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Uranium potential of the Burro Canyon Formation in western Colorado

By

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URANIUM POTENTIAL OF THE BURRO CANYON FORMATION IN WESTERN COLORADO

By Lawrence C. Craig

Abstract

The Burro Canyon Formation of Early Cretaceous age overlies the Morrison Formation (Late Jurassic) and underlies the Dakota Sandstone (Late Cretaceous) over most of southeastern Utah and southwestern Colorado. It consists mainly of alternating beds of fluvial sandstone and overbank mudstone with sandstone dominating in the lower part of the formation and mudstone in the upper part. At the outcrop, the sandstones in the formation exhibit almost all the characteristics that are considered favorable for the occurrence of sandstone-type uranium deposits, but only a few small deposits have been discovered in the Colorado-Utah area. The major deficiency of the Burro Canyon in these outcrop areas is the absence of a reductant such as carbonaceous debris, humic or humate materials, or pyrite. Reductants were probably removed during a period of extensive oxidation at the time of deposition and during a subsequent erosional episode prior to deposition of the Dakota Sandstone.

The formation reaches a lobate, inexactly located eastern margin that extends from near Meeker, Colorado, southward through the Piceance basin to near Aztec, New Mexico, in the northwestern part of the San Juan Basin. Along much of this distance, the formation is in the subsurface and has been penetrated by only a few drill holes. Along this eastern margin, the lobes project eastward where fluvial distributary streams built minor alluvial fans of relatively high-energy deposits out from the main axis of Burro Canyon stream deposition. The lower and distal reaches of these lobes may have survived the period of post depositional erosion and oxidation in a reduced condition because of low relief and the protection of a high water table. If so, the peripheral and distal parts of these lobes may have retained the precipitants necessary to form a uranium deposit. Two of the lobes extend into the southwest margin of the Piceance Basin and are considered the possible location of uranium deposits. Two additional lobes extend into the northwestern part of the San Juan Basin but have not been evaluated in this study.

Introduction

The Lower Cretaceous Burro Canyon Formation (Stokes and Phoenix, 1948) is present in a broad area in southeastern Utah and southwestern Colorado. It consists of alternating lenticular beds of conglomeratic sandstone and layers of dominantly greenish mudstone. Sandstone generally dominates in the lower part and mudstone in the upper part of the formation. The Burro Canyon overlies the uranium-bearing Upper Jurassic Morrison Formation and underlies the Upper Cretaceous Dakota Sandstone.

In the quest for new uranium supplies, the Burro Canyon Formation in western Colorado should attract consideration as a potential host rock for uranium deposits because it has many characteristics in common with the major uranium-producing units of the Colorado Plateaus province.

This report summarizes the stratigraphic relations of the Burro Canyon

Formation, discusses the uranium possibilities of the formation, and points to areas considered favorable by the author for exploration--either as a secondary goal or as a primary aim. The work is based on material and data gathered in a study of the Morrison Formation by the author and others (Craig and others, 1955, 1959) of the U.S. Geological Survey on behalf of the Atomic Energy Commission in the early 1950's; it draws heavily on a study by Donald G. McCubbin for his Ph. D. thesis at Harvard University (1961) and a report by Robert G. Young (1960). A minimal amount of field work during the summers of 1974 through 1976 was undertaken to develop and check concepts expressed in the report. No original sedimentary petrologic work has been done and available drill-hole samples have not been studied; considerable work remains to be done to develop and refine conclusions presented here.

Stratigraphy of the Burro Canyon Formation

Definition and distinguishing characteristics

The Burro Canyon Formation as defined by Stokes and Phoenix (1948), is a sequence of lenticular conglomeratic sandstone and variegated mudstone that intervenes between the upper member or Brushy Basin Member of the Morrison Formation and the Dakota Sandstone. The type locality for the Burro Canyon is near Slick Rock in western San Miguel County, Colorado.

The formation is distinguished from the underlying Brushy Basin Member in that it consists of coarse, generally conglomeratic, sandstone and interbedded generally nonswelling mudstone dominantly of greenish-gray color. The Brushy Basin contains only few conglomeratic sandstone beds particularly in its upper part and is mostly composed of alternating red, green, and gray swelling mudstone that forms distinctly color-banded outcrops. The Burro Canyon Formation is distinguished from the overlying Dakota Sandstone by the greenish mudstone and by the absence of carbonaceous material and organic-rich shale, lignite, or coal. The Dakota consists of interbedded sandstone and carbonaceous shale; the sandstone is in part conglomeratic and generally contains much cabonaceous debris and common impressions of twigs, stems, and branches.

Distribution and stratigraphic relations

The Burro Canyon Formation is recognized over a broad area in southeastern Utah and western Colorado, and recently the name has been extended to similar rocks occupying a similar stratigraphic position in the Chama basin of north-central New Mexico (Saucier, 1974).

The southern limit of the Burro Canyon (pl. 1) is an erosional limit where the Burro Canyon is cut out by the regional unconformity at the base of the overlying Dakota Sandstone. This limit is along a northwest-trending line that passes near the Four Corners. South of this limit the pre-Dakota unconformity progressively bevels the Morrison Formation and older formations southward.

To the east, beds equivalent to the Burro Canyon are believed to be present in central and eastern Colorado (Lytle Formation and Lytle Sandstone Member of Purgatoire Formation). However, the Burro Canyon itself reaches a poorly known pinchout along an irregular north-south line extending from the eastern part of the Piceance basin in northwestern Colorado to the northern part of the San Juan Basin in northwestern New Mexico (fig. 1). The nature of this pinchout is uncertain. In part it is probably the result of pre-Dakota erosion, but in part it also may be due to depositional thinning of the formation. In the poor exposures along the few outcrop belts that cross the feather edge, the sandstone beds in the Burro Canyon appear to thin as the pinchout is approached. However, pre-Dakota erosion seems the most important factor in the pinchout of the formation, because beds as much as 69 m thick (pl. 1) have been mapped as Burro Canyon to the east in the Aspen area, central Colorado (Freeman, 1972), and beds called Burro Canyon have been reported also in the Chama basin of north-central New Mexico (Saucier, 1974), and implies initial continuity of the formation across the region.

To the west in Utah, the Burro Canyon Formation passes laterally into the Cedar Mountain Formation (Stokes, 1944, 1952). The Cedar Mountain consists of a relatively thin basal conglomeratic unit, the Buckhorn Conglomerate Member, and a relatively thick upper shale unit, the shale member. The Cedar Mountain differs from the Burro Canyon in that the shale member consists dominantly of pastel-colored swelling claystone and mudstone, including purples and reds, as well as green, and it generally contains an abundance of limestone nodules that cover the weathered slopes. The Cedar Mountain Formation differs from the underlying Brushy Basin Member of the Morrison Formation in that it lacks the brilliant colors and distinct color banding of the Brushy Basin, and it has abundant limestone nodules.

The line of separation between the Burro Canyon Formation and the Cedar Mountain Formation is arbitrarily placed along the Colorado River in Utah (Stokes, 1952, p. 1774), although for a distance of approximately 40 km west of the river the characteristics of the two formations intermingle.

Similarly, to the north in Colorado and northeastern Utah the Burro Canyon Formation passes laterally into the Cedar Mountain Formation. In this area north of the Colorado River, the line of demarcation between the Burro Canyon and Cedar Mountain is placed where Burro Canyon characteristics give way to Cedar Mountain characteristics in the subsurface as interpreted from sample logs.

The Cedar Mountain Formation is recognized over much of central-southern and northeastern Utah and northwestern Colorado. The southern limit is south of the Henry Mountains (pl. 1) and is an erosional limit along which the Cedar Mountain is cut out by the erosional unconformity at the base of the Dakota. This limit is poorly known; recent field studies by Fred Peterson (oral commun., 1982) show that outliers of Cedar Mountain more than 30 m thick are present in the vicinity of Escalante, Utah, considerably southwest of the limit shown on plates 1-4 of this report. These are interpreted as downfolded remnants of Cedar Mountain preserved beneath the pre-Dakota erosion surface. The western limit also is poorly known but the Cedar Mountain Formation extends beneath the High Plateaus of central Utah. To the north the formation is identified to the Wyoming State line in both northeastern Utah and northwestern Colorado.

