URANIUM RESOURCE EVALUATION
MARFA QUADRANGLE
TEXAS

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ABSTRACT

The uranium favorability of the Marfa 1° by 2° Quadrangle, Texas, was evaluated using criteria established for the National Uranium Resource Evaluation. Only that portion in the United States was evaluated. Surface and subsurface studies, to a 5,000 ft (1500 m) depth were employed, along with chemical, petrologic, hydrogeochemical, and airborne radiometric data. The entire quadrangle is in the Basin and Range Province, and is characterized by Tertiary silicic volcanic rocks (both caldera and outflow facies), overlying mainly Cretaceous carbonate rocks and sandstones.

Strandplain sandstones of the Upper Cretaceous San Carlos Formation and El Picacho Formation possess many favorable characteristics and are tentatively judged as favorable for sandstone-type deposits (Class 240). However, reductants have not been found in outcrop, and there is no known uranium mineralization.

The Tertiary Buckshot Ignimbrite contains uranium mineralization at one location, the Mammoth Mine. This deposit may be an example of the hydroauthigenic class (530); alternatively it may have formed by reduction of uranium-bearing ground water produced during diagenesis of tuffaceous sediments of the Vieja Group. Although the presence of the deposit indicates favorability, the uncertainty in the process that formed mineralization makes delineation of a favorable environment or area difficult. The Allen Intrusions are favorable for authigenic deposits (360). Basin fill in several bolsons possesses characteristics that suggest favorability, but insufficient data are available for complete evaluation. Accordingly, these bolsons are classified as unevaluated. All Precambrian, Paleozoic, other Mesozoic, and other Cenozoic environments are unfavorable.

INTRODUCTION

PURPOSE AND SCOPE

The Marfa Quadrangle, Texas, was evaluated to identify and delineate geologic units and areas exhibiting characteristics favorable for the occurrence of uranium deposits. Surface and subsurface data were used to evaluate all environments to a depth of 5,000 ft (1500 m). Because subsurface data in the area are sparse, evaluation of the subsurface was based primarily on extrapolation from surface data. All geologic environments within the quadrangle were classified as favorable, unfavorable, or unevaluated, using the recognition criteria of Mickle and Mathews (1978). A favorable environment in this study is defined as one that could contain at least 100 tons U_3O_8 with an average grade of at least 100 ppm U_3O_8.

Evaluation of this quadrangle was a joint effort of Bendix Field Engineering Corporation (BFEC) and The University of Texas at Austin Bureau of Economic Geology (BEG) for the National Uranium Resource Evaluation (NURE). NURE is managed by the Grand Junction, Colorado, office of the Department of Energy. BFEC was responsible for evaluation of pre-Tertiary rocks, which are predominantly sedimentary rocks, and BEG was responsible for evaluation of the Tertiary rocks, which are predominantly igneous or igneous-derived sedimentary rocks.

ACKNOWLEDGMENTS

Discussions with other geologists, particularly A. W. Walton (University of Kansas), J. A. Wilson (The University of Texas at Austin), Pat Kenney of Marfa, Texas, W. E. Bourbon of Alpine, Texas, James A. Wolleben, formerly head of the Geology

Department at Sul Ross State University, Alpine, Texas, students at Sul Ross State University, and students at The University of Texas at El Paso helped the authors clarify their ideas on regional geology.

The staff of the Bureau of Economic Geology, Austin, was very helpful and cooperative during all phases of the investigation. Of particular assistance were Drs. L. F. Brown, Jr., and V. E. Barnes.

Many landowners in the Marfa Quadrangle generously allowed access to their property to examine geologic relationships, to examine uranium occurrences or radiometric anomalies, and to collect geochemical samples. Without their cooperation this study could not have been done.

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PROCEDURES

Because the evaluation of this quadrangle was a cooperative effort, this section is divided into two parts, one applicable to the BFEC contribution, written by W. P. Wilbert, and the other applicable to the BEG contribution, written by C. D. Henry and T. W. Duex.

