GEOLOGICAL CHARACTERIZATION OF NEW MEXICO URANIUM DEPOSITS FOR EXTRACTION BY IN SITU LEACH RECOVERY

New Mexico Bureau of Mines and Mineral Resources
Open-File Report No. 251

by

Harlen K. Holen[1]
and
William O. Hatchell[2]

Funded
by
New Mexico Energy and Minerals Department

August 1986

1 Consulting Geologist (U.S. Dept. of Energy, retired)
2 Staff Geologist, New Mexico Energy and Minerals Dept.

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

Sandstone-type uranium deposits, which in general are in a geologic setting favorable for exploitation by in situ leach (ISL), are located primarily in the San Juan Basin and account for more than 99 percent of New Mexico's remaining reserves of more than 367,000 tons of U_3O_8. The Morrison Formation, and to a lesser extent, the Dakota Sandstone, account for the bulk of the reserves amenable to exploitation by ISL. The Todilto Limestone, which has accounted for about two percent of New Mexico's uranium production, is probably unsuitable for ISL production. Two general types of deposits occur in the Morrison Formation: primary and redistributed. Uranium in primary deposits is coextensive with an amorphous high-carbon organic material commonly called humate. Although specific leach effectiveness data are lacking, the association with humate results in a reduction in host rock permeability and in uranium mobilization that would be expected to have an adverse effect on recovery. In contrast, the ratio of humate to uranium in redistributed deposits is highly variable and in some deposits humate is virtually absent. In many respects redistributed deposits are similar to the roll-type deposits that have been exploited successfully by ISL in Texas and Wyoming. About 83 percent of the remaining reserves in New Mexico are at depths exceeding 1,000 feet and extend to depths of over 4,000 feet, but most of the more amenable redistributed deposits are at depths of 2,000 feet or less. Primary ore is the dominant ore type in most areas except Church Rock where redistributed ore is dominant. Subequal mixtures occur in deposits at Crownpoint. There has been no commercial-scale ISL production in New Mexico and recovery factors at several pilot operations are largely unknown. Mobil's South Trend Development Area project at Crownpoint has

been the most extensively tested and is reportedly considered to be successful from the standpoint of recovery as well as groundwater restoration. The Crownpoint deposits are at a depth of 2,000 feet compared to depths of less than 800 feet for Texas and Wyoming deposits. Although the amount of uranium recovered from a specific ore block is generally less by ISL than by conventional mining, ISL may allow exploitation of lower grade fringes or isolated ore pods, thus expanding the resource target. A type of ISL involving the recovery of uranium from mine waters, where uranium values are augmented by percolating the waters through old stopes, historically has accounted for approximately 100 or more tons of U_3O_8 per year or between one to five percent of annual New Mexico production. This low-cost form of leach recovery is largely supplanting conventional mining in New Mexico during the currently depressed state of the uranium industry. Effective June 1, 1986, the Nuclear Regulatory Commission (NRC) acquired regulatory responsibility from the State of New Mexico over uranium milling and licensing activities in the state including ISL operations. Details of long-term NRC jurisdiction have yet to be resolved, but over the short-term, the NRC has essentially adopted existing State requirements, details of which are summarized in this report.

INTRODUCTION AND OBJECTIVES

The purpose of this report is to provide information on the location, magnitude, depth and geologic setting of uranium resources in New Mexico that could theoretically be exploited by in situ leach (ISL) methods. ISL technology has the potential for playing an important role in the restructuring and revitalization of the uranium industry in New Mexico where significant reserves appear to be suitable for ISL extraction. Although a detailed analysis of the technical and cost aspects of producing uranium by ISL is not intended, it is hoped that this study will provide background information for possible future studies of this nature. Site-specific descriptions of all ISL pilot projects planned or completed to date in New Mexico are included in addition to a review of ISL permitting and licensing.

Conventional ISL (also called "solution leach mining", "solution mining", "leach mining") consists of injecting a leaching solution (lixiviant) into a mineralized zone through injection wells. The leach solution migrates through the zone, dissolves the uranium values and is pumped to the surface through production wells. The pregnant (uranium bearing) solution then goes to a conventional uranium recovery system where uranium is precipitated by ion exchange (IX). The residual barren solution is regenerated with suitable leaching chemicals and recirculated to the well field.

Criteria used to judge the suitability of an ore deposit for uranium recovery by ISL include: (1) the ore must be located in a saturated zone that remains at all times below the water table; (2) the ore zone should occur in a generally horizontal bed geologically confined by relatively impermeable strata so as to retrieve as much of the leach solution as possible for economical and environmental reasons; (3) the orebody must possess adequate permeability, and (4) the orebody must be amenable to chemical leaching. With the possible exception of items 3 and 4, most uranium deposits in the San Juan Basin (which comprise over 99 percent of identified reserves in New Mexico) appear to meet these criteria. Little is known about the chemical amenability of organic, carbon-rich, primary ores although primary ores are known to be less permeable than redistributed ores.

A large portion of New Mexico deposits are beyond the depths exploited by commercial-scale ISL operations elsewhere in the United States. They are also more variable in habit and in mineralogical and trace element associations than the roll-type deposits that have been exploited by ISL in Texas and Wyoming. Most importantly, the coextensive association of uranium in Grants-type primary ores with an amorphous organic material (humate) that coats and is interstitial to sand grains results in a reduction in permeability and in mobilization problems that would be expected to have an adverse affect on leaching. This coextensive association with humate, however, is not characteristic of Grants redistributed ores or of Wyoming and Texas roll-type ores.

Almost all of New Mexico's uranium production has been from the San Juan Basin (Fig. 1). Historically, the San Juan Basin is the most productive uranium mining area in the United States, having produced about 40 percent of the nation's uranium ore. Moreover, it contains about 40 percent (U.S. Department of Energy $50 per pound cost category) of the nation's reserves, and there are excellent possibilities of finding additional deposits.

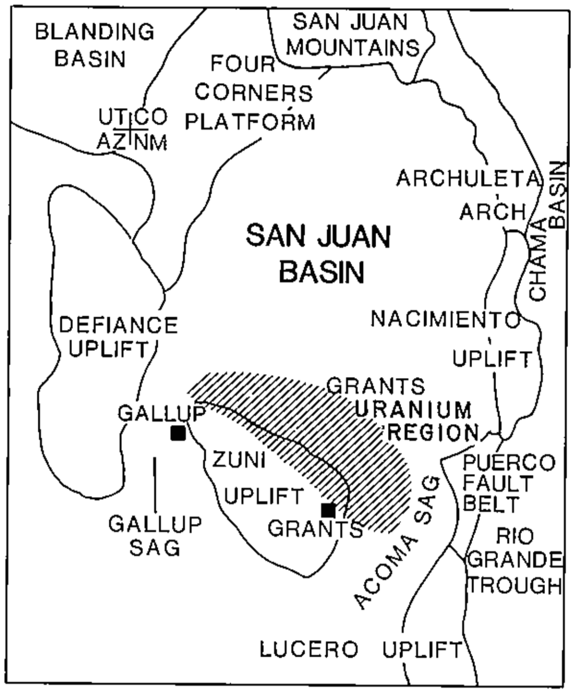


Figure 1. Index map of the San Juan Basin, Grants Uranium Region (hachured), and adjacent areas (modified from Green, 1980).

Most of the production has been from the Morrison Formation in the Grants Uranium Region. Production has been mostly from many large underground mines and a few large open-pit mines. The remaining reserves are largely beyond open-pit depths.

There has been no production on a commercial scale from conventional ISL projects in New Mexico, although there have been a few pilot projects. Of note are Mobil Oil Corporation's Crownpoint pilot projects where uranium deposits are at a depth of about 2,000 feet which is over twice the depth of the deepest ISL projects elsewhere in the United States.

Relatively minor production has been obtained by a type of ISL involving the recovery of uranium from mine waters where the uranium values are augmented by recirculating water through old stopes via surface drill holes. This recovery technique will also be discussed in detail.

The study focuses mainly on deposits in the Morrison Formation in the Grants Uranium Region since most of the identified reserves are in this unit. In the San Juan Basin, significant but relatively small sandstone-type deposits also occur in the Dakota Sandstone in the Church Rock area, and in the Burro Canyon(?) Formation in the Carjilon area (Table 1). The Todilto Limestone in the Grants Uranium Region, which has accounted for about two percent of total production, is quite impermeable and is unlikely to be amenable to production by ISL.

The deposits in the Morrison Formation are in the Salt Wash Member in the East Carrizo (Ship Rock) area; in the Recapture and Salt Wash Members in the Sanostee (Chuska) area; and in the Westwater Canyon and Brushy Basin Members in the Grants Uranium Region. The Westwater, and to a lesser extent the Brushy Basin, are by far the most important host rocks.

Beyond the San Juan Basin, significant but relatively small sandstone-type deposits occur in the Galisteo Formation in the Hagan Basin, and in the Crevasse Canyon and Baca Formations in the Riley-Pie Town areas.

Table 1. Host rocks in the San Juan Basin by mining area or district (see Plates 1 and 2).

Area	Host rock
Bernabe	Westwater
Marquez	Westwater
Laguna	Jackpile Sandstone
Ambrosia	Westwater (some Poison Canyon)
Poison Canyon	Brushy Basin (Poison Canyon)
Blackjack (Smith Lake)	Brushy Basin (Poison Canyon) - one large deposit, the Blackjack No. 1 is in Westwater
Crownpoint	Westwater
Nose Rock	Westwater
Church Rock (Gallup)	Westwater
Sanostee (Chuska)	Recapture & Salt Wash [Exxon, Tocito dome deposit in Westwater (?)]
East Carrizo (Ship Rock)	Salt Wash
Canjilon	Burro Canyon (?)

URANIUM DEPOSITS IN THE SAN JUAN BASIN

Grants Uranium Region

Morrison Formation

Most of the deposits are within the main sandstone bodies of the Westwater Canyon Member. Large deposits are also found in a series of sandstone beds, known collectively as the Poison Canyon sandstone of economic usage, which occur near the base of the Brushy Basin Member in the Blackjack (Smith Lake), Poison Canyon, and Ambrosia Lake mining areas. Deposits also occur in sandstone lenses higher in the Brushy Basin in the Blackjack (Smith Lake) mining area. In the Laguna district a bed of sandstone overlying the Brushy Basin, the Jackpile Sandstone Member of the Morrison (Owen, 1984), contains the large Jackpile-Paguate, L-Bar and Saint Anthony deposits. Figure 2 shows the relationships of the deposits in the various Morrison units. The Westwater is up to 350 feet thick, the Poison Canyon ranges to 80 feet thick, and the Jackpile is as much as 230 feet thick (Fig. 3).

Typically, at any given property, ore will occur in permeable sandstone beds separated by impermeable mudstone beds at several different horizons (Fig. 4). For this reason the isodepth contours on Plate 1 and Plate 2 can only be used as a rough guide in estimating the depth of the deposits. The deposits may occur anywhere from the base of the Westwater to 300 feet or more above the base, as well as in the Poison Canyon and other sandstone lenses in the Brushy Basin and in the Jackpile Sardstone.

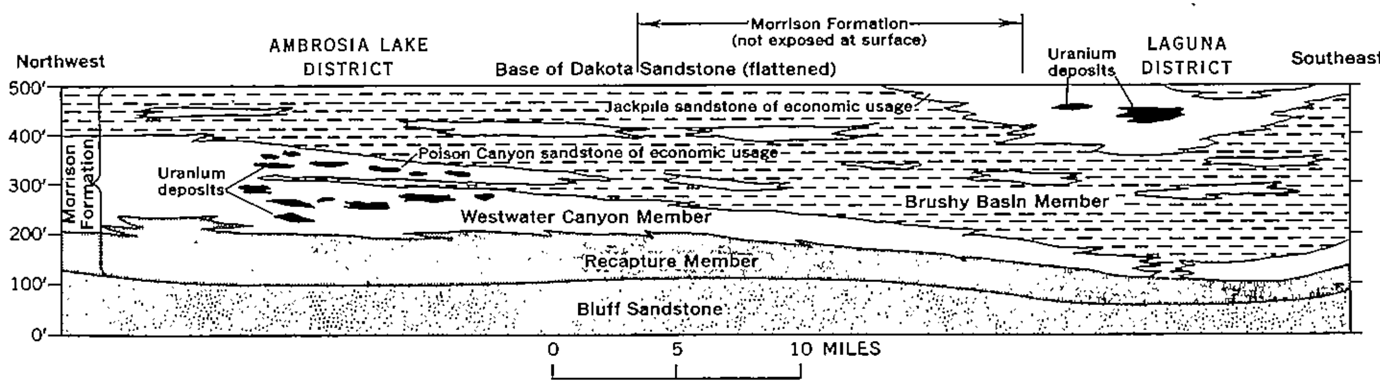


Figure 2. Generalized geologic section showing the stratigraphic relations of the Morrison Formation between Ambrosia Lake and Laguna (from Hilpert, 1969).

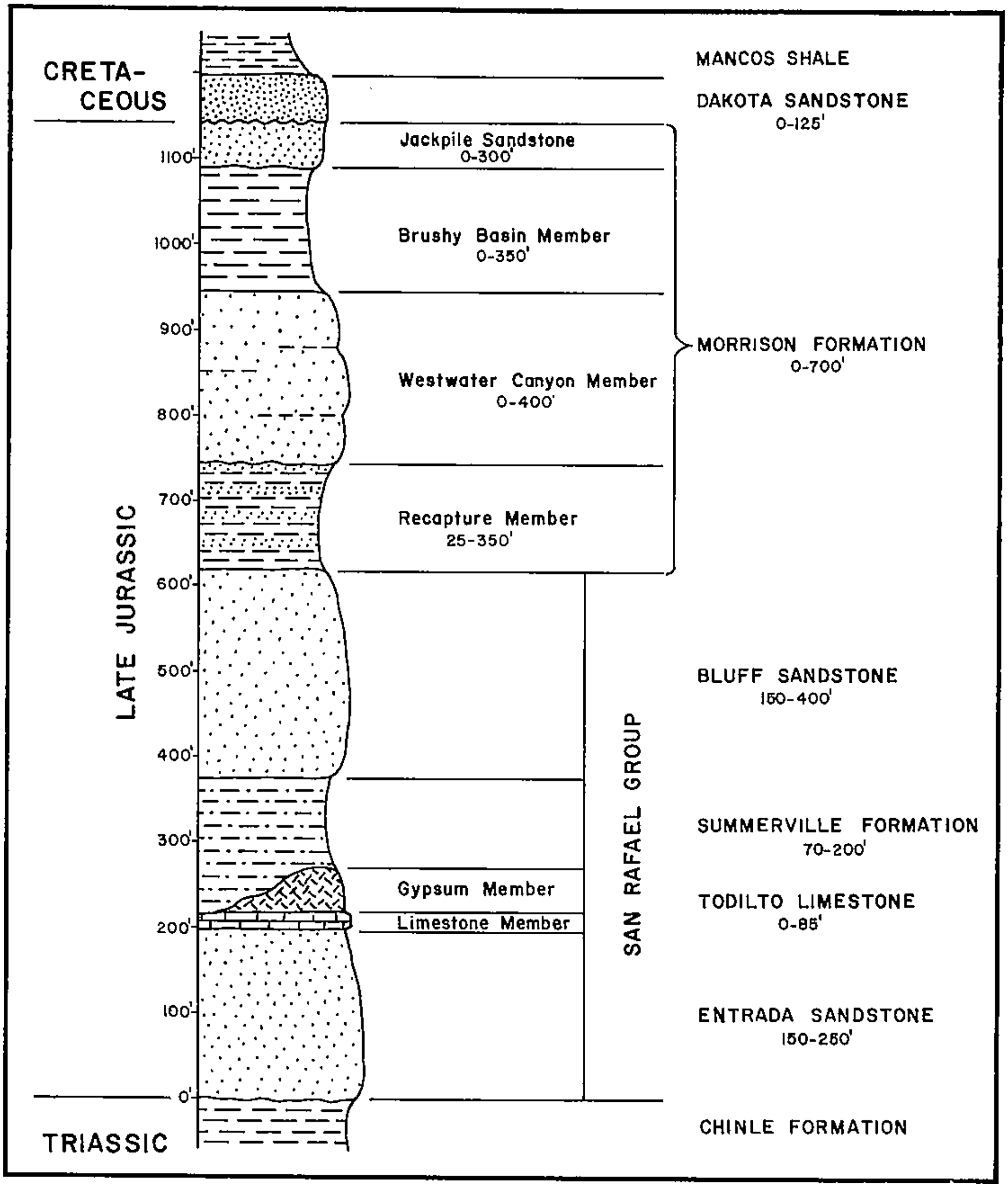


Figure 3. Columnar section for Jurassic rocks in the Grants Uranium Region (Adams and Saucier, 1981).