Lithologic characteristics

Two general rock types, sandstone and mudstone, dominate in the Burro Canyon Formation. Minor rock types are chert and limestone.

Sandstone units are generally most abundant in the lower part of the formation, although thin beds of sandstone may occur in the upper part. Sandstone may form a single thick unit at the base of the formation, but commonly the sandstone is separated into units by one or more mudstone beds, and as many as four sandstone units may be present in the formation, each more than 2 m thick.

The sandstone units are light colored, very pale orange to yellowish gray in weathered outcrop, but almost white on fresh surfaces. As reported by Shawe (1968, table 2 and p. B25), the sandstone of the Burro Canyon Formation is highly quartzose (83 percent) and contains less chert (3 percent) and feldspar (1.5 percent) than either the sandstone of the Morrison or the Dakota. Other detrital minerals are quite minor consituents (3 percent or less) and calcite cement is also present in minor amounts (6 percent).

In the outcrop the sandstone units form ledges and vertical cliffs in contrast to the gentle to steep slopes formed by the mudstone units. Many of the sandstone units show a crude sedimentation cycle that starts at the base with an irregular scour surface; scour depressions in this surface generally are filled with relatively coarse, poorly sorted sandstone and conglomeratic sandstone in trough cross-stratified sets; commonly the sets are thickest at the base and are thinner upwards. This coarse, trough cross-stratified unit passes upwards into finer grained, better sorted sandstone that is planar cross-stratified to parallel bedded and laminated and may show parting lineation, rib and furrow structures, and current ripple marks. The lower unit is deposited from a higher energy regime and the upper from a lower energy regime. Deposits of the higher energy regime are visualized as deposited from the main course of a laterally migrating stream and deposits from the lower energy regime as deposited from shallow-water stages as splays and bars following the migration of the main channel from the area. Commonly the cycle is interrupted and the low-energy beds are missing either because they were never formed, or because they were removed by scour when the next stream crossed the area.

In the conglomeratic parts of the sandstone, pebbles occur in layers and stringers, and usually are concentrated immediately above the basal scour surface of the sandstone units. Based on two pebble counts made by P. J. Katich, Jr., (written commun., 1951) the pebbles of the Burro Canyon are chert (57 percent), silicified limestone (38 percent), quartzite (5 percent), and quartz (1 percent). The coarsest pebbles in the Burro Canyon are near Blanding in southeastern Utah, where a maximum diameter of 13 cm was recorded. To the north and east, maximum diameters are smaller.

The mudstone of the Burro Canyon ranges from almost pure claystone to siltstone, but most is silty to sandy mudstone. The mudstones are dominantly pale greenish yellow to grayish yellow green. In a few places thin units of pale-reddish-brown to grayish-red mudstone are preserved. They appear to be relicts of a former more widespread red coloration that in some manner was protected from alteration to green (Shawe, 1976, p. D23). Much less common than the relict-red mudstone units are rare carbonaceous mudstone beds. These range from light gray to grayish black and are considered as unaltered relicts of beds originally deposited under reducing conditions. Based on a few analyses by Keller (1962, p. 63-83) the dominant clay mineral in Burro Canyon mudstone is illite and mixed-layer illite-chlorite, which probably accounts for the generally nonswelling properties of the mudstone on outcrop and contrasts with the mudstone of the Cedar Mountain Formation in which the clay is dominantly montmorillonite and shows considerable swelling on weathered outcrop.

Limestone and chert are minor rock types in the Burro Canyon and are generally restricted to the upper part of the formation. The limestone is generally a light-gray micrite which forms beds as much as 50 cm thick that are local in extent but when present usually make a conspicuous ledge in a mudstone slope. Chert is thought to be mainly secondary, partially or completely replacing limestone beds, and forms outcrops similar to the limestone.

Thickness

The Burro Canyon differs markedly in thickness over relatively short distances and thus yields a rather complicated isopach map (pl. 1). This irregularity is thought to be the result of initial depositional differences, post-Burro Canyon and pre-Dakota erosion, and probably compactional differences related to the sandstone-mudstone ratio.

The Burro Canyon thins to the southwest from thicknesses of more than 50 m in southeastern Utah and southwestern Colorado to an erosional pinchout that extends from southern Utah into northwestern New Mexico. The formation obtains a maximum thickness of more than 90 m in a drill hole in Disappointment Valley in southwestern Colorado (D. R. Shaw, written commun., 1975). Some of the irregularities of isopachs (pl. 1) in this salt anticline area result from depositional thinning and thickening because of subsidence of synclines and irregular uplift of the salt anticlines as a result of salt flowage during deposition of the Burro Canyon (Cater, 1970, p. 64-67). However, Shawe (1970, p. C15) reported that much of the thinning of the Burro Canyon along the anticlines is the result of pre-Dakota erosion.

In spite of these irregularities an axis of thick (40 m or more) Burro Canyon (pl. 1) extends in a north-northeast direction along the Utah-Colorado State line from near the Four Corners to west of Grand Junction. To the east of this axis, the formation thins to an irregular zero line that suggests a series of lobes extending southeastward and eastward from the thick area. To the west the Burro Canyon thins and passes into the Cedar Mountain Formation, which in turn gradually thickens westward toward central Utah, where it attains a thickness of more than 170 m. To the north in northeastern Utah and northwestern Colorado, the Burro Canyon also passes into Cedar Mountain, but control in this area is sparse. The erratic thickening of the Burro Canyon in the subsurface along the Douglas Creek arch north of Grand Junction is poorly understood, but it seems an extension of the northerly trending axis of thick Burro Canyon.

Distribution of rock types

The total thickness of sandstone, regardless of the number of units, in the Burro Canyon and Cedar Mountain Formations is shown on plate 2.

As on the total isopach map, the Burro Canyon shows an axis of thick sandstones extending north-northeastward from southeastern Utah to near Grand

Junction, Colorado. Along this axis, the cumulative thickness of sandstone exceeds 30 m. As on the total isopach map, irregularities occur in the salt anticline region of western Colorado and eastern Utah; for example, a section of Burro Canyon along the thick axis at Summit Point (loc. 43) contains only 19 m of sandstone and is near the crest of the Dolores anticline, whereas sections near the axis of the Disappointment syncline (loc. 42 and 169) contain more than 45 m of sandstone. This difference is considered to be the result of greater deposition in the subsiding synclines as a result of deep salt flowage from the synclines to the anticlines.

The lobes along the eastern margin of the Burro Canyon, in part, seem to mark lobes of relatively thick sandstone (pl. 2). Two of these lobes of thick sandstone occur between Grand Junction and Delta, Colorado. Much of the detail in isopach lines along the Gunnison River in Delta and Mesa Counties, Colorado, and then along the Colorado River westward into Grand County, Utah, is the result of contouring to an additional 47 control points provided by figures 1-3 of McCubbin (1961). These localities are not shown on plate 2. These irregularities in isopachs are probably a much better representation of the degree to which the thickness of sandstone varies than is shown on the rest of the map, where control points are widely scattered.

To the west and north of the axis of thick Burro Canyon sandstone, the sandstones thin. In these areas the total sandstone thickness of the Cedar Mountain Formation is quite thin as compared to the Burro Canyon. The sandstone in the Cedar Mountain does thicken westward and in central Utah attains thicknesses of more than 20 m.

A map of the percentage of sandstone in the Burro Canyon Formation (pl. 3) also reflects thick sandstone in the formation in southeastern Utah and to the north in westernmost Colorado. In this case, the pattern is interrupted to some degree through the salt anticline region of western Colorado where lower percentages of sandstone are recorded. Perhaps, greater amounts of mudstone were deposited in this area as a result of subsidence in synclines and the damming effects of rising salt anticlines. Between Grand Junction and Delta, Colorado, two of the lobes of relatively thick Burro Canyon show relatively high percentages of sandstone in the formation.