Bendix Field Engineering Corporation

BFEC was responsible for the pre-Tertiary rocks and Quaternary sediments in the quadrangle. During Phase I of the evaluation, Wilbert, in cooperation with the BEG, reviewed the literature and compiled maps and information on uranium occurrences. During Phase II (6/30/78-9/30/79), literature research continued and field work was performed. Field work consisted of (1) examining known uranium occurrences and areas of anomalously high radioactivity as reported in Preliminary Reconnaissance Reports (PRR's) of the U.S. Atomic Energy Commission and (2) identification and examination of other areas of potential mineralization on the basis of geologic inference and the literature. Rock samples (App. B) and scintillometer (Mt. Sopris SC-132) readings were taken at each accessible occurrence and also randomly throughout the quadrangle. After initial reconnaissance, radiometric (scintillometer) traverses were run and samples were collected for geochemical analysis. In addition to areas of anomalously high radioactivity, samples were taken from areas where radiometric background was low to establish a "normal" background for a particular rock unit in a certain area. This technique was also used to fill geographic gaps. No regular pattern for sampling was used.

Fluorometric determination of chemical U_3O_8 content and emission spectrography for 29 elements were obtained for all rock samples. Analyses were performed at three laboratories: Skyline Labs (Tucson, Arizona); Core Laboratories (Albuquerque, New Mexico); and the laboratories at BFEC's Grand Junction (Colorado) facility. Gamma spectroscopy was also done at BFEC Grand Junction laboratory after emission spectrographic analysis and U_3O_8 determination. Except for eight samples (MGE-103, MGE-104, MGE-105, MGE-106, MGE-107, MGE-109, MGE-110, and MGE-112) splits sent to Grand Junction were of insufficient volume to make gamma spectroscopy feasible. Thus, only these eight samples have values in the eK, eU, and eTh columns in Appendix B.

Subsurface data consisted almost entirely of widely spaced (average approximately 15 mi; 24 km) electric logs from hydrocarbon tests. While too widely spaced to be of much value in regional evaluation of an environment, these tests can be of local value. Data from numerous mineral exploration holes were not available.

Integral parts of the evaluation consisted of incorporation of airborne radiometric data (LKB Resources, 1979), hydrogeochemical and stream-sediment reconnaissance (Union Carbide, 1978a and b; Butz and others, 1979), and detailed studies into a geologic framework.

Bureau of Economic Geology

Procedures used by the Bureau of Economic Geology are similar to those used by Bendix Field Engineering Corporation with a few minor differences and one major difference in concept of evaluation discussed below. Minor differences include (1) Phase II lasted from 8/15/78 to 11/15/79; and (2) a Geometrics model GR-101A scintillometer was used in place of the Mt. Sopris model used by Bendix, and a Scintrex GAD-6 gamma-ray spectrometer with a 3-inch sodium iodide crystal was used locally. The spectrometer is awkward to transport on foot in the rugged terrain of Trans-Pecos Texas and was used only where access allowed.

Samples collected were analyzed at the Bureau's Mineral Studies Laboratory under the supervision of Dr. Clara Ho, chemist-in-charge. Uranium analysis was by a total-fusion fluorometric procedure. Multielement analysis for 30 elements was by inductively coupled argon plasma spectrometer. In addition, some samples were sent to Uranium West Laboratory for analysis of uranium and thorium, by neutron activation. Splits of all samples were sent to Grand Junction for analysis by gamma-ray spectroscopy as required by the contract. However, no gamma-ray analyses were provided.

The major difference in methodology employed by the Bureau of Economic Geology concerns an attempt to understand the processes that could lead to uranium ore formation in volcanic terrain, a relatively frontier field for uranium exploration. Although employed extensively, this approach can best be illustrated by using the extensive Tertiary tuffaceous sedimentary sequence as an example. Epigenetic uranium deposits require three factors acting together: (1) a source rock that has released uranium, (2) migration of the uranium from the source to a site of entrapment, and (3) entrapment and enrichment of uranium in a deposit, commonly by reduction of U^{+6} to U^{+4}. All three factors can be identified in Trans-Pecos Texas.

