SEDIMENTARY CONTROLS ON URANIUM ORE AT L-BAR DEPOSITS, LAGUNA DISTRICT, NEW MEXICO

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Abstract

Uranium at the L-Bar deposits occurs in tabular, concordant bodies that are considered segments of channel fills and bars deposited in the lower flow stages of a large, braided stream. The deposits are composed of scores and possibly hundreds of these mineralized bodies. The richer parts of the deposits are clusters of partially coalescing mineralized depositional units. Uranium mineralization is coextensive with the presence of carbonaceous material. The bulk of this carbonaceous material occurs in crossbedding laminae and as randomly distributed clasts and is detrital in origin. Accumulations of vegetal material in the flood basins of the river are the likely source of the carbonaceous matter. The partially degraded humic substances were eroded by the migrating channels of the river and incorporated into the sandstones. Both surface and ground waters carried uranium during Morrison deposition, and this uranium was extracted and fixed by the partially degraded humic material. The critical element in the formation of the deposits was the conjunction of uranium-bearing waters and the presence of humic substances effective in extracting uranium from dilute solutions.

Introduction

The L-Bar cluster of deposits is in the Laguna uranium district about 3 mi east of the small town of Bibo and 3 mi north of the Jackpile mine (fig. 1). The deposits take their name from the large ranch on which they occur, formerly owned by the L-Bar Cattle Company. The ranch and the deposits are now owned by Sohio Western Mining Company and Reserve Oil and Minerals Corporation; Sohio is the operator for the joint venture.

Uranium mineralization at the L-Bar occurs at depths of 200 to nearly 700 ft, with most of this variation caused by the local topography. Current operations are underground, and the shaft is located near the northwest end of the largest of the deposits. Shaft sinking began in February 1975, and the mine was brought into production in the third quarter of 1976. Plans for development of the remaining orebodies have not been announced. Two additional mining operations seem likely, and one of these may be an open pit.

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General geology

The deposits occur in the southeast part of the San Juan Basin, where the surface rocks are the Mancos Shale and Tres Hermanos Sandstone. A well drilled to 3,400 ft encountered the normal section of Dakota, Morrison, Bluff, Summerville, Todilto, Entrada, and Chinle Formations. Tertiary intrusives and flows are nearby, but no igneous rocks were encountered in the drilling or in-mine development.

The formations dip to the northwest, about 75 ft/mi, into the San Juan Basin. Several high-angle faults with displacements of a few feet were found in the mine, but no major faulting seems to be present. In the Jackpile area, a few miles to the south, Schlee and Moench (1961) found evidence of significant warping that occurred contemporaneously with Morrison sedimentation. Available evidence is not adequate to indicate whether the movements extended into the L-Bar area; however, the unconformity at the top of the Morrison suggests that small-scale movement probably occurred extensively during the later stages of Morrison deposition. Major uplift and tilting of the region occurred during the Laramide, with some Tertiary uplift and adjustments.

Delineated commercial mineralization is entirely within the Jackpile sandstone unit in the uppermost portion of the Morrison Formation. These deposits are the most northerly and farthest downdip of the known, significant Jackpile uranium deposits.

The contact of the Jackpile sandstone with the underlying Brushy Basin Shale Member of the Morrison Formation has at least 10-15 ft of local relief that is apparently the result of scouring as deposition gradually changed from predominantly clay to predominantly sand. The upper contact with the Dakota Sandstone is an unconformity, with the Dakota progressively truncating members of the Morrison Formation southward from the mining district. However, no angular discordance or truncation has been noted in the area immediately to the north of the L-Bar deposits.

Jackpile sandstone

The Jackpile sandstone has been identified in outcrops and bore holes in a band extending along the east flank of the San Juan Basin for at least 65 mi northward from the Laguna area. In the vicinity of the ore deposits, it is a single tabular body 10-15 mi wide, but a few miles to the north it bifurcates into two sandstone bodies; still further north it divides several times again. Its maximum thickness occurs in the vicinity of the Jackpile and Paguate mines where it is up to 200 ft thick. At the L-Bar deposits, the sandstone is 80-100 ft thick; whether this section represents all or only part of the Jackpile sandstone as defined in the Jackpile-Paguate area is unknown.

Schlee and Moench (1961) have considered the Jackpile sandstone to be the product of a northeastward-flowing braided stream that was localized by downwarping contemporaneous with deposition. Features at the L-Bar—such as obvious scour and channel forms, intraformational conglomerates, abrupt termination of local lithologic units, relative lack of interbedded shale beds and variable crossbedding—are all consistent with deposition in a braided river. The river was large, choked with sediment, and aggraded rapidly; and it probably had marked seasonal variations in flow.

Work done since that of Schlee and Moench (1961) has raised the question of the source of the Jackpile sandstone. Santos (1975), mapping in the area northeast of the ore deposits, found a strong southerly orientation for the inclination of crossbedding planes, and such an orientation would be inconsistent with the northeastward-flowing stream postulated by Schlee and Moench.

Thick, essentially uninterrupted sequences of sandstone are characteristic of the Jackpile. Shale or mudstone beds are not totally absent but they are rare, and their near absence is attributed to the extensive reworking of sediment that occurs in a braided stream. Fine-grained sediments tend to be deposited mostly in the flood basins and backwater areas, and these would have little chance of being preserved in an environment of constant channel migration. Instead, fine-grained sediments would be eroded by the stream and reworked into the sandstone. As a result, sand-sized and larger clasts of clay are a major constituent of the sandstone. Adams and others (1978) suggested the clay aggregates found in the sandstone are the result of alteration in place of volcanic-glass fragments. This hypothesis is attractive because it provides an indigenous source for the uranium, but direct evidence is sketchy, and the occurrences are much as expected in the postulated environment of Jackpile sedimentation.

