UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A PRELIMINARY REPORT ON THE GEOLOGY OF THE DENNISON-BUNN URANIUM CLAIM, SANDOVAL COUNTY, NEW MEXICO

By

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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards.

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ABSTRACT

Uranium at the Dennison-Bunn claim, south of Cuba, N. Mex., along the east margin of the San Juan Basin, occurs in unoxidized gray, fluvial channel sandstone of the Westwater Canyon Member of the Upper Jurassic Morrison Formation. The uranium-bearing sandstone is bounded on the north and south by a variable zone of buff and orange sandstone. Within the mineralized zone, the uranium has been remobilized and reconcentrated along the margins of numerous smaller tongues of oxidized rock in a configuration similar to that found in roll-type uranium deposits. In cross section, these small-scale features are zoned; they have an inner, pale orange, oxidized core, a mineralized redox rim cemented with hematite(?), and an outer shell of gray, slightly to moderately mineralized rock. The uranium content in the mineralized rock ranges from 0.001 to 0.07 percent U_3O_8.

The uranium, at this locality, is believed to have originated within the Westwater Canyon Member or to have been derived from the overlying Brushy Basin Member. Based on observed outcrop relations, two hypotheses are proposed for explaining the origin of the occurrence. Briefly these hypotheses are: (1) the mineralized zone represents the remnant of an original roll-type uranium deposit, formed during early Eocene time, which has undergone subsequent oxidation with remobilization and redeposition of uranium around the margins of smaller tongues of oxidized rock; and (2) the mineralized zone represents the remnant of an original tabular deposit which has

undergone subsequent oxidation with remobilization and redeposition of uranium around the margins of smaller tongues of oxidized rock.

INTRODUCTION

In the southern part of the San Juan Basin, uranium in the Westwater Canyon Member of the Morrison Formation occurs in tabular, humate-controlled deposits or in redistributed, stacked or roll-type deposits (Granger and others, 1961; Granger and Warren, 1974). Uranium in the redistributed deposits is believed to have been derived from preexisting tabular deposits. In contrast, along the east side of the basin uranium in the Westwater Canyon is found primarily at oxidation-reduction boundaries in a configuration suggestive of roll-type geometry. Most of the known uranium occurrences or deposits in the Westwater Canyon on the east side of the basin are located at the Goodner and Collins leases, about 27 km north of San Ysidro (fig. 1). In In this vicinity, the uranium is located along oxidation-reduction boundaries in the sandstones. The oxidized sandstone is characterized by orange colors that indicate the presence of hematite. Unoxidized sandstone is usually gray or pale buff and may contain sparse amounts of pyrite.

North from San Ysidro to Cuba along the outcrop belt, intervals of similar-appearing orange, oxidized sandstone in the Westwater Canyon are present at the surface.

South of Cuba, the Westwater Canyon Member is the host for a small uranium deposit that occurs in gray, unoxidized sandstone adjacent to orange, oxidized sandstone. This small uranium deposit is at the Dennison-Bunn claim, located in sec. 11 T. 19 N., R. 1 W., along the west flank of the Nacimiento Uplift, in

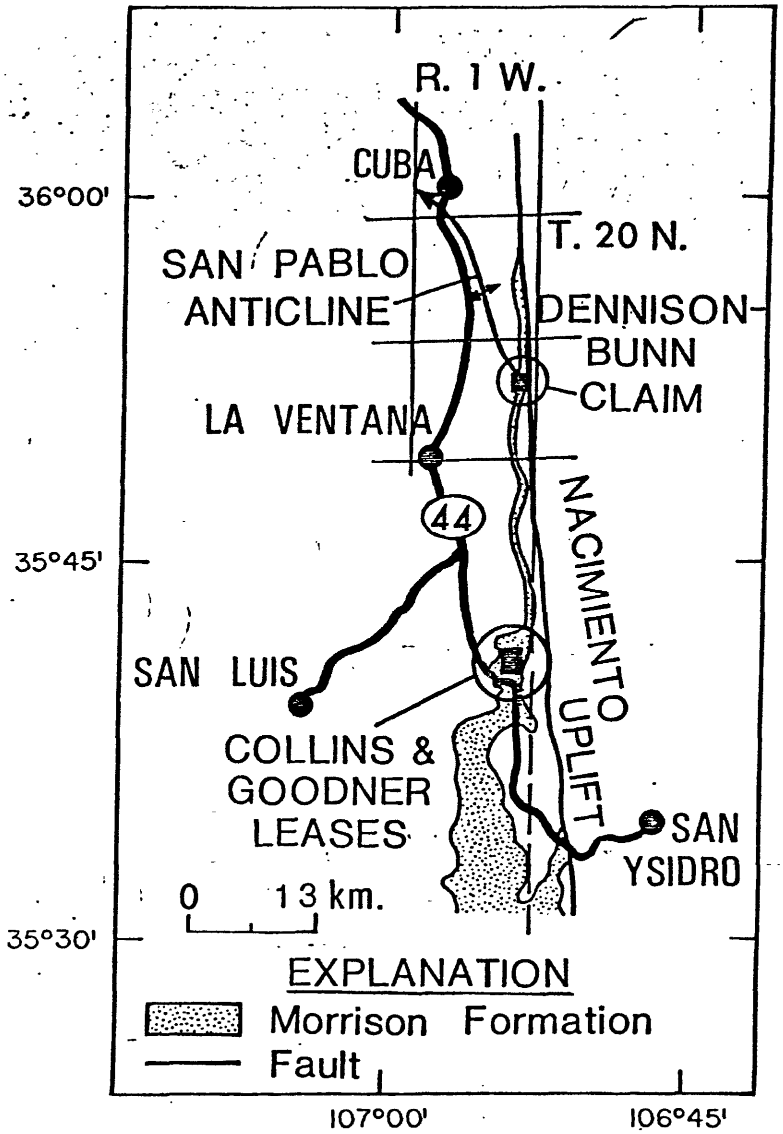


Figure 1. Location of the Dennison-Bunn claim, the Collins and Goodner leases, and outcrop area of the Morrison Formation along the east side of the San Juan Basin, New Mexico.

Sandoval County, New Mexico (fig. 1). Some preliminary results of ongoing investigations of this deposit are presented in this report. Additional findings will be presented later when the investigations are completed.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

Sedimentary rocks, ranging in age from Permian to Cretaceous, crop out in a north-south trending belt just west of the Nacimiento Uplift. In ascending order these are: the Abo, Yeso, and Chinle Formations; the Entrada Sandstone; the Todilto Limestone; the Morrison Formation; the Dakota Sandstone; and the Mancos Shale. Younger Cretaceous and Tertiary rocks are present further west in the basin. Precambrian gneiss and schist form the exposed core of the Nacimiento Uplift. Only the various members of the Morrison Formation will be discussed in this report and emphasis will be placed on the uranium-bearing Westwater Canyon Member. Additional information on the stratigraphy of the area may be found in Santos (1975b) and Woodward and Schumacher (1973).