The metaluminous to peralkaline igneous and igneous-derived sedimentary rocks contain high background concentrations of uranium (up to 20 ppm). In tuffaceous sediments the uranium is predominantly tied up in volcanic glass shards and pumice fragments. The tuffaceous sediments are highly permeable. Potential trap rocks exist in both the Tertiary sediments, either in channel sandstones containing organic trash or in lacustrine deposits with thin but extensive lignite beds, and in underlying Cretaceous sedimentary rocks. The key to evaluating uranium favorability in relation to the tuffaceous sediments is understanding the release part of factor 1. The sediments have undergone open-hydrologic-system diagenesis (Hay and Sheppard, 1977; Walton, 1975; Botros, 1976; Hively, 1976) in which the glass shards are dissolved by through-flowing ground water. All chemical constituents of the shards, including uranium, are placed in solution in ground water, seemingly an ideal situation for long-distance migration of uranium and formation of major deposits. However, previous work (Walton, 1978; Walton and others, in progress) indicates that in some types of alteration of glass, uranium enters into solution, but does not migrate sufficient distances to be concentrated. Other types of alteration do allow long-distance migration (Galloway and Kaiser, in press). Without long-distance migration of uranium, the tuffaceous sediments are only potential source rocks.

We have used extensive sampling of the tuffaceous sediments along with chemical analysis, particularly of uranium and thorium, petrographic analysis to identify types of alteration, and fission-track mapping to identify sites of uranium in unaltered (glassy) and altered sediments, to evaluate whether or not diagenesis has released significant quantities or proportions of uranium from the potential source rocks. If significant quantities have been released from a given area, that area or potential trapping environments down hydrologic gradient must be considered highly favorable. If only small or unmeasurable quantities of uranium have been released, the area is much less favorable. Under the latter case the area is not necessarily totally unfavorable, however. Release of only 1 ppm of uranium from a large volume of source rock could create immense deposits, although such release would be difficult to ascertain by almost all analytical methods.

Uraniferous fluorite comprises a second example. High concentrations of uranium are irregularly distributed in fluorite, even within a single deposit. The process that leads to erratic enrichment is not understood other than that the fluorite is in general contact-metasomatic in origin. Understanding the controls of uranium distribution in fluorite would allow better evaluation of the possible existence of significant uraniferous fluorite deposits and could provide an effective exploration technique.

Investigation of the subsurface favorability of the Tertiary rocks has been done entirely from examination of surface exposures and extrapolation to depth. This approach is feasible, and excellent regional crosssections can be constructed (Fig. 2, Pls. 8 and 9) because Trans-Pecos Texas is an area of high relief and is cut by numerous normal faults. However, logged wells are sparse, and none provide usable information about the Tertiary rocks other than giving total thickness. In some areas of extensive Quaternary cover, subsurface relations of the volcanic and volcaniclastic rocks can only be surmised, especially where rocks derived from different source areas interfinger.

The currently available aeroradiometric data (LKB Resources, 1979) are considered of little value. None of the known major uranium prospects were located, probably because the 5-mi (8-km) spacing is too wide and the area is geologically too complex. A total of 159 equivalent U aeroradiometric anomalies were identified by the survey; LKB Resources identified six of these as "preferred anomalies" (Pl. 3). However, field examination of several of the preferred anomalies revealed no anomalous uranium. Additional aeroradiometric surveys at 0.25-mi (0.4-km) spacing have been done in some areas. However, the results of these surveys are not yet available.