This map of percentage of sandstone in the formation is perhaps the least satisfactory of the three maps, plates 1, 2, and 3. For example, locality 148 (pl. 3) between Montrose and Ouray is 100 percent sandstone, but the formation is only 2 m thick. Similar irregularities occur at several places where the formation is relatively thin. In the central part of the formation, two large areas of 100 percent sandstone are shown. It is highly unlikely that the formation is all sandstone throughout these areas. Sparsity of control, however, permits the construction of the isopleths as shown on plate 3, and emphasizes the distribution of abundant sandstone in the formation.

Directions of transportation and source

A few studies of sedimentary structure orientations have been made in the Burro Canyon Formation and the Buckhorn Conglomerate Member of the Cedar Mountain Formation and are summarized on plate 4. The sedimentary structures in the Buckhorn in central Utah show an eastward direction of transport and imply a source area to the west. Sedimentary structures in the Burro Canyon

Formation in southwestern Colorado and southeastern Utah indicate a dominantly northward direction of transport and imply a source area to the south.

In the area extending from Thompson, Utah, through Grand Junction, Colorado, to Delta, Colorado, the direction of transport fans through an arc of about 100°, from north-northwest to due east. This fanning of transport directions is thought to result, primarily, from a distributary stream pattern in the Burro Canyon, and, secondarily, from the impinging and merging of sediments from two major source areas, one to the west (Cedar Mountain) and one to the south (Burro Canyon).

Petrographic studies by Shawe (1968, p. B7) indicate that typical sandstone of the Burro Canyon Formation is dominantly quartzose and contains less chert and feldspar than does the sandstone of the underlying Morrison Formation (Shawe, 1968, p. B25). This composition seems to require that the source terrane was an area dominated by quartzose sedimentary rocks. The composition of the finer grained components in the Burro Canyon also are compatible with this type of source terrane.

The conglomerate and sandstone beds in the Cedar Mountain Formation are quartzose and also were derived from a dominantly sedimentary terrane. However, the mudstone component of the Cedar Mountain contains large amounts of swelling montmorillonitic clay (Keller, 1962, p. 64) that was derived from volcanic ash. Probably, ash was delivered airborne to the source terrane, as well as to the Cedar Mountain depositional area, and was transported and reworked by Cedar Mountain streams prior to final deposition.

Age

The age of the Burro Canyon and Cedar Mountain Formations is poorly known. Fossil remains in these formations are very sparse and most have been found near the top of the formations. They include fragments of dinosaur bone, a few plants, including calcareous algae (charophytes), and a few fresh water invertebrates (gastropods, pelecypods, and ostracodes). Young (1960, p. 180-181) has summarized the fossil knowledge of these formations up to 1960. One plant, one gastropod, and two pelecypods seem to fix the age as definitely Early Cretaceous. Reeside (in Simmons, 1957, p. 2526) is cited as indicating that two pelecypods are "widespread [middle] Early Cretaceous (Aptian) species." The fossils in the Burro Canyon and Cedar Mountain are most commonly compared to like forms in the Kootenai Formation, Cloverly Formation, and Gannett Group of Montana and Wyoming.

Recently, palynomorphs have been recovered from samples, collected by R. H. and B. D. Tschudy, of dark carbonaceous mudstone near the top of the Burro Canyon Formation in southern Disappointment Valley, western San Miguel County, Colorado (NE 1/4 sec. 11, T. 43 N., R. 18 W). This is the same fossil locality reported by Simmons (1957, p. 2525-2526). Palynomorph-bearing samples have also been collected by the Tschudys from the upper part of the Cedar Mountain Formation in central Utah.

They report (Tschudy, Tschudy, and Craig, in press) that the palynomorphs from the Burro Canyon Formation point to an Aptian-early Albian age, with the remote possibility of a late Barremian age, and the palynomorphs from the Cedar Mountain are of late or latest Albian age.

The palynomorph age assignment for the Burro Canyon has been corroborated by a fission-track age determination (C. W. Naeser, written commun., 1981) of 125±10 m.y. B.P.[1] The determination was made on zircon from a thin bentonite layer associated with palynomorph-bearing carbonaceous shale and allows a range in age from Barremian to Albian.

Environment of deposition and tectonic relations

The Burro Canyon and Cedar Mountain are interpreted as two alluvial systems deposited across a broad, relatively even surface on top of the Morrison Formation. In many respects, they appear to represent a continuation of Morrison deposition. The sandstone and conglomeratic sandstone in both formations were deposited from a relatively high energy transport medium and are distinctly fluvial deposits formed by meandering and braided streams. Mudstones are largely overbank deposits formed in interfluve areas. These interfluve areas also were the site of deposition of limestone, probably in ephemeral fresh-water lakes.

The climate is visualized as warm and relatively humid with adequate moisture to support a moderate vegetation on the interfluve areas. Rainfall was probably cyclic, allowing the wetting and drying of the interfluve areas and oxidation and destruction of much of the organic material.

Much volcanic ash was contributed to the Cedar Mountain and probably was transported in part as airborne ash falls. This pumiceous material was transported by the streams and was reworked and intermixed with clastic debris derived from the source area to the west because no discrete ash beds have been reported to, or observed by, the author in the Cedar Mountain.

Stream deposits dominate at the base of both the Cedar Mountain and Burro Canyon Formations. In the Cedar Mountain Formation, the Buckhorn Conglomerate Member is a high-energy deposit and forms a widespread lenticular layer. Although other lensing fluvial sandstones occur higher in the formation, the unnamed shale member, which makes up most of the formation, appears to be a dominantly low energy deposit. The Burro Canyon, on the other hand, consists of 50 percent or more sandstone (pl. 3) over much of its extent. Higher energy conditions of deposition prevailed through much of Burro Canyon deposition. Although overbank low-energy deposits are preserved interbedded with the sandstone, they are dominant only in the upper third of the formation.

[1] /Data for fission-trach age determination by C. W. Naeser (written commun., 1981).

Sample	Mineral	p_s x10^6 t/cm^2	p_i x10^6 t/cm^2	Ø x10^{15} n/cm^2	T x10^6 yr	±2o x10^6 yr	# grains	$r,\overline{s}$	U ppm
RT-79-2	Zircon	21.98	8.64	0.828	125	10	8	0.72	330
DF-3652		(2646)	(520)						

$_f$=7.03 x 10^{-17} yr^{-1}

These parallel changes in the two formations may represent a major cycle of tectonism and sedimentation. The high-energy deposits at the bottom of both formations may mark a distinct period of uplift in the source areas. This tectonism may have been accompanied by slight increases in gradients across the depositional plain. This period of uplift was followed by a period of tectonic quiescence in which low-energy deposits became dominant. This gross sequence is similar to that shown by the Morrison Formation in much of Utah and Colorado: an abundance of high-energy deposits in the Salt Wash Member overlain by a sequence dominated by low-energy deposits in the Brushy Basin Member.

Postdepositional history

The Burro Canyon Formation was probably deposited under dominantly oxidizing conditions as indicated by the remnants of red beds and by the scarcity of gray organic-rich mudstones that are preserved very locally in the formation. Shawe has noted (1976, p. D23) that "the bleached rocks are altered equivalents of reddish rocks." The dearth of carbonaceous wood in the sandstones suggests that oxidizing conditions may have been more prevalent during deposition than in the case of the sandstones in the Salt Wash Member of the Morrison Formation where carbonaceous plant fragments are locally abundant. Silicified wood is present in the Burro Canyon, although it is far from abundant, and indicates an abundance of silica in the early post-depositional waters in the formation.

Shawe (1976) has noted three facies in the Jurassic and Cretaceous of the Slick Rock district of western Colorado. These are the red-bed facies, the altered facies, and the carbonaceous facies. He has assigned most of the Burro Canyon to the altered facies. Characteristically, the altered facies has a relatively low content of black opaque minerals, and appreciable pyrite in contrast to the other facies (Shawe, 1976, p. D42). He attributed this removal of black (iron-bearing) opaque minerals to the widespread introduction of a reducing solution (Shawe, 1976, p. D48) derived from overlying formations. The dearth of red-bed facies in the Burro Canyon indicates widespread solution and removal of interstitial iron oxides from the mudstones.