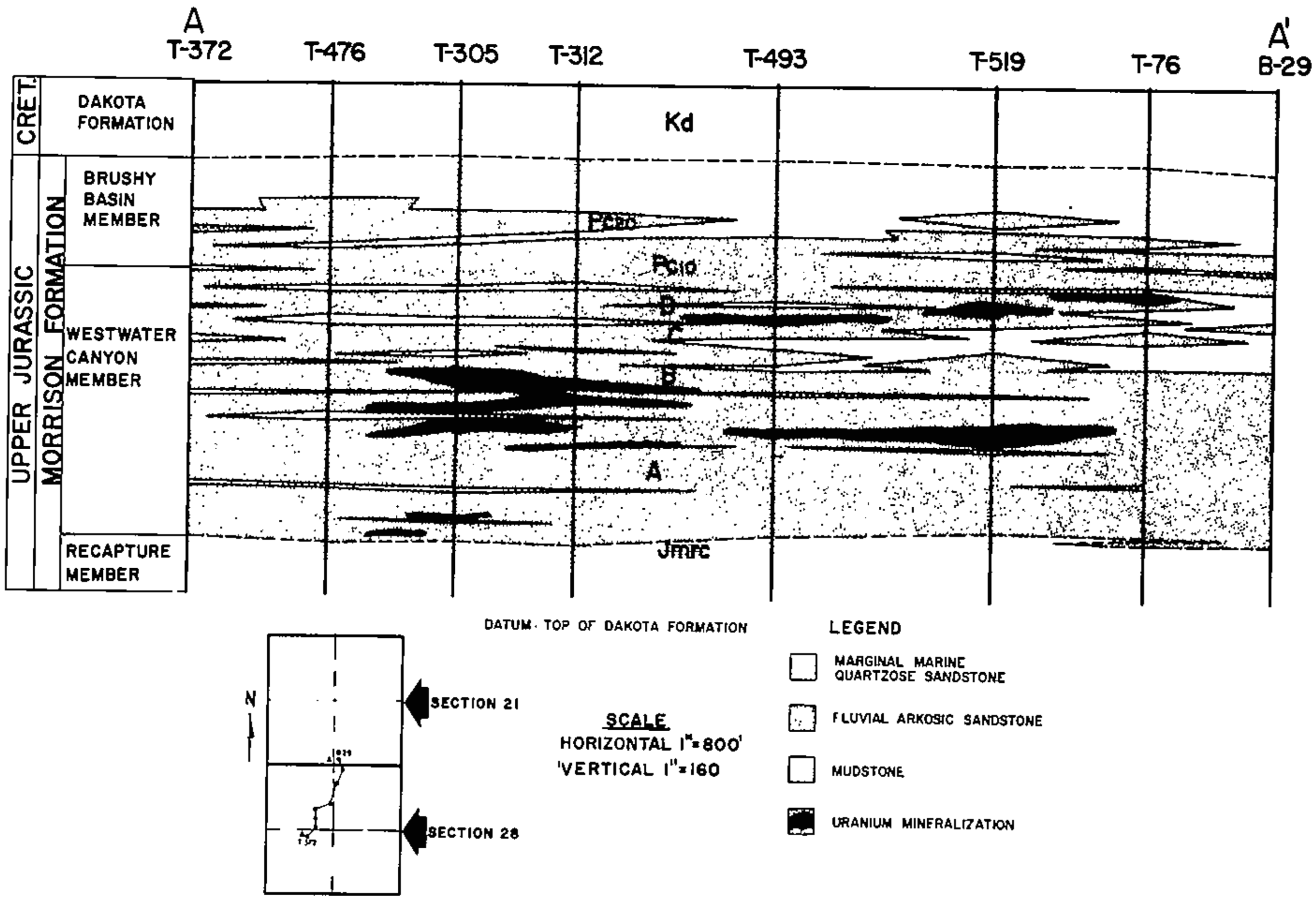


Figure 4. Stratigraphic cross section showing general stratigraphic relationships of the Morrison Formation and localization of uranium deposits (Smith and Peterson, 1980).

The deposits are, in general, lenticular tabular masses that are roughly parallel to the bedding and elongated in the direction of sediment transport of the host rocks. They are of two general types: primary and redistributed. Figure 5 summarizes the characteristics of the two types of ore deposits in the southwestern Ambrosia Lake area as they occur in the Westwater Canyon Sandstone. The uranium geology of Ambrosia Lake Poison Canyon and Todilto Limestone ore trends is depicted in cross section in Figure 6.

Characteristics of Primary and Redistributed Ore Deposits

Primary deposits (also called "pre-fault ore", "trend ore", "black-band ore") are pre-Dakota in age and are characterized by (1) being generally less than 8 feet thick; (2) having ore grades generally averaging greater than 0.20 percent U_3O_8; (3) being offset by Laramide-Tertiary faults; (4) having sharp ore-to-waste boundaries; and (5) having dark gray to black colors. The dark colors are primarily due to an amorphous organic substance called humate which coats, and is interstitial to, sand grains and which is coextensive with uranium at an approximate ratio by weight percent of 1:1 (Granger and others, 1961). A variety of orebody characteristics has resulted in confusion regarding habit and geometry of primary ore. At least three types of primary ore are described in the literature (Crawley, Holen and Chenoweth, 1982): (1) blanket ore -- an undulating blanket with pronounced subparallel thickenings, variously called rolls, trends or runs, that are subparallel to the direction of sediment transport; (2) channel ore -- ore that commonly follows individual sandstone channels for distances of several hundred feet to over a mile;

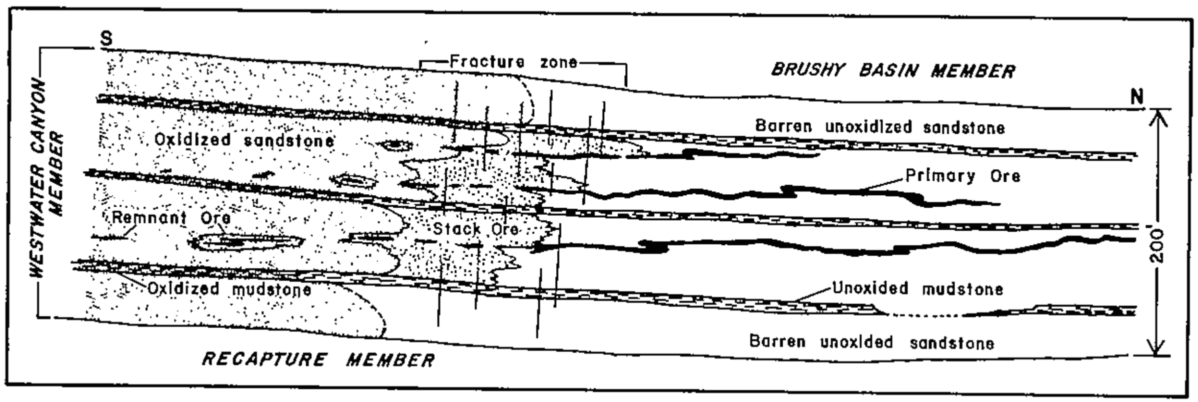


Figure 5. Idealized cross section showing stack (redistributed) and primary ore as it exists in the southwestern Ambrosia Lake area (modified from Roeber, 1972).

ORE CHARACTERISTICS—MORRISON FORMATION

PRIMARY ORE
(Also called prefault ore, trend ore, black band ore)

- Thin—generally < 8 feet.
- Higher grade—generally averages >0.20% U_3O_8.
- Offset by Laramide-Tertiary faults.
- Sharp ore to waste boundary.
- Coextensive with humate and/or carbonized vegetal material.
- Color—dark gray to black.
- Age—Pre-Dakota; field relationships indicate that at least some primary ore is immediate post-depositional in age.

REDISTRIBUTED ORE
(Also called postfault ore, stack ore, secondary ore)

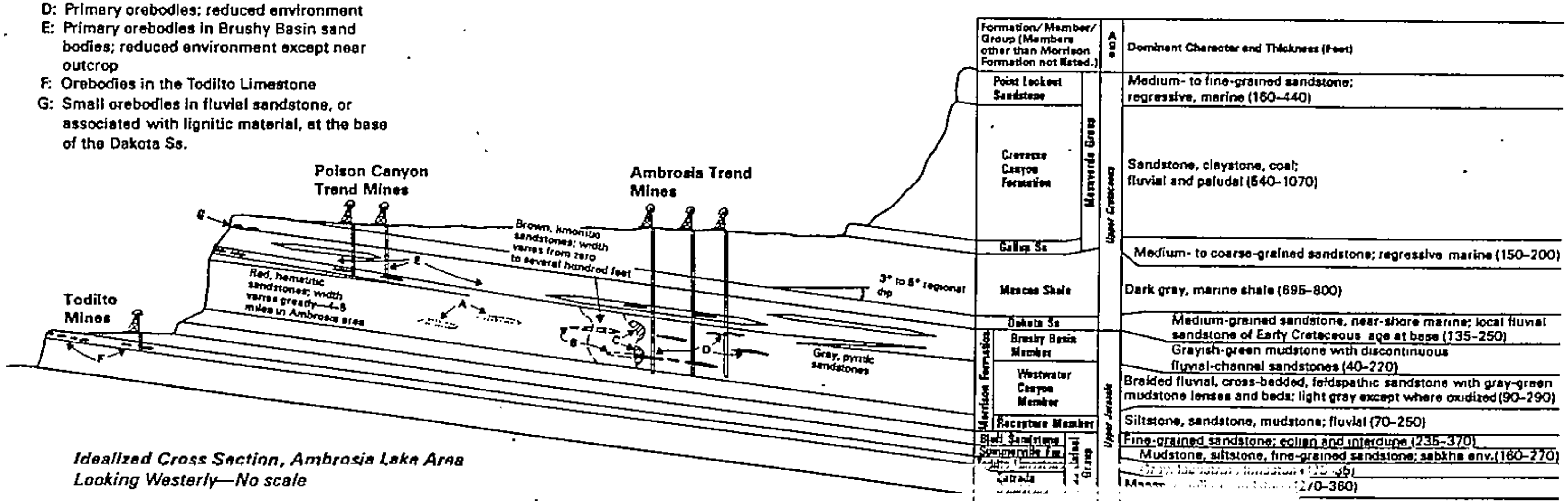
- Thick—generally > 10 feet, up to 150 feet.
- Lower grade—generally < 0.20% U_3O_8.
- Sometimes localized by Laramide-Tertiary faults and fractures.
- Diffuse ore to waste boundary.
- May or may not be associated with humate or carbonized vegetal material.
- Color varies from dark brownish gray to light gray, probably depending on amount of humic material present.
- Age—oxidation that resulted in the redistribution of primary ore started after regional uplift and erosion in late Miocene or early Pliocene time and continues to the present.

TYPES OF PRIMARY ORE

A variety of orebody characteristics has resulted in different interpretations of ore habit and genesis. At least three types of primary ore are described in the literature.

1. Blanket Ore: Undulating blanket with pronounced, ESE-trending thickenings or "rolls"; coextensive with humate; very little vegetal material.
2. Channel Ore: Stronger facies control than blanket type; sometimes follows individual channels from hundreds to a few thousand feet; associated with more carbonized and silicified vegetal material (plus humate) than blanket ore.
3. Wyoming Roll-Type Ore: Pre-Dakota age; geometry in plan and cross section is similar to Wyoming rolls, but upper and lower limbs are generally wider; oxidized interior has been rereduced. Note: Not to be confused with redistributed ore which is also thought to be genetically similar to Wyoming roll ore.

A: "Ghost orebodies"; oxidized environment
B: Remnant primary orebodies; oxidized environment
C: Redistributed orebodies at advancing Tertiary-Quaternary oxidation front
D: Primary orebodies; reduced environment
E: Primary orebodies in Brushy Basin sand bodies; reduced environment except near outcrop
F: Orebodies in the Todilto Limestone
G: Small orebodies in fluvial sandstone, or associated with lignitic material, at the base of the Dakota Ss.



Idealized Cross Section, Ambrosia Lake Area
Looking Westerly—No scale

Harlen K. Holen
U.S. Dept. of Energy
Grand Junction Area Office
October, 1981

Figure 6. Idealized cross section, Ambrosia Lake area, summarizing the uranium geology of the Grants Uranium Region (Holen, 1982).

and (3) roll-front ore (Clark, 1980) -- ore that is similar in geometry to that of Wyoming roll-front deposits, except that the upper and lower limbs are wider and thus could be confused with blanket-type deposits. Roll-front, primary ore is thought to be pre-Dakota in age, is humate-rich (Clark, 1980), and should not be confused with redistributed ore.

Redistributed deposits (also called "post-fault ore", "stack ore", "secondary ore") are much younger than primary deposits and are simply remobilized and reprecipitated primary deposits that formed on the fringes of an advancing regional oxidation (redox) front that started after regional uplift and erosion in Late Miocene or Early Pliocene time and continues to the present. They are characterized by (1) being generally more than 10 feet and up to 150 feet thick; (2) having ore grades generally averaging less than 0.20 percent U_3O_8; (3) being commonly localized by faults that offset primary ore; (4) having diffuse ore-to-waste boundaries and (5) having brownish-gray to light gray colors. Primary ore is sometimes found remote from redistributed ore, but redistributed ore is usually in proximity to primary ore.

Minerals that occur with primary ore include jordisite, ferroselite, pyrite, marcasite, calcite and kaolinite (Granger and Santos, 1982). Molybdenum in the form of jordisite, and commonly selenium, are zonally distributed around primary ore bodies. Vanadium minerals, pyrite, ferroselite, and elemental selenium are associated with redistributed ores, but molybdenum is virtually absent. Selenium is commonly concentrated near the contact of oxidized and reduced rock.

In contrast to primary ore, the ratio of uranium to humate in redistributed ore is highly variable. This apparent variability may be due to the fact that the two types of ore are commonly complexly intermixed near the edge of oxidized tongues. Granger and Santos (1981) note that redistributed ore at the Section 23 mine in the Ambrosia Lake area is essentially free of organic carbon. Fishman and Reynolds (1983) report that on the basis of young isotopic age dates, all of the ore at the Church Rock No. 1 and No. 1 East mines in the Church Rock area may be redistributed, and they found organic carbon contents in ore samples to be uniformly low with most less than 0.01 percent.

The principal control of redistributed ore is the oxidized tongue. The shape of the tongue and the shape of the ore are dependant on permeability factors which are influenced by fractures and by sedimentary structures and textures. In unfaulted areas redistributed ore is generally thinner than in faulted areas. In faulted areas bodies of redistributed ore as much as 150 feet thick have been encountered in the Section 23 mine (William Harrison, Homestake Mining Company, written communication, Sept. 1981).

In many respects redistributed ore is similar in habit and genesis to the roll-front ores of Wyoming and Texas. The occurrence of ore at the boundary between oxidized and reduced sandstone is the most important similarity. Although some Texas deposits are wholly within reduced sandstone, it is thought that oxidized tongues were subsequently re-reduced (Adams and Smith, 1980). Redistributed deposits sometimes assume the C-shape geometry of Wyoming and Texas roll-type deposits, but usually they do not. Grants redistributed ores differ from the Texas and Wyoming ores in that they consist of redistributed ore derived from a precursor primary ore layer which has been partially destroyed by encroachment of oxidation.

Although some organic carbon is present in Wyoming and Texas deposits and in New Mexico redistributed deposits, there is no direct correlation of uranium and organic carbon as there is in primary deposits. Harshman and Adams (1980) state that "There seems to be no consistant direct correlation between the organic carbon and uranium contents of mineralized sandstone, a fact that throws some doubt on the belief that organic carbon was directly involved in the precipitation of uranium in roll-type uranium deposits." Moreover, Adams and Smith (1980) state that "...the uranium deposits in south Texas, with the exception of the deposits in the Jackson Group and possibly the Carrizo Sand, contain negligible quantities of carbonaceous material." The organic carbon that is present in the Wyoming and Texas deposits is usually in the form of vegetal detritus and not humate.

From an ISL standpoint, the most significant difference between Grants primary ores and Grants redistributed and Wyoming and Texas roll-type ores may be the association with humate. The humate associated with primary ore significantly reduces permeability of the ore and could be expected to have an adverse effect on leaching chemistry. Vogt and others (1982a) state that at Mobil's Crownpoint ISL project "The shielding of coffinite by organic material would be expected to adversely affect leachate contact of the uranium mineral and reduce leaching efficiency" and that "Due to the heterogeneity observed in the mineralogy of the Crownpoint ores, areal leaching effectiveness would be expected to be very dependent on the characteristics of the individual ore trends." They reported that coaly kerogen comprised most of the humate. Although erratic in distribution calcite cement, in addition to humate, is sometimes present in quantities sufficient to seriously affect the permeability of primary ore.