GEOLOGIC SETTING

The Marfa Quadrangle, an area of 4,200 mi^2 (11,000 km^2), is located in the southern Basin and Range Province of Trans-Pecos Texas. The quadrangle is bounded on the east by long 104°W. and on the north and south, respectively, by lat 31° N. and 30°N. The western boundary follows the Rio Grande, which crosses lat 31°N. at about 104°34' and lat 30°N. at about 104°41'. The Rio Grande roughly follows the boundary between the Basin and Range Province and the Chihuahua Tectonic Belt, a Mesozoic depocenter complexly deformed during Laramide time. Physiographically, the western half of the quadrangle consists of a series of mountain ranges separated by fault-bounded basins. The northeastern half is occupied by the high Davis Mountains, which are largely unaffected by Basin and Range faulting. Rocks in the quadrangle range in age from Precambrian to Recent.

Precambrian Rocks

Precambrian rocks crop out only in the north-central part of the quadrangle, primarily in the Carrizo Mountains, one of the structurally highest parts of Trans-Pecos Texas. Smaller outcrop areas occur in the Wylie Mountains to the east, the Van Horn Mountains to the south, and the Eagle Mountains to the west of the Carrizo Mountains. Precambrian rocks consist of a thick sequence of metamorphosed sedimentary rocks (limestone, phyllites, schists, quartzites), which are intruded by metamorphosed rhyolite and diorite. This sequence is thrust to the north over a thick sequence of limestone, volcanic rocks, and sandstone that has also undergone extreme deformation. The age of the rocks is late Precambrian, although there is evidence of previous deformation. After Carrizo Mountain deposition, alluvium now designated Van Horn sandstone (McGowen and Groat, 1971) was deposited. Thickness of the formation in the Marfa Quadrangle is undetermined. Precambrian rocks occur in the subsurface throughout much of the quadrangle; with the exception of the Carrizo Mountain area, Precambrian rocks probably occur at depths greater than 5,000 ft (1500 m). Details of Precambrian geology are summarized by King and Flawn (1953), Hay-Roe (1957), Twiss (1959), and Underwood (1963).

Paleozoic Rocks

Two distinct facies represent the Permian System. The first facies is composed chiefly of pure to slightly silty shelf carbonates that crop out in the Delaware Basin, Guadalupe Mountains, and the extreme northwestern portion of the Marfa Quadrangle. This facies is represented by the Hueco and Victorio Peak Limestones and the Seven Rivers Formation. The second facies consists of the Cibolo, Pinto Canyon, Ross Mine, and Mina Grande Formations. This "dirty" (sandy, cherty, shaly, at places conglomeratic carbonate) facies is present to the south of the "clean" facies and crops out chiefly in Pinto Canyon and in the Presidio Quadrangle to the south. The "dirty" facies represents marine environments of varying subsea depth. The increased volume of terrigenous admixture, reflecting increased detrital influx to the south, may be associated with local uplifts of sedimentary rocks originally deposited in the early Paleozoic Ouachita Geosyncline.

A total of about 6,000 ft (1800 m) of Permian rocks is preserved at the surface in the quadrangle. About 3,300 ft (1000 m) of sandstone, shale, and conglomerate in the south part of Pinto Canyon is thought to be of Late Pennsylvanian age (Amsbury, 1958) and is designated the Cieneguita Formation (Jones and Reaser, 1970).

The "dirty" Permian facies is host for the silver and base-metal deposits at Shafter, Texas, in the Presidio Quadrangle. There are no known silver, base-metal, or uranium occurrences in other Permian rocks of the Marfa Quadrangle.

Older Paleozoic rocks may be present in the subsurface, but probably at depths greater than 5,000 ft (1500 m).

Cretaceous Rocks

Cretaceous sedimentary rocks may be divided into two megafacies: (1) an Early Cretaceous, almost Bahama-like, complex of carbonate banks (now thick "nondescript" limestones with minor dolomite) and (2) a Late Cretaceous sequence of fluvial and strandplain sandstone, prodelta clay, and minor, very shallow water carbonates. In contrast to the Permian, this division is temporal, not geographic. Cretaceous rocks of equivalent age are similar throughout the quadrangle. The lithology differs slightly, but not significantly.