The time of this change from oxidizing to reducing conditions most probably followed the erosional interval at the end of Burro Canyon deposition and began with the onset of reducing conditions during deposition of the Dakota Sandstone. Reducing solutions probably penetrated the Burro Canyon as the underflow from streams depositing the basal Dakota Sandstone. The formation was then buried beneath a thick section of dominantly marine Upper Cretaceous rocks, the upper part of the Dakota Sandstone and the Mancos Shale. Reducing conditions probably prevailed throughout this long time.

Oxidizing conditions in the Burro Canyon were probably not reestablished until after uplift of the Colorado Plateaus province in the Tertiary and incision of the present-day drainage to expose the formation at the surface. The formation is probably undergoing oxidation today as a result of percolation of surficial oxygen-bearing water. At the outcrop, the only sign of oxidation in the sandstone is the slight, light-yellow-brown color developed at the rock surface, which appears to be a deposit of dustlike particles of limonite on sand grains. The limonite is formed as the result of oxidation of the very sparse pyrite in the unweathered rock. The mudstones have remained green in the present weathering cycle probably because all the readily soluble iron has been removed during reduction in the previous cycle. The iron in the mudstones is probably held in the ferrous or in mixed ferric-ferrous state in the crystal lattice of the clay minerals and, at least in part, is responsible for the greenish coloration of the mudstone (Keller, 1962, p. 47-48). The remnant red beds in the Burro Canyon are probably red because the surficial ferric-oxide pigment on the clay minerals was not removed (Keller, 1962, p. 46).

Uranium potential of the Burro Canyon Formation

Model for sandstone-type uranium deposits

Fischer (1974) presented a conceptual model for the occurrence of sandstone-type uranium deposits. This model indicates that uranium deposits occur in gently dipping, lenticular sandstone beds of continental origin. Deposits are formed by mineralizing ground water moving downdip to a reducing environment. More specifically uranium-in-sandstone deposits occur in intermountain basins, in alluvial fans, or in coastal plain sediments. The host sandstone is fine to coarse grained and may be conglomeratic; host sandstone beds range from quartzose to arkosic. Coalified plant fossils are characteristic of uranium host beds and are interpreted to indicate a low-lying terrane accompanied by a high water table. Major uranium districts are localized in zones a few miles from the depositional or erosional edge of the host beds. Adequate reducing conditions are required to cause precipitation of the uranium from the mineralizing solutions. The most commonly proposed reducing agents are carbonized plant fossils, humic material, and/or bacterial or petroleum-derived H_2S. Fischer also noted that tabular uranium deposits appear to be formed quite early after the deposition of the host sandstone, whereas roll-type uranium deposits were formed quite late after deposition of the host sandstone and following a period of erosion.

The Burro Canyon Formation as a potential host for uranium

The Burro Canyon Formation, as it is known in the outcrop through southeastern Utah and southwestern Colorado, has most, but not all, of the characteristics called for by Fischer's (1974) conceptual model for sandstone uranium deposits. It is a continental deposit containing lenticular sandstones and throughout most of the Colorado Plateaus province it has very gentle dips. Mineralizing water could move downdip through the sandstone. The formation is thought to have been deposited as a large alluvial fan. The sandstone is quartzose and ranges from fine grained to conglomeratic. In all these respects the sandstone of the Burro Canyon Formation fit the Fischer model for sandstone uranium deposits.

Perhaps the major failing of the Burro Canyon as an obvious host rock for uranium is the apparent lack of precipitant in the sandstone. Fischer's model calls for a reducing environment, and precipitation of uranium through interaction with carbonaceous plant fossils, humic material, or bacterial or petroleum derived H_2S. Throughout the outcrop area of the Burro Canyon in southeastern Utah and most of southwestern Colorado, carbonaceous plant fossils are very sparse. Such plant remains as are preserved are silicified, and virtually all the carbonaceous material has been removed. Dark humic or humate material is not evident in these outcrops. Of course, H_2S is not evident at the outcrop, but pyrite and organic material, from which to derive the H_2S, are scarce or lacking in sandstone of the Burro Canyon (Shawe, 1968, p. 87, table 2).

A few relevant exceptions to the limiting generalizations of the preceding paragraph must be mentioned. At the Lone Cedar claim (sec. 35, T. 46 N., R. 17 W., Montrose County, Colorado) on the south rim of Paradox Valley, a small uranium mine has been developed in the basal sandstone of the Burro Canyon Formation. An abundance of carbonaceous plant debris, stems, branches, and twigs of carbonized wood is associated with the ore. Approximately 3 m above the ore-bearing sandstone is a unit of medium- to dark-gray organic-rich mudstone about 3 m thick. In this small area at least, a part of the formation was protected from oxidation.

Several uranium prospects in the Burro Canyon Formation near Cortez, Colorado, are reported to be associated with organic material (J. E. Motica, oral commun., 1977). Uranium deposits in rocks called Burro Canyon (Saucier, 1974) in the Chama basin, north-central New Mexico also are reported to be associated with organic material in the sandstones (A. E. Saucier, oral commun., 1977). The Jackpile sandstone, an economic unit at the top of the Morrison Formation in the Laguna mining district in central New Mexico, occupies the same stratigraphic position as the Burro Canyon Formation, although it may not correlate precisely with the Burro Canyon Formation of the Chama basin (Saucier, 1974, p. 213-215). The Jackpile sandstone contains two of the largest sandstone uranium deposits in the world. These deposits are associated with humic materials and scattered coalified logs and other carbonized plant debris (Moench and Schlee, 1967, p. 74-80).

These special cases, and there are probably more, indicate that uranium-bearing solutions did pass through the Burro Canyon Formation and that in some areas carbonaceous and humic materials are preserved and were at least partially responsible for the precipitation of uranium minerals.

East of the Uncompahgre Plateau, the Burro Canyon Formation is probably the most transmissive unit between the Precambrian and the Upper Cretaceous Mesaverde Group. The Uravan mineral belt may have been localized (Shawe, 1962, p. C7) at the toe of a small fan of sandstone of the Salt Wash superimposed on the major fan of the Salt Wash Member where sandstone deposited in a relatively high energy fluvial environment gives way to deposits of a lower energy environment. The lobate nature of the eastern margin of the Burro Canyon suggests the development of such subsidiary fans, and the highly transmissive character of the formation makes it a favored host for uranium deposits along this eastern margin.

Possibility of discovering additional uranium deposits

A final criterion of the Fischer (1974) model stipulates that major districts are restricted to zones a few miles from the depositional or erosional edge of the host beds. As shown in plates 1 and 2, the Burro Canyon Formation and the sandstones within it reach a depositional or erosional edge that extends in an irregular southerly direction from the Piceance basin to the San Juan Basin. Most of this limit is in the subsurface and is not well known, but a moderate amount of drilling information suggests that it may be somewhat lobate in pattern.

These lobes seem to correspond to thick, fingerlike distributaries toward the distal end or edge of the Burro Canyon alluvial fan. As a corollary to the preceding criterion, Fischer observed that the preservation of the coalified plant fossils in the uranium host beds resulted from deposition in a low-lying terrain under conditions of a high water table. The most favorable area for preservation of coalified plants in the Burro Canyon, then, is west of, but along, this lobate margin.

If this margin is a depositional margin to the Burro Canyon fan, it would be the area least likely to be oxidized during pre-Dakota erosion. This area or belt would have been the lowest lying part of the Burro Canyon fan, and the water table might have been high enough to prevent oxidation of the plant material deposited in the sandstone. In this event, an oxidation-reduction interface may exist somewhere within and west of the margin, and uranium deposits may be expected in association with the interface.

If the pinchout of the Burro Canyon is the result of pre-Dakota erosion, it is possible that oxidation was sufficient to remove all carbonaceous material as well as all pyrite and uranium before erosion stripped the Burro Canyon from the area east of the margin. On the other hand, oxidation may not have progressed that far and reducing conditions may have persisted at the toe of the fan.

Whether caused by erosional pinchout or depositional pinchout, the thinned sandstone in the Burro Canyon Formation would impede the movement of ground water. The impedence of ground-water flow has been suggested by Moench and Schlee (1967, p. 106-107) as a contributing factor to uranium deposition in the Jackpile sandstone in the Laguna district, New Mexico.

