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Origin of Intraformational Folds in the Jurassic Todilto Limestone, Ambrosia Lake Uranium Mining District, McKinley and Valencia Counties, New Mexico

By

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Abstract[1/]

The Todilto Limestone of Middle Jurassic age in the Ambrosia Lake uranium mining district of McKinley and Valencia Counties, New Mexico, is the host formation for numerous small- to medium-sized uranium deposits in joints, shear zones, and fractures within small- to large-scale intraformational folds. The folds probably were formed as a result of differential sediment loading when eolian sand dunes of the overlying Summerville Formation of Middle Jurassic age migrated over soft, chemically precipitated, lime muds of the Todilto shortly after their deposition in a regressive, mixed fresh and saline lacustrine or marine environment of deposition.

Encroachment of Summerville eolian dunes over soft Todilto lime muds was apparently a local phenomenon and was restricted to postulated beltlike zones which trended radially across the Todilto coastline toward the receding body of water. Intraformational folding is believed to be confined to the pathways of individual eolian dunes or clusters of dunes within the dune belts.

During the process of sediment loading by migrating sand dunes, layers of Todilto lime mud were differentially compacted, contorted, and dewatered, producing both small- and large-scale plastic deformation structures, including convolute laminations, mounds, rolls, folds, and small anticlines and

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synclines. With continued compaction and dewatering, the mud, in localized areas, reached a point of desaturation at which sediment plasticity was lost. Prolonged loading by overlying dune sands thus caused faulting, shearing, fracturing, and jointing of contorted limestone beds. These areas or zones of deformation within the limestone became the preferred sites of epigenetic uranium mineralization because of the induced transmissivity created by sediment rupture.

Along most of the prograding Todilto coastline, adjacent to the eolian dune belts, both interdune and coastal sabkha environments dominated during Todilto-Summerville time. Sediments in coastal areas consisted mainly of clay, silt, sandy silt, and very fine-grained sand, which was apparently derived from the winnowing of the finer grained fraction of sediment from adjacent dune fields during periods of eolian activity. Most of the sabkha sediments were probably carried in airborne suspension to the low-lying, ground-water-saturated coastal areas, where they were deposited as relatively uniform blanket-like layers. Deposition of sabkha deposits was apparently slow and uniform over most of the Todilto coastal areas and crested only small-scale deformation features in underlying Todilto rocks. Large-scale deformation features and uranium deposits are both notably absent in the Todilto where it is overlain by finer textured sabkha deposits in the Summerville.

Introduction

The Todilto Limestone of Middle Jurassic age in the Ambrosia Lake uranium mining district of McKinley and Valencia Counties, New Mexico, is the host formation for numerous small- to medium-sized epigenetic uranium deposits that occur in joints, shear zones, and fractures within a series of small- to large-scale intraformational folds in the formation. Field evidence presented in this report indicates that the intraformational folds were formed as a result of localized differential sediment loading when eolian sand dunes of the overlying Summerville Formation, also of Middle Jurassic age, migrated over soft, chemically precipitated lime mud flats at marginal areas of the regressive Todilto saline lake or arm of the sea.

The area of study is located at the southern margin of the San Juan basin within the Ambrosia Lake uranium mining district of the Grants mineral belt (fig. 1). Todilto uranium deposits are concentrated along the southern edge of the mining district in the area between Haystack Butte on the west and the west flank of Mount Taylor on the east (fig. 2). Isolated areas where intraformational folding has occurred in Todilto rocks are also present west of the Mount Taylor-Haystack area. The area studied is approximately 12 miles (19.3 km) long and three-quarters to one mile (1.2-1.6 km) wide and includes virtually all of the area where the Todilto crops out as an erosion-resistant caprock on top of the Jurassic Entrada Sandstone within the mining district.

Stratigraphy and Environments of Deposition

The Todilto Limestone occupies an area of approximately 34,000 mi^2 (88,060 km^2) that includes the present Tertiary San Juan basin and an adjacent region east of the basin in north-central New Mexico. The Todilto correlates with and is considered the age equivalent of the Pony Express Limestone Member of the Wanakah Formation of southwest Colorado and the Curtis Formation of