The high-organic carbon ores are known to be a problem in conventional uranium mill circuits in the Grants region. These ores are sometimes stockpiled and run through the mills in small amounts with other, less refractory ores. A study by the U.S. Bureau of Mines (Nichols and others, 1979) on ore samples from the Jackpile mine indicated that, using conventional leaching techniques at ambient temperatures, uranium recovery decreased with increasing organic carbon (degraded humate) content and that recovery was very poor from samples with high-carbon organic content. Only by roasting was a high recovery (greater than 95 percent) obtained. The samples ranged from 0.18 percent U_3O_8 and 0.26 percent organic carbon, 0.26 percent U_3O_8 and 0.71 percent organic carbon, and 1.08 percent U_3O_8 and 10.9 percent organic carbon.

That primary ore is resistant to dissolution by geochemical processes is evidenced by the fact that remnant bodies of primary ore completely surrounded by oxidized rock have been found for a distance of over one-half mile behind the regional oxidation front (Fig. 7). Leventhal (1980) states that "The organic material also plays a role in preserving the deposit: coatings of amorphous and refractory (due to oxidation, radiation, and time) organic material on uraninite and coffinite molecules can protect the uranium from oxidation or mobilization. The organic material fills the interstices, thus decreasing possible water flow."

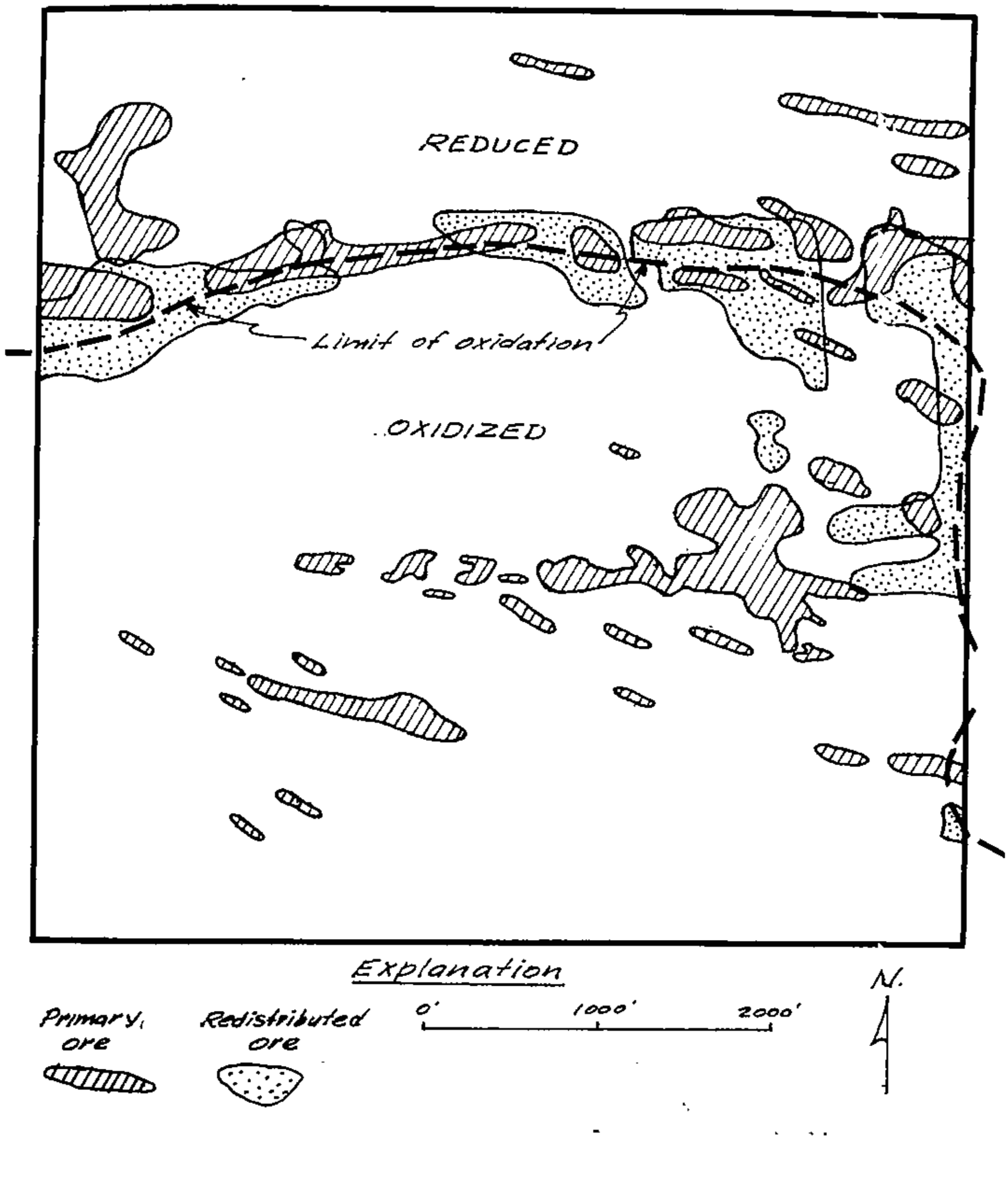


Figure 7. Areal distribution of known ore bodies in section 23, T.14 N., R.10 W. showing their relation to the regional oxidation front. (adapted from a map in a unpublished report by William Harrison, Homestake Mining Co; limit of oxidation is from Granger and Santos, 1981, p. 9).

It is not intended in the above discussion to imply that primary deposits are necessarily unfavorable for production by ISL. The generally higher grades of primary ore could tend to offset the unfavorable aspects. William Harrison, in a discussion of the Homestake Mining Company mines on the west end of the Ambrosia Lake trend (written communication, September 1981), notes that "Primary ore is of rather high grade, sometimes attaining U_3O_8 content of over 10 percent. The mining grade of such ore is usually considerably lower than the grade of an ore sample due to dilution from surrounding barren rock that must be taken. Nevertheless, stopes in primary ore frequently average 0.30 percent and higher". In contrast, he notes that "The grade of secondary ore is noticeably lower than that of primary ore. While the grade of an individual sample may reach approximately 0.40 percent, stopes in secondary ore normally average between 0.10 and 0.20 percent."

More research data are needed to determine relative ISL favorability under various combinations of deposit type, grade, depth and price. The need for conducting site-specific pilot operations before going into a full-scale operation is a recurrent theme in the literature on ISL. This may be especially true in the Grants Uranium Region where the ores are more complex than they are in the roll-type deposits of Wyoming and Texas.

Areal Distribution of Primary and Redistributed Ore in the Morrison Formation in the Grants Uranium Region

The general areal distribution of the two ore types in the Grants Uranium Region is discussed in the following paragraphs. Published data are insufficient to categorize each deposit, but there is believed to be sufficient information so that a reasonable extrapolation can be made for each of the major ore areas. For the location of the areas see Plate 2.

Church Rock area: dominantly redistributed

Fishman and Reynolds (1983) report that most of the ore in the Church Rock No. 1 and No. 1 East mines is redistributed. They found the organic carbon content of ore samples to be mostly less than 0.01 percent. Adams and Saucier (1980) state that in the Northeast Churchrock mine "stack [redistributed ?] ore occurs in every sandstone unit from the top to the bottom of the Westwater Canyon Member ...".

Peterson (1980) reports that most of the deposits in section 13, T.16 N., R.17 W. are in elongate tabular masses that are associated with humate which would indicate that they are primary deposits. The deposits appear to him to be genetically related to a hematitic oxidation front which he believes was generated during the Late Jurassic-Early Cretaceous erosional interval.

Crownpoint area: mixed

Day and others (1983) note that in the vicinity of the Dalton Pass deposits the distribution of selenium, uranium, vanadium and molybdenum is similar to that in the roll-type deposits in Wyoming and Texas. However, they are unclear as to whether they believe the deposits are pre-Dakota roll deposits or if they are redistributed deposits associated with the Tertiary oxidation front.

Wentworth, Porter and Jensen (1980) report that in the Crownpoint section 20 deposit "Rubidium-strontium age dating of ore stage clay minerals supports a Late Jurassic age (139 m.y.) of uranium mineralization...", and that "The controlling factor for ore emplacement seems to have been the presence of large buried masses of organic derivitives." However, they also suggest that some of the ore may have been moved northward by an encroaching regional oxidation front.

Vogt and others (1982b), in a discussion of Mobil Oil Corporation's Crownpoint ISL pilot project, report that "At Crownpoint, we observe two uranium mineral trends. When coffinite is the predominant form, it is intimately associated with carbonaceous material (kerogen). The other type of Crownpoint mineral trend is predominantly uraninite, and while carbonaceous material is present, the finely divided crystals of uraninite are not associated with the organic material in any abundance."

Nose Rock area: primary

Clark (1980) states that the uranium in the Nose Rock area "... is coextensive and intimately associated with black carbonaceous matter", and that "both the Nose Rock ores and the primary Ambrosia Lake uranium ores were emplaced during the Late Jurassic-Early Cretaceous erosional interval under the same geologic conditions by the same geochemical cell process." Although Clark states that the ore is in gray, unoxidized Westwater Canyon sandstones, Adams and Saucier (1981) suggest that recent oxidation has affected the redistribution of mineralization, thus implying that the ores are redistributed. An isotopic date on a single sample of Nose Rock ore, however, indicates that the uranium in that sample was emplaced more than 60 m.y. ago (Harry C. Granger, written communication, June 1983), thus being too old to have been redistributed by oxidation associated with the present erosional interval which started with regional uplift in Late Miocene or Early Pliocene time.

Blackjack (Smith Lake) area: dominantly primary

The Blackjack No. 1 deposit in section 12, T.15 N., R.13 W., which is in the Westwater Canyon Member, is reported by MacRae (1963) to be partly primary ore and partly redistributed ore. Most of the remaining ore in the area is in the Mariano Lake-Ruby Wells trend and is in the Poison Canyon. The ore genesis is interpreted differently by individual geologists.

Pierson, Spirakis and Robertson (1983) state that "The organic-rich character of the Mariano Lake and Ruby deposits indicates they are of primary origin." Fishman and Reynolds (1982) note that in the Mariano Lake deposit "The presence of amorphous organic material suggests the orebody may represent a tabular [primary] deposit, whereas the close proximity of the orebody to the redox interface is suggestive that the uranium was secondarily redistributed by oxidation processes from pre-existing tabular orebodies." They concluded, however, that "Geochemical data (primarily the positive correlation of uranium content to both organic carbon and vanadium contents) indicate that the Mariano Lake orebody is a tabular-type uranium deposit."

Sachdev (1980), based on elemental zonation, association with a redox interface and the "C"-shaped geometry, concludes that the Mariano Lake deposit is roll-type, but is unclear as to whether it is primary or redistributed.

Ristorcelli (1980) notes that the ore in the eastern part of the Smith Lake trend "... generally occurs at the redox boundary, but occasionally will be up to 1,500 feet updip." He suggests that both Late Jurassic, trend-type ore and Laramide or post-Laramide roll-front ore is present.

A polygenetic model is proposed by Place, Della Valle and Brookins (1980) for the Mariano Lake deposit. They believe that elemental associations and the location of ore deposition at an iron-sulfur redox front indicate that the ore appears to have been remobilized in the Cretaceous, or later, from an earlier stage of mineralization deposited in Late Jurassic time.

The writers favor the interpretation that most of the ore is primary and is genetically unrelated to the Tertiary oxidation front, but recognize the enigma over the apparent paucity of organic-poor redistributed uranium in the deposits at the redox boundary. It should be noted, however, that Adams and others (1978) found no secondary uranium concentrations at the redox boundary at the Jackpile-Paguate deposit.

Ambrosia Lake area:

mixed, primary and redistributed - remaining ore mostly primary

The deposits on the western end of the trend are a mixture of primary and redistributed ores with the amount of redistributed ores decreasing with depth toward the east. On the deep eastern end of the trend, the Mt. Taylor, Johnny M, and other deposits are all organic-rich primary ores.

Papers by Granger and others (1961), Granger and Santos (1981), and Gould and others (1963) have good descriptions of the primary and redistributed ores that occur on the western end of the trend. The extensively mined Section 23 and 25 mines are typical of many of the properties in this area. William Harrison, Homestake Mining Company, (personal communication, June 1985) estimates that in Sections 23 and 25 about 60 percent of the tonnage to be mined will be primary ore, and because the primary ore is higher grade, will contain about 70 percent of the pounds of U_3O_8. An accurate estimate is not possible because both types of ore are mined at the same time, sometimes from the same stope, and production is not split out.

The deposits at the Cliffside mine, which are about in the middle of the trend, are associated with considerable oxidation, but the bulk of the ore is remnant primary (George Hazlett, personal communication, February 1986). These exceptionally high-grade deposits contain a large amount of calcite cement which Hazlett believes helped protect them from oxidation and redistribution.

At the Johnny M mine, Falkowski (1980) reports that "All of the ore that has been or is being mined is intimately associated with black to dark brown carbonaceous material in the sandstones; no ore has been found in sandstone devoid of this carbonaceous matter."

At the Mt. Taylor deposit, on the eastern end of the trend, Riese and others (1980) reports that there is a positive correlation between uranium and organic material and that the orebody is not located at an iron redox interface.

<u>Poison Canyon area:</u>

<u>mixed, but dominantly primary</u>

Rapaport (1963) and Tessendorf (1980) note the presence of considerable redistributed ore in the mines on the shallow western end of the Poison Canyon trend but the impression is given that primary ore is dominant. As one progresses eastward, the deposits are deeper and the proportion of redistributed ore lessens.

At the Marquez mine, which is in about the middle of the trend, Weege (1963) reports that almost all of the ore is associated with structureless carbonaceous material and notes that there is no evidence of appreciable oxidation.

The deposits in the easternmost and deepest mine on the trend, the San Mateo mine, have not been described in the literature, but the writers' observations indicate that most if not all of the ore is humate-rich and primary.

Marquez area: dominantly primary

Livingston (1980) states that at the Marquez Canyon and southeast deposits "Ore deposition is peneconcordant and primarily of the pre-fault trend type", and that "... remobilization was probably minimal."

The nearby San Antonio Valley deposit is reported to be a flat-lying, tabular, trend-type deposit (Moore, 1980). Marquez area deposits are in the Westwater Canyon Sandstone.

Bernabe area: dominantly primary

The Bernabe Montano deposit lies at the extreme eastern end of the Grants Uranium Region in Sandoval County. Kozusko and Saucier (1980) describe the deposit as "... stacked blankets of mineralized humate", and state that "The mineralization is clearly prefault in age." They report that some redistribution of mineralization is now taking place along the northern edge of the trends owing to recent incursion of oxygenated ground water, but apparently the redistributed ore is only a very small part of the total ore.

Laguna area: dominantly primary

Features of the Jackpile-Paguate deposit are reviewed by Beck and others (1980) who state that "All significant mineralization in the Jackpile mine occurs in sandstone, where the matrix is impregnated and cemented by dark, epigenetic, carbonaceous material... field and petrographic observations suggest the principal concentrations of uranium were formed early in the history of the Jackpile sandstone, well before the deposition of the Dakota." Adams and others (1978) report that "Recent oxidation has produced hematite and limonite within the sandstone, particularly near outcrops and faults", but that "... no uranium enrichment was observed at the oxidation-reduction boundary in the mine area. although uranium has definitely been leached from the oxidized zones. This alteration is postore and there is no evidence that it formed secondary uranium concentrations as it did locally in the Ambrosia Lake district."

Jacobsen (1980) states that at the L-Bar deposits "Uranium mineralization is coextensive with the presence of carbonaceous material." His observations indicate that the bulk of the carbonaceous material is in the form of finely divided vegetal detritus with a subordinate amount of humate.

Baird, Martin and Lowry (1980) report that at the Saint Anthony mine, well-mineralized rock contains high concentrations of organic carbonaceous material. Although an oxidation front occurs on the south-southwest side of the orebody, oxidation has resulted in destruction of ore, leaving remnants of primary ore.