A source for uranium in the Burro Canyon may be similar or identical to one of those postulated for the Morrison deposits in western Colorado and eastern Utah. The most likely source seems to be derivaiton from volcanic ash in beds adjacent to the sandstones in the Burro Canyon. Upward leakage of uranium-bearing solutions from the Brushy Basin Member of the Morrison Formation during the argillization of the abundant volcanic materials in that member and gradual compaction of that unit may have taken place during or shortly after deposition of the sandstones of the Burro Canyon. Similar argillization of the richly volcanic shale member of the Cedar Mountain also might have contributed uranium-bearing solutions to the sandstones of the Burro Canyon shortly after deposition of the Burro Canyon. Although the percentage of volcanic ash in the Burro Canyon seems relatively minor, it also could have contributed to uranium-bearing solutions in the sandstone during the argillization of the volcanic glass. A granitic source rock for the uranium in the source terrain for the Burro Canyon seems most unlikely because of the markedly quartzose and nonarkosic character of the Burro Canyon.

Two periods for the advance of oxidation and the development of uranium deposits seem possible. One period would be during and shortly after deposition of the Burro Canyon and before deposition of the Dakota Sandstone. During this period the Burro Canyon in the outcrops of western

Colorado and eastern Utah appears to have been greatly oxidized. As noted by Fischer (1974, p. 373) such early formed uranium deposits would probably be of the tabular type. A second opportunity for a mineralizing-oxidizing front to pass through the Burro Canyon would be during the present erosion cycle after the formation was first exposed on structurally positive elements such as the Uncompahgre Plateau in western Colorado. Such an oxidation front could carry with it uranium that was disseminated in the sandstone, or perhaps could remobilize uranium from previous concentrations to produce the roll-type deposits which Fischer (1974, p. 373) observed to be characteristic of the more recent deposits.

Guides for exploration

The purpose of this report is to call the attention of the exploration geologist to a formation that has largely been disregarded as a potential uranium-bearing formaiton, at least in the area of this study. The study has stopped short of one obvious geologic requirement. Drill-hole cuttings from the few holes available between the outcrop and the limit of the Burro Canyon must be examined to see if any area of unoxidized sandstone can be identified.

Inasmuch as this study was a part of a larger study of the Uinta and Piceance basins, most of the effort was devoted to outcrops extending from Thompson, Utah, east to Grand Junction, Colorado, and southeast to Montrose, Colorado. In this interval, two noteworthy areas of thick massive sandstone (pl. 2) were observed in the Burro Canyon, one near Whitewater, just south of Grand Junction and one near Roubideau, just west of Delta, Colorado. In these areas, the sandstone is as thick as 30-50 m and contains few mudstone partings. Away from these two areas, the sandstones in the Burro Canyon generally form two or more beds separated by several meters of mudstone; the sandstone units are quite lenticular, and the cumulative thickness of sandstone is generally considerably less than 30 m. The author interprets these two thick sandstone areas as lobes of thick sandstone extending northeasterly and easterly as minor alluvial fans out from the main part of the Burro Canyon fan. This is supported by the available surface and subsurface control (pl. 2). These lobes would be the most transmissive parts of the Burro Canyon and could have served as pipelines for the downdip migration of uranium-bearing ground water. If a precipitant for uranium is preserved in these beds, it should be in the peripheral or distal parts of these lobes. Other lobes of Burro Canyon to the south may be equally interesting as potential uranium-bearing host rocks but have not been examined in the course of this preliminary study.

Exploration must first locate reduced sandstone, characterized by containing pyrite, carbonaceous trash, humic material, and/or H_2S. Secondly, the updip direction should be tested to locate an "interface" with oxidized rocks. Such an "interface" might be sharp, but also it could be a broad area; it could lie parallel with the bedding in places. This "interface" if discovered should be the favorable location for uranium deposits, and obviously should be tested laterally along its trend.

Drill holes that have penetrated the Roubideau lobe indicate that the base of the Burro Canyon lies at a depth of 1,234 m (4,047 ft) near the distal end of the lobe (loc. 65), and at shallower depths of 780 m (2,570 ft) (loc. 87) and 345 m (1,120 ft) loc. 85) as one approaches the outcrops west of

Delta. If the Whitewater lobe trends northeasterly to the Roberts Creek area (locs. 59-63) as projected on the isopach maps (pls. 1, 2), the Burro Canyon base reaches a maximum depth of 2,340 m (7,700 ft) but has an average depth of about 2,130 m (7,000) in the Roberts Creek field. The Burro Canyon should be shallower to the southwest towards the margin of the Piceance basin. Probably only in-situ leaching could be used to extract uranium from these deep parts of the lobes, but regular underground mining practices could be used if the uranium were lodged in shallower parts of the lobes.

It should be noted that the Burro Canyon and Cedar Mountain Formations produce natural gas from several fields around the nose of the Uncompahgre Plateau extending from near Thompson, Utah, to north of Grand Junction, Colorado (Young, 1975, p. 141-142). A small shut-in gas field, in which the producing horizon is listed as Dakota, lies east of Delta, Colorado. The latter field (Happy Hollow) lies along the axis of the southern (Roubideau) lobe of Burro Canyon discussed in preceding paragraphs. These lobes of thick sandstone should provide good reservoirs for the accumulation of natural gas, if a structural control of some sort exists to provide an up-dip seal to trap the gas. Of course, H_2S or possibly methane (C. G. Warren, oral commun., 1976) in the natural gas could have served as a precipitating agent for any uranium migrating through the rock.

At least the first two steps of an exploration program as outlined in a preceding paragraph should require coring of the entire Dakota-Burro Canyon part of the section in order to eliminate confusion created by contamination of Burro Canyon cuttings with cuttings from the Dakota and overlying Mancos Shale.

Resource potential

Uranium

Little can be said regarding uranium resource potential until the eastern margin of the Burro Canyon is tested to determine the presence or absence of a reductant. The report of carbonaceous material in prospects near Cortez, Colorado, is most encouraging, for these prospects are near the periphery of one of the lobes. If a border of reduced sandstone in the Burro Canyon lies within the eastern margin of the formation, it is not unreasonable to project that several Jackpile-sized deposits might lie in this belt extending from the southwest edge of the Piceance basin to the northwestern San Juan Basin. If the deposits are not the large tabular Jackpile-type of ore body, but are smaller and scattered as suggested by early information on the Chama basin deposits in the Burro Canyon, on the prospects in the Burro Canyon near Cortez, and on the Lone Cedar claim in the Burro Canyon on the south rim of Paradox Valley, then not only are the subsurface targets more difficult to define and hit, but also the potential speculative resource is considerably reduced.

Natural gas

Natural gas may be a second potential resource of the Burro Canyon in at least the northern and southern parts of the marginal belt of the formation. Again an "if" must precede any appraisal of amount. If stratigraphic or structural up-dip barriers exist to trap natural gas or oil, then one might reasonably expect one or two South Canyon-like fields (Young, 1975, p. 142) in the northern two lobes of the Burro Canyon (Whitewater and Roubideau) and similarly, one might expect one or two South Canyon-like fields in the two southern lobes extending into the northernmost part of the San Juan Baisn. The South Canyon field, northwest of Grand Junction, had produced 7,144,423 MCF of gas from the combined Dakota and Cedar Mountain (Burro Canyon) by January 1, 1975 (Young, 1975, p. 142). The existence of stratigraphic or structural traps in at least one of the lobes is indicated by the shut-in Happy Hollow field east of Delta.

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Appendix

The following list provides the data on localities and drill holes used as control in this study of the Burro Canyon and Cedar Mountain Formations. Initials after the name of the locality indicate authorship or source of the data. The sources are as follows:

Initials LCC, CNH, VLF, TEM, HAJ, LRS, JJF, JOR, PJK, GAW, GWW, JDS, JWH, indicate data derived from:

Craig, L. C., Holmes, C. N., Freeman, V. L., Mullens, T. E., and others, 1959, Measured sections of the Morrison and adjacent formations: U.S. Geological Survey Open-File Report 485, approx. 700 p.