Morrison Formation

At the Dennison-Bunn claim, the Morrison Formation rests conformably on the Todilto Limestone and is unconformably overlain by the Dakota Sandstone. It is approximately 231 m thick and may be divided into three members that are, in ascending order: the Recapture Member, the Westwater Canyon Member, and the Brushy Basin Member. Figure 2 shows the outcrop relations of the three members at the Dennison-Bunn claim.

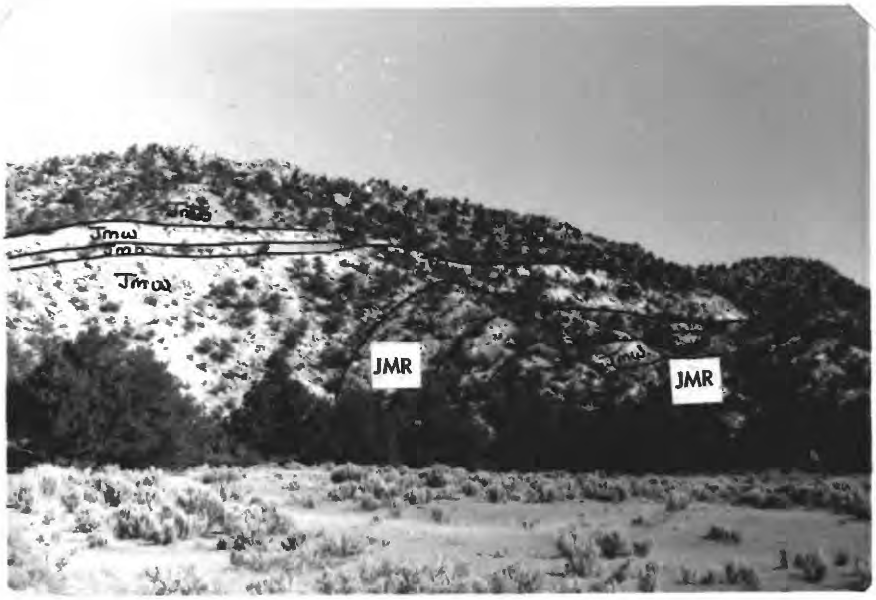


Figure 2. Outcrop relations of the Recapture (Jmr), Westwater Canyon (Jmw), and Brushy Basin (Jmb) Members of the Morrison Formation at the Dennison-Bunn claim. View looking west in direction of dip.

Recapture Member

Throughout the area the entire Recapture Member is poorly exposed; it usually forms an easily eroded slope above the Todilto Limestone and below the slightly more resistant sandstone of the Westwater Canyon Member (fig. 2). Contact with the underlying Todilto Limestone is sharp and conformable; contact with the overlying Westwater Canyon is sharp to intertonguing and involves an increase in grain size and a change in color from light red brown to white and buff.

The Recapture Member is composed of about 96 m of interbedded fine- to very fine- grained sandstone and mudstone.

The sandstone is light reddish brown or pinkish gray and is composed of subrounded to rounded quartz and chert grains and minor amounts of subangular feldspar grains. Accessory minerals include zircon, tourmaline, and black opaques. The sandstone is cemented with calcite and is friable or indurated. Sorting ranges from good to poor; grain size decreases upward in the unit.

Mudstone beds in the Recapture are gray, black, or greenish gray near the bottom and are reddish brown in the middle and upper parts. X-ray diffraction studies on selected mudstone samples indicate that montmorillonite, mixed-layer montmorillonite-illite, and minor amounts of kaolinite are the primary clay minerals present. Limey concretions weather out from mudstone intervals in the middle and upper parts of the member.

Although good exposures are limited, the alternation of sandstone and mudstone intervals gives the member a banded and flat-lying appearance. Bedding is obscure to indistinct due to poor exposures and moderately steep dip of the beds. However, at a few outcrops, the beds appear to be laminated or to contain low-angle cross stratification. The low angle of cross stratification, the fine grain size, and the repetition of sandstone-mudstone intervals indicate deposition in floodplain environments in the distal portion of a fluvial regime.

Westwater Canyon Member

In this study area, the Westwater Canyon Member is not characterized by the massive ledge-forming sandstone so prevalent in the southern part of the San Juan Basin. Rather, the sandstone form low ridges between the slope-forming Brushy Basin and Recapture Members (fig. 2). The Westwater and Brushy Basin intertongue; the contact between the two has been arbitrarily placed where claystone becomes the dominant lithology. The Westwater is approximately 63 m thick, although the thickness varies laterally, both to the north and south. It is composed of coarse- to fine-grained sandstone and interbedded mudstone.

Sandstone intervals ranging in thickness up to 14 m are the dominant lithology. The sandstone is dark and light orange, buff, yellow gray, white, or light gray, depending on the degree of oxidation of iron. Subrounded quartz grains and minor feldspar, chert, and rock fragments comprise the sandstone. Accessory minerals include zircon, iron oxides, and locally, iron sulfides. The sandstone is friable to indurated and is cemented with calcite, chert, clay, or iron oxide. Sorting ranges from moderate to poor; grain size decreases from coarse to medium near the base of the member to medium to fine near the top.

Mudstone beds vary in thickness from a few centimeters to several meters. They are dominantly grayish green, but may also be maroon, reddish brown, or pale orange. Commonly just below an overlying sandstone, the mudstone may be rusty tan in color. X-ray diffraction studies on selected mudstone samples indicate that montmorillonite, mixed-layer montmorillonite-illite, and, locally, kaolinite are the principal clay minerals present.

Bedding is rather indistinct due to surface weathering and moderately steep dip of the beds. However, close examination indicates that the sandstones contain low-angle crossbeds and exhibit some cut-and-fill structures.

Although paleocurrent measurements have not been made, the geometry of the channel sandstones indicates that the axes of the channels lie in a roughly west-southwest to east-northeast orientation. The margins of the channels appear to thin to the north and south. Laterally and vertically, the Westwater Canyon is characterized by a thick sequence of interconnected sand bodies split by discontinuous mudstone horizons. The interbedded sequence of the sandstone and mudstone intervals and the channel form of some of the sand bodies suggest deposition under fluvial conditions of moderately low to low energy.

Brushy Basin Member

In this area, the Brushy Basin Member is characterized by two distinct types of lithology. The basal part of the member is composed of claystone interbedded with siltstone and medium- to fine-grained sandstone; the upper part of the member is composed of a thick sequence of coarse- to fine-grained sandstone (fig. 2). Thickness of the lower interval averages 54 m and that of the upper interval averages about 18 m.

