1978b) defined four classes of uranium occurrences based on the stages of caldera development as described by Smith and Bailey (1968) and on the mechanism of uranium concentration. Briefly, these classes are uranium enrichment by magmatic differentiation, initial magmatic (Class 510); uranium precipitation from uranium-enriched gases, pneumatogenic (Class 520); syngenetic deposition of uranium from uranium-enriched fluids, hydroauthigenic (Class 530); and epigenetic redistribution of uranium by groundwater systems, hydroallogenic (Class 540).

Recognition criteria (Pilcher, 1978b; Mathews and others, 1979, p. 24-27) for all classes of volcanogenic uranium occurrences emphasize the importance of highly differentiated volcanic rocks. Favorable host rocks are peralkaline and have high fluorine contents and commonly high silica contents. The rocks are commonly rhyolites, trachytes, or their coarse-grained equivalents and contain alkali feldspars and sodic pyroxenes and (or) amphiboles.

None of the major ash-flow units in the San Juan volcanic field are peralkaline. The ash-flow units, except for the Sunshine Peak Tuff, range from quartz latite to rhyolite (Table 2). Most are calc-alkaline in composition. The Sunshine Peak Tuff is the most highly differentiated of the ash-flow units and is silicic rhyolite. The Sunshine Peak Tuff is associated with the Lake City caldera and is the youngest (22.5 m.y. old) of the ash-flow units (Table 2).

Several lava domes as much as 200 m thick but less than 1 km² in outcrop area have been mapped by Lipman (1974) around the Summitville caldera. These domes are composed of high-silica rhyolites of the bimodal (basalt-rhyolite) Hinsdale Formation and postdate the Summitville caldera. These lava domes have been eroded but tend to be preserved near their vents. Vent areas
Figure 3. Map of the San Juan volcanic field showing calderas and area of the Durango Quadrangle.
TABLE 2. ASH-FLOW STRATIGRAPHY IN THE SAN JUAN VOLCANIC FIELD*

<table>
<thead>
<tr>
<th>Ash-flow unit</th>
<th>Estimated volume (km$^3$)</th>
<th>Dominant composition</th>
<th>Age (m.y.)</th>
<th>Related caldera</th>
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<tr>
<td>Sunshine Peak Tuff</td>
<td>100-500</td>
<td>Silicic rhyolite</td>
<td>22.5</td>
<td>Lake City</td>
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<tr>
<td>Snowshoe Mountain Tuff</td>
<td>&gt;500</td>
<td>Quartz latite</td>
<td>26.5(?)</td>
<td>Creede</td>
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<td>Zoned rhyolite to quartz latite</td>
<td>&gt;26.4 &lt;26.7</td>
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<td>Zoned rhyolite to quartz latite</td>
<td>&gt;26.4 &lt;26.7</td>
<td>San Luis</td>
</tr>
<tr>
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<td>Rhyolite</td>
<td>&gt;26.4 &lt;26.7</td>
<td>Early stage San Luis</td>
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<tr>
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<td>&gt;26.7 &lt;27.8</td>
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<td>La Garita</td>
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<td>Rhyolite</td>
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<td>Uncompahgre and San Juan</td>
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<td>&gt;27.8 &lt;28.4</td>
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<td>--</td>
<td>Quartz latite</td>
<td>&gt;27.8</td>
<td>Bonanza</td>
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</table>

*From Steven and Lipman, 1976
have been identified within three of the lava domes (Lipman, 1975b, p. 96). Sample MFS 073 from Elephant Mountain and sample MFS 074 from the vent area of Grayback Mountain contained 12 ppm and 48 ppm U₃O₈, respectively. These small erosional remnants are considered unfavorable for uranium deposits.