Early Cretaceous carbonate deposition was interrupted only occasionally by influx of sand, mud, and gravel. Clastics become finer grained and less abundant higher in the sequence. Early Cretaceous time was tectonically the most stable period, represented by sedimentary rocks in the Marfa Quadrangle. Aggregate thickness is several thousand meters.

Deposition of the Ojinaga Formation, a prodelta black shale, marked the beginning of the Late Cretaceous regression. Progradation, chiefly from the west (Weidie and others, 1972), culminated in the mainly continental El Picacho Formation. Continental depositional environments existed earlier in the Cretaceous, mainly at the time of deposition of the Cox Sandstone, but these environments were relatively ephemeral and intertongue with thicker marine carbonates.

Total thickness of the progradational unit, from the base of the Ojinaga Formation to the base of the overlying Tertiary volcanic pile, is about 3,300 ft (1000 m).

Tertiary Rocks

The Tertiary rocks are predominantly volcanic rocks or volcaniclastic sediments. Intrusive rocks occur almost exclusively in a few volcanic centers in the Davis, Wylie, and Eagle Mountains and near the southwest corner of the quadrangle. In general, several volcanic centers both within and outside the quadrangle produced thick sequences of lava flows and ash-flow tuffs. Thick sequences of waterlaid and minor air-fall tuffs separated by a few, thin ash-flow tuffs and lava flows accumulated in basins between eruptive centers. The Davis Mountains are the major volcanic center in the area, but the Chinati Mountains in the Presidio Quadrangle immediately to the south probably provided much of the volcaniclastic sediment within the quadrangle. Smaller volcanic centers occur in the Eagle Mountains and probably the Wylie Mountains; another center, which provided some volcanic material to the quadrangle, occurs in the northern Quitman Mountains just off the northwest edge of the quadrangle.

The Davis Mountains consist of a series of alkalic, silicic flows and pyroclastic units with subordinate mafic flows. Major activity was limited to a period between 38 and 35 m. y. ago (Parker and McDowell, 1979), but other volcanic units are of late Eocene to Oligocene age. The volcanic rocks were intruded by stocks, sills, and dikes of approximately the same compositional range during the latter part of the period of eruptive activity. No calderas have been positively identified in the Davis Mountains within the Marfa Quadrangle, although the presence of numerous major ash-flow tuffs suggests that calderas must occur there.

The Chinati Mountains and an area around them, including parts within the Marfa Quadrangle, were volcanic centers through much of the Tertiary. Documented volcanic activity in the Chinatis is dominantly around 31 m.y. old (Cepeda, 1979), but reconnaissance by the authors shows the presence of an older resurgent caldera, partly truncated by the Chinati Caldera, along the south-central border of the quadrangle. Also several small rhyolite-porphyry intrusions occur along the south border of the quadrangle.

The Eagle Mountains appear to be a resurgent caldera, having a thick sequence of caldera-filling ash-flow tuff. Volcanic rocks derived from this caldera have been largely eroded away in the Eagle Mountains vicinity. The Wylie Mountains may also be a caldera but are now so highly dissected that only a central intrusion, possibly a resurgent dome, remains. Volcanic rocks of the Garren Group, south of the Wylie Mountains, may have been erupted from this area.

Much of the volcanic material in the quadrangle consists of tuffaceous sediments of the Vieja Group in the Sierra Vieja and various equivalents in the south and southeast parts of the quadrangle. The Vieja Group is divided into three sedimentary formations separated by an ash-flow tuff and a major rhyolitic lava flow. Probably all of the volcanic centers discussed above contributed material to the sediments at various times. The major sources were probably in the Davis Mountains and Chinati Mountains. Contributions from the Eagle and Wylie Mountains may have been more minor.