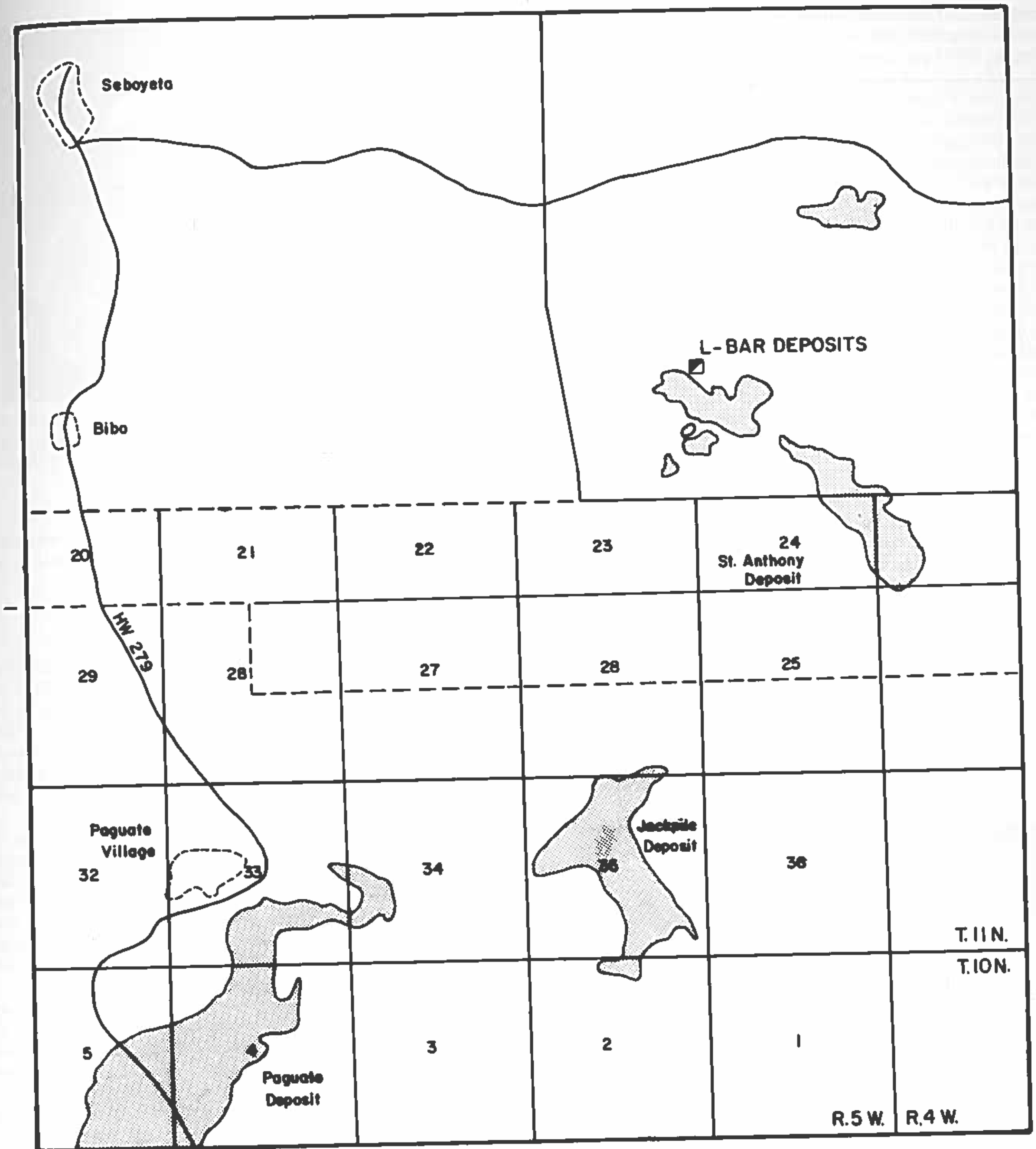

FIGURE 1—MAJOR URANIUM DEPOSITS IN THE JACKPILE SANDSTONE, LAGUNA DISTRICT.

The Jackpile is a fine- to medium-grained, clayey, feldspathic sandstone. Large samples from the milling operation suggest the median grain size is about 0.2 mm; since the clay masses undoubtedly disaggregate during size analysis, the median size of the framework grains is probably somewhat larger. A few granules are present along an occasional bedding plane. Sorting of the framework grains is good, and rounding is markedly variable. Where fresh and unmineralized the sandstone is very light gray but may have a pinkish cast where feldspar is coarse and abundant. Mottling, in the form of patches of white clay several millimeters in diameter, is conspicuous. Local small areas of hematite staining are seen, and near the base of the sandstone, red bands up to several inches thick are present. The uranium-bearing sandstone ranges from light to very dark gray; the color is contributed by black carbonaceous material.

The Jackpile is composed of about 60 to 90 percent quartz, with most of the remainder comprising feldspar and clay. A few grains of chert and other rock fragments are present. Overgrowths occur on a small proportion of the quartz grains but do not contribute to the cementation of the rock. The feldspar is predominantly potassium feldspar with some plagioclase. Microcline is relatively fresh, but orthoclase and plagioclase are moderately to badly altered.

Clay is present in two varieties: One is white kaolinite which occurs as disseminated white dust, as nests encompassing several grains, and occasionally as wormy-looking booklets. Similar occurrences of kaolinite, along with quartz overgrowths, are a common diagenetic feature of feldspathic sandstone (Wilson and Pittman, 1977) and have been described in outcrops of the Jackpile sandstone well removed from the known uranium deposits (Flesch and Wilson, 1974).

The second, and quantitatively more important, clay is gray green and apparently is mostly composed of montmorillonite and mixed-layer clays (Nash, 1968). Silt-sized particles of quartz and feldspar are commonly incorporated in the clay. This type of clay occurs as dispersed matrix, as aggregates ranging in size from sand to pebbles, and as lenses and layers ranging from a mere wisp to beds several feet thick. The greatest amount of the clay seems to be in the form of aggregates, and these locally make up 10-15 percent of the sandstone. Clearly, this clay is detrital in origin, and it does not appear to differ significantly from the clay that makes up the underlying Brushy Basin mudstone. Uranium mineralization is strongly associated with this type of clay, and the highest-grade occurrences of ore seem to be in clayey sandstone or immediately adjacent to clay partings or pebbles.