Claystone beds in the lower interval are of various colors but are usually orange, grayish green, or olive gray. Orange claystone occurs mainly in the lower part of this interval. The claystone beds are sandy to silty and may be shaly or indurated.

X-ray diffraction studies of this same stratigraphic interval near Cuba show that montmorillonite, mixed-layer montmorillonite-illite, and locally minor kaolinite are the main clay minerals present.

Many indurated, siliceous, thin siltsone beds are interbedded with the claystone in the lower interval of the Brushy Basin. In the basal part of this lower interval they are orange and in the upper part grayish green. Unpublished studies by the author as well as a published study by Santos (1975b) show that several of the orange siltstone horizons contain the zeolite, clinoptilolite. Santos (1975b) has also reported the presence of analcime in some of the gray-green siltstone beds further south.

Sandstone beds in the lower interval are generally less than 6 m thick and in the lower part of this interval are similar to sandstones of the Westwater Canyon. They are medium to fine grained, may be crossbedded, and are usually orange, buff, rusty tan, or gray in color. Sorting ranges from good to poor; grain size decreases upward through the interval. Quartz and lesser amounts of feldspar and chert fragments comprise the sandstones. Some of the sandstone beds are friable and others are indurated; cementing may be by calcite, chert, or clay. The discrete nature of the sandstone beds and the large volume of interbedded mudstone indicate deposition in low energy fluvial and local lacustrine environments.

A thick crossbedded sandstone sequence overlies the lower interval. This sandstone sequence may be equivalent to the Jackpile sandstone (an economic unit). However, paleocurrent measurements made by Santos (1975b) indicate that this sandstone sequence had a different source. His paleocurrent measurements indicate a dominantly south to southeast direction of transport. This is at odds with the usual east to northeast direction of transport reported for the Jackpile (Schlee and Moench, 1961; Flesch, 1974).

The sandstone beds are coarse to fine grained; sorting ranges from poor to moderate. Locally, the basal part of this upper sandstone sequence is conglomeratic. Chert pebbles and clay clasts, usually less than 1.5 cm, comprise the coarser fractions of the conglomeratic sandstone. Finer-grained sandstones are present in the upper part of this unit. The sandstones are composed primarily of quartz with lesser amounts of feldspar and chert fragments. Quartz overgrowths are common; cementing may be by chert, clay, or calcite.

No mudstone beds were observed at this locality, although they have been reported elsewhere in this interval (Santos, 1975b). The large volume of crossbedded sandstone indicates deposition by large fluvial systems of moderate energy.

STRUCTURAL HISTORY

Major structural features in this area can be related to deformation that began in Late Cretaceous time and continued, at least intermittently, into Eocene time (Baltz, 1967). Studies by Baltz (1967) and Santos (1975b) do not indicate the presence of any pre-Dakota folds in this area; however, some local folding may have begun along the east side of the basin during deposition of the Upper Cretaceous Kirtland Shale and Fruitland Formation (Baltz, 1967, p.27). Structure contours drawn on the base of the overlying Paleocene Ojo Alamo Sandstone (Baltz, 1967, pl. 1) indicate the presence of rather broad northwest trending folds.

The contact between the Ojo Alamo Sandstone and the underlying Kirtland-Fruitland sequence is an angular unconformity, although it is not always easily detected (Fassett and Hinds, 1971). The Ojo Alamo rests on progressively older parts of the Kirtland Shale and on the Fruitland Formation from west to east across the basin (Fassett and Hinds, 1971, p. 29). This relationship suggests truncation of the Kirtland-Fruitland sequence by erosion prior to deposition of the Ojo Alamo. The contact between the Ojo Alamo and the overlying Paleocene Nacimiento Formation is conformable and intertonguing.

Overlying the Nacimiento Formation with erosional and angular unconformity is the Eocene San Jose Formation. Only the relationship between the basal Cuba Mesa Member and the overlying Regina Member of the San Jose Formation are of interest to this report. From north to south along the east side of the basin, the Cuba Mesa Member of the San Jose rests on progressively older parts of the Nacimiento Formation. To the north of the study area, the Cuba Mesa Member rests with angular unconformity on steeply dipping beds of the Nacimiento Formation (Baltz, 1967). This relationship indicates the presence of folding and erosion after deposition of the Nacimiento Formation and prior to deposition of the San Jose Formation.

The following quote from Baltz (1967, p. 54) summarizes the stages of deformation during the Paleocene-Eocene interval.

> "The stratigraphic relations of the Cuba Mesa and Regina Members indicate at least three stages of deformation. The first stage of deformation and erosion occurred in late Paleocene or early Eocene time and resulted in the regional unconformity between the Nacimiento Formation and the Cuba Mesa Member of the San Jose Formation. This stage resulted also in sharp folding of the north-northwest-plunging anticlines in the eastern part of the area, and the attendant locally sharp angular unconformities between the Cuba Mesa Member and the Nacimiento near the east margin of the Central basin. The second stage of deformation occurred in early Eocene time during deposition of the Regina Member and resulted in a local intraformational unconformity along the east margin of the area. During the second stage,the lower part of the Regina Member, the Cuba Mesa Member, and the older rocks on the east margin of the area were steeply tilted west and were eroded and then overlapped by the youngest part of the Regina Member. The third stage of deformation occurred after deposition of the San Jose Formation. During the third stage, the overlapping beds of the Regina Member and the older rocks along the east margin of the area were tilted west and faulted, and the San Jose Formation on the southwest limb of the Central basin was tilted gently northeast."

During these tectonic events rejuvenation of the Nacimiento Uplift occurred. However, according to Baltz (1967), the Precambrian core was apparently not exposed at this time as the Regina Member of the San Jose Formation does not contain abundant granitic detritus. The Regina Member does contain Cretaceous shark teeth, Cretaceous rock fragments, and detritus of presumably Jurassic and Triassic age (Baltz, 1967). This seems to indicate that younger rocks still covered the Precambrian core. Exposure of the Precambrian core took place in Eocene (after deposition of the San Jose Formation) or Oligocene time and additional development of the uplift took place in Miocene time during formation of the Rio Grande Rift. It was during this latter period of deformation that the structural relief of at least 10,000 feet between the Nacimiento Uplift and the San Juan Basin was achieved.

The regional dip is locally more than 10° in the study area and becomes progressively less northwest into the basin. The broad northwest plunging folds are asymmetric; the west limbs of the folds dip more steeply than the east limbs. At the southeastern terminus of these folds the rocks have been unfolded and tilted steeply toward the basin or have been overturned along a hinge line that marks the position of the synclinal bend that parallels the Nacimiento Uplift. The formation of the synclinal bend is closely associated with the formation, in early Eocene time, of the high-angle fault that bounds the west side of the Nacimiento Uplift.