Dakota Sandstone

A few small to medium-sized uranium deposits occur in the Dakota Sandstone in the San Juan Basin. Most of them, and by far the largest, are in the Church Rock (Gallup) area. The Dakota in the Grants Uranium Region consists of a basal, marginal marine sequence of distributary-channel sandstones, carbonaceous shales, siltstones and thin coal seams; and an upper near-shore marine sequence consisting mainly of fine- to medium-grained sandstone. Most of the deposits are in fine- to coarse-grained sandstones and interbedded carbonaceous shale and lignite in the basal unit (Pierson and Greene, 1980). Uraninite and coffinite are found in deposits that lie below the water table, and in near surface deposits these have been oxidized to form carnotite and other secondary minerals (Kittel, Kelley and Melancon, 1967). The uranium minerals are closely associated with carbonaceous debris. Hilpert (1960) reports that "... the deposits consist of tabular masses that range from thin seams a few feet in width and length to crudely tabular masses as much as 2,500 feet in length and at least 1,000 feet in width. The larger deposits range from a few inches to 25 feet in thickness, but generally average a few feet..."

Total production from the Dakota is approximately 492,000 pounds U_3O_8 (Table 2). The largest deposit probably does not exceed 1.5 million pounds of contained U_3O_8, and the potential for finding larger deposits does not appear to be good as none have been found with all of the thousands of drill holes that have tested the underlying Morrison Formation.

Other Areas in the San Juan Basin (see Plate 1)

Canjilon area

Significant uranium mineralization, as indicated by closely spaced drilling, has been delineated in the Cretaceous Burro Canyon(?) Formation in two areas in the Chama Basin south of the village of Canjilon in T.25 N., R.5 E. (Saucier, 1974). The Burro Canyon(?) is a stream-deposited, conglomeratic sandstone with thin discontinuous lenses of mudstone that lies between the Late Cretaceous Dakota Sandstone and the

Table 2. Uranium production by host rock in the San Juan Basin, New Mexico through 1985 (data compiled from U.S. Department of Energy, 1982, as reported by McLemore, 1983b) and from additions and adjustments to these data through 1985 using New Mexico Energy and Minerals Department production data as reported by uranium operators, and Chenoweth, 1985a and 1985b).

Area	Host Formation	Production (lbs. U_3O_8)	Period
Nacimiento, Farmington	Ojo Alamo, Fruitland, Dakota, Morrison, Todilto, Chinle, and Cutler Formations	2,298	1954-59
Ship Rock-Carrizo Mts.	Salt Wash Member[1]	159,850	1948-67
Sanostee	Recapture Member[1]	331,000[2]	1952-82
	Salt Wash Member[1]	1,858	1952-55
	Todilto Limestone	25	1954
Grants	Dakota Sandstone	492,000[2]	1951-70
	Morrison Formation (Brushy Basin, Westwater Canyon & Jackpile Sandstone Members, Poison Canyon sandstone)	328,150,000[2]	1951-85
	Breccia pipe	134,014	1953-56
	Todilto Limestone[3]	6,671,520	1950-81
	Mine water	4,561,000[2]	1963-85
	TOTAL	340,504,000[2]	1948-85

[1] Member of Morrison Formation
[2] Approximate figure, rounded to nearest 1,000 lbs.
[3] Some 64,480 lbs. formerly credited to the Todilto has been correctly added to the Morrison at Grants (William Chenoweth, written communication, August 1986)

Late Jurassic Morrison Formation. The sandstone bodies are thick, laterally continuous, and possess excellent permeability. Mudstone intervals, and overlying and underlying less permeable rocks of the Dakota Sandstone and Brushy Basin, serve to confine ground water to various parts of the sandstone bodies (Green and others, 1982).

Little has been published about the deposits. They are apparently roll-type deposits at oxidation-reduction interfaces. One deposit lies at or below the water table and the other is well above the water table. Uranium appears to be associated with small amounts of carbonaceous material and pyrite. The size of the deposits is not known, but Saucier (1974) reports that ore-grade material up to 50 feet thick has been penetrated. There has been no production to date from the Burro Canyon(?) in this area.

East Carrizo (Ship Rock) area

The Salt Wash Member of the Morrison Formation is the host rock for significant deposits in the East Carrizo area of San Juan County, New Mexico and in adjacent areas of Arizona. Historically, the area was the first to produce uranium in New Mexico. Production from the East Carrizo area has been relatively small, but mines in the Lukachukai Mountains in Arizona produced considerable ore and the area as a whole supported a mill at Ship Rock from 1954 to 1968. The Salt Wash is an important host rock in the Uravan Mineral Belt in Colorado and Utah.

The Salt Wash is a fluvial-fan deposit consisting of sandstone with lesser amounts of interbedded claystone and siltstone (Fig. 8). It is

Stratigraphy of the East Carrizo Area

System	Formation and member	Thickness, feet	Description
Cretaceous	Dakota sandstone	30	Conglomerates and conglomeratic sandstone, white to grayish-pink; mostly quartz; pebbles up to 4" diameter.
	Burro Canyon formation(?)	100	Sandstone, orange, medium- to coarse-grained; claystone, gray to brown.
Jurassic	Morrison formation		
	Brushy Basin member	85	Siltstone, gray, green, and red;
	Westwater Canyon member	265	sandstones, mostly gray, fine- to coarse-grained, thick; clay-stones, thin, gray-green.
	Recapture member	190	Claystones, grayish-red; sandstones, light brown.
	Salt Wash member	220	Sandstone, light gray to light red, very fine- to medium-grained, cross-bedded, interbedded with claystones, calcareous cement; claystones, thin, mostly red.
	Bluff sandstone	15-20	Sandstone, light brown to orange, frosted quartz grains.
	Summerville formation	135	Sandstones, light red to chocolate brown, laminated, interbedded; fine-grained.
	Todilto limestone	0-3	Limestone, abundant disseminated quartz sand, light gray.
	Entrada sandstone	80	Sandstone, reddish-orange, massive.
	Carmel formation	40	Siltstone and claystone, red, interbedded.
Triassic	Wingate sandstone	350-475	Sandstone, orange, cross-bedded, massive.
	Chinle formation	1000±	Shale and siltstone, red, purple and gray.
	Shinarump member	20	Sandstone, coarse-grained and conglomerate, light gray.
Permian	DeChelly sandstone	200(?)	Sandstone, massive, cross-bedded, light brown to orange.

Figure 8. Stratigraphic section, northwestern Carrizo area (Masters and others, 1955).

about 220 feet thick in the East Carrizo Mountain area. Siltstone and claystone intercalated with the sandstone lenses constitute between 5 and 50 percent of the member and are distributed throughout.

The ore deposits are essentially uranium-bearing vanadium deposits. Chenoweth and Learned (1984) report that the average production grade for the East Carrizo Mountain area (including deposits in adjacent Arizona) was 2.43 percent V_2O_5 and 0.23 percent U_3O_8, a ratio of about 10:1. This compares to a ratio of about 4:1 for ores in the nearby Lukachukai Mountains (Chenoweth and Learned, 1983). Tyuyamunite and metatyuyamunite are the only uranium minerals identified in the Carrizo deposits (Chenoweth and Malan, 1973). Vanadium, clay and montroseite are present and these minerals have been oxidized to form a large number of secondary vanadium minerals. Calcite is a common cementing agent in the ore and pyrite, iron oxides, and gypsum may also be present.

The deposits are largely above the regional groundwater table, and have been mined by open-pit methods, adits, inclined shafts and a few shallow shafts. The orebodies are elongate and lenticular in shape and consist of one or more ore pods surrounded or separated by protore. Claystone and/or siltstone beds nearly always underlie and typically overlie the host sandstone units. Ore occurs most commonly in cross-stratified sandstone which fills scours and channels in the underlying claystone. Detrital cabonaceous material is widely distributed and locally abundant. The majority of the ore in the East Carrizo Mountains is closely associated with carbon trash (Masters and others, 1955).

Sanostee (Chuska) area

Several deposits occur in the Salt Wash and Recapture Members in the Sanostee area. The number of mines is about equally divided between the two members, but the bulk of the production has come from one deposit in the Recapture, the Enos Johnson mine, west of Sanostee in west-central San Juan County. Total production from the area is about 332,900 pounds U_3O_8 (Table 2).

The Recapture in this area is about 500 feet thick and consists predominantly of fine- to coarse-grained sandstone with some interbedded mudstone and siltstone. The larger deposits are in sandstone in the upper part of the member and occur as tabular layers along mudstone beds, as halos around mudstone galls, and as calcareous pods. They range in width from 150 to 200 feet, in length from 500 to 600 feet, and in thickness from 1 to 20 feet. The deposits in the lower part occur as fracture fillings in calcified logs and impregnations of the enclosing sandstone (Blagbrough and others, 1959).

The deposits in the Salt Wash Member are in the upper part where they occur as thin, tabular bodies in sandstones that are generally less than 30 feet thick. They generally bound mudstone beds, impregnate sandstone around concentrations or pockets of carbonized plant debris, fill fractures in carbonized logs, and are disseminated as halos from a few inches to about 2 feet, and vary in length and width from a few feet to as much as 50 feet (Hilpert, 1969). The Sanostee area is near the southern margin of Salt Wash deposition and the member there is only about 50 feet thick.

The ores in both the Recapture and Salt Wash are above the regional groundwater table and are oxidized. Carnotite has been reported as the most obvious mineral in most of the deposits, but tyuyamunite is probably also abundant. Ores from the Recapture were quite low in vanadium with V_2O_5 to U_3O_8 ratios ranging from 1:2 to 1:0.5. Salt Wash ores at Sanostee had V_2O_5 to U_3O_8 ratios ranging from 1:5 to 1:3 (Chenoweth, 1985).

Significant deposits reportedly have been discovered by Exxon Minerals Company U.S.A. at Tocito dome, about 15 miles northeast of Sanostee (Plate 1). Nuclear Fuel (March 1, 1981) states that "... exploration was completed last fall, and Navajo Tribal officials say the company is still pondering whether to mine the properties." The exact location of the deposits is not given, but drill hole records on file in the New Mexico Office of State Engineer indicate that intensive drilling was done on and near sections 3 and 4, T.26 N., R.18 W. The deposits are reported to be in the Westwater Canyon Member, but information is unavailable on the specific geologic setting. Presumably, they would be similar to Westwater deposits in the Grants Uranium Region. Drill depths to the base of the Westwater in this area average about 1,560 feet (Plate 1) and the deposits are below the groundwater table.

URANIUM DEPOSITS IN OTHER AREAS IN NEW MEXICO

Hundreds of uranium occurrences in a wide variety of host rocks have been found in New Mexico outside of the San Juan Basin (McLemore, 1983a; Hilpert, 1969). In only two areas have significant reserves been delineated in sandstone: (1) the Hagan Basin between Albuquerque and Santa Fe, and (2) the Riley-Pie Town area in Socorro and Catron Counties.

Hagan Basin

In the Hagan Basin, uranium mineralization occurs in two distinct fluvial sandstone units in the Eocene Galisteo Formation. The Galisteo is a fluvial-lacustrine sequence of sandstones, siltstones, conglomerates, and some interbedded tuffs ranging in thickness from 900 to 4,000 feet.

The deposits are described by Moore (1980). They are in sandstone channels along oxidation fronts in a modified roll-type form. Carbonaceous detritus is commonly abundant, but the uranium is not necessarily correlated with it. Pyrite is generally present where uranium occurs. Other elements associated with the ore are selenium and molybdenum. Reserves are estimated to be 900,000 pounds U_3O_8 in rock averaging 0.09 percent U_3O_8 (Moore, 1980). Limited lateral drilling indicates that ore can be developed at several points on the property. Depth to ore ranges from 10 to 400 feet.

Riley-Pie Town area

In the Riley-Pie Town area in Catron and Socorro Counties, several deposits occur in the Eocene Baca Formation and in the uppermost part of the underlying Cretaceous Crevasse Canyon Formation. Each unit has produced only a few hundred pounds of U_3O_8, but closely spaced drilling in several areas indicate the existence of larger concentrations.

The Crevasse Canyon Formation consists of sandstones, siltstones, shales, and coal seams deposited in a coastal-plain environment. Locally, at the top of the Crevasse Canyon, and beneath an unconformity that separates it from the Baca Formation, is an altered or transition zone of bleached and oxidized sandstone that is the host for most of the uranium deposits in the unit (Chamberlin, 1981). Nothing has been published about the size of the deposits, but they reportedly do not exceed 500,000 pounds of contained U_3O_8. Uranium is associated with organic material, iron staining, clay galls and sandstone-shale interfaces. Chamberlin (1981) believes that the presence of ghost rolls indicates that roll-type deposits are likely to occur in the subsurface. The known deposits are believed to be above the water table.

The Baca Formation consists of a sequence of continental sediments up to 1,500 feet thick consisting of mudstones, siltstones, sandstones and conglomerates. Several small deposits and minor prospects occur on and near the outcrops of the middle and lower members of the formation where uranium is associated with carbonaceous material, carbonaceous shale lenses, and fossil logs in fluvial sandstones.

The most significant deposits are in the middle member. Chapin and others (1979) state that "The middle member of the Baca has several characteristics which are favorable to the occurrence of uranium deposits" and that "Lithologically, the middle member of the Baca is similar to terrestrial sandstones elsewhere that contain abundant carborized wood fragments that could provide a reducing environment for precipitation of uranium. The sands are clayey, but are friable and moderately permeable to the passage of ground water."

Sargent (1983) reports that in the Riley area of the Bear Mountains, Socorro County, uranium mineralization is closely associated with organic material in reduced sandstone of the middle member of the Baca Formation.

Sargent states that "Detailed drilling has indicated a few hundred-thousand pounds of U_3O_8 exceeding 0.10 percent." Widely spaced drilling has also outlined an adjacent area of favorable (reduced) sandstone. The deposits are reported to be below the groundwater table at depths of 250 tc 300 feet (John Borkert, personal communication, 1985).

URANIUM RESOURCES AND PRODUCTION IN NEW MEXICO

Reserves are the firmest class of resource comprising deposits that have been delineated by drilling or by other direct sampling methods. Reserves are termed Reasonably Assured Resources (RAR) by the Energy Information Administration of the U.S. Department of Energy (Fig. 9). Potential resources are the quantities of uranium believed to be present in deposits that are incompletely defined or undiscovered. They are divided into Estimated Additional Resources (EAR) and Speculative Resources (SR) based on their spatial relationships to defined resources (i.e., reliability of measurement). All potential resources in the Morrison Formation in the San Juan Basin are EAR. Reserves and resources are further subdivided into forward-cost categories. Forward costs include all direct costs of mining or extraction but do not include sunk costs associated with exploration and development. Higher, medium and lower forward-cost categories are currently defined as \$100 per pound, \$50 per pound and \$30 per pound U_3O_8 respectively.

Mineral ownership of New Mexico reserves recoverable by ISL may differ somewhat from shares of past production ownership. The bulk of reserves in the Church Rock area are located on Navajo Reservation lands wheras those

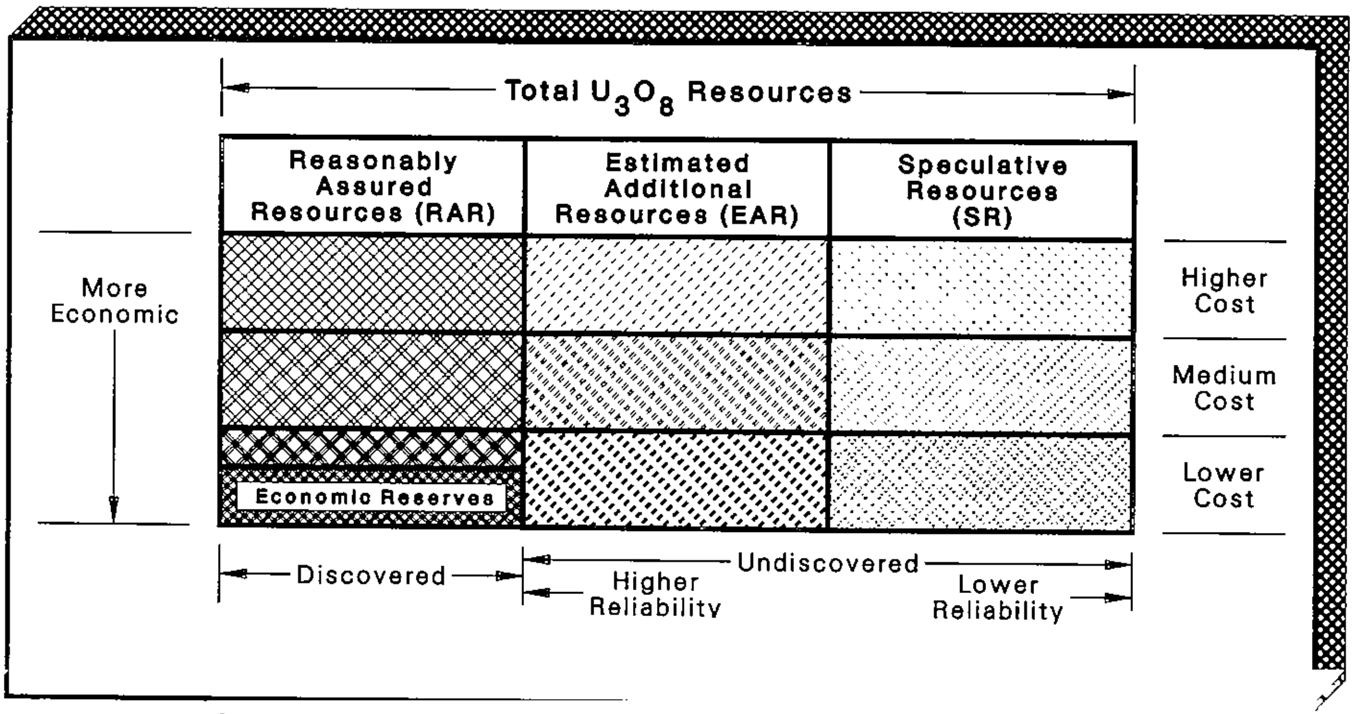


Figure 9. U.S. Department of Energy uranium resource classes (U.S. Dept. of Energy 1984, p. 27).

in the Crownpoint area are primarily on Indian Allotted acreage although Federal and State lands also account for substantial Crownpoint reserves. Conventional production from Indian and state lands has constituted the smallest share of New Mexico production in the past compared to production from private (fee) and federal lands (Hatchell, and Wentz, 1982; Hatchell, 1984).