A limy zone a few feet thick commonly is present near the base of the sandstone, but the sandstone is notable for the absence of calcite or other carbonates.

Crossbedding is conspicuous and seems to be present everywhere. Crossbedding is particularly obvious in the underground workings, because the carbonaceous material that gives the rock its gray color is differentially concentrated among the laminae (fig. 2). In the ore-bearing zones, the dominant form of crossbedding is tabular (fig. 2). The sets range in thickness from a few inches to about a foot. The base typically is undulatory, the laminae are planar to gently curved, and the orientation of the sets is variable. Large-scale trough crossbedding also is present, but it is not as prominent underground as it is at the outcrop (Moench and Schlee, 1967; Flesch and Wilson, 1974; Santos, 1975). The more common occurrence of tabular crossbedding in orezones suggests these zones are the product of the lower range of stream velocities. Small-scale trough crossbedding occasionally is defined by vegetal remains (fig. 3); commonly, it may be superimposed on the larger scale features, but it is not seen readily except where small amounts of carbonaceous residue are present.

FIGURE 2—Tabular crossbedding in medium-grade ore; dark layers are carbonaceous.

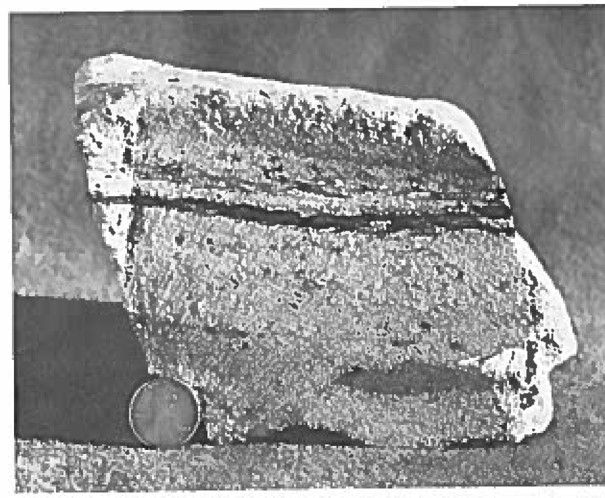

FIGURE 3—Zone of small-scale trough crossbedding marked by carbonaceous debris in upper half of specimen; darker gray areas at top and lower right are areas of humic staining; scattered dark specks are carbonaceous grains.

Distribution of mineralization

The ore deposits shown in fig. 1 are the significant uranium accumulations found in the Jackpile sandstone by mid-1979. They occur in a northeast-trending band approximately parallel to the axis of the Jackpile sandstone unit. Anomalous uranium mineralization is common in the vicinity of the deposits but is much less widespread to the northeast; and, despite moderately intensive exploration, only minor indications of uranium have been found to the northeast of the L-Bar group of deposits.

Orientation of the individual deposits is not consistent (fig. 1) and bears no obvious relation to the overall trend of the district. Similarily, bodies of mineralization within the ore deposits are oriented in diverse directions and without a consistent relationship to the trend of the deposit or the district. At the L-Bar, uranium has been found at all levels within the Jackpile sandstone, but the accumulations in the upper part are characteristically smaller and less continuous than those in the lower part.

Bodies of ore-grade mineralization occur suspended in a much larger envelope of low-grade mineralization. In a sample of 18 holes (figs. 4, 5, 6), the thickness from the uppermost anomalous mineralization to the lowermost ranged from 22 to 70 ft. Zones with grades above 0.10 percent ranged from 2 to 30 ft. The aggregate thickness of these intervals was 969 ft; of that footage, 28 percent had mineralization of 0.10 percent or higher, 54 percent had anomalous mineralization but less than 0.10 percent, and 18 percent was barren. These grade levels were determined from gamma logs; assays of core samples indicate much of the "barren" material has 20 to 80 ppm of uranium.

Fig. 4 is a cross section extending southeast about 1,000 ft from the northwest end of the main orebody. Shown for each hole is the ore grade above 0.10 percent in 6-inch intervals as interpreted from gamma logs. In this section the ore is thick and continuous. Fig. 5 is a parallel section approximately 150 ft to the southwest, and fig. 6 is a section normal to the other two. In these latter two sections, a large number of individual uranium accumulations are apparent. These may coalesce or they may be isolated, and they probably vary considerably in size. Surface drilling is not sufficiently closely spaced (mostly 142 ft) to permit detailed mapping of each of these ore zones, but the major ones are extensive enough to be followed from borehole to borehole. Fig. 7 is an interpretation solely from surface boreholes of the