Initials DGMc indicate data derived from:

McCubbin, D. G., 1961, Basal Cretaceous of southwestern Colorado and southeastern Utah: Harvard University Ph. D. thesis, p. 172.

Initials LCH refer to unpublished data of Lyman C. Huff, USGS.

Initials EBE and FNH refer to unpublished data of E. B. Ekren and F. N. Houser, USGS.

Initials JG and JBR indicate data derived from:

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U.S. Geological Survey Professional Paper 150-D.

Initials AAB indicate data derived from:

Baker, A. A., 1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U.S. Geological Survey Bulletin 951.

Initials DRS indicate data derived from:

Shawe, D. R., Simmons, G. C., and Archbold, N. L., 1968, Stratigraphy of the Slick Rock District and vicinity, San Miguel and Dolores Counties, Colorado: U.S. Geological Survey Professional Paper 576-A.

AmStrat refers to lithologic drill hole logs produced by the American Stratigraphic Company.

E-log or R-log refers to mechanical logs of drill holes obtained from Petroleum Information Company.

BURRO CANYON AND CEDAR MOUNTAIN LOCALITIES

1	Salt Valley (LCC & VLF)	Grand Co., Utah	Sec. 29, T. 22 S., R. 20 E.
2	Yellow Cat (LCC)	" " "	NW sec. 30, T. 22 S., R. 22 E
3	Dewey (CNH & TEM)	" " "	Sec. 7, T. 23 S., R. 24 E.
4	Westwater Section (DGMc)	" " "	Sec. 34, T. 19 S., R. 25 E.
5	Granite-Ryan Cr. (CNH & TEM)	" " "	Sec. 20, T. 22 S., R. 25 E.
6	State Line (CNH)	Mesa Co., CO	Sec. 6, T. 11 S., R. 104 W.
7	Loma (CNH & TEM)	" " "	Sec. 8, T. 1 N., R. 3 W.
8	Black Ridge sect (CNH)	" " "	Sec. 18, T. 11 S., R. 102 W.
9	No Thoroughfare Canyon (DGMc)	" " "	Sec. 21, T. 1 S., R. 1 W.
10	Ladder Canyon (CNH & LCC)	" " "	Sec. 19, T. 12 S., R. 100 W.
11	Whitewater (DGMc)	Mesa Co., CO	Sec. 33, T. 12 S., R. 99 W.
12	E. Unaweep Canyon (CNH)	" " "	Secs. 1 & 2, T. 14 S., R. 100 W.
13	Bridgeport (CNH)	Delta Co., CO	Sec. 20, T. 14 S., R. 98 W.
14	N. Fk, Escalante Cr. (CNH & TEM)	Mesa Co., CO	Sec. 34, T. 51 N., R. 14 W.
15	Escalante Forks (CNH)	Delta Co., CO	Secs. 9 & 10, T. 51 N., R. 13 W.
16	Roubideau (DGMc)	Delta Co., CO	Sec. 19, T. 15 S., R. 96 W.
17	Roubideau Cr. (CNH & TEM)	Montrose Co., CO	Sec. 3, T. 48 N., R. 12 W.
18	Monitor Cr. (CNH & TEM)	" " "	Sec. 9, T. 50 N., R. 12 W.
19	Polar Mesa (LCC & VLF)	Grand Co., Utah	Sec. 3, T. 25 S., R. 25 E.
20	John Brown Canyon (LCC & HAJ)	Mesa Co., CO	Secs. 31 & 32, T. 51 N., R. 19 W.
21	N. Sinbad Valley (LCC & HAJ)	Montrose Co., CO	Secs. 30 & 31, T. 50 N., R. 19 W.
22	Lone Tree Mesa (LCC & HAJ)	" " "	Sec. 3. T. 48 N., R. 18 W.
23	Dolores Group	" " "	Sec. 20, T. 48 N., R. 17 W.
24	Uravan (DGMc)	" " "	Sec. 26, T. 48 N., R. 17 W.
25	Tabequache Canyon (CNH)	" " "	Sec. 34, T. 48 N., R. 15 W.
26	Skein Mesa (LCC & RAC)	Montrose Co., CO	Sec. 9, T. 46 N., R. 18 W.
27	Dry Creek Anticline (LCC & LRS)	" " "	Sec. 34, T. 46 N., R. 16 W.
28	Calamity Draw (DGMc)	" " "	Sec. 11, T. 46 N., R. 16 W.
29	Cottonwood Creek (DGMc)	" " "	Sec. 2, T. 46 N., R. 14 W.
30	Nucla (DGMc)	" " "	Sec. 15, T. 46 N., R. 15 W.
31	Redvale (DGMc)	Montrose Co., CO	Sec. 9, T. 45 N., R. 14 W.
32	Norwood Hill (DGMc)	San Miguel Co., CO	Sec. 30, T. 45 N., R. 12 W.
33	San Miguel Canyon (CNH)	" " " "	Sec. 29, T. 44 N., R. 11 W.
34	Cushman Creek (DGMc)	Montrose Co., CO	Sec. 11, T. 49 N., R. 11 W.
35	Dry Creek (DGMc)	" " "	Sec. 34, T. 48 N., R. 11 W.

36	Montrose (DGMc)	Montrose Co., CO	Sec. 34, T. 49 N., R. 10 W.
37	Austin (DGMc)	Delta Co., CO	Sec. 5, T. 15 S., R. 94 W.
38	Telluride (DGMc)	San Miguel Co., CO	Sec. 26, T. 43 N., R. 10 W.
39	Hamm Spring (CNH)	" " " "	Secs. 25 & 26, T. 45 N., R. 18 W
40	Gypsum Valley (DGMc)	" " " "	Sec. 3, T. 43 N., R. 16 W.
41	McIntyre Canyon (LCC, VLF)	San Miguel Co., CO	Sec. 12, T. 44 N., R. 20 W.
42	Slick Rock (LCC)	" " " "	Secs. 27-33, T. 44 N., R. 18 W.
43	Summit Point LCC, JJF)	" " " "	Secs. 8 & 9, T. 43 N., R. 19 W.
44	Horseshoe Group (LCC, JDR)	" " " "	Sec. 6, T. 42 N., R. 17 W.
45	Overlook (DGMc)	Dolores Co., CO	Sec. 19, T. 41 N., R. 17 W.
46	Dove Spring (LCC, VLF)	Dolores Co., CO	Sec. 9, T. 40 N., R. 17 W.
47	Williams Draw (DGMc)	" " "	Sec. 17, T. 39 N., R. 17 W.
48	Cane Spring (LCC)	San Juan Co., UT	Sec. 7, T. 28 S., R. 23 E.
49	La Sal Creek (LCC et al)	" " " "	Secs. 28-33, T. 28 S., R. 26 E.
50	Dry Valley (LCC)	" " " "	Sec. 10, T. 31 S., R. 24 E.
51	Church Rock (LCC, VLF)	San Juan Co., UT	Sec. 30, T. 31 S., R. 24 E.
52	Hart Draw (LCC, VLF)	" " " "	Sec. 17 T. 32 S., R. 23 E.
53	Pearson Point (LCH)	" " " "	Sec. 30, T. 35 S., R. 25 E.
54	Frontier Refining Co. Bar X unit (AmStrat)	Mesa Co., CO	Sec. 31, T. 8 S., R. 104 W
54a	Sunray Midcontinent #1 unit (AmStrat)	" " "	Sec. 8, T. 9 S., R. 99 W.
55	Ambassador Oil Co. No. 1-D Fed. (AmStrat)	" " "	Sec. 34, T. 9 S., R. 99 W.
56	Amerada Petroleum Co. Unit #1 (Amstrat)	Mesa Co., CO	Sec. 14, T. 9 S., R. 101 W.
57	Amerada Petroleum Co. #1 (AmStrat)	" " "	Sec. 2, T. 9 S., R. 103 W.
58	General Petroleum Co. Schulte #1 (Amstrat)	Garfield Co. CO	Sec. 15, T. 6 S., R. 103 W.
59	Pacific Nat. Gas Expl. Co. No. 31-2 Shire Gulch (AmStrat)	Mesa Co., CO	Sec. 2, T. 10 S., R. 97 W.
60	Big Horn-Powder River N1-A Big Horn Gov't (AmStrat)	" " "	Sec. 7, T. 10 S., R. 97 W.
61	Texaco Inc., No. 2 Roberts Can Unit (AmStrat)	Mesa Co., CO	Sec. 33, T. 9 S., R. 97 W.
62	Texaco Inc., No. 1 Heffelmire-Gov't.(AmStrat)	" " "	Sec. 32, T. 9 S., R. 97 W.
63	Pacific Nat. Gas Explor. Co (AmStrat)	" " "	Sec. 35, T. 9 S, R. 97 W.