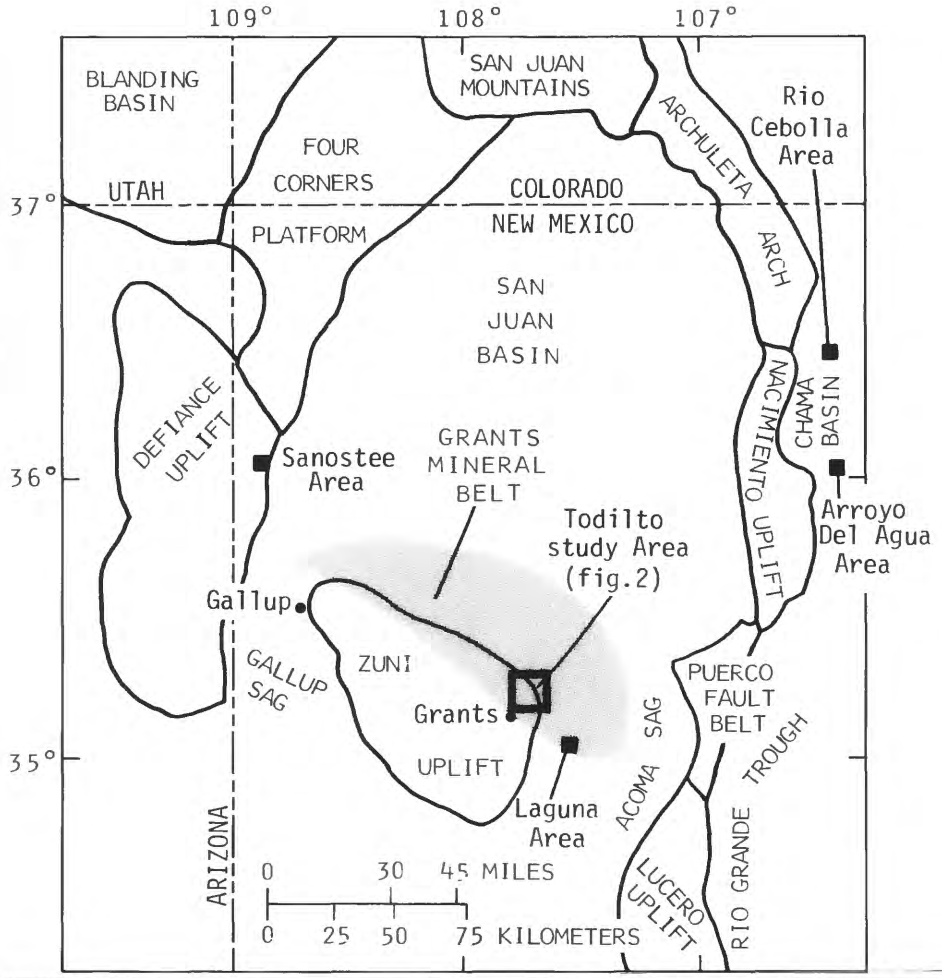

Figure 1.--Index map showing location of mineral belt, the Todilto study area, and adjacent areas where Todilto rocks contain occurrences in the San Juan and Chama basins in northwest New Mexico.

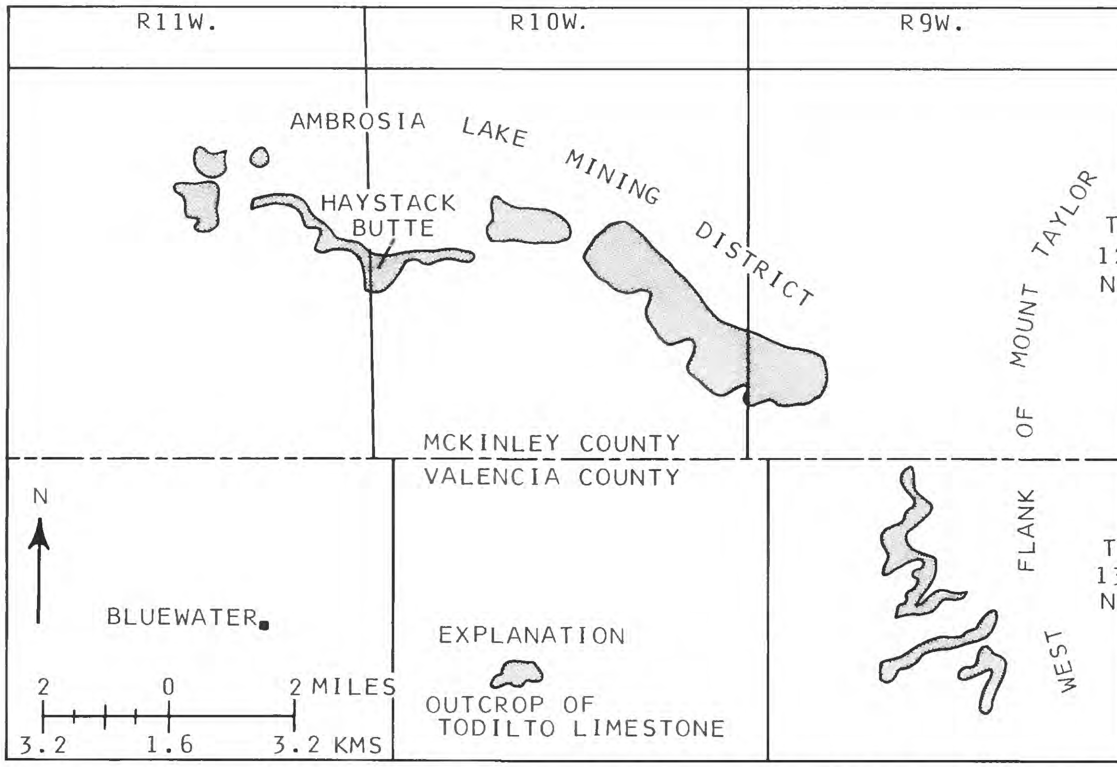

Figure 2.--Index map of the Ambrosia Lake uranium mining area showing outcrops of the Todilto Limestone where it contains load-induced intraformational folds. See figure 1 for location.

southeastern and central Utah (Harshbarger and others, 1957, p. 46). Harshbarger and others depict the Todilto-Pony Express depositional basin as a gulf or bay connected on the northwest with the Curtis sea in Utah via a narrow strait in extreme northeastern Arizona. Although Harshbarger and others (1957) favored a marine source for the Todilto, later workers (Anderson and Kirkland, 1960) conclude that the Todilto was deposited in either an enclosed saline lake basin, or, if connected to the sea, a mixed paralic basin which received both fresh and saline water. Rawson (1980) also attributes the origin of the Todilto to deposition in a lake basin. The origin of uranium deposits he attributes to coastal sabkha processes. Evidence in favor of a lacustrine origin includes a general lack of confirmed marine fossils, the lack of marine dolomitic rocks in the sequence, the presence of fresh-water ostracodes, and the presence of varved sequences of sediment as described by Anderson and Kirkland (1960, p. 38). Presently, the origin of the Todilto remains debatable in light of seemingly conflicting field evidence, however, studies underway by M. B. Goldhaber and J. L. Ridgley of the U.S. Geological Survey on Todilto oxygen and sulfur isotopes may aid in more precisely defining the environment of Todilto deposition.

The Todilto Limestone consists of two distinct facies; a lower, locally carbonaceous, limestone facies ranging in thickness from 0 to about 40 feet (0 to 12.2 m), which is present throughout the Todilto depositional basin, and an overlying gypsum-anhydrite facies, which ranges from 0 to more than 170 feet (51.8 m) thick. The gypsum-anhydrite facies is restricted in areal extent to the middle part of the Todilto depositional basin and, where present, conformably overlies the limestone facies. The gypsum-anhydrite facies is absent in the Ambrosia Lake uranium district. Within the Ambrosia Lake district the Todilto has conformable contacts with both the underlying Entrada

Sandstone and the overlying Summerville Formation.