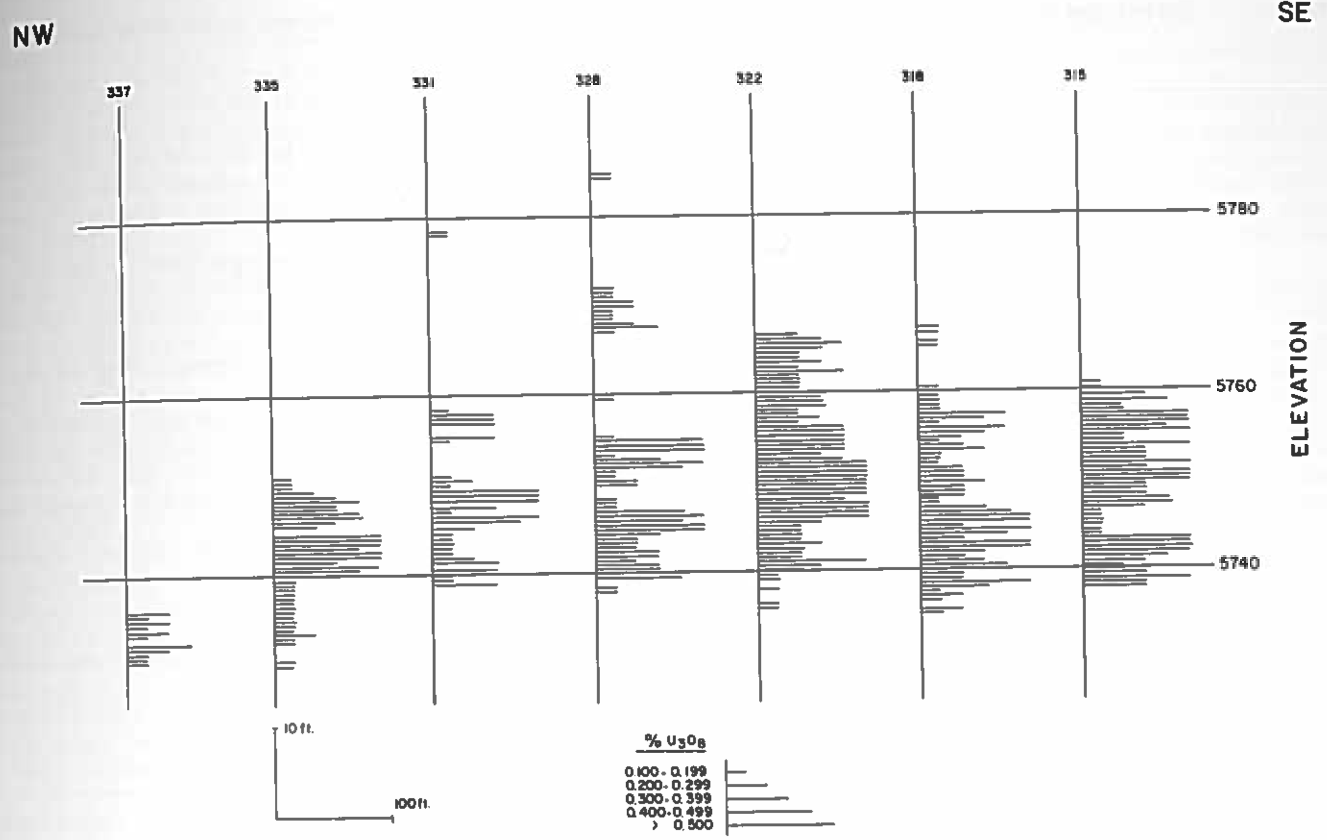

FIGURE 4—NORTHWEST-SOUTHEAST CROSS SECTION SHOWING ORE GRADE BY 6-INCH INTERVALS.

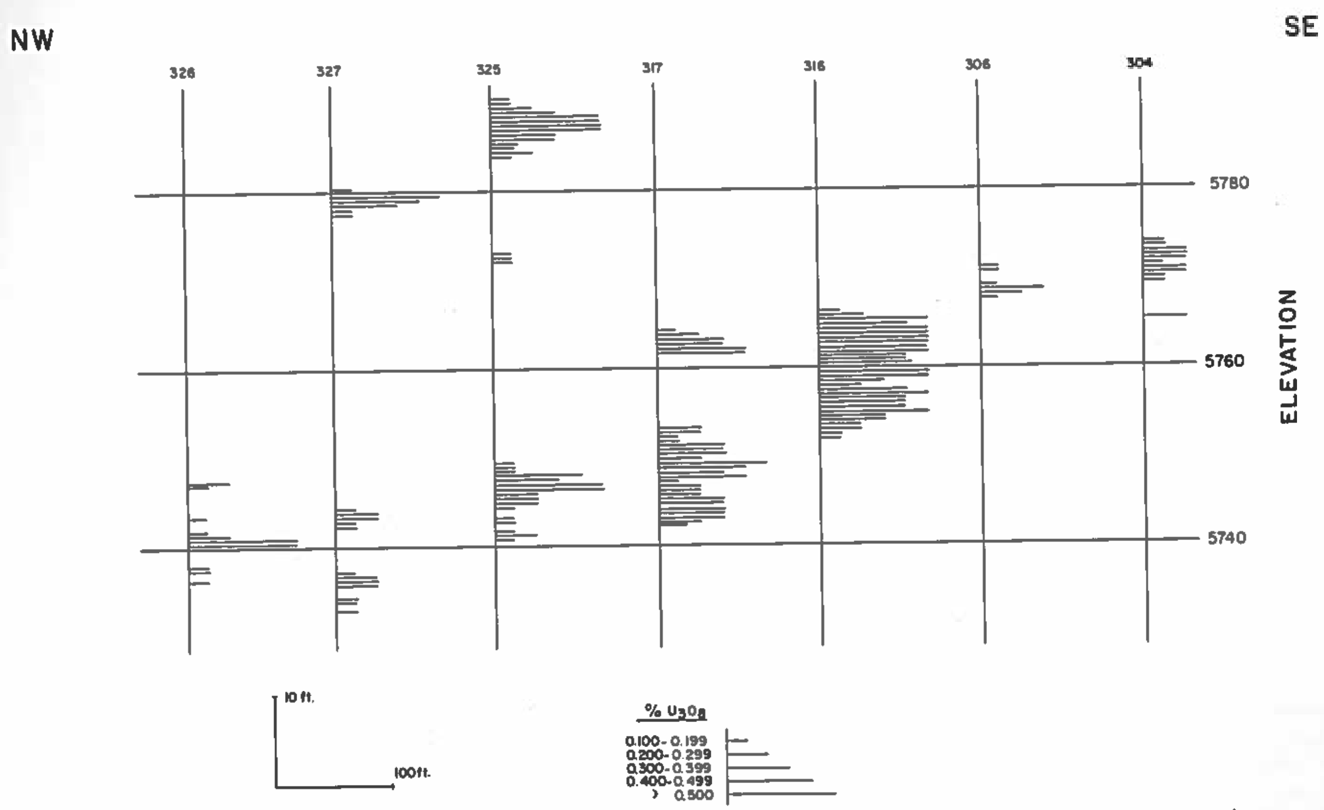

FIGURE 5—NORTHWEST-SOUTHEAST CROSS SECTION PARALLEL TO AND APPROXIMATELY 150 FT SOUTHWEST OF SECTION IN FIG. 4.