Less than one percent of total production from the San Juan Basin has been from outside the Grants Uranium Region, and almost all of this was from the East Carrizo and Sanostee areas (Table 2). Except for small, sporadic production from the Enos Johnson mine in the Sanostee area, there has been no production from outside the Grants Uranium Region since 1967.

Over 99 percent of the remaining identified reserves in the San Juan Basin are in the Grants Uranium Region. Other areas containing significant but relatively small reserves are the East Carrizo, Sanostee and Canjilon areas. For more detailed information on uranium production and reserves in New Mexico see Hatchell and Wentz (1981) and Annual Resource Reports of the New Mexico Energy and Minerals Department.

All commercial ISL production of uranium in the United States has been from depths of less than 1,000 feet. Mobil Oil Corporation has conducted pilot operations in the Crownpoint area at depths of about 2,000 feet. Because much of the remaining reserves and potential resources in the San Juan Basin are considerably deeper than 1,000 feet, and as costs increase with depth, the depth of deposits is of critical importance. Table 3 gives the reserves in New Mexico by depth increments. In the DOE $50 per pound forward-cost category, 83 percent of the reserves are at depths greater than 1,000 feet and 31 percent are at depths greater than 2,500 feet (Table 3). It is not known what proportion of the reserves are associated with mined and/or developed areas, but Plate 2 shows that a majority of unmined deposits are at depths in the vicinity of 2,000 feet or greater. It is worthy to note that the average production depth for uranium contained in ore mined in 1984 in New Mexico was 1,282 feet (Hatchell, 1985). Moreover, it should be noted that remaining reserves in the Grants Uranium Region are very large and there are still large deposits at relatively shallow depths. New Mexico RAR in the $30 per pound and $50 per pound forward-cost categories, comprise fully 40 percent of total U.S. RAR.

Since it might be assumed that reserves remaining in deposits near mined areas, or those that have been developed by mine entries will be mined, such deposits have been identified on Plate 2.* This is not necessarily a valid assumption, as a flooded underground mine could be converted to an ISL operation. Sequoyah Fuel Company (Kerr-McGee) and Pathfinder Mines (Utah Construction) did just that at undergound mines in the Powder River and Shirley Basins respectively, in Wyoming and In Situ, Inc. reportedly plan to initially develop the Church Rock, New Mexico properties in this manner. Also, small pods peripheral to underground mines that are below the economic mining cut-off grade or that are too remote to develop might also be exploited by ISL. However, draw-down of

* It should be noted that shafts have been completed or partially completed at Phillip's Nose Rock mine, sec. 31, T.19 N., R.11 W. Conoco's Crownpoint mine, sec. 24, T.17 N., R.13 W.; Bokum's Marquez mine, sec. 25, T.13 N., R.5 W,; and Kerr-McGee's Lee mine, sec. 17, T.13 N., R.8 W.. There has been neither mining nor ore development at these properties, and this is indicated by the absence of cross- hatching on Plate 2.

Table 3. Reserves (RAR) in New Mexico by depth increment and forward-cost category as of January 1, 1983 (data from U.S. DOE, written communication, Sept., 1983).

Cost Category \$/lb. U_3O_8	Tons U_3O_8 by depth (ft) depth unknown	0-500	500-1000	1000-2500	2500 & deeper	Total
\$30	---	2,571	7,517	31,870	56,271	98,229
\$50	4,500	10,931	27,185	126,924	77,632	247,172
\$100	6,000	21,829	54,306	188,844	96,593	367,572

the water table due to pumping of the mines is a factor that would have to be considered. Kaufman (1976), Kelly, Link and Schipper (1980) and Lyford and Frenzel (1980) discuss the effects of uranium mining on groundwater levels in the Grants Uranium Region.

In addition to the identified reserves tabulated on Table 3. the DOE has estimated potential U_3O_8 reserves in the San Juan Basin of 377,063 tons U_3O_8 in the \$50 per pound cost category (McLemore, 1983). Since by definition potential reserves are in unexplored areas, and the deeper areas are usually the last to be explored, potential reserves are, in general, at greater depths than the identified reserves. They are mostly in the Morrison Formation in the Grants Uranium Region.

Resources estimated by DOE are grouped into selected cost categories (\$30, \$50 and \$100 per pound of U_3O_8) to cover a broad spectrum of economic availability . The applicable costs used to assign the uranium resources to these categories are forward costs, comprising operating and capital costs, that would be incurred in producing the uranium. The reserve estimating procedure used by DOE incorporates the following formula for determining the cut-off grade which is defined as the lowest grade in percent U_3O_8 that can be mined at an operating cost that is lower than or equal to the chosen cost per pound.

$$\text{Cut-off grade} = \frac{\text{cost of mining, hauling, royalty and and milling per ton of ore}}{\text{chosen cost/lb. } U_3O_8 \times \text{mill recovery} \times 20}$$

Material that is below the cut-off grade and higher grade material that is too thin to stand dilution to minimum mining heights is not included in reserves. The minimum mining height for underground mines in the Grants Region is generally in the range of 6 to 8 feet depending on orebody characteristics and the mining method. Also not included are deposits that may be of sufficient thickness and grade, but are too small and remote from workings to stand development costs.

The DOE estimates reserves recoverable by ISL by another method. It should be kept in mind that most of these reserve estimates that have been made by DOE are in Texas and Wyoming where deposits are much shallower than most of deposits in the Grants region. Reserves deemed recoverable by ISL above a selected minimum thickness, generally 1 to 2 feet, are calculated for those properties on which solution mining is in progress or planned. The uranium content above 0.01 percent U_3O_8 is estimated and the reserves are the estimated amount of U_3O_8 determined by multiplying by a recovery factor which is generally 50 to 60 percent (W.A. Roberts, U.S. DOE, personal communication, 1985). Obviously, if reserves for the San Juan Basin were calculated by ISL parameters they would be considerably larger than those calculated by underground mining parameters. However, there would be considerable uncertainty about the recovery factor. Nevertheless, in discussing its Crownpoint ISL project, Mobil Oil Corporation (1977) states that "total uranium resources in-place appear several times larger than the commercial-quality ore which could be recovered by shaft mining methods. Laboratory tests and engineering studies indicate it may be possible to recover much of this uranium by in situ leaching."

IN SITU LEACHING--GENERAL

Larson, W.C. (1978) defines ISL mining as "that selective mining technique whereby the ore mineral(s) that has not been transported from its geologic setting is preferentially leached (dissolved) from the surrounding host rock by the use of specific leach solutions and the mineral value(s) recovered . . . dump or heap leaching operations are not included because, in these systems, the material has been mechanically transported to prepared areas for leaching and thus removed from the original geologic setting." This definition is used in this report and dump and heap leaching operations (which have not been significant in New Mexico) are not discussed.

Conventional ISL consists of injecting a leaching solution (lixiviant) into the mineralized zone through injection wells. The leach solution migrates through the zone, dissolves the uranium values and is pumped to the surface through production wells. The pregnant solution then goes to a conventional uranium recovery system where uranium is recovered by ion-exchange (IX). The residual barren solution is renewed with suitable leaching chemicals and recirculated to the well field. The procedure is depicted graphically in Figure 10.

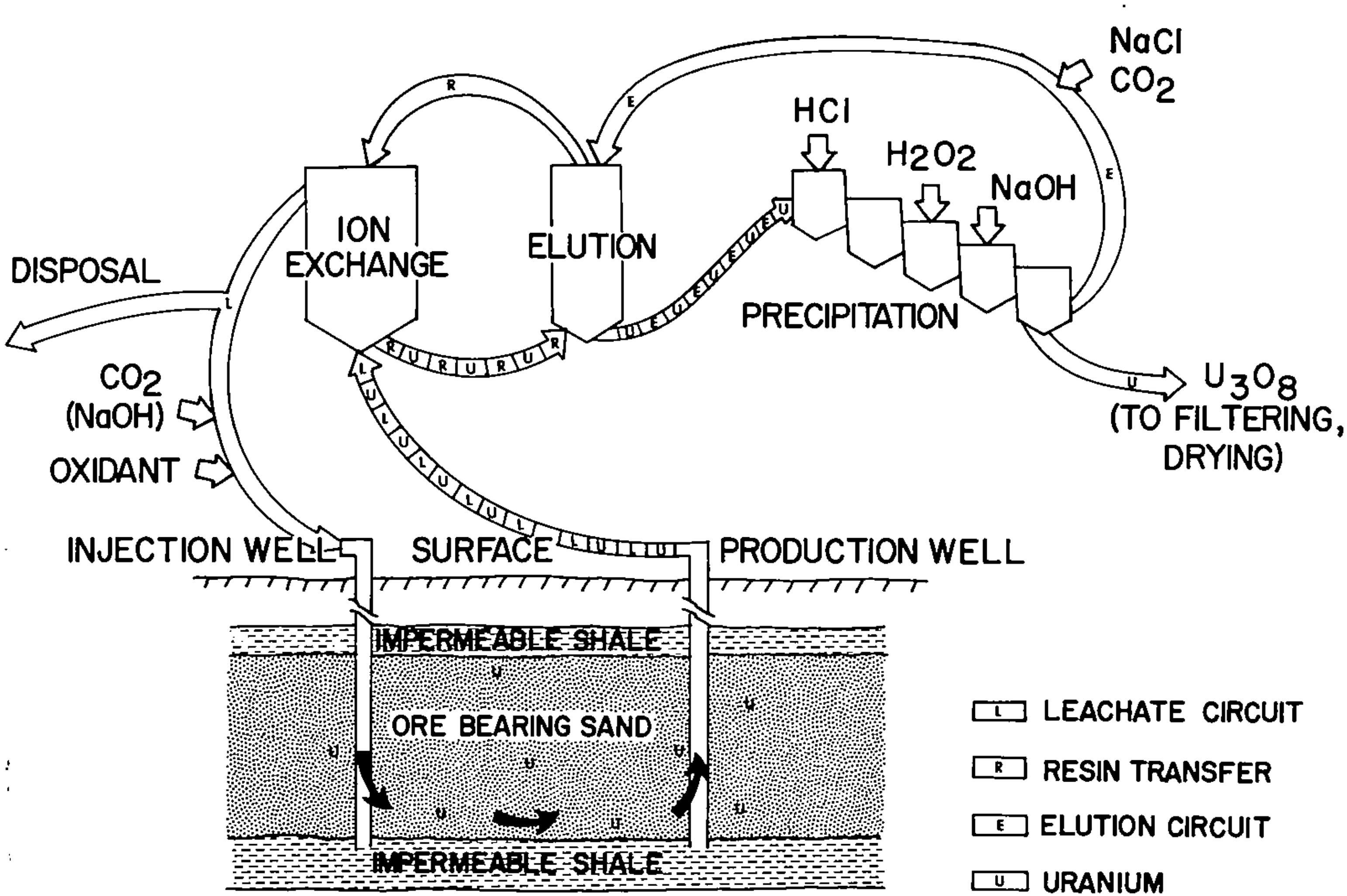


Figure 10. Flow diagram showing a typical uranium ISL process (Hatchell and Wentz, 1981, p. 54, as modified after Conine, 1980).

Criteria cited in the literature to judge the suitability of an ore deposit for uranium recovery by ISL stipulate that (1) the ore must be located in a saturated zone that remains at all times below the water table; (2) the ore body must possess adequate permeability and be amenable to chemical leaching, and (3) the ore zone should occur in a generally horizontal bed confined by relatively impermeable stratum so as to retrieve as much as possible of the leach solution for economical and environmental reasons. Most deposits in the San Juan Basin appear to meet these criteria. "It is important to remember that conditions favorable for uranium deposition [sandstone-type deposits] also are likely to be favorable for uranium in situ leaching" (Borkert, 1975).

The advantages of ISL over conventional mining methods that are cited in the literature include: (1) surface impact is minimal since ISL does not require large production facilities, excavations, or extensive land use; (2) the increase in levels of radioactivity are relatively small since the orebody itself remains totally beneath the surface; (3) the number of personnel required to operate the plant and well field is relatively small, and road and traffic requirements are modest and unlikely to disturb the character of the community; (4) production techniques are not energy-intensive, i.e., a leaching system consumes only 13 percent of the energy required for conventional mining and milling methods (Hohne, 1977); (5) significantly less total water is required, resulting in less regional hydrological disturbance and aquifer drawdown; (6) over-all resource target is expanded to include lower-grade ore zones and there are fewer restrictions on both horizontal and vertical continuity of the ore; (7) ISL is not nearly as sensitive to the economy of scale in plant size, and incremental modular expansion from relatively small projects is feasible; (8) ISL is less hazardous, since it does not require employees to work underground and it eliminates the major source of radiation exposure; (9) production can be obtained sooner than from conventional mining methods, even allowing time to complete on-site pilot operations; (10) ISL requires less capital and lower operating costs than a conventional mine and milling operation, and (11) an insignificant amount of extraneous solid-waste material is brought to the surface, unlike that associated with conventional mining methods including tailings piles and their associated maintenance, reclamation, and environmental costs.

Possible disadvantages of ISL include (1) potential for groundwater contamination by leachate excursions and by leakage from waste-storage ponds; (2) possible problems with aquifer restoration; (3) possible problems with disposal of waste solutions; (4) testing an ISL mining situation short of actual field operations sometimes proves difficult; (5) ISL recovery factors are generally only 50 to 60 percent of conventional mining/milling recovery, and (6) most critically, ore must be amendable to extraction by ISL.

ISL PROJECTS IN TEXAS, WYOMING AND NEBRASKA

Uranium was originally produced by ISL in the Shirley Basin of Wyoming in 1960 by Utah International and has been carried out extensively in south Texas (Table 4) and Wyoming (Table 5). The first ISL project in Texas was the Clay West project of Atlantic Richfield Corporation, originally permitted in 1975. The Clay West/Burns Ranch deposits have been the

Table 4. ISL projects planned or operating in Texas as of February, 1986 (Texas Water Commission, Underground Injection Control Section, personal communication, April 1986).

Operator	ISL Project	Location	Average Production Depth(s)(ft)	Geologic Host Rock	2/27/86 Status
Caithness	McBryde	Hebronville	300	Oakville Fm.	Restoration
Chevron	Palangana Dome	Benavides	275	Goliad Fm.	Standby
Conoco	Trevino	Hebronville	300	Oakville Fm.	Restoration
Everest	Hobson-1	Hobson	200	Jackson Gp.	Restoration
Everest	Hobson-2 (formerly Tex-1)	Hobson	375	Jackson Gp.	Standby
Everest	Las Palmas	Hebronville	600	Oakville Fm.	Restoration
Everest	Mt. Lucas	Dinero	40-380	Goliad Fm.	Production
IEC[1]	Lamprecht	Lamprecht	270	Oakville Fm.	Production
IEC	Pawnee	Pawnee	235	Oakville Fm.	Restoration
IEC	Zamzow	Ray Point	170	Oakville Fm.	Production
Mobil	El Mesquite	Bruni	658	Catahoula Tuff	Production
Mobil	Holiday/O'Hearn	Bruni	530-569	Catahoula Tuff	Production
Mobil	Nell	Pawnee	535	Catahoula Tuff	Restoration Complete
Mobil	Piedra Lumbre/ Brelum	Freer	340	Catahoula Tuff	Restoration Complete
Tenneco	West Cole	Bruni	225	Catahoula Tuff	Production
URI[2]	Benavidez	Bruni	300	Catahoula Tuff	Restoration
URI	Kingsville Dome	Kingsville	550-750	Goliad Fm.	Evaluation
URI	Longoria	Kingsville	575	Goliad Fm.	Evaluation
U.S. Steel	Boots/Brown	George West	400	Oakville Fm.	Restoration
U.S. Steel	Burns Ranch	George West	400	Oakville Fm.	Production
U.S. Steel	Clay West	George West	400	Oakville Fm.	Restoration
U.S. Steel	Tawlik	George West	400	Oakville Fm.	Restoration
Westinghouse Electric	Bruni	Bruni	190	Catahoula Tuff	Restoration

[1] Intercontinental Energy Corp.
[2] Uranium Resources, Inc.