The Summerville Formation is conformably overlain, in turn, by the Bluff and Cow Springs Sandstones, also of Jurassic age. The Bluff and Cow Springs sequences are composed dominantly of eolian crossbedded sandstone with minor thin, horizontal interbeds of siltstone and claystone. Both units were deposited in arid eolian climates within eolian dune and inland interdune sabkha environments. The eolian dune facies of the underlying Summerville, which is responsible for Todilto intraformational folding, is similar in origin and composition to overlying Bluff and Cow Springs eolian dune facies, even though the units are vertically separated by intertonguing fine-grained sabkha deposits of the Summerville in most areas. Apparently, deposition of the Bluff and Cow Springs into the Todilto depositional basin was continuous with deposition of the underlying Summerville sequence. Eolian transport directions in Summerville, Bluff, and Cow Springs dune facies are all dominantly west to east in the basin.

Deposition of the Todilto Limestone apparently represents a major change in depositional conditions from those of the Entrada Sandstone. The Entrada Sandstone was deposited exclusively under arid eolian dune and inland interdune sabkha environments where fluvial processes were virtually absent. Transport and deposition of Entrada sediment was exclusively by wind. With the advent of the Todilto depositional basin and the deposition of the limestone facies of the Todilto, a fluvial drainage system into the basin apparently was established in the region. The initiation of surface drainage was apparently abrupt in the overall Entrada-Todilto depositional cycle and probably resulted from a change in tectonic conditions within the region, which was accompanied by a change to a climate more conducive to rainfall and surface run-off.

The study of varved sediment sequences in the Todilto (Anderson and Kirkland, 1960, p. 38-40) indicates that the Todilto was deposited during a period lasting at least 14,000 years. Whether the body of water in the Todilto basin originated as an arm of the Curtis sea or whether it formed in an enclosed lake basin remains to be proven, however the areal distributions of the lower and upper facies indicate that, near the end of the Todilto depositional cycle, the of water receded toward the center of the basin, and its salinity characteristics became conducive to the deposition of the gypsum-anhydrite facies. Basinward regression of Todilto waters could conceivably have resulted because regional tectonic change effected a change back to an extremely arid climate similar to that which dominated during Entrada deposition. Regression could also have resulted from changes in surface drainage patterns or from a regressive phase of marine invasion.

A study of the depositional environments of the Todilto and Summerville Formations and resultant facies relationship suggests that Summerville sediments encroached marginally onto Todilto sediments during the Todilto regressive phase. Lateral facies changes from the dominant Summerville lithology (claystone, sandy siltstone, and mudstone) to gypsum-anhydrite lithology indicate that the two lithologies may be contemporaneous (fig. 3). As the Todilto receded toward the center of its depositional basin and the gypsum-anhydrite facies was forming offshore, Summerville eolian and sabkha sediments apparently encroached, at the margin of the Todilto basin, over the limestone facies. Summerville facies, in turn, were later covered by encroaching Bluff and Cow Springs facies. Deposition of the Summerville occurred dominantly in coastal and inland interdune sabkha environments. Most of the Summerville sediment in the mineral belt is composed of fine-grained material, including claystone, siltstone, and sandy siltstone. This facies of

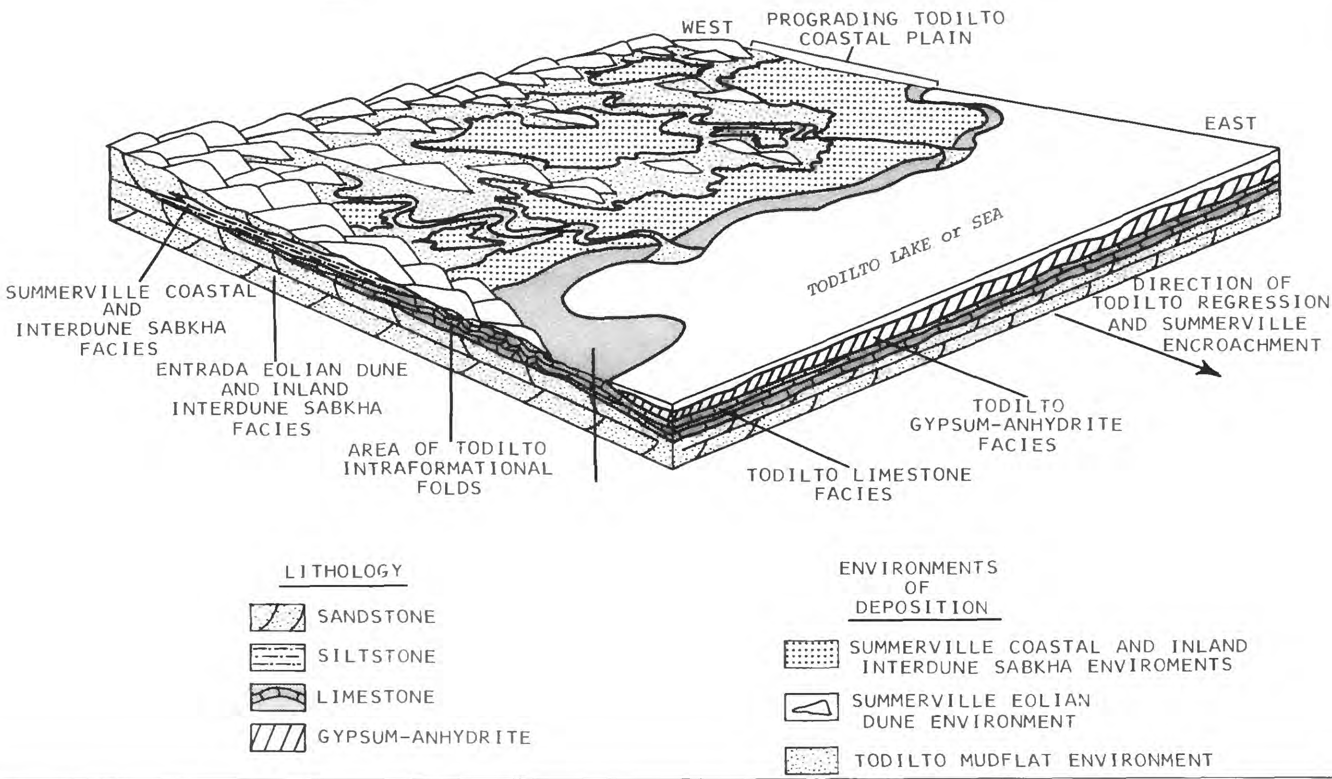

Figure 3.--Schematic diagram showing a segment of the Todilto depositional basin, postulated environments of deposition, and facies relationships.