64	California Co. Hurd Gov't #1 (AmStrat)	Mesa Co., CO	Sec. 36, T. 8 S., R. 91 W.
65	Murfin and Sutton No. 1 Ferrier (AmStrat)	Delta Co., CO	Sec. 21, T. 13 S., R. 93 W.
66	Kerr-McGee and Phillips No. 1, Garmesa (AmStrat)	Garfield Co, CO	Sec. 8, T. 8 S., R. 102 W.
67	United Producing Co. No. 1-31 Gov't. (AmStrat)	Mesa Co., CO	Sec. 31, T. 8 S., R. 98 W.
68	El Paso Nat. Gas Co. No. 4 Twin Buttes (AmStrat)	Garfield Co., CO	Sec. 13, T. 5 S., R. 102 W.
69	Argo Oil Co. No. 1 Gov't-Buttram (AmStrat)	" " "	Sec. 30, T. 5 S., R. 102 W.
70	Greenbriar Fed. Gov't. No. 1 (AmStrat)	" " "	Sec. 24, T. 5 S., R. 102 W.
71	Mendota-Greenbriar Oil Co. Kelley No. 1 (AmStrat)	Garfield Co., CO	Sec. 29, T. 5 S., R. 102 W.
72	Pan-Amer. Petr. Corp. N 4-25 Baxter Pass, S. unit (AmStrat)	" " "	Sec. 25, T. 5 S., R. 103 W.
73	El Paso Nat. Gas Co. No. 6 unit (AmStrat)	" " "	Sec. 23, T. 5 S., R. 102 W.
74	National Associated Petr. No. 1-A Fed. (AmStrat)	" " "	Sec. 22, T. 7 S., R. 104 W.
75	Gulf Oil Unit No. 1 (AmStrat)	" " "	Sec. 8, T. 7 S., R. 103 W.
76	Forest Oil Co. Gov't No. 1 (AmStrat)	Garfield Co., CO	Sec. 2, T. 7 S., R. 104 W.
77	Honolulu Oil No. 1 Prairie Canyon-Gov't (AmStrat)	" " "	Sec. 19, T. 7 S., R. 104 W.
78	Clayton Oil Co. No. 1 Vera Bowen (AmStrat)	" " "	Sec. 3, T. 5 S., R. 92 W.
79	F. M. Tully No. 1 Roberst (AmStrat)	" " "	Sec. 7, T. 5 S., R. 91 W.
80	Conoco-Amerada-Calif.-Superior Alder No. 1 (David Miller) (AmStrat)	Mesa Co., CO	Sec. 36, T. 8 S., R. 91 W.
81	Norris Oil No. 1-14 Gov't (AmStrat)	Garfield Co., CO	Sec. 14, T. 5 S., R. 102 W.
82	Petro-Lewis Corp. No. 15-9 Coal Gulch (AmStrat)	" " "	Sec. 9, T. 8 S., R. 101 W.
83	Pan-Amer. Petr. #1 C. G. McGee (E-log)	Delta Co., CO	Sec. 25, T. 15 S., R. 95 W.

84	W. S. Meador Hotchkiss No. 1 (E-log)	Delta Co., CO	Sec. 12, T. 15 S., R. 93 W.
85	Williamson Drilling No. 1-B Gov't (E-log)	" " "	Sec. 22, T. 14 S., R. 94 W.
86	Cushman and Pilcher No. 1 Hawkins (E-log)	Delta Co., CO	Sec. 35, T. 13 S., R. 95 W.
87	Petro-Lewis Corp Powers-Fed. 11-30 (E-log)	" " "	Sec. 30, T. 12 S., R. 92 W.
88	M. Cline Oil Co. Gov't No 1 (R-log)	" " "	Sec. 31, T. 14 S., R. 93 W.
89	James M. Cline Oil Co. Colup No. 1 (E-log)	" " "	Sec. 25, T. 14 S., R. 94 W.
90	Four Mile Creek (LCC field notes)	Garfield Co., CO	Sec. 9, T. 7 S., R. 89 W.
91	Walcott (CNH & TEM) Eagle Co., CO	Eagle Co., CO	Sec. 8 & 9, T. 4 S., R. 83 W.
92	Walcott II (LCC field notes)	" " "	Sec. 22, T. 4 S., R. 83 W.
93	Burns (CNH)	" " "	Sec. 21, T. 2 S., R. 85 W.
94	Gore Pass (LCC field notes)	Grand Co., CO	Sec. 15, T. 1 N., R. 82 W.
95	Meeker (LCC field notes)	Rio Blanco Co., CO	Sec. 15, T. 1 S., R. 93 W.
96	Lime Kiln Hill Road (LCC field notes)	Rio Blanco Co., CO	Sec. 35, T. 1 S., R. 94 W.
97	Calif. Co. Raven No. 2-A Rangeley (AmStrat)	" " "	Sec. 31, T. 2 N., R. 102 W.
98	Superior Oil Co. Douglas Cr. Unit No 1 (AmStrat)	" " "	Sec. 5, T. 3 S., R. 101 W.
99	Phillips Petrol Douglas No. A-1 (AmStrat)	" " "	Sec. 19, T. 1 S., R. 101 W.
100	Superior Oil Co. Fee No. 1 (AmStrat)	" " "	Sec. 12, T. 4 S., R. 102 W.
101	Skull Creek (CNH & TEM)	Moffat Co., CO	Sec. 36, T. 4 N., R. 101 W. Sec. 3 T. 3 N., R. 101 W.
102	Vermilion Creek (CNH)	" " "	Sec. 25, T. 10 N., R. 101 W.
103	Main Elk Creek (CNH)	Garfield Co., CO	Sec. 15, T. 5 S., R. 91 W.
104	Rifle Creek (LCC field notes)	" " "	Sec. 36, T. 4 S., R. 93 W.
105	Sapinero (CNH)	Gunnison Co., CO	Sec. 23, T. 49 N., R. 4 W.
106	Almont (DGMc)	Gunnison Co., CO	Sec. 28, T. 51 N., R. 1 E.
107	Stoner (CNH)	Montezuma Co., CO	Sec. 3, T. 38 N., R. 1 E.
108	Mancos (DGMc)	Montezuma Co., CO	Sec. 21, T. 36 N., R. 12 W.
109	Durango (CNH)	La Plata Co., CO	Sec. 17, T. 35 N., R. 9 W.
110	Lower McElmo (LCC)	Montezuma Co., CO	Sec. 30, T. 36 N., R. 18 W.
111	Upper McElmo (LCC)	Montezuma Co., CO	Sec. 20 & 21, T. 36 N., R. 17 W
112	Sand Creek (EBE & FNH)	Montezuma Co., CO	Sec. 13 & 24, T. 36 N., R. 18 W