The Dennison-Bunn claim is located at the southern terminus of one of these folds, the San Pablo Anticline (fig. 1). The uranium deposit occurs in the upturned beds which once may have been part of the west limb of the anticline. Using limited outcrop data, structure contours drawn on the base of two Cretaceous formations (the Mancos Shale and the Menefee Formation) clearly reflect the structure of the San Pablo Anticline. In both cases, the dip of the west limb of the fold was calculated to be just under 10°. This dip may indicate the magnitude of the dip imposed by folding prior to deposition of the Eocene San Jose Formation.

In contrast, the Cretaceous Dakota Sandstone and older rocks at the outcrop generally dip between 35° and 50° west-northwest into the basin. Using outcrop data, structure contours drawn on the base of the steeply dipping Morrison Formation do not clearly reflect the San Pablo Anticline structure; the computed structural dip exceeds 30°. The relatively high dip of Dakota and older strata reflect, in part, the original dip imposed by pre-San Jose folding but may be mostly due to increased steepening along the synclinal bend which formed just west of the high-angle fault bounding the Nacimiento Uplift (Baltz, 1967, pl 8; Woodward and others, 1973)). Just west of this belt of steeply dipping rocks the dips probably flatten out and would be conformable to those of the Mancos and younger rocks (Woodward and others, 1973). Additional information on the structural history of the east side of the San Juan Basin may be found in Baltz (1967), Santos (1975b), and Woodward (1974).

URANIUM DEPOSIT

Uranium mineralization occurs in varying degrees in all sandstone horizons of the Westwater Canyon Member in this area. However, the greatest concentration occurs in the uppermost sand intervals.

Geometry

Background radioactivity in barren sandstone of the Westwater Canyon in the vicinity, but away from any uranium occurrence, ranges from 60 to 80 counts per second (cps) on a scintillometer having a 38.1 mm by 38.1 mm sodium iodide crystal. A minimum reading of twice background was used to define anomalous radioactivity. The approximate outcrop area that is anomalous is about 275 m wide, parallel to strike, and about 24 m thick, including interbedded mudstone intervals. However, the most continuous and greatest concentration of radioactivity is in the upper 11 m of this interval. The extent of radioactivity in the third dimension, down dip, is not known.

This upper 11 m consists of fluvial sandstone which is the host for the uranium deposit at the Dennison-Bunn claim. The sandstone beds within this deposit are light gray, buff, or orange depending on the degree of oxidation of iron. Figure 3 is a schematic representation of the outcrop showing the relation of the uraniferous zone to areas of oxidized sandstone. Contacts between oxidized and mineralized rock in the upper part of the sandstone interval are poorly exposed; thus, the relations shown are inferred. The area of unoxidized mineralized rock is bounded on the north by a large area of orange oxidized sandstone and on the south by an area of buff- to rusty-tan-weathering sandstone over 800 m wide. Much further south along the outcrop belt, large areas of bright orange, oxidized sandstone of the Westwater Canyon are present. According to Sears and others (1974), equivalent rocks just west in the basin are not oxidized.

The mineralized rock does not occur directly adjacent to the orange sandstone that bounds it on the north, but is separated from it by nearly 20 m of gray to buff, weakly radioactive sandstone. Local anomalous radioactivity is also present 424 m and 756 m south of the deposit in light-gray to buff sandstone of the Westwater Canyon.

Petrographic data and chemical analyses are not yet available for these large areas of orange and buff oxidized sandstone; thus, they will not be discussed further. The rest of the paper deals with the anomalous, unoxidized sandstone and the relation between oxidized and mineralized sandstone in this zone.

Within the mineralized zone the uranium appears to have been mobilized and reconcentrated along the margins of numerous smaller-scale tongues or zones of oxidized rock that do not appear to be related to the larger tongues of oxidized rock present to the north and south (fig. 3). The oxidized sandstone is pale orange or yellow brown and is surrounded by light-gray or yellow-gray, unoxidized sandstone. The boundary between unoxidized and oxidized rock is always marked by a black to dark-orange, iron-rich, uranium-bearing zone, hereafter referred to as the redox zone, which ranges up to several centimeters thick.

These small-scale tongues of oxidized rock range in size from a few to several tens of meters wide and from less than one to several meters thick. The largest of these is about 100 m in width and has an irregular configuration (fig. 3). Laterally, the zones of oxidized rock are closed. Vertically, this oxidized rock may terminate at the upper or lower contact of the sandstone