Table 5. ISL projects planned or operating in Wyoming and Nebraska as of April 1986; (Wyoming Dept. of Environmental Quality, Land Quality Div., personal communication, April 1986).

Operator	ISL Pilot Project	Location	Production Depth(ft)	Host Rock	4/1/86 Status
Arizona Pub Ser/ Malapai Res	Christensen Ranch	Pumpkin Buttes, WY	440-460	Wasatch	Restoration, R&D planned 1986
Arizona Pub Ser	Peterson	Douglas, WY	220-260	Ft. Union	Push-pull comp.
CEGB[1] (formerly Teton)	Leuenberger	Glenrock, WY	250-360	Ft. Union	Comm. permit issued
Cleveland Cliffs	Collins Draw	Pumpkin Buttes, WY	450	Wasatch	Restoration comp.
Cotter	Charlie	Pumpkin Butes, WY	310	Wasatch	Restoration comp.
Exxon Minerals/ Everest	Highland	Powder River B., WY	340	Ft. Union	R&D phase
Malapai Resources	Irigarey	Powder River B., WY	100-500	Wasatch	Restoration comp., R&D planned 1986
Nuclear Dynamics	Sundance	Crook Co., WY	250-300	Fox Hills	Fully Restored
OPI-Western[2]	Bison Basin	Powder River B., WY	480	Green River	Shut down
RME/Mono/Hall.[3]	Nine Mile Lake	Casper, WY	500	Teapot	Unsucc. demo.
RME/Mono/Hall.	Reno Creek	Powder River B., WY	140-170	Wasatch	Pilot Complete
Santa Fe Minerals	Ruby Ranch	Pumpkin Buttes, WY	300	Wasatch	Pump test comp.
Sequoyah Fuels	Bill Smith	Powder River B., WY	770-800	Ft. Union	Pilot testing and production
Sequoyah Fuels	Q-Sand	Powder River B., WY	550-600	Ft. Union	Pilot testing and production
Union minerals	Sweetwater	Red Desert, WY	300-400	Green River	Suspended
Uranerz, USA	Ruth	Pumpkin Butes, WY	550	Wasatch	Restoration
URI/ Urang.[4]	North Platte	Powder River B., WY	550	Ft. Union	Restoration complete
Ferret Exploration	Crow Butte	Chadron, NB.	385	Bruhl	Pilot test pending 1986

1 Central Electricity Generating Board (Great Britain)
2 Ogle Petroleum, Inc. of California
3 Rocky Mountain Energy/Mono Power/Halliburton
4 Uranium Resources, Inc./Urangesellschaft

largest producers in Texas to date. The Goliad (Pliocene) and the Oakville (Miocene) are considered to be the most favorable hosts for the higher grade, larger deposits in Texas. In Wyoming, the Wasatch (Eocene) and Fort Union (Paleocene) are the most prolific producers. The Crow Butte deposit is currently under development in Nebraska. Experience gained from Texas and Wyoming indicates that ISL engineering will be essentially the same for New Mexico but will involve some modification. Differencies will be in permitting and licensing, specific recovery techniques, ore body configuration, host rock lithology and amenability, and aquifer restoration.

In addition, the depth considerations in New Mexico compared to those in Texas and Wyoming demand more precise control of the lixiviant circuit. Just as clay and calcite have presented operating problems at some localities in Texas, humate in dominately primary deposits (cited earlier in this report) may complicate ISL operations in some areaa of the Grants Uranium Region. In addition, molybdenum circuits will be necessary, and groundwater restoration in the Crownpoint area has encountered minor problems with selenium values at or slightly above allowable limits. Improved ISL technology, particularly in the area of high-oxidant lixiviants, may offer increased recovery in the less amenable, high-carbon New Mexico deposits. For example, Union Carbide has patented a liquid oxygen lixiviant process which will be tested by Sequoyah Fuels in the Powder River Basin of Wyoming (Ernie Orell, personal communication, April 1986). Greater depth and attendant elevated temperature and pressure in deep San Juan Basin deposits could, theoretically, facilitate leaching especially in combination with high-oxidant lixiviants such as liquid oxygen.

ISL PERMITTING AND REGULATION IN NEW MEXICO

As of June 1, 1986 the State of New Mexico transferred its responsibility as an "agreement state" to regulate uranium mills and mill tailings back to the Nuclear Regulatory Commission (NRC). It is unclear at this point as to exactly what effect this shift from State to Federal responsibility may have on licensing of ISL facilities in New Mexico. Until the NRC can establish long-term regulations for the State, existing State standards have been adopted by the Federal agency. It is clear, however, that NRC requirements, in general, will exceed those of the State. NCR jurisdiction will be felt principally in the areas of radiation protection, radioactive materials licensing, site inspection, and surety bonding. Pending further clarification of this, a brief review of ISL permitting and licensing as it has existed may help. Connie (1980) and Simpson (1983) listed the various permitting and licensing requirements for ISL operations in New Mexico. These requirements are summarized and updated in Table 6 since the State will still have regulatory authority over most non-radiological aspects. It should be noted that unlike Wyoming, New Mexico did not require that ISL pilot plants be constructed prior to commercial operations in order to demonstrate adequate groundwater restoration. Restoration capability demonstrated by the applicant in another state could generally satisfy New Mexico requirements. New Mexico, while an NRC "agreement state" under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRA), required all applicants to submit a Radioactive Material License Application (Form RPS-16) to the State Environmental Improvement Division (EID), Radiation Protection Bureau. An environmental report (EIS) was also required for review by the Radiation Protection and Water Pollution Control Bureaus, EID. Provisions of Section 204 (UMTRA) for agreement states became effective November 8, 1981 and

Table 6. Permits and regulation requirements for ISL operations in New Mexico as of March 1983; modified from Conine (1980) and Simpson (1983).

Permit/Regulation	Review Agency/Granting Authority
Well Drilling and Completion Permits	USGS, USBIA, USNPS, SE
Pilot Test Mine Plant	USGS, USBIA
Notice of Intent to Discharge	EID (WPCB)
Radioactive Source Materials License	EID (RPB)
Groundwater Discharge Permit	EID (WPCB)
Underground injection	WQCC
Archaeological Clearance	USNPS, SHPD
Endangered Species Protection	NMNRD
Air Quality Control Permit	EID (AQB)
Solid Waste Disposal Registration	EID (CSSB)
Water Appropriation Permit	SEO
Mine Registration	EMD (MMD)

Note:

USBIA - Bureau of Indian Affairs

EID - Environmental Improvement Division, New Mexico Health and Environment Department
- AQB - Air Quality Bureau, EID
- CSSB - Community Support Services Bureau, EID
- RPB - Radiation Protection Bureau, EID
- WPCB - Water Pollution Control Bureau, EID

WQCC - New Mexico Water Quality Control Commission

EMD - New Mexico Energy and Minerals Department
- MMD - Mining and Minerals Division (State Mine Inspector)

SHPD - New Mexico Historic Preservation Division, Office of Cultural Affairs

SEO - New Mexico State Engineer Office

NRD - New Mexico Natural Resources Department

USNPS - National Park Service

USGS - U.S. Geological Survey

Congress required agreement states to implement the provisions of Section 204(e) including written analyses. Written analyses include:

(1) assessment of radiological and nonradiological impact to the public health
(2) assessment of impact on groundwater
(3) consideration of alternatives sites, engineering methods and activities, and
(4) consideration of long-term impact including decommissioning, decontamination and reclamation, and management of any byproduct material.

New Mexico has additional regulations which require an applicant to obtain a number of permits and approvals. These regulations apply to all ISL applicants in addition to any required by the NRC and include:

(1) Water appropriation approval (State Engineer),
(2) New facility construction permit (EID, Air Quality Bureau).
(3) Groundwater discharge plan (EID, Water Pollution Control Bureau)
(4) Registration certificate for solid waste disposal (EID, Community Support Service Bureau)
(5) Underground injection permit (Water Quality Control Commission Regulations, Parts 3 and 5)
(6) Registration of facility with State Mine Inspector (Energy & Minerals Department)

EID was the lead agency for insuring that all permitting and licensing was coordinated among the various review agencies, and that the proper Water Appropriation Permit (State Engineer) was approved prior to the issuance of the Radioactive Source Materials License (EID,RPB). All permits except for the Groundwater Discharge permit (EID, WPCB) must be issued in conjunction with the Radioactive Source Materials license (Simpson, 1983). Underground injection of wastes and brines is overseen by the State Water Quality Control Commission. Archeological clearance (SHPD) also preceeded issuance of a Radioactive Source Materials license. Finally, EID as the lead agency sought concurrence on endangered species protection from the Natural Resources Department prior to final licensing approval. Past licensing experience in New Mexico indicated that the entire process required from a few months to about two years from initial application. Federal licensing is not expected to accelerate this process.

Minimal surety arrangements were required by the State, and more stingent surety may be required by the NRC to guarantee restoration and clean-up compliance. Surety was approximately $23,000 per acre when the State transferred responsibility to the NRC in June 1986 (Eloy Montano, EID, personal communication, August 1986).

PAST (COMPLETED) ISL PROJECTS IN NEW MEXICO

ISL pilot testing is not new to New Mexico. Anaconda was probably the first to test ISL in New Mexico at its North Windwhip project at Laguna (Jackpile-Paguate mine) in April, 1970 (Mining Magazine, 1971). Grace Nuclear experimented with ISL at two separate sites in the Grants Uranium

Region as early as 1975 using ISL technology developed in Texas and Wyoming. Teton Exploration carried out a pilot ISL (push-pull) project near Church Rock in 1980, and Mobil successfully tested ISL at the South Trend Development Area near Crownpoint in late 1980. Mobil is licensed to begin commercial ISL production at two Crownpoint sites should market conditions permit (Table 7).

Table 7. Past (completed) pilot ISL projects in New Mexico.

Company	Project	Location Sec.,Twp.,Rge.	Approx. Depth (ft)	4/1/86 Status
Mobil/TVA	Crownpoint (South Trend)	9-17N-13W	2000	Pilot Completed; commercial lic. approved
Mobil/TVA	Crownpoint (Monument)	28-17N-12W	2000	Pilot on Standby
UNC-Teton	Push-pull, Sec. 13	13-16N-17W	1300	Completed
Grace Nuclear	Leach Site No. I	23-16N-17W	500	Completed
Grace Nuclear	Leach Site No. II	13-12N-4W	380	Completed
Anaconda	North Windwhip	35?-10N-5W	200-240	Completed

Anaconda (North Windwhip)

Based on review of the available literature, Anaconda was the first to experiment with ISL in New Mexico in early 1970 in section 35, T.10 N., R.5 W. at the Jackpile-Paguate mine area near Laguna (Hunkin, 1971).

Pump tests commenced in April, 1970 after two well fields had been completed into an isolated mineralized pod in the lower 40 feet of the Jackpile Sandstone Member of the Morrison at a depth of 200 to 240 feet. At the site, the Jackpile is some 140 feet thick, overlain by the Dakota

Sandstone (high kaolinitic clay zone) and underlain by the Brushy Basin Shale Member of the Morrison. Calcite cement predominates toward the top of the ore pod and clay toward the base. Host rock porosity ranges from 20 to 32 percent and permeability ranges from 12 to 350 millidarcies (Mining Magazine, 1971). The mineralized zone is below the groundwater table. Different but similar well patterns were used in the two fields in order to comparatively test engineering characteristics. Each field consisted of a central injection well surrounded by 9 production wells on 200-foot centers. Monitor wells were arrayed at various distances up to 1,000 feet from the well field centers. Each field covered approximately 0.5 acre and was saturated with approximately 1.3 million gallons by pore volume (Mining Magazine, 1971). A sulfuric acid lixiviant was used in combination with chloride elution. Production wells were pumped at a rate of 115 gallons per minute (gpm). The field layout proved to be unsatisfactory in providing sufficient control over the piezometric surface beyond the well centers. Production well spacing was adjusted for better control which resulted in a total of 2 injection wells and 29 production wells.

The pregnant liquor was pumped to a central surge tank and from there to IX(resin) tanks on the site. Loaded resin was subsequently transferred to the Anaconda Bluewater mill some 50 miles west of the site where elution, precipitation, clarification, decantation, drying and packaging were done. Production is not available, but the pilot at North Windwhip undoubtedly was a significant pioneering effort in ISL technology development in New Mexico. It is unclear as to the degree of success achieved by Anaconda at North Windwhip, although the lack of continued testing during a major boom cycle in the industry (1970-1978) would appear to indicate generally negative results (Dick Chamberlin, written communication, June 1986). In addition, the prevalence of primary deposits in the Laguna area could have contributed to poor recovery.

Grace Nuclear

In addition to Anaconda, Grace Nuclear was one of the first New Mexico operators to use ISL at two projects, probably in early 1975 or earlier (Table 6). The first project, known as Site No. 1, was in the NE¼ of section 23, T.16 N., R.17 W. near Church Rock in McKinley County. Six injection wells and two production wells were completed into the Westwater approximately 500 feet below the surface. The production wells were pumped at approximately 40 gpm. Site No. 2 was located in the NW¼ of section 13, T.12 N., R.4 W., in Sandoval County northeast of Seboyeta. The ore horizon is at a depth of 380 feet in the Jackpile Sandstone. Leaching operations were begun without proper permitting at the two projects in 1975 or earlier and terminated by the end of 1975 by order of the EID (Grace Nuclear open-file, EID). The lixiviant used by Grace was not identified but in all probability was an acid. It was reported that a slurry tanker truck operated between the two sites and the Kerr-McGee (Ambrosia Lake) mill approximately once each month during operations (Hatchell and Wentz, 1981). At the time of this writing, the EID is proceeding with litigation to force reclamation compliance at both sites.

Teton Push-Pull Project

In April 1980, the New Mexico EID permitted Teton Exploration Drilling, Inc. to conduct a limited push-pull test in the SE¼ section 13, T.16 N., R.17 W., McKinley County, near Church Rock. The test was completed in June, 1980 (Teton Exploration Drilling, Inc. open-file, EID).

At the site, Teton injected some 4,500 gallons of water into the uranium bearing zones of the Westwater Canyon Member at a depth of approximately 600 feet. Mineralized Westwater occurs in the B-zone at depths ranging from 675 to 725 feet. Total reserves at Church Rock, including Section 13, have been estimated at 41.9 million pounds U_3O_8 (contained in ore) at an average grade of 0.12 percent U_3O_8 (Nuclear Assurance Corp., 1982).

According to the EID, the lixiviant ran approximately 2 grams per liter of sodium carbonate/bicarbonate solution and 0.75 grams per liter of hydrogen peroxide. After 5 days, the well was pumped at the rate of 5 gpm. The fluid was then run through a portable, trailer-mounted IX facility at the site. After precipitation, uranium slurry was sealed in 55-gallon barrels for shipment to the UNC (Church Rock) mill. Waste liquid was pumped from a storage pool into trucks and carried to the UNC mill for disposal. Total uranium recovered was expected to be less than 5 pounds. Although results of the Teton push-pull test are unknown, the company indicated that it could not proceed with commercial production due to depressed market conditions.

Mobil In Situ Leach Projects (Crownpoint)

Introduction

Mobil had more than 12,000 acres under lease for ISL development in the Crownpoint area in 1976. Two mineralized trends, the South Trend Development Area (STDA) and the East Trend Development Area (ETDA) or

Monument, have been permitted and licensed to date. A third trend, the North Trend area, may also be pilot tested in the future.