Summerville sediment probably represents, for the most part, silt and clay winnnowed from eolian dune fields along the margins of the Todilto basin. Fine-grained Summerville sediments apparently accumulated in areas saturated by subsurface recharge from the Todilto standing body of water or from ground water derived from the basin margins. It is evident that coarser bedload eolian dune sediments also encroached over Todilto mudflats locally. In the Ambrosia Lake area, the Summerville is locally composed of eolian dune sediment lying in contact with Todilto Limestone. It is postulated that dune fields may have migrated within dune belts which trended radially toward the Todilto shoreline areas from basin margins. At or near the Todilto shoreline, these dunes probably formed backshore dune fields similar to those found in a number of modern coastal sedimentary settings (fig. 3).

The Formation of Intraformational Folds

Rapaport, Hadfield, and Olsen (1952, p. 6) attribute the origin of intraformational folds to sediment "creep," as they termed it, down the primary depositional slope. Gableman (1956, p. 389) attributes their origin to dehydration during diagenesis of the lime mud sediment. Evidence presented in this report show both interpretations are in part correct; however, neither interpretation defined a driving mechanism for sediment creep or differential dehydration.

As Summerville eolian dunes locally encroached over Todilto lime mud flats, differential loading of the muds occurred. Initial stages of load deformation apparently occurred in conjunction with dehydration of muds. This stage of deformation is marked by numerous small- and large-scale plastic deformation structures, including rolls, folds, mounds, convolute laminations and small anticlines and synclines. The magnitude and complexity of load features is apparently related to the number, size, and configuration of dunes in the vicinity. Structural trends of folded zones in the Todilto are believed to have been controlled by Summerville eolian transport directions. Although most of the Summerville has been eroded in the study area, a few eolian dunes remain above the limestone (fig. 4). As dunes continued to migrate over Todilto mud flats in the area, the lime muds were sufficiently dehydrated by compaction to lose their plasticity. As plasticity was lost, load deformation was marked by sediment rupture of the lime mud sequence. During this second phase of deformation, joints, shears, fractures, and small scale thrust faults were induced along the crests of the intraformational folds; thus, the limestone sequence acquired sufficient transmissivity to become suitable host rocks for epigenetic uranium mineralization.

Within the Ambrosia Lake area, limited eolian transport data obtained from remnants of Summerville dunes indicates that dunes were migrating west to east at approximate right angles to the general trend of intraformational fold axes and the inferred Todilto shoreline. In light of this evidence, it appears that dunes or clusters of dunes within a dune belt were migrating basinward over the mud flats and were pushing up and distorting layers of mud in their path. Figure 5 indicates the five stages of deformation that have been documented in the field. Stages 1 through 3 represent the plastic-deformation phase, and stages 3 through 5 indicate the sediment-rupture phase of load deformation. Figures 6 through 11 show phases of load deformation in association with folds preserved in open-pit uranium mines within the district.

In local areas within the larger study area, only the uppermost layers of Todilto Limestone show evidence of load deformation. Figures 12 through 16 show a variety of load-induced features in one local area. Within this area the lower part of the limestone facies is not load deformed. No uranium ore

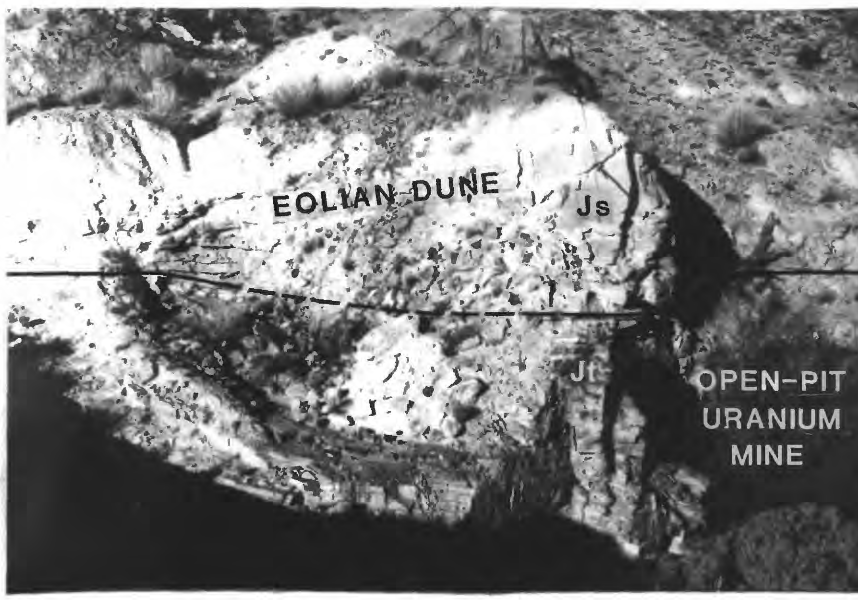

Figure 4.--Remnants of a Summerville (Js) eolian dune overlying the Todilto Limestone (Jt) in the southern part of the Ambrosia Lake uranium mining district. Dune has been disected east-west by open-pit mining activity. Uranium ore was taken from a northeast-southwest trending intraformational fold in the Todilto formed by dune loading.