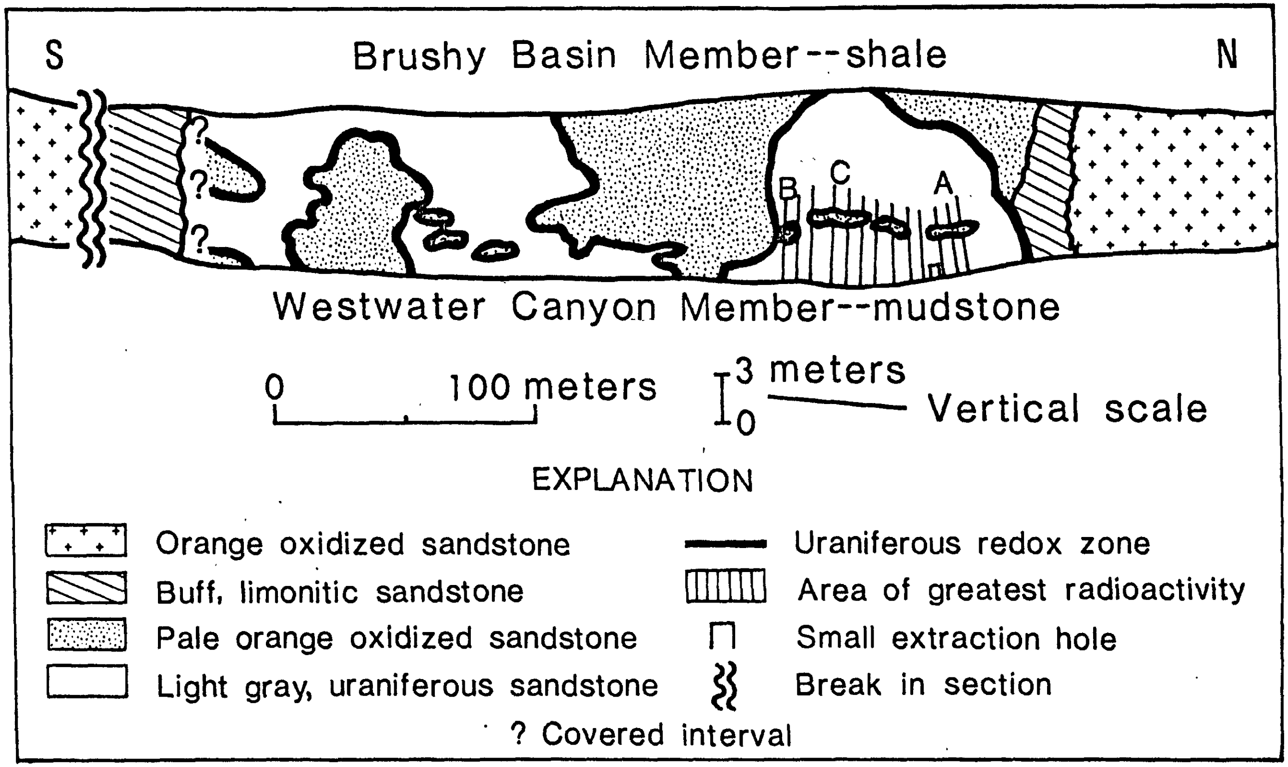


Figure 3. Schematic representation of the outcrop of the uranium-bearing bed in the Westwater Canyon Member of the Morrison Formation, showing the relation of uraniferous zones to areas of oxidized sandstone. View looking west in the direction of dip. Scale is approximate. Features labelled A, B, and C are shown in larger scale in figure 4.

unit or along a thin internal clay seam (fig. 3). Also, some tongues of oxidized rock may be wholly enclosed within the unoxidized sandstone (fig. 3). The shape and geometry of these areas of oxidized rock indicate that the flow of oxygenated groundwater was roughly in an east to west direction, somewhat parallel to the present direction of dip of the beds and the long dimension of the sandstone channels.

Figure 4 is a schematic representation of several of the smaller tongues of oxidized rock. The small features shown in figure 4 are representative of those found at the surface along the entire length of the mineralized zone. These features and the observed scintillometer readings are from the area of highest mineralization shown in figure 3. No scintillometer readings were made for the feature shown in figure 4A.

Uranium concentration throughout the radioactively anomalous sandstone interval is highly variable. Readings on the scintillometer range from 180 to 4500 cps (2 to 60 times background); the average radioactivity is about 300-600 cps (4 to 8 times background). The highest readings occur in the northern part of the anomalous zone, one meter north of the northern boundary of the largest tongue of oxidized rock (fig. 3). In this area, scintillometer readings range from 1000 to 4500 cps over a distance of about 25 m. Some excavation has occurred at this locality but the amount of material removed and the average grade is not known.

The uranium occurs at the irregular boundaries between

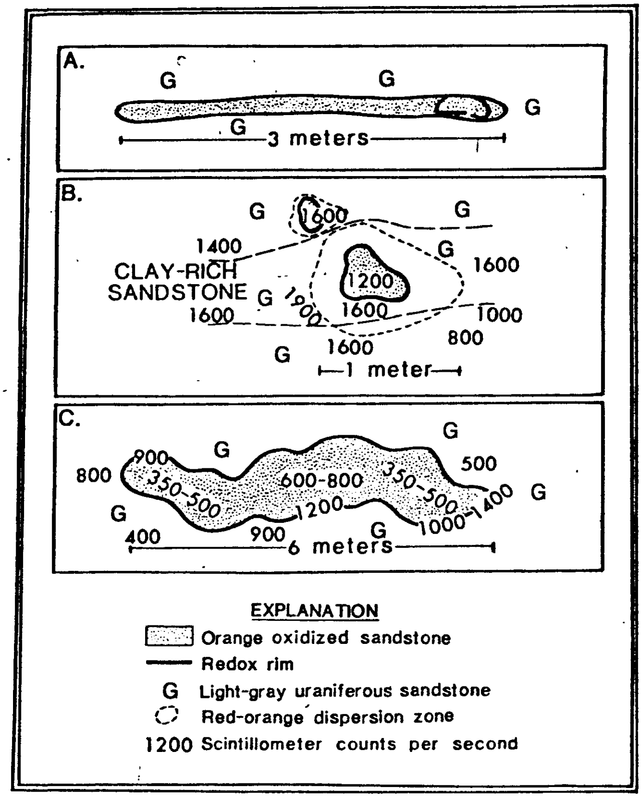


Figure 4. Schematic cross-sections of some of the small-scale tongues of oxidized rock (see fig. 3) and associated levels of radioactivity as determined by scintillometer. No radioactivity measurements are available for A. Scale is approximate.

oxidized and unoxidized sandstone, in a configuration which indicates small-scale roll-type geometry (figs. 3 and 5). The uranium content is generally highest immediately adjacent to a redox interface on the unoxidized side and decreases away from the redox boundary further into the unoxidized rock. The zone of uranium concentration varies from a third of a meter to several tens of meters in width, however, it is usually less than a meter

Figure 5. Cross-section view showing the relation between orange oxidized sandstone (dark area), redox zone (dark band), and light-gray uraniferous sandstone (to the left and below the dark band) on the margin of a small roll-type feature.

wide.

The redox zones also contain variable concentrations of uranium and levels of radioactivity, generally from 4 to 25 times background. The tongues of oxidized rock usually yield low levels of radioactivity, generally between two and three times background. Some tongues of oxidized rock exhibit the same black to dark-orange color found in the redox zone and yield radioactivity levels up to ten times background.

The configuration of the oxidized rock and uranium-bearing sandstone indicates that the uranium at the outcrop represents limbs of ore rolls. Higher uranium concentration may be down dip from these tongues of oxidized rock.

Distribution of Elements

Only a few samples from the mineralized zone have been completely analyzed for various elements. Table 1 lists the chemical analyses for samples that have been analyzed; concentrations of elements were determined by semiquantitative 6-step spectroscopy. All available chemical analyses are from surface samples; the effects of weathering are not known. This suite of samples is too small to allow one to make any accurate statement on the correlation or distribution of elements. However, in all six surface samples the concentrations of molybdenum and vanadium are low. Only the distribution of carbon and uranium will be discussed below.

Carbon analyses for selected samples are shown in table 2. Total, mineral, and organic carbon analyses are very low. Whether this reflects low original carbon values or reflects the effects of leaching cannot be determined. Moreover, because the analyses are from surface samples, the measured organic carbon content may reflect contamination by recent living organisms. Samples submitted for analysis did not contain visible recent organic material.

If one assumes that leaching of organic carbon and the presence of recent organic material is uniform across the outcrop, some relative differences in carbon content are noticeable. The highest values of organic carbon occur in the

Table 1.--Chemical analyses of samples from the Dennison-Bunn uranium claim, Sandoval County, New Mexico

[Analyses determined by semiquantitative 6-step spectroscopy. Values for FeO, MgO, CaO, TiO_2, Na_2O, K_2O, and Al_2O_3 are in percent; values for all other elements are in ppm. L indicates detected, but below limit of detection. N indicates not detected.]