The STDA pilot was located in section 9, T.17 N., R.13 W. The skid-mounted ISL pilot leach plant was successfully operated from November 1979 through September 1980 with groundwater restoration beginning in October 1980 (Mobil open-file, EID). Groundwater restoration was completed and Mobil has received a commercial license valid for a period of 5 years for the STDA. ETDA (Monument) has never been pilot leached, although a permanent leach facility has been licensed and constructed on section 28, T.17 N., R.12 W. Mobil has obtained all required State permits for ETDA including a Water Appropriation permit. Should market conditions improve, the firm could begin production at Monument following the section 28 pilot-leach phase. STDA shares most, if not all, engineering and geological aspects with Monument and other Mobil Crownpoint ISL properties. Permanent production facilities are planned to be located within the STDA with evaporation ponds in the SE¼ section 15, T.17 N., R.13 W. A total of 10 well fields will be located in sections 8, 9, 15 and 16 of T.17 N., R.13 W. Uranium reserves are estimated at 10 million pounds U_3O_8 at an average depth of 2,000 feet. Average ore grade is reported to be 0.20 percent U_3O_8. Projected life of the STDA project is 27 years, including decommissioning, decontamination and reclamation (Vogt and others, 1982b).

Phased Development Plan

Three ISL operational phases are planned in each of the 10 well fields:

(1) an initial injection rate of 600 gpm in the SE¼ of section 16 and the SW¼ of section 15.

(2) a secondary phase to consist of an injection rate of 2,100 gpm in combination with the start-up of a yellowcake drying and packaging unit dependent on market conditions.

(3) a third-phase to involve a maximum injection rate of 3,000 gpm with maximum annual production of 1 million pounds U_3O_8. Individual ISL phases are projected to run from 6 to 10 years each, and were to have begun in September 1982 and end in December 1986. Groundwater restoration is planned to immediately follow each ISL phase in each well field.

Employment

The project will employ about 30 workers initially with total employment increasing to about 80 under full third-phase production. Little socio-economic impact would be expected although a least 80 percent of the workforce will be hired and trained locally. A conventional mine of the same production capacity would employ about 315 workers (Simpson, 1983).

ISL well field plan

A total of 40 injection wells, 27 production wells, and 23 monitor wells are planned across the ten-well field STDA project. A five-spot well field pattern typically contains 9 injection wells and 4 production wells ringed by monitor wells. Two of the monitor wells will be in the Dakota Sandstone, while 21 will be in the Westwater. In order to insure that net groundwater flow is toward production wells, each of the production wells will pump from 1 to 5 percent more fluid volume than injected. A typical five-spot well pattern is planned consisting of 4 injection wells and a production well spaced on 200-foot centers.

Lixiviant chemistry

The lixiviant or leach solution will be slightly alkaline (pH greater than 7) using sodium carbonate (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$). Sodium hydroxide is to be used to control pH. Oxygen will be added to produce a water-soluble uranium carbonate complex which will be pumped to the surface as the pregnant solution. Na_2CO_3 will complex and solubilize all uranium existing in an oxidized state. Once steady-state is attained within the lixiviant, oxygen will be introduced to oxidize uranium from the insoluble +4 (reduced) state to the soluble +6 (oxidized) state. The resulting pregnant solution (uranyl tricarbonate) is then pumped to the surface plant where it is passed through an IX column.

Precipitation, decantation and drying

Uranium is adsorbed onto resin pellets in the IX column and is then stripped from the column by elutriation. The barren resin is fed back into the IX column for reuse. The concentrated eluant is decomposed with acid and uranium precipitated by a 6-cell precipitation unit as U_3O_8 which is passed through a clarifier. In the clarifier, solution and solids separate, producing a decant and a yellowcake slurry. The decant is recirculated back to the barren eluant for reuse while the yellowcake slurry is filtered, washed, reslurried and shipped in bulk. A yellowcake dryer will be brought on-line at the 2,100 gpm ISL phase, allowing yellowcake to be packaged and shipped in 55-gallon drums. A molybdenum recovery circuit will also be used.

Groundwater Restoration

Mobil is required by license to begin groundwater restoration on mined-out ore bodies within 30 days or sooner following cessation of leaching in each field (Simpson, 1983). Non-operational groundwater areas serve as buffer zones to preclude contamination from leached areas.

Wells are to be plugged with cement and casings cutoff 3 feet below the surface to facilitate surface reclamation. All disturbed land, including evaporation ponds, are to be restored to blend with the contours of the landscape with seeding and restoration of mature vegetation. Surface facilities are to be dismantled and removed.

Several techniques will be used individually or in combination to restore groundwater within the ore-bearing Westwater aquifer, and include:

- Groundwater sweep
- Clean water injection
- Chemicals

At the STDA pilot plant, section 9, T.17 N., R.13 W., acceptable groundwater restoration (with the exception of ppm molybdenum) was achieved after the circulation of 6 pore volumes of surface-treated water through the leached Westwater aquifer.

Groundwater depletion or drawdown

ISL recovery has a distinct advantage over conventional underground mining and milling in its conservation of groundwater resources, as it requires significantly less water to produce yellowcake. For example, since 97 to 99 percent of total pumped water volume is ultimately reinjected, one million pounds of yellowcake may be produced per year by a typical ISL operation using groundwater at the rate of 100 to 150 gpm compared to 1,500 to 3,000 gpm for underground mining and conventional milling to produce the same volume. ISL water usage, exclusive of aquifer restoration, thus translates into about 160 to 240 acre-feet of water per year (Mobil open-file, EID).

Geologic Setting and Suitability to ISL at STDA

At the STDA, the uranium host rock is the Westwater Canyon Sandstone Member of the Morrison Formation (Jurassic). The Westwater is about 260 feet thick (Vogt and others, 1982b), is a major aquifer beneath the potentiometric surface, is permeable, and stratigraphically confined below by the Recapture Shale (150 feet thick), and confined above by the Brushy Basin Shale (190 feet thick). Both the Recapture and the Brushy Basin are members of the Morrison Formation. Within the Westwater, thin beds and lenses of impermeable clay-shale (mudstone) confine individual ore zones. Total depth from surface to base of the Morrison (Recapture Member) is approximately 2,300 feet. Structural dip is to the north-northeast toward at approximately 1° to 2°.

Groundwater is available, not only from the Westwater which is the principal aquifer producing at the rate of 13 to 350 gpm, but from 2 other units, the Gallup Sandstone and the Dakota Sandstone (both stratigraphically higher than the Westwater). Water availability in the Dakota and Gallup is small to moderate (10 gpm or less).

Lithologically, the Westwater is a fine to coarse-grained, poorly sorted, crossbedded sandstone with thin clay-shale (mudstone) lenses and conglomeratic zones. Calcium carbonate averages about 6 percent and clay content about 2 percent. Porosity is about 20 percent and permeability ranges from 400 to 1,500 millidarcies (Conine, 1980). Westwater aquifer storage coefficient is 8 x 10^{-5} and reflects geological confinement by non-water-bearing rock units resulting in an artesian water level which rises to 1,600 feet above the top of the Westwater and within 200 to 300 feet of the surface. Conine (1980, p.342) states that hydrostatic pressure in the host rock is 740 psi. Uranium occurs in concentrations of about 0.20% U_3O_8 in the form of coffinite where primary, and uraninite where redistributed. Molybdenum occurs chiefly as the mineral jordisite (Rhett, 1980). Mobil reported laboratory recovery levels of 65 to 87 percent from samples of ore from the STDA pilot test area (Vogt and others, 1982b).

PROPOSED ISL PROJECTS IN NEW MEXICO

Several ISL projects were proposed or were actually in the planning stages between 1980 and 1983 on newly discovered and delineated uranium deposits across the Grants Uranium Region including Nose Rock Section 32 (Phillips Uranium Company), Borrego Pass (Conoco-Wyoming Mineral Corporation), and San Antonio Valley (Exxon). All of these projects have subsquently been cancelled or placed on indefinite hold due to the currently depressed uranium market. At this time, however, several of these and other properties are reported by EID to be under consideration by established ISL firms for pilot testing and ultimate commercial development. Uranium Resources, Inc. (URI) and Saarberg Interplan, for example, are negotiating for the Church Rock properties of United Nuclear, including the Section 13 orebody which has been tested (push-pull) by Teton. Similarly, In Situ, Inc. is negotiating with Conoco for acquisition of the Borrego Pass property southwest of Crownpoint (Table 8).

Conoco-WMC Borrego Pass

Conoco applied for both a Radioactive Materials and Groundwater Discharge permit in early 1982 to operate a pilot in situ leach project at Borrego Pass, McKinley County, about 10 miles southeast of Crownpoint. The Borrego Pass ISL project would have been Conoco's first ISL project outside of Texas. Mineralization occurs at depths of 2,100 to 2,200 feet within the Westwater Canyon Member and is mixed primary and redistributed. Reserves are estimated at 15 million pounds U_3O_8 in ore averaging 0.15 percent U_3O_8. The firm cancelled ISL plans, however, in late 1982 and sold its 50 percent interest in the Borrego Pass properties to its joint venture partner, Wyoming Mineral Corporation (WMC). At the time of this writing, In Situ, Inc. is seeking to acquire the Borrego Pass property and has applied for EID approval to proceed with an ISL pilot operation (Table 8).

Exxon Minerals (San Antonio Valley)

Exxon planned a pilot ISL project in section 21, T.12 N., R.4 W., at their San Antonio Valley orebody on the L-Bar Ranch between Bibo in Cibola County and Marquez in Sandoval County. Exxon owned mineral rights on a total of 60,000 acres in this area. The orebody is dominately primary and is in the Westwater Canyon Member of the Morrison Formation at a depth of approximately 850 feet (Hatchell and Wentz, 1981). Reserves are estimated at 3.4 million pounds U_3O_8 in ore averaging 0.098 percent U_3O_8. The mineralized sands are 55 to 70 feet thick. Exxon planned for 20 production wells, 12 injection wells and 10 monitor wells with a five-spot configuration. Four production wells would ring each injection well. Seventy-foot diagonal spacing was planned between injection and production wells. The entire project was to occupy some 2.75 acres.

Table 8. Proposed ISL projects in New Mexico since 1980 (proposals submitted to New Mexico Environmental Improvement Division).

Company	Project	Location Sec.,Twp.Rge.	Approx. Depth (ft)	4/1/86 Status
Exxon	San Antonio Valley	21-12N-4W	925	Cancelled
Phillips	Section 32-Nose Rock	32-19N-12W	3400-3700	Cancelled
Conoco-WMC[2]	Borrego Pass	13-16N-11W	2000	See "In-Situ Inc" below
		18-16N-10W	2200	
URI[3]/Saarberg Interplan	Church Rock	12N-4W	1300-2100	Under negotiation
In-Situ, Inc	Borrego Pass	13-16N-11W 18-16N-10W	2000-2200	Under negotiation

1 United Nuclear Corporation
2 Wyoming Mineral Corporation
3 Uranium Resources, Inc.

An alkaline fluid was to be injected in order to solubilize the uranium. Up to 20 grams per liter each of Na_2CO_3 and $NaHCO_3$, plus up to 1.5 grams per liter of hydrogen peroxide were to be added to the injection fluid of approximately 140 gpm. The pregnant solution from the production wells was to be taken to an IX facility where the uranium would be transferred from the solution to resin beads. Sodium chloride and Na_2CO_3 were to be used to remove the uranium from the beads. This concentrated

U_3O_8 solution would then produce a 15-percent solids slurry through pH change using either an acid and base or acid and hydrogen peroxide. The slurry would then be sent by truck to a drying and packaging facility. Barren solution from the IX plant would be reinjected.

Target U_3O_8 slurry production was to be approximately 9,000 pounds of U_3O_8 per month (Hatchell and Wentz, 1981). Construction of the facility was originally planned to begin in late 1980, but was indefinitely deferred in March, 1981 (EID, Exxon open-file).

Phillips Uranium (Nose Rock Sec. 32)

Phillips Uranium Corporation discovered large, primary roll-type deposits in the Nose Rock area of McKinley County in 1975 (Clark, 1980). Mineralization occurs in at least three zones in the upper part of the Westwater Canyon at depths ranging from about 2,800 feet to more than 4,000 feet basinward. The sinuous roll-front trends generally from southwest (T.19 N., R.12 W.) to northeast (T.20 N., R.10 W.) and contains up to 30.8 million pounds U_3O_8 in ore averaging about 0.15 percent U_3O_8 (Nuclear Assurance Corp., 1984). The middle portion of the trend contains ore rolls that "may be in excess of 50 feet thick" (Clark, 1980) and accounts for a significant portion (approximately 25 million pounds) of total Nose Rock reserves. Underground mining was being developed but has subsequently been terminated and the shafts allowed to flood. In contrast, ore rolls in section 32, T.19 N., R.12 W. are reportedly thin and discontinuous, and appear to be more amenable to recovery using ISL. Consequently, Phillips proposed in June 1980 to develop an ISL pilot in section 32. The section

32 ore bodies are in the Westwater at a depth at some 2,600 feet. C-shaped rolls with very thin limbs occur between mudstones and offer potential for ISL. The company proposed to drill 2 wells into the mineralized zone, wells which would have ultimately become part of a five-spot pattern. One well would have been used for injection using sulfuric acid to mobilize the uranium; the other well would have been used for recovery. Development of the section 32 ISL pilot never proceeded beyond the licensing application and planning stages, and Phillips suspended development of the Nose Rock properties in 1981 after the uranium market began its decline.

OLD STOPE-LEACH PROJECTS IN NEW MEXICO

Uranium operators in the Grants region have utilized a form of ISL in old mine stopes by IX recovery of concentrations of uranium in the range of 2 to 12 ppm (Merritt, 1971) from recirculated mine water. United Nuclear-Homestake Partners (UN-HP) first developed the method in 1964 (Wyrick, 1977). Gulf (now Chevron), Kerr-McGee (now Quivira) and United Nuclear and Homestake have all utilized this low-cost recovery method primarily at Ambrosia Lake (Table 9). Hatchell (1985) reported that mine-water recovery amounted to 108 tons of U_3O_8 in 1983 or slightly more than 4 percent of total New Mexico production for that year, and accounted for almost 28 percent of total production in 1985 as ore production virtually ceased. Net recovery from mine waters is expected to increase and even exceed recovery from ore as mines are placed on standby modes during currently depressed market conditions (Table 10).

Since mine-water recovery does not take place within the zone of groundwater saturation _per se_, but within a cone of groundwater depression,

Table 9. Current and past old stope-leach uranium projects in New Mexico; data modified from Hatchell and Wentz (1981, p. 103).

Operator	Location	Mine	Net Water Production (gpm)
United Nuclear-Homestake Partners (later United Nuclear)	Ambrosia Lake	Sec. 27	
		Ann Lee	
		Sandstone	500-600
United Nuclear	Church Rock	Northeast Church Rock	1,200
		Old Church Rock	600-800
Kerr-McGee (Quivira)	Ambrosia Lake	Sec. 17	
		19	
		22	
		24	
		30	
		30W	
		33	2,500
		35	1,500-1,600
	Church Rock	Church Rock I	3,800
United Nuclear-Homestake Partners (now Homestake)	Ambrosia Lake	Sec. 15	
		23	
		25	
		32	1,700-1,800
Gulf	Smith Lake	Mariano Lake	200-230
Gulf (Chevron)	San Mateo	Mount Taylor*	4,000
Sohio-Western	Seboyeta	JJ No. 1	60

* Although licensed, the Mount Taylor IX facility will not become operational until further underground mine development permits.

Table 10. Mine-water recovery of uranium in New Mexico compared to total recovery from 1980 through 1985; data from EMD, Resource Assessment Bureau.

	---------- lbs. U_3O_8 in Concentrate ----------		Percent Share of New Mexico
Year	Total Recovery	Mine-Water Recovery	Recovery
1985	1,156,047	320,962	27.7
1984	2,757,496	233,930	8.5
1983	5,100,000	216,000	4.2
1982	7,974,000	282,000	3.5
1981	12,660,000	300,000	2.4
1980	15,500,000	320,000	2.1

old-stope leaching may not conform to the strict definition of ISL mining. Net IX recovery is ultimately from an admixture of uranium-bearing waters derived from drill-hole injection, stope sprinkling and natural groundwater (Virginia McLemore, written communication, June 1986).

Stope leach injection wells are drilled from surface to the top of underground stopes where low-grade mineralized material can be leached. Spray nozzles or specially designed "rainbirds" are installed at the base of the wells where recirculated mine and surface water is injected into the low-grade material (Wyrick, 1977). Air is circulated down the holes from surface to facilitate oxidation. Additional uranium is dissolved from the weakly alkaline mine water as uranyltricarbonate. Spraying is regulated to allow for further oxidation and dissolution as indicated by monitoring uranium content of the mine waters.

The pregnant solution is collected in sumps within the mine workings and then pumped to surface settling and holding ponds. Water can be recirculated for further enrichment in uranium or can be piped to the central IX facility. After removal of uranium in the IX unit, barren water can be discharged, recirculated, or sent to the mill for use as process water. Natural mine water inflow also contains uranium in solution and is circulated and treated within the total mine-water regime.