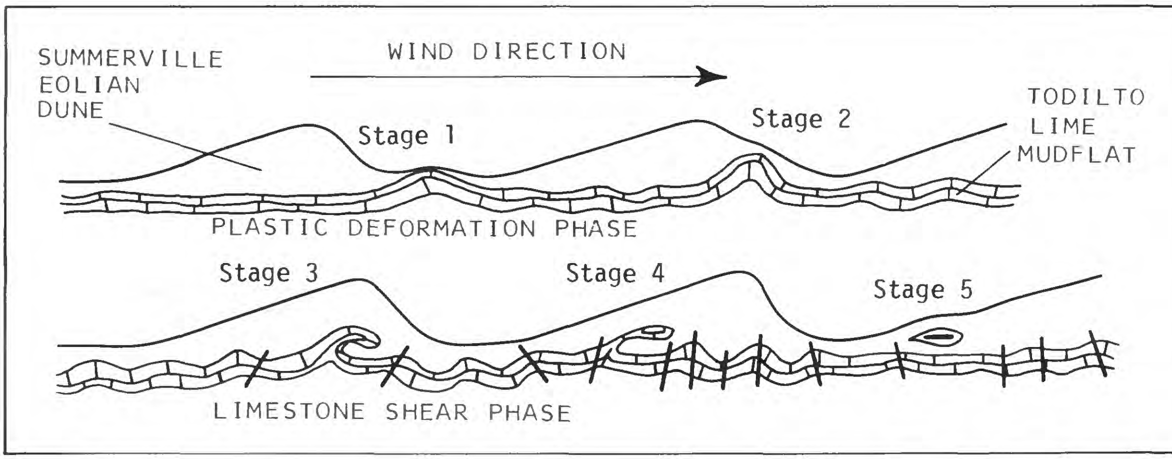

Figure 5.--Schematic diagram showing the plastic deformation and shear phases of Todilto load deformation. Stages 1-5 represent the successive stages of limestone deformation documented in outcrops within the Ambrosia Lake uranium mining district.

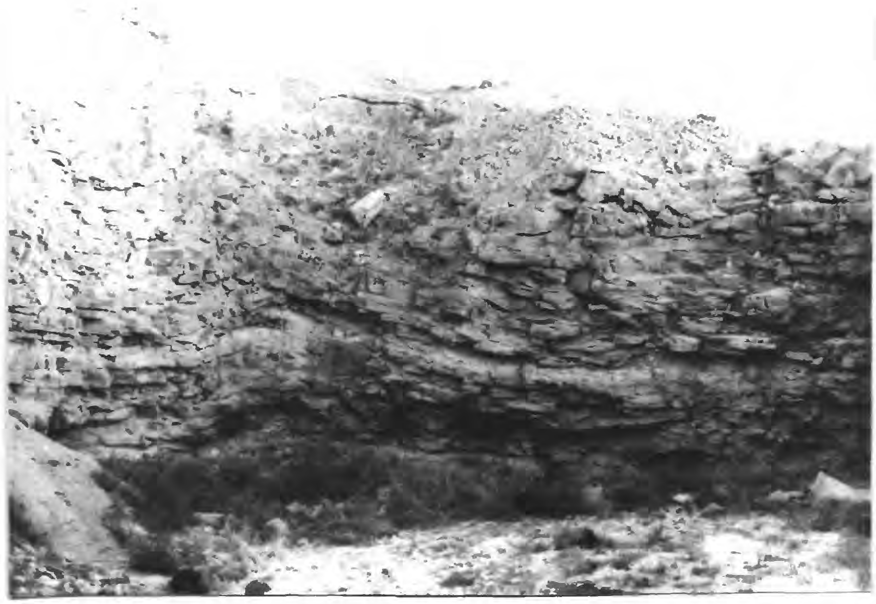

Figure 6.--Large-scale, low-amplitude intraformational fold within the Todilto Limestone. Uranium ore occurs in the basal part of the fold in joints and fractures and along limestone bedding planes.

Figure 7.--Large-scale, high-amplitude intraformational fold within the Todilto Limestone. Both plastic and shear phase deformation occurs within individual limestone beds. See figures 9, 10, and 11.

Figure 8.--Medium-to small-scale intraformational fold within the Todilto Limestone sequence. Uranium ore occurs within the upper folded and contorted part of the sequence.

Figure 9.--Sandy limestone bed within a folded sequence showing plastic and shear phases of load-induced deformation of sediment laminations.

Figure 10.--Limestone bed showing shear-phase deformation of sediment laminations. Lighter areas of the rock are sites where voids created by shear have been filled with calcite. Fluorite and secondary uranium minerals are also associated with similarily induced voids.

Figure 11.--Limestone bed showing plastic-phase deformation of sediment laminations.