The Mitchell Mesa Welded Tuff was erupted from the Chinati Caldera about 31 m.y. ago. It caps the Vieja Group throughout much of the Sierra Vieja and is the major ash-flow tuff of Trans-Pecos Texas. It also caps the undifferentiated Pruett-Duff Formations in the southeastern part of the quadrangle. The Pruett and Duff

Formations are time-equivalent to the Vieja Group sediments; continuity of the two sequences beneath younger rocks in the south-central part of the area is uncertain.

The Tascotal Formation overlies the Mitchell Mesa in the southern part of the area. It was deposited as an alluvial fan of tuffaceous sediment derived from the Chinati Mountains during waning stages of pyroclastic activity (Walton, 1979).

Total thickness of the tuffaceous sedimentary sequence ranges up to 3,300 ft (1000 m) in the central part of the Sierra Vieja. Open-hydrologic-system diagenesis has converted the initially glass-rich tuffaceous sediments to a zoned assemblage of zeolites, including clinoptilolite and analcime, montmorillonite, opal, and calcite. Glass was preserved only in upper parts of the Vieja Group in the southern Sierra Vieja and in the upper part of the Tascotal Formation. Diagenesis probably occurred penecontemporaneously with deposition of the sediments.

The Petan Basalt caps the Mitchell Mesa or the Tascotal Formation in the southern part of the quadrangle; several similar basalts at the western edge of the Davis Mountains and all the way north to the Wylie Mountains have been correlated with the Petan.

The Perdiz conglomerate is a thick alluvial fan composed of volcanic debris shed from the Chinati Mountains following cessation of pyroclastic activity there (Walton, 1978; Jordan, 1978). Perdiz caps the Tascotal Formation or Petan Basalt throughout much of the southern part of the quadrangle. It consists of a coarse boulder conglomerate in proximal areas grading to finer sediment in distal areas. The Perdiz is diagenetically altered, having calcite in proximal areas and a combination of opal-clinoptilolite and montmorillonite in distal areas. Diagenesis occurred in a hydrologic system apparently unrelated to that which affected the underlying tuffaceous sediments.

Basin and Range faulting began about 23 m.y. ago, following cessation of almost all igneous activity (Dasch and others, 1969; McDowell and Henry, unpublished data). Faulting has broken the western two-thirds of the quadrangle into a series of north- or northwest-trending mountain ranges, separated by basins (bolsons) largely filled with debris shed from the ranges. Major basins are Lobo Valley - Ryan Flat, Eagle Flat, Red Light Bolson, Presidio Bolson, and Hueco Bolson. Most of the latter two areas occurs in the Presidio Quadrangle and Van Horn Quadrangle, respectively. Basin fill is as thick as 4,000 ft (1250 m) in Lobo Valley and in Presidio Bolson but is generally thinner in the other bolsons in the Marfa Quadrangle. The bolsons were closed basins during deposition. Basin-fill deposits grade from coarse boulder conglomerate (accumulated as alluvial fans adjacent to the range) to fine mud (toward the middle of the basin). Playa-lake and evaporite deposits occur in Presidio Bolson and probably in other basins, but the others are relatively undissected, so basin-center facies are not exposed. Integration of the Rio Grande drainage system has destroyed the closed-basin nature of the bolsons along the Rio Grande. Lobo Valley and Eagle Flat are still part of a closed basin, which drains into Salt Basin to the north in the Van Horn Quadrangle. However, both surface and ground water drain out of Lobo Valley and Eagle Flat at present.

Igneous activity during basin filling was negligible. Numerous dikes along Basin and Range faults in the Sierra Vieja may have fed basalt flows interbedded with basin-fill deposits. Rhyolitic volcanism and ash deposition were not active after about 26 m.y. before present, however.

Quaternary Rocks

The Quaternary Period was characterized by valley filling, in part a continuation of bolson-fill deposition. Lithology of the fill consists of mud, sand, and gravel, chiefly volcanic debris derived from the Tertiary volcanic piles. Lithology varies, depending upon local sources of fill. Degree of induration varies with caliche content.