	Elements																								
Sample No.	FeO	MgO	CaO	TiO_2	Na_2O	K_2O	Al_2O_3	Mn	B	Ba	Be	Co	Cr	Cu	Mo	Nb	Ni	Pb	Sr	V	Y	Zr	Ga	Yb	Th
AP-JW-3B[1]	0.2	0.07	0.07	0.03	0.5	3.0	2.0	15	L	500	N	L	1.5	3	N	L	L	10	70	20	L	70	7	L	N
AP-JW-3C[2]	5.0	0.07	0.1	0.03	0.7	3.0	5.0	500	L	700	2	20	1.5	5	7	L	7	15	100	30	50	30	7	3	N
AP-JW-3D[3]	1.0	0.15	0.15	0.2	0.3	3.0	5.0	50	20	500	L	L	7	10	7	15	5	15	70	30	15	300	7	2	N
DB-1[4]	0.7	0.07	0.15	0.03	0.3	3.0	2.0	15	L	500	N	N	2	3	30	N	N	15	70	30	N	50	5	L	N
DB-2[5]	0.1	0.05	0.15	0.02	0.2	3.	2.	3000	N	500	N	20	1	5	50	N	L	10	70	30	N	30	5	L	100
DB-3[6]	0.2	0.05	0.07	0.07	0.2	2.0	2.0	50	N	300	N	N	7	5	N	N	L	10	30	15	N	70	L	L	N

1Light-orange sandstone from an oxidized tongue.
2Dark-orange, iron-rich sandstone from a redox zone.
3Light-gray sandstone from most radioactive area.
4Gray to light-tan sandstone containing manganese oxide (see fig. 7).
5Manganese oxide separate from gray uraniferous sandstone.
6Light-gray sandstone from horizon above the main mineralized zone.

Table 2.--Carbon analyses of selected samples from the zone of anomalous radioactivity

[Sample descriptions may be found in table 1; Values shown below are in weight percent.]

Sample number	Total carbon	Organic carbon	Mineral carbon
AP-Jmw3B	0.09	0.05	0.04
AP-Jmw3C	0.12	0.12	<0.01
AP-Jmw3D	0.07	0.07	<0.01
DB-1	0.05	0.05	<0.01
DB-2	0.10	0.10	<0.01
DB-3	0.06	0.06	<0.01

redox zone and in association with manganese oxide. Organic carbon contents of samples from a tongue of oxidized sandstone, from a light-gray, uraniferous sandstone, and from a bleached, nonuraniferous sandstone above the mineralized horizon are approximately the same. The only sample showing any mineral carbon is from a tongue of oxidized sandstone. The mineral carbon value reflects the presence of calcite cement in the tongue.

Although only a few samples have been analyzed for uranium a pattern of uranium distribution is discernible (table 3). The concentration of uranium is variable across a roll-boundary. Based on scintillometer readings made during various traverses, uranium appears to be most abundant in unoxidized rock adjacent to the redox zone and decreases in concentration laterally in both directions from this zone. Uranium is also concentrated in the redox zone. Uranium in lesser concentration is found in the oxidized rock, in the sandstone bed below the main mineralized zone, and in claystone intervals associated with these rocks.

Table 3.--Uranium and equivalent uranium (eU) values of selected samples from the zone of anomalous radioactivity

Sample number	U, ppm	eU, ppm	Description of sample
AP-Jmw2	22.73	190	Light-orange-gray sandstone from sandstone channel below main uraniferous horizon.
AP-Jmw2A	83.37	180	Gray mudstone bed in main uraniferous horizon.
AP-Jmw3A	73.24	240	Gray mudstone from just below main uraniferous horizon.
AP-Jmw3B	52.15	110	Light-orange sandstone from an oxidized tongue.
AP-Jmw3C	324.62	310	Dark-orange, iron-rich sandstone from a redox zone.
AP-Jmw3D	657.14	610	Light-gray sandstone from most radioactive area.

Table 3 shows the uranium and equivalent uranium values of selected samples. Uranium concentration of the samples was determined radiometrically and by delayed neutron activation. Uranium content ranges from 0.001 to 0.07 percent U_3O_8. Equivalent uranium values shown in table 3 are similar to those reported by Sears and others (1974) from this deposit.

As shown in table 3 uranium is not in equilibrium with its daughter products. This pattern of disequilibrium is characteristic of uranium deposits in sandstones (Harshman, 1972; Santos, 1975a). As in other sandstone deposits, if the uranium concentration determined by chemical or delayed neutron methods is less than 0.01 percent, the corresponding equivalent uranium, eU, value is usually greater. Samples which contain greater than 0.01 but less than 0.1 percent uranium show an approximate equivalence between delayed neutron and radiometrically determined uranium values, although slight disequilibrium in this range of uranium values can occur. Santos (1975a) has attributed this pattern of uranium disequilibrium to migration of the daughter product Ra226 rather than to the movement of uranium.

Mineralogy

The principal epigenetic minerals in the radioactive anomalous zone are hematite, iron sulfide, calcite, manganese oxide, and secondary uranium minerals. Hematite occurs in the oxidized rock and in the iron-rich zone at the redox boundary. In oxidized rock, hematite occurs as coatings on grains, as discrete grains, as irregular masses, and along cleavage planes in feldspar and biotite. Invariably the hematite masses contain a remnant core of some preexisting iron-bearing mineral, whose original composition has not yet been determined.

In the uranium-bearing iron-rich zone at the redox boundary, iron oxide (hematite?) appears to be the principal cementing material. The hematite occurs as thick to thin concentric rims around other grains and as an alteration of feldspar grains. The material rimming the grains may have originally contained other iron-bearing minerals and perhaps carbonaceous material. The presence of carbonaceous material has not been confirmed visually, but rather is suggested by a slightly higher value of organic carbon for this zone (table 2). This iron-rich cement is also radioactive. Fission tracks recorded on a thin strip of mica show a one to one correlation with the distribution of iron-rich cement (fig. 6). The nature of the uranium has not yet been determined. It may occur as tiny discrete minerals or may be adsorbed onto the surface of the iron oxide (van der Weijden, 1976).

Iron sulfide occurs sparsely in the uxoxidized rocks, usually as extremely small aggregates and as coatings on sand grains. Further study of polished thin sections should determine the identity of the sulfide species.

Calcite has been observed only in the oxidized rocks from the mineralized area, in rocks from the lower sandstones of the Westwater Canyon, and from the basal sandstone of the Brushy Basin directly above the mineralized area. In the oxidized sandstone fine-grained quartz cement coexists with calcite cement. The calcite occurs as large, optically continuous crystals, enclosing many grains. Feldspar grains enclosed in these crystals show varying degrees of replacement by calcite.