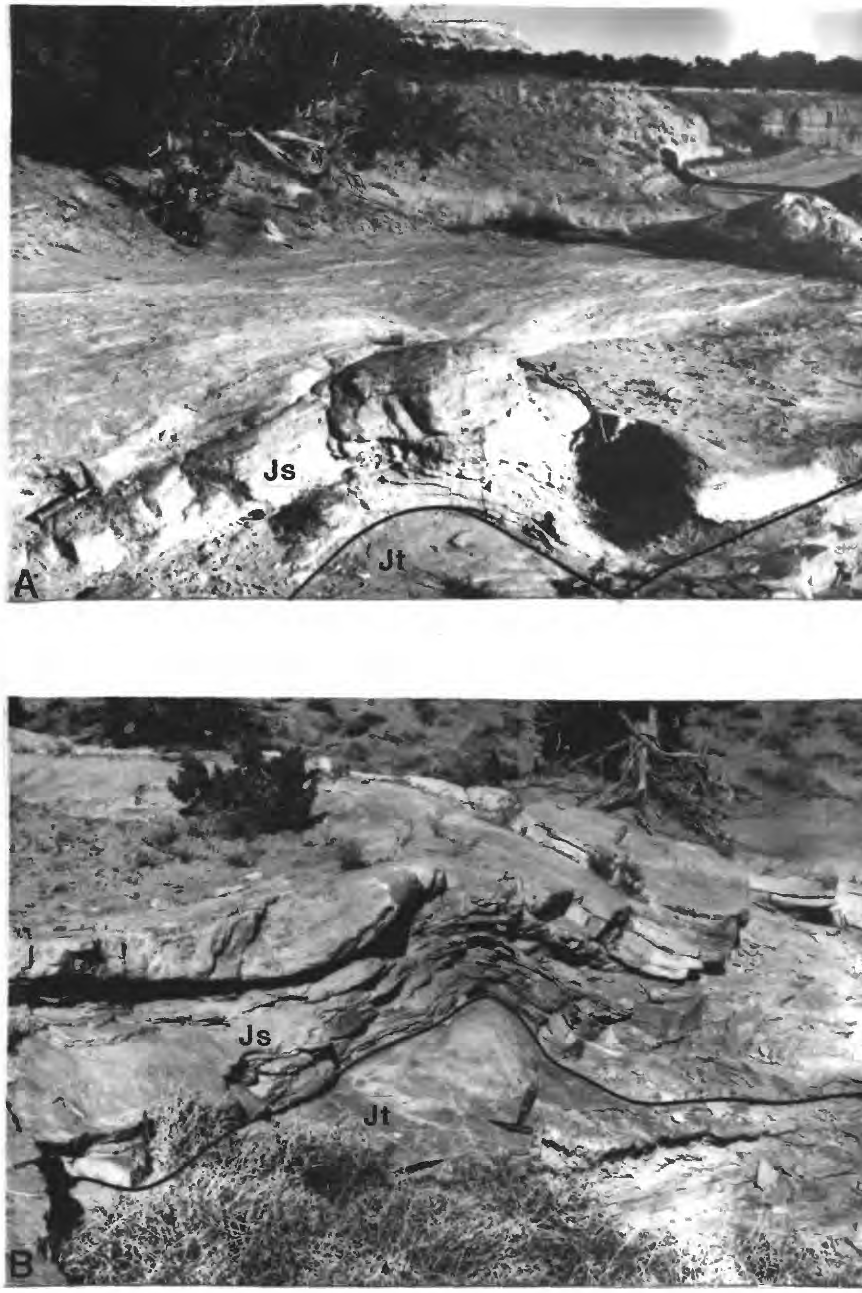

Figure 12A and B.--Small-scale rolls formed on the upper surface of the Todilto (Jt). Rolls apparently formed by lateral migration of Summerville (Js) eolian dunes over soft lime muds of the Todilto mudflat shortly after the mudflat was exposed by a regression of Todilto water from the area.

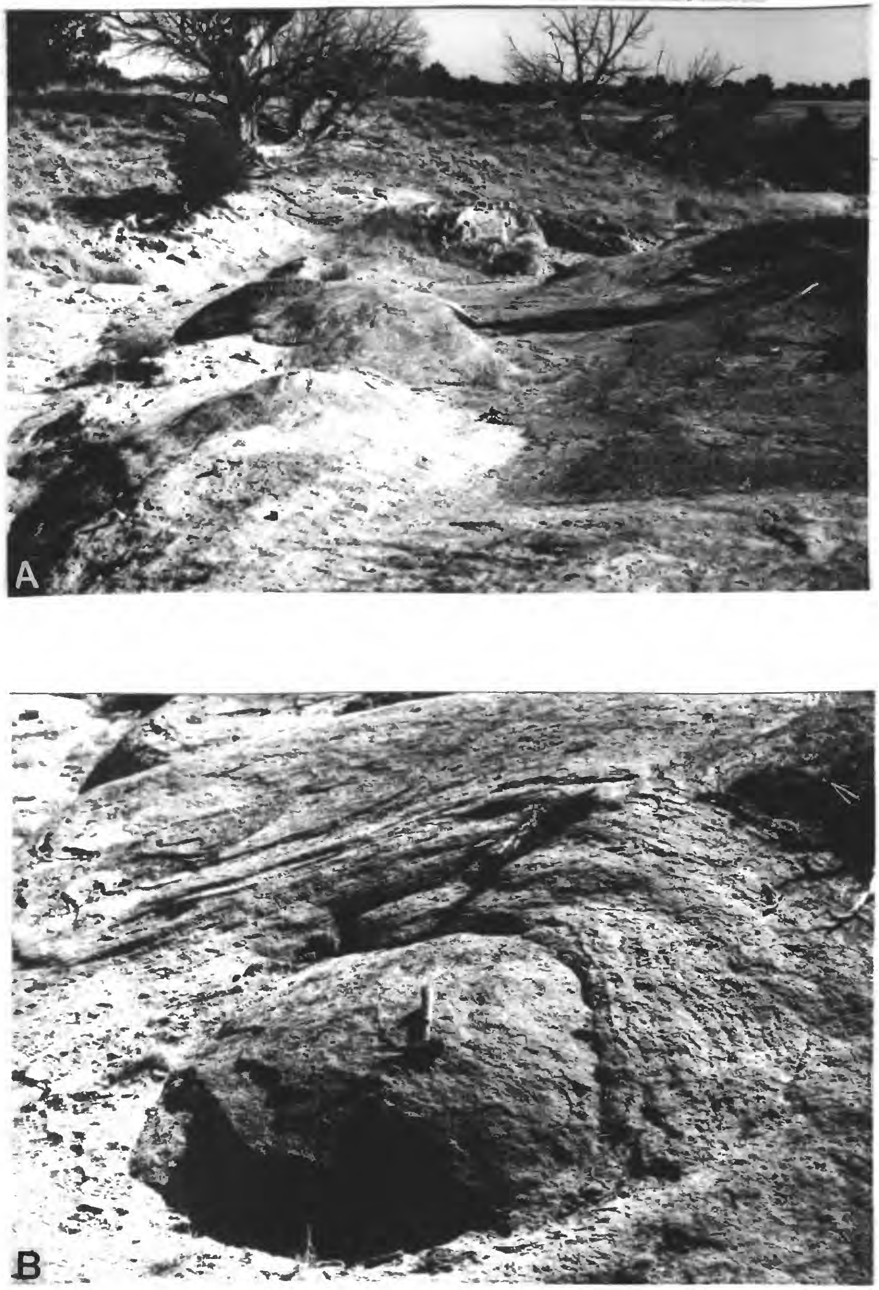

Figure 13A and B.--Large-scale mounds formed on the upper surface of the Todilto Limestone by differantial loading of Todilto lime mud by overlying Summerville eolian dunes.