USBM COMPUTER-COST MODEL FOR ISL IN NEW MEXICO

A computer-cost model for ISL mining has been developed by the U.S. Bureau of Mines (USBM) for San Juan Basin deposits to depths of 2,500 feet (USBM, 1982). The data base, originally developed for the Wyoming basins and the south Texas area, has been expanded to include parameters for the San Juan Basin including State and local taxes, royalty payments, depths of deposits, drilling and electrical costs. Mobil, as the only pilot ISL operator in the San Juan Basin at the time of the study, apparently provided a substantial amount of engineering and cost data. The model is written in FORTRAN IV Code. Although considered to be a major improvement toward a generic approach to ISL cost analysis for the San Juan Basin, the model will evolve as more pilot-tests and commercial properties add to the San Juan Basin data base.

The writers regard the USBM cost model to be more responsive to ore grade and depth considerations for New Mexico deposits than to the geological parameters of amenability and ore type (primary vs. redistributed). For example, chemical costs, especially those costs incurred for oxidizers, may prove to be higher for primary deposits than for redistributed deposits at the same depth and average ore grade.

Table 11 summarizes selected cost categories and unit costs as calculated using the USBM model for New Mexico. Some costs cannot be calculated other than on a site-specific basis. Because the New Mexico cost-model database is primarily derived from only one site (Mobil's STDA at Crownpoint), calculations presented in Table 11 are not necessarily

Table 11. Selected unit-cost calculations for New Mexico ISL based on the USBM computer-cost model (U.S. Bureau of Mines, 1982).

Cost Category	Cost per Unit ($)
Wellfield	
Drilling, casing, cementing, perforation	25.00 per ft per well
Downhole equpment-production well	
Pump and motor	4,040.00 per well
Discharge pipe/electrical line	2.00 per ft per well
Flow meter/totalifter	150.00 per well
Control valve	200.00 per well
Electrical switch panel	1,000.00 per well
Pressure guage	50.00 per well
Restoration equipment (capping)	1,000.00 per well
Downhole equipment-injection well	
Flow meter	180.00 per well
Pipe	30.00 per well
Stainless steel tubing	0.34 per ft per well
Pressure guage	50.00 per well
Restoration equipment (capping)	120.00 per well
Downhole equipment-monitor well	
Pump and motor	565.00 per well
Discharge pipe	0.54 per ft per well
Electrical line	0.70 per ft per well
Restoration equipment	120.00 per well
Surface equipment	
Piping[2]	11.90 per ft per well
Mobile equipment	
Well service truck	25,000.00 per wellfield
Trailer	10,000.00 per wellfield
Mobile crane	120,000.00 per wellfield
Road grader	90,000.00 per wellfield
Bulldozer	110,000.00 per wellfield
Extraction plant	
Upflow continuous IX column	
400 gpm size	497,550.00 per wellfield
1,000 gpm size	508,250.00 per wellfield
2,000 gpm size	561,750.00 per wellfield
Capital costs	
Permitting[3]	600,000.00 per wellfield
Pilot plant	125,000.00 per wellfield
Equipment installation/bldg. construction	125,000.00 per wellfield
Drilling & casing (production/injection/monitoring)	1,250,000.00 per wellfield

Pattern surface equipment	12,111.60 per wellfield
Chemical reagent, leachate, oxidizer	
O_2	0.76 per lb. U_3O_8
H_2O_2	3.58 per lb. U_3O_8
Production well equipment	31,760.00 per wellfield
Injection well equipment	9,540.00 per wellfield
Monitor well equipment	3,329.40 per wellfield
Maintenance/operating supplies	11,051.37 per wellfield
Power	100,000.00 per wellfield
Manpower	301,050.00 per wellfield
Restoration	
Brine well	600,000.00
Evaporation pond[4]	4,025.00
<u>Operating costs</u>	
Manpower	301,050.00 per wellfield
Reagent consumption	
Oxidizer	
O_2	0.52 per lb. U_3O_8
H_2O_2	2.78 per lb. U_3O_8
Other chemicals	1.15 per lb. U_3O_8
Resin	0.08 per lb. U_3O_8
Utilities[5]	________
<u>Discounted cash flow</u>	
Royalty payments	10.00%
State taxes[6]	________

1 Variable with depth
2 Insulated pipe
3 New Mexico time frame may lengthen with NRC jurisdiction
4 Based on costs in Wyoming
5 Variable relative to Hp per well (depth) and restoration time
6 See discussion of tax rates, end of this section

representative of all or even most of San Juan Basin deposits, and extrapolations for costs per pound U_3O_8 would be difficult with such a limited database.

All costs presented here are in 1982 U.S. dollars and are calculated for reserves in the 1,000- to 2,500-foot depth increment which constitutes the largest single reserve group in New Mexico (Table 3). Increased depths will cause some costs to increase progressively.

Pilot plant costs are based on the following assumptions:

- ° Average pilot plant solution grade is ½ of the first production wellfield solution grade
- ° Process plant capacity is 100 gpm
- ° Number of drill hole patterns is four 5-spot based on 20 gpm production flow
- ° Labor includes plant superintendent, chemist-assayer, 6 operators, 2 pipe fitters, 2 wellfield operators
- ° Pilot phase will use same leach and oxidizers as full-scale production
- ° Physical characteristics of orebody are same for both pilot phase and full-production phase
- ° Uranium produced during pilot phase is sold during year prior to first production phase

Manpower costs in New Mexico include average annual labor costs of $20,750 and average annual salary costs of $28,500 with a 35% overhead default. These costs are somewhat higher than those in Texas and slightly less than those in Wyoming according to the model.

Restoration cost are estimated to be lower in New Mexico than in Texas where the removal of ammonia from clay prolongs the restoration period. In New Mexico, "...where sodium carbonate-bicarbonate leach solution is assumed, the sodium ion does not attach itself to the clay as tightly", and "...restoration time will be half the production time" (USBM, 1982, p. 19). Thus, costs of reverse osmosis and evaporation ponds are projected to be reduced considerably due to the increased restoration fluid flow rate. The model assumes that deep wells will be used for brine and waste disposal in New Mexico (as in Texas) unlike evaporation ponds in Wyoming. It should be noted, however, that Mobil utilized evaporation ponds exclusively for their STDA pilot. Costs for deep well brine disposal are considerably higher than for surface evaporation ponds.

Pumping capacity of production wells require that horsepower be based on depth of orebody. New Mexico wells will utilize horsepower ratings of about 7.5 Hp per well according to the model. Total power use may be modified also by the shortened restoration times required for New Mexico sites. On the other hand, longer leach phases may be necessary for primary deposits than for redistributed deposits where the uranium is less mobile due to humate.

The model assumes that make-up water requirements will be about 20% of the restoration flow rate and states that "...the restoration flow rate [in

New Mexico] is the same as the production flow rate." Cost of water in New Mexico is about $0.50 per 1,000 gallons.

Five separate State taxes are imposed on uranium in New Mexico and include:

- ° Resource excise
- ° Severance
- ° Conservation
- ° Ad Valorem
- ° Continued care fee

The resource excise tax is calculated on 0.75% of the taxable value or sale price per pound U_3O_8. A deduction is allowed for royalty payments to the State or the United States. The severance tax rate on uranium is 3.5% applicable to 50% of the sales price per pound of the U_3O_8 content contained in severed, saved (stockpiled) or processed uranium. Severance tax is to be paid on or before the twenty-fifth day of the month following the month in which the taxable event occurs (New Mexico Taxation and Revenue Dept., 1985).

CONCLUSIONS

1. New Mexico has very large resources of uranium in deposits that are, in general, in geologic settings suitable for exploitation by ISL methods; redistributed ores are considered to be more amenable to recovery by ISL than primary ores.

2. Most of the deposits are in gently dipping sandstones of the Morrison Formation, and to a lesser extent in the Dakota Sandstone, both in the Grants Uranium Region; primary ore is the dominate ore-type in most areas except Churck Rock, where ores are dominately redistributed, and to some extent at Crownpoint where subequal mixtures of both primary and redistributed ores occur.

3. The deposits are mostly in permeable sandstones interbedded with low-permeability mudstones, and are below the groundwater table, criteria deemed favorable for production by ISL.

4. About 83 percent of the identified reserves are deeper than 1,000 feet, which exceeds the deepest commercial ISL operation in the United States to date; the more amenable redistributed deposits are, in general, at depths of 2,000 feet or less.

5. The deposits in the Morrison Formation in the San Juan Basin are of more than one age and type, and are more variable in habit, mineralogy, trace element and organic carbon association than the roll-type deposits which have been exploited by ISL in Texas and Wyoming.

6. High-carbon (primary) ores may pose the greatest ISL recovery problem for New Mexico deposits, although the higher temperatures and pressures at depth may actually enhance the mobility of uranium when combined with high-oxidant lixiviants. Primary ores are also generally higher in grade than redistributed ores.

7. The mobility of uranium in primary ore in association with degraded humate is the most significant area of uncertainty in the characterization of New Mexico uranium for recovery by ISL.

ACKNOWLEDGMENTS

We would like to thank the Energy and Minerals Department for funding this study and for supplying much-needed data. The report could not have been completed without the encouragement and support of both the New Mexico Energy and Minerals Department and the New Mexico Bureau of Mines and Minerals Resources. Dee Holen did the drafting and kindly assisted in many other ways. We wish to express our appreciation to Frank Kottlowski, Virginia McLemore, Dick Chamberlin, Bill Chenoweth, George Hazlett and John Borkert whose critical reviews of the manuscript resulted in a greatly improved report. Discussions with Dick Chamberlin and Virginia McLemore were most helpful. The New Mexico Environmental Improvement Division and the Office of State Engineer were cooperative in making their files available. Sam Simpson, Eloy Montoya, Roy Spears, Chuck Green, Warren Snell, and Ernie Orell provided generous assistance in the area of ISL project and permitting status. Lee May guided the senior author on a very worthwhile tour of Sequayah Fuels (Kerr-McGee) ISL operations in the Powder River Basin, Wyoming.

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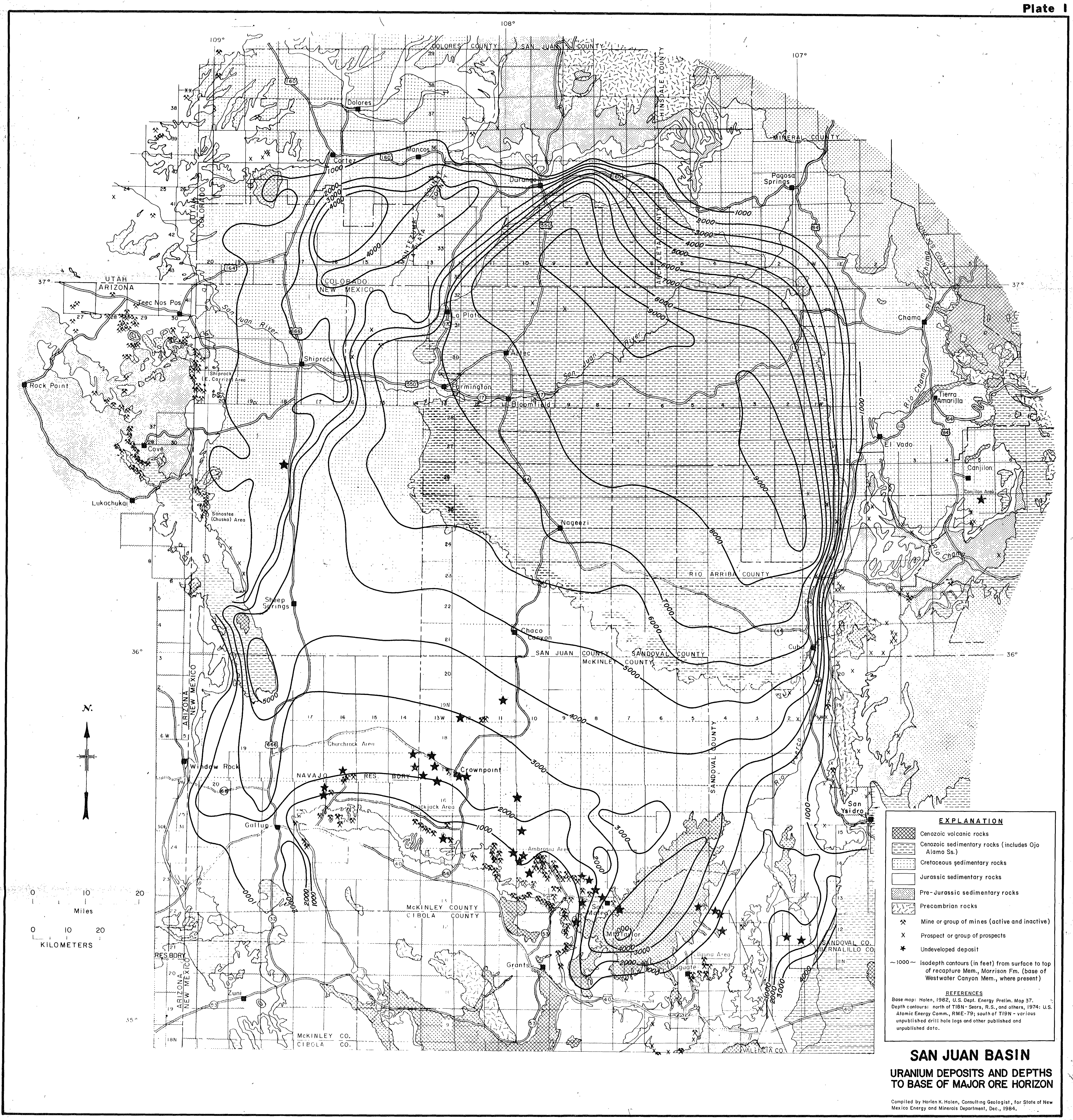

SAN JUAN BASIN

URANIUM DEPOSITS AND DEPTHS TO BASE OF MAJOR ORE HORIZON

Compiled by Harlen K. Holen, Consulting Geologist, for State of New Mexico Energy and Minerals Department, Dec., 1984.


EXPLANATION
Qv Tv
Undifferentiated Quaternary and Tertiary volcanic rocks; mostly basaltic
T
Tertiary sedimentary rocks undivided
K
Cretaceous sedimentary rocks undivided
Jm
Morrison Fm: consists of Recapture Mem. (at base), Westwater Canyon Mem. and Brushy Basin Mem.
J
Jurrasic strata beneath Morrison Fm., undivided
Triassic sedimentary rocks undivided
P
Permian sedimentary rocks undivided
Pennsylvanian sedimentary rocks undivided
pЄ
Precambrian rocks undivided
Uranium deposit in Morrison Fm. of known shape and extent
Locality of close-spaced drilling indicating uranium mineralization in Morrison Fm.
Areas mined, or with mine development (Morrison Fm.)-generalized. Depletion of deposit is not implied.
Deposit (Mine) or cluster of deposits in the Todilto Ls.
Deposit (Mine) in the Dakota Ss.
~ 1000 ~
Iso-depth contours (in feet) from surface to top of Recapture Mem., Morrison Fm. (base of Westwater Canyon Mem., where present).
REFERENCES
Base map and geology: adapted from Chapman, Wood and Griswold, Inc, 1979 (N. Mex. Bureau of Mines & Mineral Res. Geol. Map 31).
Uranium deposits: Chapman, Wood and Griswold, Inc., 1979 (NMBM Geol. Map 31), McLemore, 1984 (NMBM Open File Rpt. 183); Holen, 1982 (U.S. Dept. Energy Prelim. Map 37); Hilpert, L.S., 1969 (U.S. Geol. Survey Prof. P. 603); unpublished drill hole data in files of N. Mex. State Engineer.
For mine locations see NMBM Geol. Map 31 and NMBM Open File Rpt. 183.
GRANTS URANIUM REGION
URANIUM DEPOSITS
Compiled by Harlen K. Holen, Consulting Geologist, for State of New Mexico Energy and Minerals Department; Dec., 1984. Drawn by dmh.
1 2 3 4 5 10 Miles
NAVAJO INDIAN RESERVATION
Crownpoint
Gallup
Thoreau
Grants
Milan
Ramah
Zuni
Laguna
San Ysidro
McKINLEY COUNTY
CIBOLA COUNTY
SANDOVAL COUNTY
Nose Rock Area
Crownpoint Area
Churchrock Area
Smith Lake Area
Ambrosia Area
Poison Canyon Area
Marquez Area
Bernabe Area
Laguna Area
5000
4000
3000
2000
1000