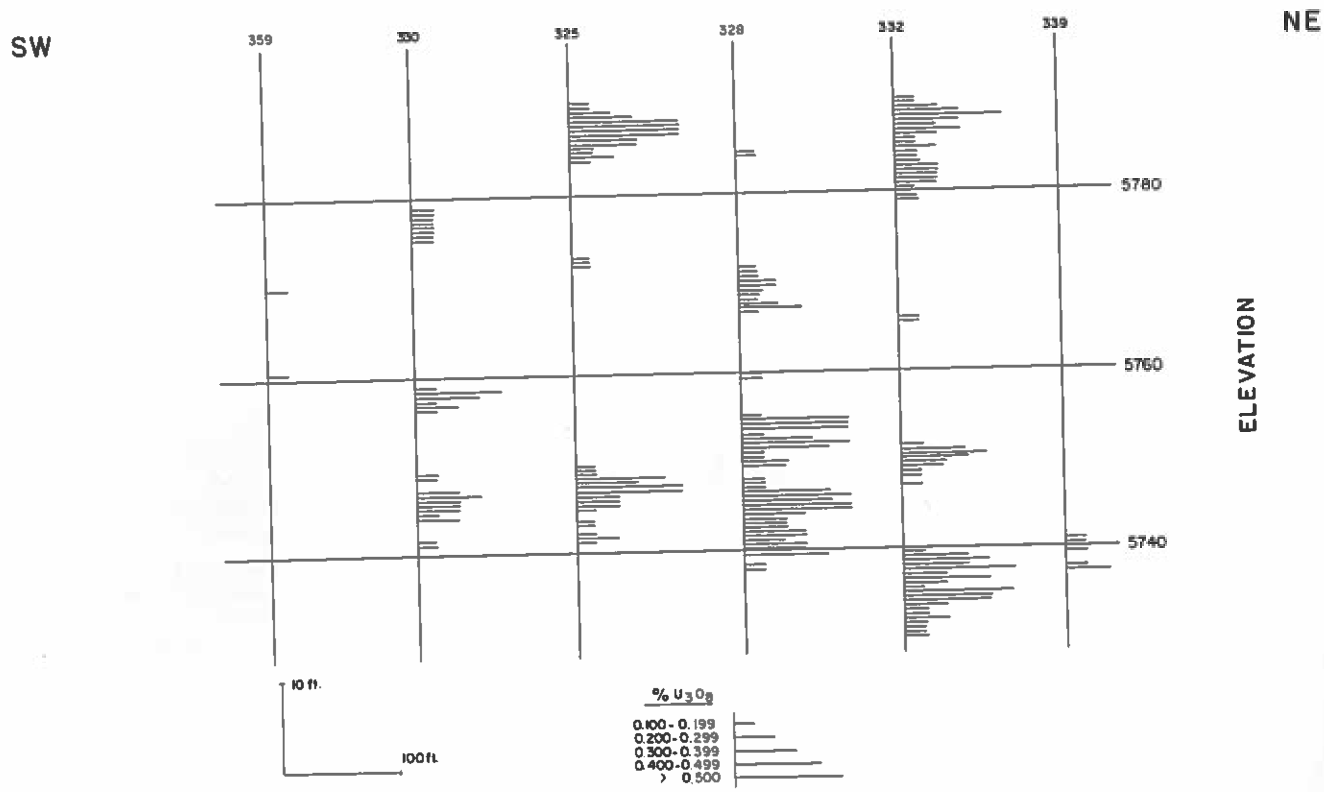

FIGURE 6—SOUTHWEST-NORTHEAST CROSS SECTION SHOWING ORE GRADE.