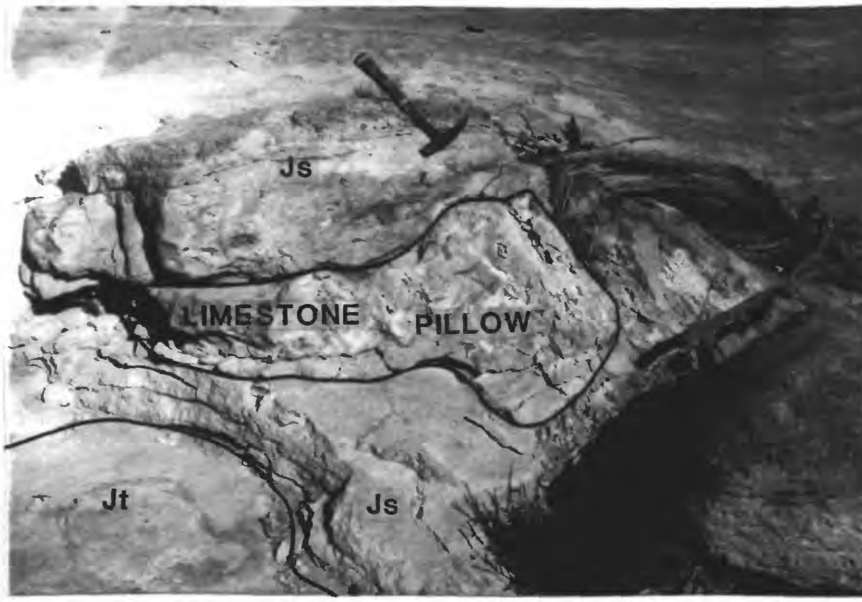

Figure 14.--Limestone pillow surrounded by eolian dune sandstone of the Summerville Formation. Pillows formed by lateral shear along the upper surface of Todilto mudflats caused by migrating Summerville eolian sand dunes.

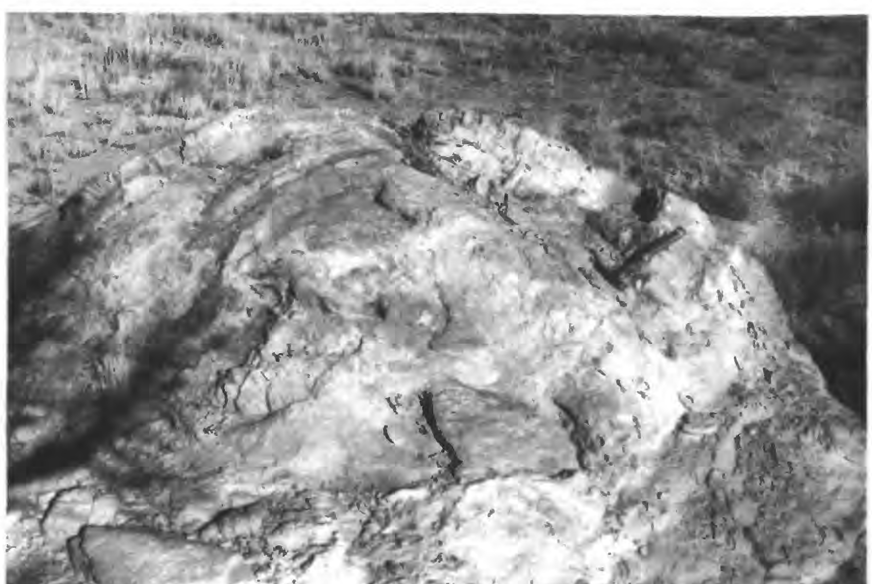

Figure 15.--Large-scale mound of Todilto Limestone (core of mound) showing a concentric layer of cross-laminated Summerville sandstone cemented by calcite. Calcite apparently was injected into overlying sandstone during dehydration of the lime mud.

Figure 16.--Large-scale anticlinal fold in the upper surface of the Todilto Limestone showing diagonal fractures produced by sustained dune load stress after lime mud was desaturated.

is associated with these surface deformation features; the reason for its absence in this area is unknown.

The timing of geologic events associated with intraformational fold development apparently is a critical factor in fold development. In the Ambrosia Lake area, encroachment of Summerville dunes apparently occurred soon after limestone deposition and subsequent withdrawal of the Todilto standing body of water, but prior to the time that the lime muds were dehydrated, for the dunes could not have deformed the more resistant dehydrated mud. In all likelihood, the need for rapid dune encroachment shortly after the mud flats were exposed is the key to the scarcity of deformation features elsewhere in the Todilto sequence. On the western margin of the Todilto depositional area near Gallup, New Mexico, several Summerville eolian dunes directly overlie the limestone facies of the Todilto, and yet no limestone deformation has occurred. It is surmised that lime muds in the area were sufficiently dehydrated to resist load deformation before the dunes migrated into the area. Dune encroachment and subsequent deformation of soft mud may thus have been a relatively rare phenomenon.

In areas adjacent to dune belts, the Todilto is overlain by Summerville coastal and interdune sabkha deposits of claystone, mudstone, and sandy siltstone. These loessal deposits apparently accumulated along broad coastal areas or within dune complexes where suspended load sediment settled out of the air after major wind storms. Sediments accumulated as relatively uniform blanket-like layers within water-saturated coastal and interdune sabkha areas. Primary sedimentary structures are rare in the sequence. The rate of deposition of sabkha sediments was probably slow and uniform, allowing sufficient time for the dewatering of underlying Todilto mudstone layers without the development of load-deformation features. As a result, Todilto overlain by these loessal accumulations of Summerville sediment show a notable absence of load-deformed structures.