Black, opaque material coating grains or occurring as botryoidal masses along fractures (fig. 7) has been identified, through use of the scanning electron microscope, as manganese oxide. X-ray diffraction studies were performed on this material but the specific manganese oxide could not be determined. In figure 7, the light colored area surrounding the manganese oxide is composed of quartz and feldspar which are coated with effluorescent gypsum and secondary uranium minerals. The dark gray area of the rock is composed of quartz, feldspar, and effluorescent secondary uranium minerals. Semi-quantitative

Figure 6. Photomicrograph showing the correlation of fission tracks (short dark lines) to iron-oxide cement (dark gray areas).

Figure 7. Manganese oxide (black areas) occurring along fracture White material in fracture consists of quartz and feldspar grains coated with gypsum and secondary uranium minerals. Gray host rock surrounding fracture consists of quartz, feldspar, and secondary uranium minerals.

spectrographic analyses of the manganese oxide separate show a slight enrichment of molybdenum and organic carbon and a greater content of thallium as compared to the manganese-poor part of the surrounding host rock (tables 1 and 2). The manganese oxide is found at the outcrop surface and was probably formed under surface or near-surface oxidizing conditions.

Yellow and yellow-green secondary uranium minerals are visible in hand specimens of uranium-rich rocks. These minerals have been identified by Schott and Wegrzyn (Chenoweth, 1974; written commun., 1978), using x-ray diffraction techniques, as bayleyite and liebegite. Bayleyite, a hydrated magnesium uranium carbonate, occurs as thin yellow crusts coating grains and is weakly fluorescent under long and short wave ultra-violet light. Liebegite, a hydrated calcium uranium carbonate, is yellow-green and occurs as a thin crust on grains or as discrete crystals. It has a yellowish-green fluorescence in both long and short wave ultra-violet light.

Origin of the Deposit

In understanding the origin of any uranium deposit, two basic related questions must be answered. The first involves the source of the uranium; the second involves the method of transport and concentration of the uranium.

There is no direct evidence for the origin of the uranium at the Dennison-Bunn claim. Some possible sources include the Westwater Canyon and the Brushy Basin Members of the Morrison Formation, the Ojo Alamo Sandstone, the Cuba Mesa Member of the

San Jose Formation, or the Pleistocene Bandelier Tuff. All of these units contain arkosic sandstone or volcanic ash layers or are known to be radioactive. The Ojo Alamo and Cuba Mesa are composed of arkosic sandstones. However, it cannot be demonstrated that either of these units at any time directly overlay the Westwater Canyon. Instead, over 600 m of sediment separate these units from the Westwater Canyon.

Chenoweth (1974) has postulated that the Bandelier Tuff, which contains up to 20 ppm uranium in grab samples, once covered a broader area and could have been the source of uranium for a number of small occurrences in the Nacimiento area and in the southern part of the Chama Basin. Although it is possible that the Bandelier Tuff could have been the source for the uranium at the Dennison-Bunn prospect, the formation of a uranium deposit in the already steeply dipping rocks is unlikely. Also, there is no direct evidence that the Bandelier Tuff was ever deposited west of the Nacimiento Uplift.

The Westwater Canyon and overlying Brushy Basin appear to be the most likely sources of uranium. It is not known whether the uranium was first concentrated into local tabular-type deposits, before being redistributed in its present form, or whether it was disseminated.

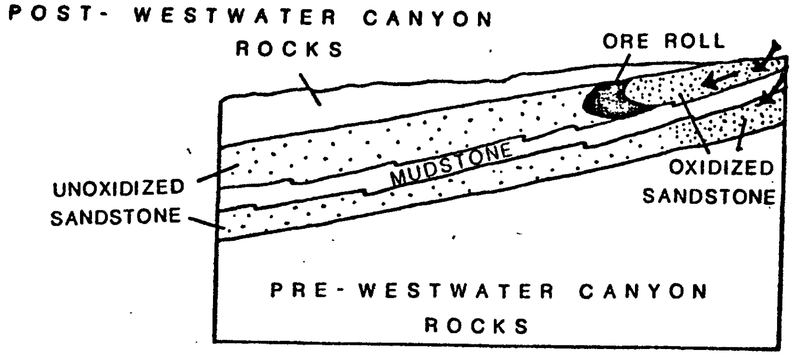
Conclusive answers on the origin of this deposit have not been reached. Based on observed outcrop relations, there are two hypotheses that could explain the method of transportation and concentration of uranium in this deposit. Briefly these hypotheses are: the anomalous zone of radioactivity represents (1) the remnant of an original roll-type uranium deposit or (2) the remnant of an an original tabular deposit which has undergone subsequent modification by oxidation with remobilization and redeposition of uranium around the margins of smaller tongues of oxidized rock. These hypotheses are conjectural owing to the lack of nearby subsurface data, to the removal of the updip portion of the strata, and to modification by later oxidation. The hypotheses are discussed below.

The first hypothesis for explaining the origin of the deposit is that the mineralized zone represents the remnant of an original roll-type uranium deposit largely destroyed by near-surface oxidation. The pattern of uranium mineralization at the Dennison-Bunn claim suggests at least two major stages of uranium remobilization and redeposition. The first stage involved concentration of uranium (previously disseminated in the tuffaceous portion of the Westwater Canyon or Brushy Basin Member or preconcentrated in small areas) in a roll-type deposit at the boundary between oxidized and unoxidized rock. The large outcrop area of anomalous radioactivity has an obvious relation to the large tongue of orange oxidized rock to the north, although it is quite probable that the oxidized rock associated with the original deposit actually lay updip and has been subsequently removed by erosion. This relationship suggests that uranium was concentrated in these rocks by ground water flow in a process similar to that which formed the Tertiary roll-type uranium deposits in Wyoming and Texas.

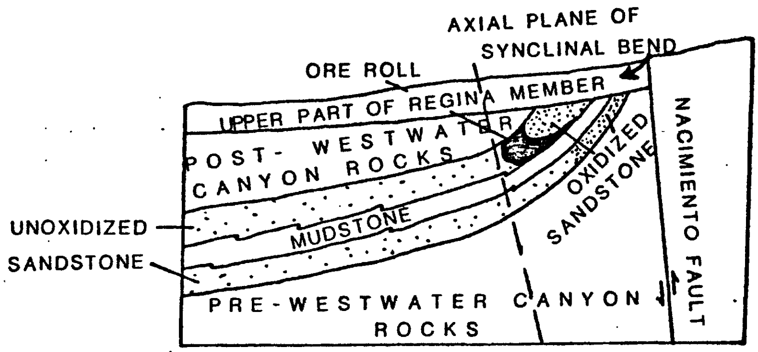
Structural and geochemical conditions suitable for uranium mineralization may have existed in early Eocene time, during erosion of the crests of the north-west trending folds and of the emerging Nacimiento Uplift, and prior to steepening of the beds along the hinge line of the synclinal bend. The calculated dip of less than 10° for the west limb of the San Pablo Anticline may closely approximate the local structural dip during the mineralization. This dip would have been favorable for the formation and preservation of uranium deposits, assuming all other necessary factors were present.