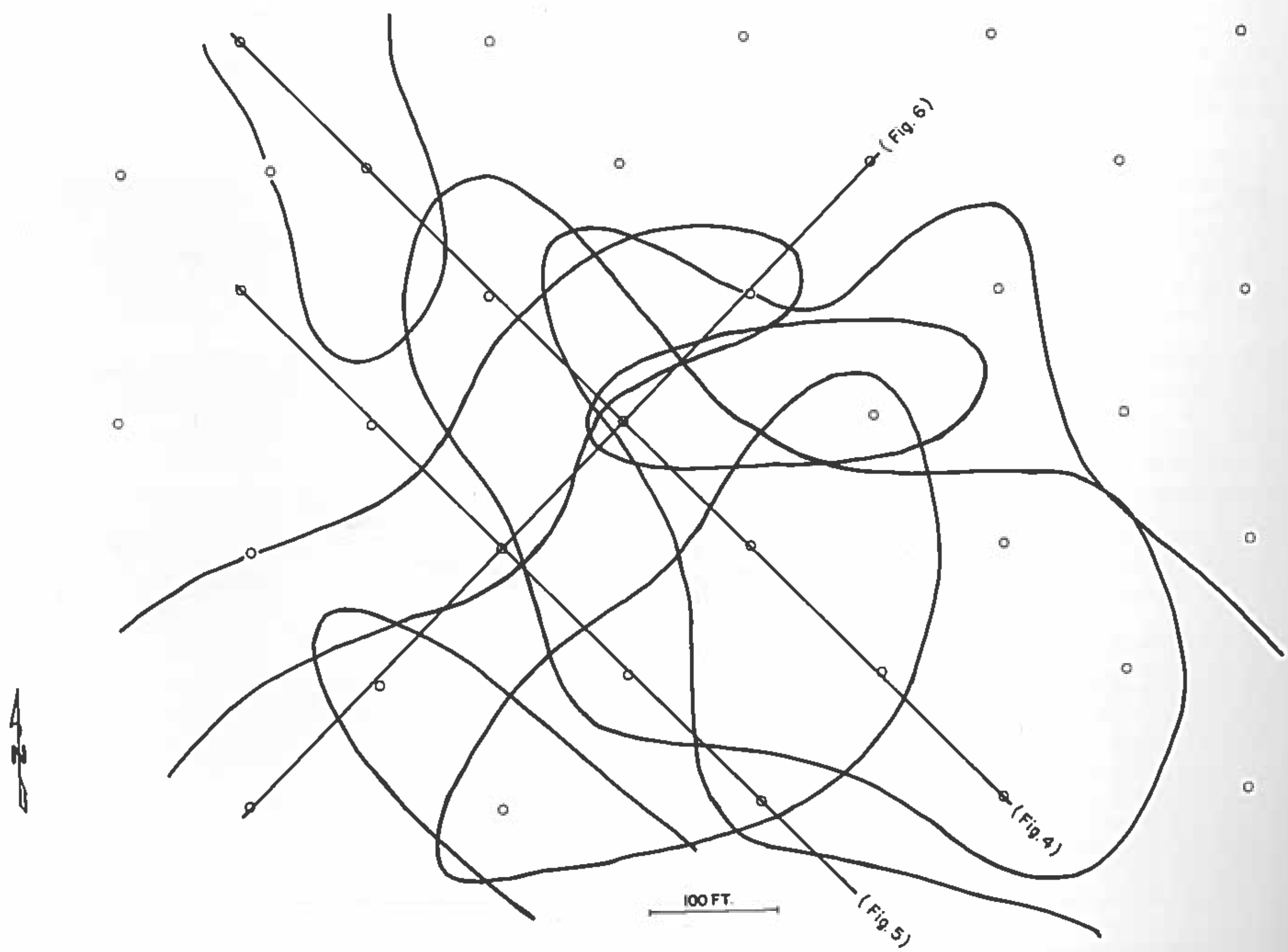

FIGURE 7—AREAL EXTENT OF INDIVIDUAL ORE ZONES IN PART OF A COMPOSITE ORE DEPOSIT.

areal extent of the major ore zones indicated on the cross sections.

With the information obtained from underground drilling, details of orebody configuration become available. Fig. 8 is an example of more or less isolated orebodies near the margin of the deposit that have been defined by intensive underground drilling. The longitudinal division of ore zones and the partial overlapping of ore zones at slightly different elevations (fig. 8) are common features.

The pattern seems reasonably clear. Ore occurs in elongated tabular bodies up to several hundred feet wide and 1,000 ft long. Some are straight and some are moderately sinuous. They may be oriented in any direction but are approximately concordant with the bedding. The maximum thickness seems to be about 10-12 ft, and the upper and lower boundaries are usually abrupt and more or less planar. The basal portion commonly is a zone of mixed lithology with clay and clay pebbles, poorly sorted sand, and carbonaceous clasts. The grade of mineralization is variably—but not randomly—distributed through the orebody. Higher grade mineralization invariably is in the interior of the orebody, and the lateral margins are usually gradational and irregular.

Some tendency exists for individual orebodies to develop in clusters that compose nodes in the deposit. Coalescence of several units results in the development of a central mass appreciably more extensive and thicker than the individual orebodies and with protuberances at various elevations. Fig. 7 illustrates one of these nodes. Because the ore is thick and high grade in these areas, they are of great economic importance. No specific control for these concentrations has been recognized.

The morphology of the orebodies strongly suggests they are depositional features, probably segments of bars and channel fillings. The size and distribution is consistent with the interpretation that the Jackpile sandstone is a braided-stream deposit. The characteristic crossbedding of the ore zones (fig. 2) is that expected from a sediment-choked stream in the lower flow regime.

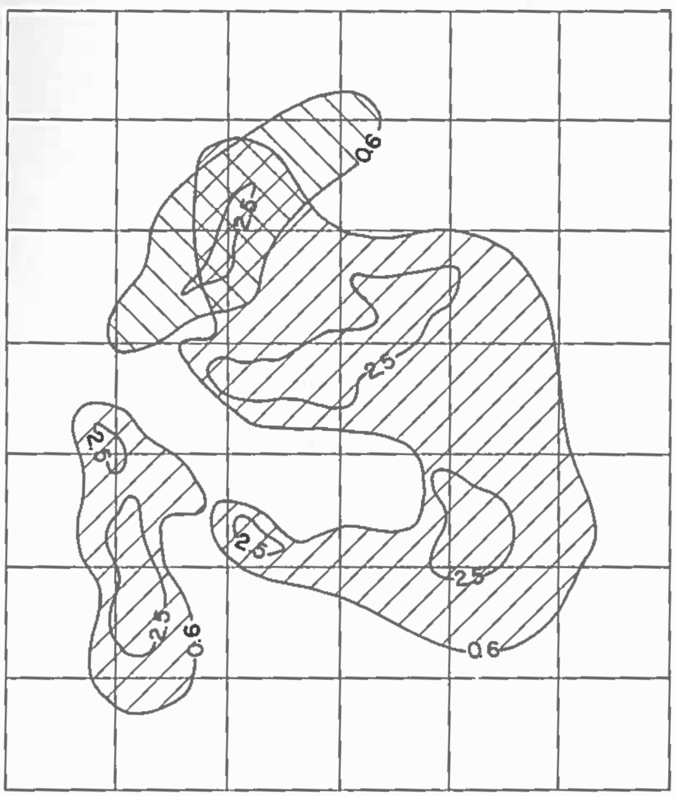

FIGURE 8—INDIVIDUAL OREBODIES AS DELINEATED DURING DEVELOPMENT.