Todilto Uranium Deposits

The original discovery of uranium in the Grants mineral belt was in the Todilto Limestone of the study area. Subsequent discoveries approximately 2 miles (3.2 km) north in the Morrison Formation have dwarfed the importance of the Todilto; however, the Todilto contains the most important uranium deposits in the United States hosted in limestone (McLaughlin, 1963).

Epigenetic uranium deposits occur within numerous intraformational folds and small anticlines, which trend generally north-south and northeast-southwest throughout the area. During the period 1950 to 1978, 43 properties produced approximately 30,000 tons of U_3O_8 from Todilto orebodies within the Ambrosia Lake district (Chenoweth and Holen, 1980, p. 17). With the exception of only a few shallow underground mines, most of the Todilto ore deposits have been mined from open pits on the Todilto outcrop bench. In addition to the Ambrosia Lake area, four other localities in the San Juan basin region contain Todilto uranium occurrences. These areas are the Laguna and Sanostee areas of the San Juan basin and the Rio Cebolla and Arroyo del Agua areas of the adjacent Chama basin (fig. 1). The Laguna area has produced a small quantity of ore; other areas of occurrence remain unexploited. In these areas, geologic relationships are similar to those at Ambrosia Lake, but occurrences are much less extensive. Gableman (1956, 1970) provides an excellent detailed description of several Todilto uranium deposits in the study area.

Gableman (1970) describes three types of Todilto ore deposits in the Ambrosia Lake district. The first type consists of unoxidized primary deposits of pitchblende, which occur in local masses or disseminations as a replacement of limestone in zones protected from oxidation. The second type of deposit occurs in oxidized zones where primary uraninite has been converted to secondary minerals such as tyuyamunite, metatyuyamunite, and uranophane. The third type are termed "vagrant secondary deposits" by Gableman and are those that never contained primary minerals; rather, they consist of uranium that has migrated a considerable distance from primary deposits. Uranium deposits occur in association with the joints, fractures, small scale thrust faults, and shear zones of intraformational folds whose origin is here attributed to differential sediment loading.

It is evident that primary uranium deposits formed after the Todilto and Summerville sequences were deposited. Ore zones, although primarily restricted to Todilto rocks, locally extend across the contacts into the basal part of the overlying Summerville as well as into the underlying Entrada Sandstone. Concordant lead-uranium isotopic ages of primary Todilto ores from the study area, determined by Berglof (1970, p. 42-64) indicate that the deposits formed 148 to 154 m.y. B.P. Assuming a late Jurassic Oxfordian age for Todilto rocks of 150 to 155 m.y.b.p. (Imlay, 1952), it follows that mineralization of intraformational folds probably occurred shortly after deposition of the Todilto-Summerville sequence.

The source of uranium contained in the Todilto and associated rocks is unknown. It is, however, surmised that uranium could have been derived either from normal ground waters flowing basinward through Jurassic aquifers or from concentrated brines moving shoreward from the receding Todilto body of water. In either case, it is likely that mineralizing ground-water solutions migrated downward through permeable Summerville eolian dune facies into associated folded zones in the Todilto. Thus, the eolian facies of the Summerville served as a conduit to funnel solutions into zones of maximum transmissivity induced within the limestone sequence by dune loading.

Apparently, the detrital organic content of the Todilto Limestone served as a reductant to precipitate uranium from solutions once they gained access to Todilto rocks. Considering the variation in types of uranium deposits, it is likely that several episodes of mineralization, oxidation, and remineralization occurred during the period of ore deposition.

Exploration and Favorability

If the interpretation presented here regarding the origin of Todilto intraformational folds is valid, it follows that exploration for remaining Todilto uranium deposits may be enhanced by a search for eolian sandstone facies in the Summerville immediately overlying the Todilto limestone facies. It is not likely that uranium deposits will occur in areas of the Todilto where limestone deformation has not occurred. Areas of the Todilto limestone overlain by a silty facies of Summerville or by the upper gypsum-anhydrite facies of Todilto are thus not considered favorable exploration target areas.

References cited

Anderson, R. Y., and Kirkland, D. W., 1960, Origin, varves, and cycles of Jurassic Todilto formation, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 1, p. 37-52.

Berglof, William R., 1970, Absolute age relationships in selected Colorado Plateau uranium ores; Columbia University Ph. D. dissertation, 149 p.

Chenoweth, W. L., and Holen, H. K., 1980, Exploration in the Grants uranium region since 1963, in Rautman, Christopher A., compiler, Geology and mineral technology of the Grants uranium region, 1979: New Mexico Bureau of Mines and Mineral Resources Memoir 38, 1980, p. 17-21.

Gableman, J. W., 1956, Uranium deposits in limestone, in Page, L. R., Stocking, H. E., and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, 1955: U.S. Geol. Survey Prof. Paper 300, p. 387-404.

______1970, The Flat Top uranium mine, Grants, New Mexico: U.S. Atomic Energy Comm. RME-4112, 81 pages, 20 plates.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geol. Survey Prof. Paper 291, 74 p.

Imlay, R. W., 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, p. 953-992.

McLaughlin, E. D., Jr., 1963, Uranium deposits in the Todilto Limestone of the Grants district, in Geology and technology of the Grants uranium region: New Mexico State Bur. Mines and Mineral Resources Memoir 15, p. 136-149.

Rapaport, Irving, Hadfield, J. P., and Olson, R. H., 1952, Jurassic rocks of the Zuni uplift, New Mexico: U.S. Atomic Energy Commission, RMO-642, Tech. Inf. Service, Oak Ridge, Tenn., 47 p.

Rawson, R. R., 1980, Uranium in Todilto Limestone (Jurassic) of New Mexico--Example of a sabkha-like deposit, in Rautman, Christopher A., compiler, Geology and mineral technology of the Grants uranium region, 1979: New Mexico Bureau of Mines and Mineral Resources Memoir 38, 1980, p. 304-312.