Prior to early Eocene time, the Morrison Formation was buried by a thick sequence of Cretaceous and Tertiary strata that prevented access of oxygenated ground water necessary for the formation of a roll-type uranium deposit. After early Eocene time, tilting of the strata along the synclinal bend produced dips in the host rock that are probably too steep (45°) to allow the formation of a roll-type uranium deposit.

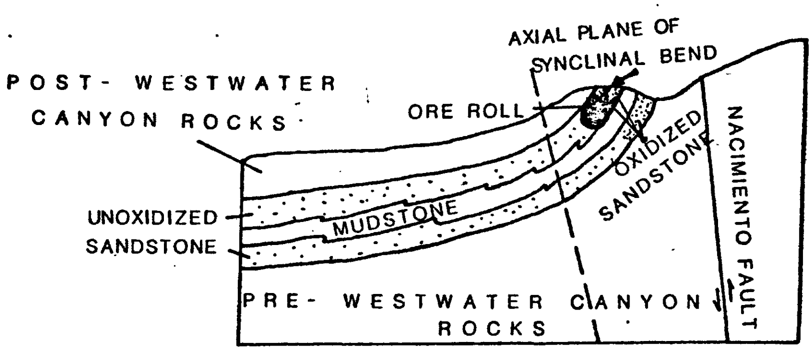
Figure 8 contains schematic diagrams showing the inferred relation of the position of the uranium-bearing sandstone of the Westwater Canyon Member to ground water flow during the formation, preservation, and destruction of the uranium deposit during Eocene and post-Eocene time. The stratigraphic relations shown are based on stratigraphic relations present just north of Cuba, as erosion has removed all traces of the Regina Member from the study area. The sequence of events that are presumed to have



A. Formation of the uranium deposit during early Eocene time



B. Preservation of the uranium deposit during early Eocene time (after deposition of the upper part of the Regina Member of the San José Formation)



C. Destruction of the uranium deposit during post-Eocene time

Figure 8. Generalized diagrams showing the position of the uranium-bearing sandstone of the Westwater Canyon Member of the Morrison Formation to ground water flow during successive stages of formation, preservation, and destruction of the uranium deposit. Arrows indicate inferred path of ground water movement.

taken place during the formation, preservation, and destruction of the uranium deposit are discussed below.

In early Eocene time the Morrison Formation may have been exposed, or nearly so, during erosion of the crest of the San Pablo Anticline. During this period, uranium-bearing, oxygenated ground water would have entered the bevelled edges of the then gently dipping Westwater Canyon Member. Where this water encountered reducing conditions a roll-type uranium deposit was formed (fig. 8A).

Subsequently, the rocks at the southeastern end of the San Pablo Anticline were turned up along the hinge line of the synclinal bend and were then covered by sediments of the upper part of the Regina Member and later sediments, which have since been removed from the area (fig. 8B). This upturning of the beds and subsequent burial affected the hydrologic regime in the area and may have prevented the influx of oxygenated ground water, thus protecting the deposit from destruction.

A second stage of uranium remobilization and redeposition took place during subsequent periods of erosion, interrupted by periods of sedimentation and continued uplift of the Nacimiento Uplift, when oxidizing ground water again entered the truncated edges of the Morrison Formation. During this stage remobilization, removal, and subsequent redeposition of uranium around the small tongues of oxidized rocks in the mineralized zone occurred (fig. 8C).

Destruction of the deposit continues to this day. The where most recent oxidation has destroyed the deposit.

Economic Speculations

The uranium analyses shown in table 3 reflect the concentration of uranium at the Dennison-Bunn claim now present at the surface and may not reflect the original concentration. The low uranium concentration may reflect removal of uranium by various stages of oxidation and solution or it may reflect an original low concentration. If the roll-type hypothesis is correct, it may be that the time available for formation of the initial deposit was too short to produce a very large deposit. The steepening of the beds containing the deposit along the synclinal bend would have disrupted the hydrologic regime responsible for formation of the initial roll-type deposit. If the tabular hypothesis is correct, the low concentration of uranium may reflect low amounts of uranium available to the system and/or a low concentration of reductant in the host rock during mineralization.

Based on surface data, the deposit at the Dennison-Bunn claim is not now economic. The small size of this deposit and of those mined near San Ysidro may indicate that any deposits found in the subsurface on the east side of the San Juan Basin will be smaller than those in the Grants area. Roll-type uranium deposits would be limited in location to the margins of large tongues of oxidized sandstone. These large areas of oxidized sandstone are present only at intervals along the outcrop belt from San Ysidro to Cuba, thus limiting the area favorable for locally radioactive buff, limonitic sandstone that bounds the deposit on the north and south may represent areas where most recent oxidation has destroyed the deposit. The present distribution of uranium concentration in the mineralized zone may reflect portions of the original deposit and portions that have resulted from redeposition of uranium around the variously shaped tongues of oxidized rock.

The gross aspects of uranium mineralization at the Dennison-Bunn claim and its similarities to the roll-type uranium deposits and occurrences near San Ysidro suggest that a roll-type origin is the most probable for this deposit.

A second hypothesis for explaining the origin of this deposit is possible, although firm evidence to support it is lacking. This hypothesis proposes that the uranium occurrence represents the remnant of a small tabular uranium deposit in various stages of destruction by successive stages of oxidation. The orange oxidized sandstone that bounds the north side of the mineralized zone may represent one of the later stages of oxidation which would remobilize and remove uranium from the area. The remainder of the deposit, which was not destroyed during the period of oxidation that produced the large tongues of oxidized rock to the north and south, reflects later modification with remobilization and redeposition of uranium at the oxidation-reduction boundaries of the smaller tongues of oxidized rock. The locally radioactive buff, limonitic sandstone that bounds the deposit to the north and south may represent areas roll-type uranium exploration.

Only the presence of tabular-type uranium deposits would make the east side of the basin economically favorable for uranium exploration. If the deposit at the Dennison-Bunn claim does represent an oxidized, partly remobilized tabular deposit, it could mean that all the conditions necessary to produce tabular uranium deposits exist this far north in the basin. Similar small- to medium-size deposits may exist along the major sandstone trends in the subsurface to the west.

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