113	Woodchuck (EBE)	Montezuma Co., CO	Sec. 2, T. 35 N., R. 19 W. Sec. 35, T. 36 N., R. 19 W
114	Gulf Oil Fulks No. 1 (AmStrat)	Montezuma Co., CO	Sec. 27, T. 37 N., R. 17 W
115	Three States Nat. Gas No. 2 White (AmStrat)	Montezuma Co., CO	Sec. 33, T. 39 N., R. 19 W
116	Slick Moorman Carl Weaver No. 1 (AmStrat)	Montezuma Co., CO	Sec. 1, T. 35 N., R. 14 W.
117	Tidewater Assoc. Ute No. 1 (AmStrat)	Montezuma Co., CO	Sec. 8, T. 33 N., R. 14 W.
118	Continental Ute Mtn. No. 1 (AmStrat)	Montezuma Co., CO	Sec. 7, T. 32 N., R. 19 W.
119	McPhee (CNH & TEM)	Montezuma Co., CO	Secs. 28 & 34, T. 39 N., R. 16
120	Dunton Meadows (DGMc)	Dolores Co., CO	Sec. 23, T. 41 N., R. 11 W.
121	Humble Oil and Refng Co. No. 1-c Navajo (AmStrat)	San Juan Co., NM	Sec. 8, T. 31 N., R. 18 W.
122	Humble Oil and Refng Co. No. 1-B Navajo (AmStrat)	San Juan Co., NM	Sec. 29, T. 32 N., R. 20 W.
123	Honolulu Oil Co. Navajo No. 1 (AmStrat)	San Juan Co., NM	Sec. 6, T. 31 N., R. 17 W.
124	Texas Co. Navajo A No. 1 (AmStrat)	San Juan Co., NM	Sec. 34, T. 31 N., R. 17 W.
125	Continental Unit No. 1 (AmStrat)	San Juan Co., NM	Sec. 17, T. 26 N., R. 18 W.
126	Stanolind Oil and Gas Navajo Tribal (AmStrat)	San Juan Co., NM	Sec. 12, T. 29 N., R. 17 W.
127	Southern Union Barker No. 17 (AmStrat)	San Juan Co., NM	Sec. 27, T. 32 N., R. 14 W.
128	Delhi Ute No. 4 (AmStrat)	San Juan Co., NM	Sec. 10, T. 32 N., R. 14 W.
129	Skelly Navajo No. 1-B (AmStrat)	San Juan Co., NM	Sec. 14, T. 26 N., R. 12 W.
130	Stanolind Oil and Gas Unit No. 1 (AmStrat)	Rio Arriba Co., NM	Sec. 11, T. 31 N., R. 6 W.
131	T. W. Doswell Scott Fed. No. 1 (AmStrat)	Rio Arriba Co., NM	Sec. 10, T. 26 N., R. 6 W.
132	Amerada Petr. Corp. Allison Unit No. 1 (AmStrat)	Rio Arriba Co., NM	Sec. 17, T. 32 N., R. 6 W.
132a	Vernal (CNH-TEM)	Uintah Co., UT	Sec. 7, T. 3 S., R. 22 E.
133	Gulf Oil Ute Fed. No. 1 (AmStrat)	Uintah Co., UT	Sec. 12, T. 4 S., R. 22 E.
134	Phillips Petroleum Watson B No. 1 (AmStrat)	Uintah Co., UT	Sec. 34, T. 9 S., R. 25 E.
135	Phillips Petroleum Two-waters No. 1 (AmStrat)	Uintah Co., UT	Sec. 22, T. 14 S., R. 25 E.
136	Carter Oil Co. Minton State No. 1 (AmStrat)	Uintah Co., UT	Sec. 32, T. 14 S., R. 20 E.
137	Pacific Western Unit No. 1, Gordon Cr. (AmStrat)	Carbon Co., UT	Sec. 24, T. 14 S., R. 7 E.

138	Equity Oil Co. Mounds Gov't. No. 1	Carbon Co., UT	Sec. 35, T. 15 S., R. 12 E.
139	Gothic (DGMc)	Gunnison Co., CO	Sec. 35, T. 12 S., R. 86 W.
140	Mounds (LCC & VLF)	Carbon Co., UT	Sec. 17, T. 16 S., R. 12 E.
141	Summerville Draw (LCC & VLF)	Emery Co., UT	Sec. 12 & 23, T. 18 S., R. 13 E.
142	Tidwell Ranch (LCC & VLF)	Emery Co., UT	Sec. 27, T. 21 S., R. 14 E.
143	Little Grand Fault (LCC & VLF)	Emery Co., UT	Sec. 29, T. 21 S., R. 16 E.
144	Great Western Drilling & R. S. Berman, Fed. No. 1 (AmStrat)	Grand Co., UT	Sec. 21, T. 18 S., R. 24 E.
145	Cabeen Explor. Corp. State No. 1 (AmStrat)	Grand Co., UT	Sec. 36, T. 20 S., R. 21 E.
146	Equity Oil Co. Gov't. No. 1 (AmStrat)	Grand Co., UT	Sec. 20, T. 21 S., R. 23 E.
147	Floy (PJK & GAW)	Grand Co., UT	Sec. 26, T. 22 S., R. 17 E.
148	Colona (DGMc)	Ouray Co., CO	Sec. 4, T. 46 N., R. 8 W.
149	San Rafael River (AAB)	Emery Co., UT	Sec. 26, T. 22 S., R. 14 E.
150	Buckhorn Flat (LCC & VLF)	Emery Co., UT	Secs. 2 & 3, T. 19 S., R. 9 E.
151	Drunk Man's Point (LCC & VLF)	Emery Co., UT	Sec. 31, T. 21 S., R. 8 E.
152	Horn Silver Gulch (JG & JBR)	Emery Co., UT	Sec. 35, T. 20 S., R. 8 E.
153	Last Chance (LCC & VLF)	Sevier Co., UT	Sec. 6, T. 25 S., R. 6 E.
154	Hanksville (LCC & GAW)	Wayne Co., UT	Sec. 13, T. 28 S., R. 10 E.
155	Spring Canyon (LCC & VLF)	Garfield Co., UT	Secs. 8 & 17, T. 32 S., R. 8 E.
156	Halls Creek-The Post (LCC)	Garfield Co., UT	Sec. 24, T. 34 S., R. 8 E.
157	Pine Creek (VLF, TEM, GWW)	Garfield Co., UT	Sec. 24, T. 34 S., R. 2 E.
158	Shootering Point (LCC)	Garfield Co., UT	Sec. 31, T. 35 S., R. 11 E.
159	Cebolla (DGMc)	Gunnison Co., CO	Sec. 28, T. 49 N., R. 3 W.
160	Butler Wash (LCC)	San Juan Co., UT	Sec. 28, T. 38 S. R. 21 E.
161	Blanding (DGMc)	San Juan Co., UT	Sec. 19, T. 38 S., R. 23 E.
162	Recapture Creek (LCC)	San Juan Co., UT	Sec. 18, T. 40 S., R. 23 E.
163	Desert Creek (LCC, JDS, TEM, JWH)	San Juan Co., UT	Sec. 23, T. 42 S. R. 23 E.
164	Hatch Trading Post (LCC & VLF)	San Juan Co., UT	Sec. 14, T. 39 S., R. 25 E.
165	Hatch Trading Post (EBE & FNH)	San Juan Co., UT	(Approx.) Sec. 24, T. 39 S., R. 24 E.
166	White Mesa (LCC)	San Juan Co., UT	Sec. 2, T. 39 S., R. 22 E.
167	Navajo Point (VLF, TEM, GWW)	Kane Co., UT	Sec. 14, T. 41 S., R. 8 E.
168	Ruby (LCC)	Mesa Co., CO	Sec. 6, T. 10 S., R. 103 W.
169	Drill hole DVR-1 (DRS)	San Miguel Co., CO	Sec. 30, T. 43 N., R. 16 W.
170	Drill hole DVR-2 (DRS)	San Miguel Co., CO	Sec. 36, T. 44 N. R. 18 W.

171	Factory Butte (LCC & VLF)	Emery Co., UT	Sec. 33, T. 26 S., R. 9 E.
172	Caineville (LCC)	Wayne Co., UT	Sec. 15, T. 28 S., R. 8 E.
173	Unnamed locality (DGMc)	Delta Co., CO	Sec. 30, T. 15 S., R. 92 W.
174	Unnamed locality	Delta Co., CO	Sec. 35, T. 15 S., R. 92 W.
175	Little Snake River (CNH)	Moffat Co., CO	Sec. 32, T. 7 N., R. 98 W.
176	Woody Creek Quad. (VLF) GQ-967	Pitkin Co., CO	Sec. 34, T. 8 S., R. 86 W.