Some calderas contain rock units that would be well suited as hosts for uranium deposits but lack a source of uranium. At Rita Gato on the northwest side of the Platoro Reservoir, volcaniclastic sandstones that formed within the Platoro caldera contain abundant carbonaceous plant fragments. Radiometric traverses indicated that these sandstones are not more radioactive than the associated tuffaceous rocks. The Creede Formation, deposited within the moat of the Creede caldera, also contains plant fragments but, likewise, is no more radioactive than the related ash flows. These areas are unfavorable for uranium deposits. They lack a suitable source and evidence of a uranium concentration process.

The metal-mining districts of the San Juan Mountains have been examined for concentrations of uranium associated with base and precious metals. Much of the early work was conducted for the U.S. Atomic Energy Commission by the U.S. Geological Survey and by others during the early 1950's, and has been reported by Burbank and Pierson (1952 and 1953) and Pierson and others (1958). Many mines and prospects in the Red Mountain district and the Silverton area were examined.

Although many PRR's were filed, apparently on the basis of a field examination, not all reported evidence of uranium concentration. In addition, some uranium occurrences could not be verified by our examinations. Most of these properties are inactive, the ore piles have been removed, and many shafts and adits have collapsed. Uranium-occurrence forms (App. C) have been completed for PRR's that were documented by significant sample results even though these occurrences could not be verified by us.

Most occurrences in the Red Mountain district are pneumatogenic (Class 520) (App. A-1) and are mineralized chimneys and breccia pipes that are associated with silicic quartz-porphyry intrusions. These intrusions are 5 to 6 m.y. younger than the Silverton caldera and suggest that the primary function of calderas in mineralization is the preparation of zones of weakness (Steven and Lipman, 1976, p. 34). Pitchblende(?) is associated with mixed-sulfide ores that contain galena, chalcocypirite, enargite, tennantite, and sphalerite. The known chimneys of high-grade sulfide ore in the Red Mountain district have been mined. In any case, the uranium content in these small deposits would have been less than 100 tons U₃O₈.

This study is in general agreement with the work of Pierson and others (1958, p. 389) who reported, "No anomalous radioactivity was found in the Silverton, Ophir, Eureka, Animas Forks, Mineral Point, Galena, Lake, Spar City, Embargo, Beidell, Summitville, Platoro districts, or in several smaller districts."

All volcanic rocks within the quadrangle except those in the Lake City caldera are unfavorable for uranium deposits of the four volcanogenic classes. Our conclusion is based on the lithology and chemistry of the host rocks, the proximity between favorable source and host rocks, the lack of evidence of a uranium concentration process, and the importance of postulated deposits based on size and grade criteria as defined for this study.
UNEVALUATED ENVIRONMENTS

HSSR results indicated anomalous concentrations of uranium in eight stream-sediment samples (Pl. 4, no. I) taken near the southern part of the Lake City caldera. Concentrations of uranium ranged from 14 to 25 ppm. Results (App. B-3) of a detailed followup survey, including samples from several drainages, confirmed that the anomalous uranium values are associated with the Sunshine Peak Tuff and the Lake City caldera. Concentration symbols have been plotted for U_3O_8 (Pl. 10b), U_3O_8 extracted by nitric-acid leach (Pl. 10c), arsenic (Pl. 10d), and molybdenum (Pl. 10e). Strong positive correlation between U_3O_8, arsenic, and molybdenum suggests initial magmatic concentration. But, the uranium concentration is too low to be favorable for initial magmatic deposits. The higher-than-normal uranium concentration in the Sunshine Peak Tuff is a possible source of uranium for hydroallogenic occurrences, but no suitable host is known in the area. The Lake City caldera requires further work and is considered unevaluated.

The roscoelite belt in favorable Area A is unevaluated below 1,000 ft (300 m) because of lack of information. The Eolus Granite in favorable Areas E, E', and F is unevaluated at depths greater than 0.5 mi (800 km) because of lack of information.

The Precambrian Y melasyenite of Ute Creek is unevaluated because of lack of access and information, and the Animas Formation within the Southern Ute Indian Reservation is unevaluated because of lack of access.
SELECTED BIBLIOGRAPHY