Carbonaceous material

In addition to having exploitable uranium mineralization, the orebodies are characterized by the presence of carbonaceous material. This material clearly is the local and immediate control for the uranium mineralization. No significant mineralization has been seen without the carbonaceous material, and in general, the grade of mineralization varies with the carbonaceous content. Analytical work in several laboratories (Granger and others, 1961; Moench and Schlee, 1967; Schmitt-Collerus, 1969) have shown this material to be coal-like and humic.

The amount of such organic material ranges from a trace to a proportion that, locally, makes up a significant rock-forming constituent. Concentration is extremely variable, and the variability applies to every scale, from thin section to orebody. Typical variability on the microscopic (thin-section) scale is shown in fig. 9a.

Some of the carbonaceous material was deposited as detritus, and some was deposited from a mobile fluid as staining and grain coatings. The detritus has two distinctive forms of occurrence. The most common form is as randomly distributed coal-like particles that are the same size or slightly larger than the mineral grains (fig. 9b). These particles are typically somewhat deformed by pressure of adjacent grains. They are distinguished from pore fillings by their random distribution and by being larger than pores. These particles are the product of ordinary sedimentary processes, and similar particles are found in many sedimentary rocks (Bostick, 1974). Where the particles are relatively rare, as they are with subeconomic mineralization, the coal-like fragments are not obvious and are best seen with a binocular microscope. As concentration increases, the ore takes on a speckled appearance; finally, when in abundance (fig. 9c), the ore approaches homogeneity.

The other and more obvious detrital occurrence is as concentrations along bedding and crossbedding planes (figs. 2, 3, 9d). These concentrations are similar to occurrences in modern sediments described by Coleman (1969) for the Bhramaputra River and by Harms and Fahnestock (1965) for the Rio Grande. Most bedding-plane concentrations are only a millimeter or two thick, but masses up to several centimeters thick occasionally are found. Contacts with clay are usually sharp, but contacts with sand usually show some intermixing and corrosion of the sand grains by the organic material. Pressure phenomena are occasionally seen, which suggests that the carbonaceous material went through a stage in place in which it was deformable and probably gel-like. Most of this coaly material is now vitreous and without apparent structure, but a small portion is dull and sooty—probably a natural charcoal. Large-scale plant structures are rare, although not totally absent. This rarity suggests that plant debris was significantly degraded before it was deposited.

Carbonaceous material is found throughout the textural range of the sandstone, but the greatest concentrations are in the finer grained sandstone and in association with green clay beds or claystone pebble conglomerates. The association of the organic substance and the green clay is considered the product of normal sedimentary processes. Clay deposits and accumulations of plant debris are both the product of flood basins and backwater areas. Such environments, probably swampy, would be favorable to plant growth and the development of peat deposits. The deposits would, however, have little chance to be preserved in place and would be eroded and transported together by the migrating channels of the Jackpile River. Because both the peat and the clay are slack-water sediments, they would be deposited together during periods of decreasing stream velocity. Occasionally such a deposit would be buried rapidly enough for the organic matter to be protected from oxidation.

The grain coatings and staining are considered the products of humic acids formed by the decay of vegetation. The coatings occur in masses ranging from a few grains to large bodies with lateral dimensions in the tens or possibly hundreds of feet. The masses commonly are lenticular, but highly irregular shapes and

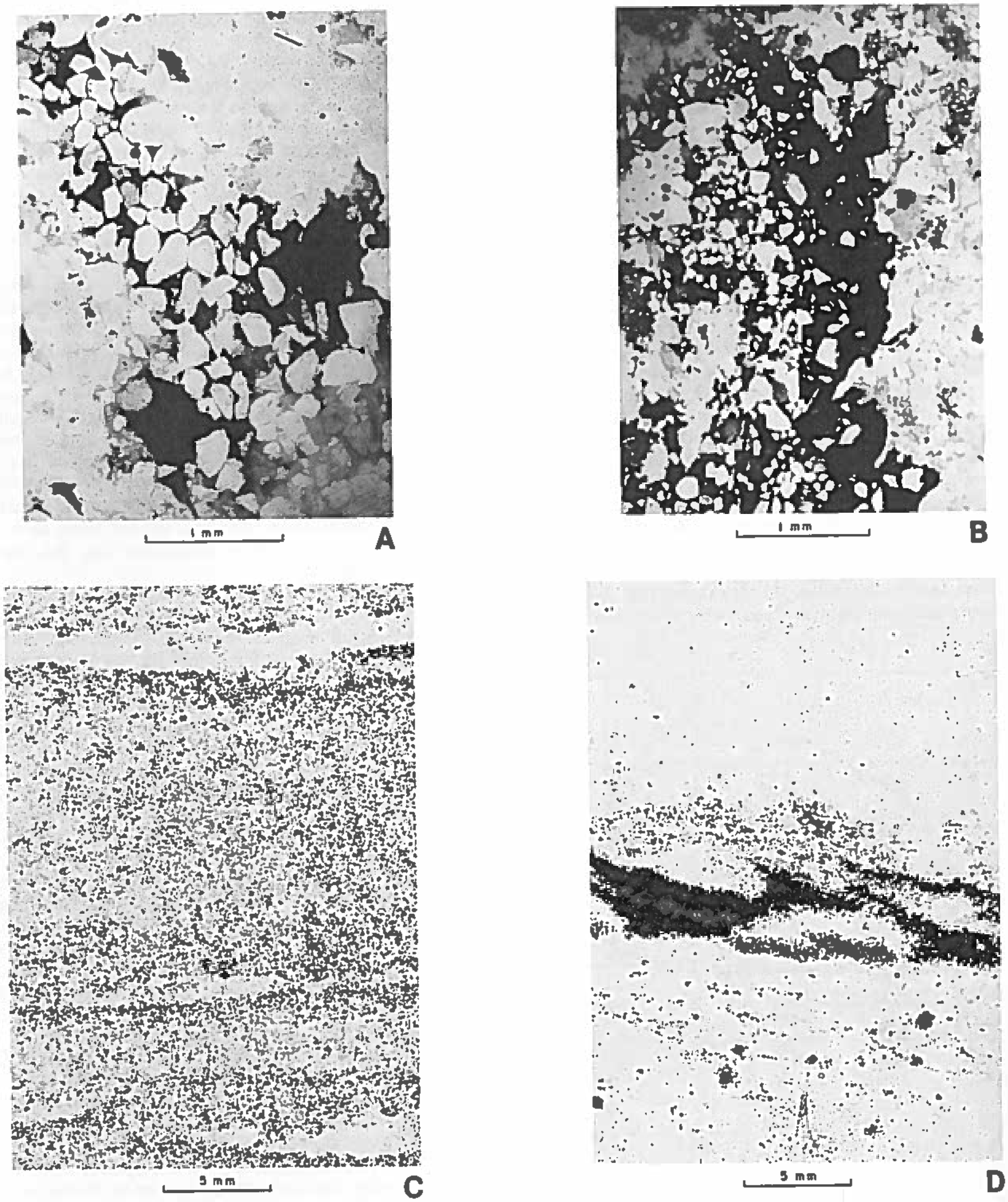

FIGURE 9—A) BEDDED AND FRAGMENTAL CARBONACEOUS MATERIAL; B) LARGE AND SMALL CARBONACEOUS FRAGMENTS SHOWING DEFORMATION AROUND SAND GRAINS AND INDICATIONS OF CORROSION; C) ABUNDANT DISPERSED CARBONACEOUS GRAINS IN HIGH-GRADE ORE (LIGHTER STREAKS ARE CLAY LAMINAE); D) CARBONACEOUS DEBRIS ALONG SMALL-SCALE CROSSBEDDING.

boundaries are also seen. Staining frequently cuts sedimentary structures. At the L-Bar, staining has been seen only in close association with detrital carbonaceous matter. Characteristically, the staining is found only a short distance from the clasts or carbonaceous laminae, and large masses of stained sandstone have abundant and relatively closely spaced particles of detrital carbonaceous material. The coextensive occurrence of the grain coatings and the detrital matter strongly suggests that the humic acids that formed the coatings were derived from the decay in place of detrital vegetal material. The humic acid apparently was exuded from the decaying organic debris, migrated outward from the parent material, and formed a general halo around the detrital nucleus. The highly irregular shape of some of the boundaries and smaller masses suggests that, at least in part, this process occurred when the sandstone was not completely saturated with water.

In the early stages of degradation, humus is extremely effective in removing uranium from solutions of low concentrations (Szalay, 1958). Both the detrital humus and the humic acid apparently were at a stage of degradation in which they could effectively remove and fix uranium at the time when uranium in groundwater solutions became available.

The reasons explaining why the requisite conditions for the deposition and preservation of abundant humic material are particularly well developed in the L-Bar–Jackpile area are not clear. A possible explanation is that gentle warping contemporaneous with deposition, which is marked in the Jackpile area, contributed to the development of extensive and long-lived swamps that may have served both as the source and as traps for the vegetal debris that became the primary ore control.

Discussion

Available evidence at the L-Bar deposits suggests strongly that the key controls on uranium mineralization are the products of common and normal sedimentary processes. This interpretation differs significantly from those on the Jackpile-Paguate deposits (Moench and Schlee, 1967; Nash, 1968; Adams and others, 1978) in minimizing the importance of sandstone mineralogy and diagenesis, in recognizing that the ore deposit is a composite of individual bodies which probably are depositional units, and in rejecting the concept of an epigenetic origin for the carbonaceous material that is the primary control of mineralization.

The host sandstone, in both texture and mineralogy, is a common type of sedimentary rock. Similar sandstones are found in a variety of environments in the Mesozoic and Cenozoic sediments of the world, and specific features have not been shown to be unique to uranium occurrences.

The Jackpile sandstone is the deposit of a braided stream and has all the internal complexities expected from deposition in constantly migrating channels and rapid alternation between erosion and deposition. Where individual uranium orebodies can be defined, they appear to have the shape and size expected in remnants of depositional units that were channel fills or bars in such a stream. Crossbedding in the ore-bearing sandstones indicates deposition in relatively shallow water and within the lower flow regime of the depositing stream. Depositional units are considered to be an important secondary control of mineralization, and the ore deposit is made up of scores and possibly hundreds of these individual units. Why these units should occur in clusters is unknown, but possibly some small-scale tectonism was contemporaneous with the controlling sedimentation.

The primary control of mineralization is the carbonaceous residue found within the sandstone. The erratic distribution of this material, on every scale from thin section to orebody, argues against an extrinsic source for the humic parent substance. The abundant detrital carbonaceous matter seemingly was an adequate source consistent with the observed physical relationships. A simple one-source explanation for the several forms of carbonaceous residue has considerable merit.

The critical element in the formation of the ore deposits seems to have been the conjunction of uranium-bearing water with vegetal material in a stage of degradation in which it was efficient in assimilating and fixing uranium. How these two factors came together is not clear. The conventional interpretation (Moench and Schlee, 1967) is that both the uranium and the humic matter are extrinsic and were introduced by ground water as separate events shortly after burial of the sediments. Adams and others (1978) have suggested a markedly different theory: they propose that the uranium was released from volcanic glass deposited with the sandstone and altered in place. A third alternative, consistent with what is known of the sedimentary history, is that deposition of the sandstone and accumulation of uranium were concurrent processes. If the uranium was derived from alteration of Morrison volcanic ash, which seems probable, uranium would have been present in both surface and ground water during Jackpile deposition. Uranium in water of the Jackpile River probably would have been captured by the peat deposits that were forming in the backwater areas. These deposits were periodically eroded by the migrating channels of the river and were incorporated into the sandstone with the uranium already fixed in the humic material. The process of accumulation may well have continued after burial as uranium-bearing ground water came into contact with the carbonaceous residue in the sandstone. Resolution of these alternatives probably would be aided by detailed information describing uranium distribution and fixation in the carbonaceous material.

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