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

SUMMARY

Three environments in the Marfa Quadrangle are favorable for uranium deposits. One area (Area A, Pl. 1), 10 mi (16 km) north of Candelaria, meets some of the criteria for both non-channel-controlled peneconcordant sandstone-type deposits and "Texas"-type roll fronts (Class 240, Subclasses 244 and 242, Austin and D'Andrea, 1978). Potential host rocks are the El Picacho - San Carlos sequence, which includes strandplain and fluvio-deltaic Upper Cretaceous sandstones.

The Buckshot Ignimbrite contains significant uranium mineralization of uncertain origin at one location: the Mammoth Mine. Although the area around the Mammoth Mine is considered favorable, the uncertainty in origin makes precise delineation of a favorable area difficult. We have designated Area B, Plate 1 as potentially favorable. However, this area was chosen more from ignorance as to origin of the Mammoth Mine than from a thorough knowledge of the uranium favorability of the area. A complete discussion of the geologic setting, possible mechanisms of uranium mineralization, and rationale for selection of favorable areas is given below. The Allen Intrusions (Area C, Pl. 1) are favorable for authigenic deposits (Class 360).

Small uranium shows in other areas have been thoroughly explored and judged unfavorable.

EL PICACHO - SAN CARLOS SEQUENCE

Porous and permeable sandstones of the Upper Cretaceous (Gulf) El Picacho and San Carlos Formations are favorable for sandstone-type uranium deposits in an area extending along the Rio Grande from 15 mi (24 km) north of Candelaria, Texas, to about 35 mi (56 km) north of Candelaria (Area A, Pl. 1). The favorable area is entirely west of the Buckshot Rim. Because the boundary between the formations is paleontologic, no attempt was made in this study to differentiate between them; the entire section from the top of the Ojinaga to the base of the overlying Tertiary volcanic pile is referred to as the El Picacho - San Carlos sequence. Tuffaceous sediments and ash-flow and air-fall tuffs of the Tertiary Vieja Group are likely sources of uranium-bearing fluids.

The El Picacho - San Carlos sequence meets important criteria for "Texas"-type roll-front uranium deposits. Host-rock lithology, uranium source, sandstone geometry, local structures, associated rocks, and inferred depositional environments are very similar to regions where "Texas"-type deposits are found. However, host-rock lithology, potential uranium source, and sandstone geometry are criteria for non-channel-controlled peneconcordant uranium deposits (Subclass 244) that the sequence also meets. Significant criteria for Subclass 244, which are not present in the El Picacho - San Carlos sequence, are (1) an adjacent highland, to serve as a source for the potential host rocks, (2) mudstone interbeds, derived largely from devitrification of overlying tuff (mudstone interbeds are thought to be lagoonal and/or interdistributary deposits), and (3) the absence of fault-controlled porosity. Because the sequence has not been studied to a great extent and is inaccessible by vehicle, the sequence is here considered favorable for both "Texas"-type deposits (Subclass 242) and for non-channel-controlled peneconcordant deposits (Subclass 244). Subclass 242 is much more likely because the sequence meets more recognition criteria for that subclass.

Sandstone beds in the sequence are 10 to 17 ft (3 to 5 m) thick. They consist of fine- to medium-grained, fairly well sorted, quartzose to feldspathic arenites. The beds are generally blanket-like, but a few are lenticular. Both are crossbedded. Marine and brackish-water fossils (mostly pelecypods) and Ophiomorpha burrows are common in the blanket sandstone beds, but are found very infrequently in the slightly coarser-grained channels (tidal channels?). Mudstones, coal beds, and lignite interfinger with the sandstone. These interbeds are interpreted as lagoonal in the lower part of the sequence and as interdistributary or bay deposits in the upper part. A sequence of strandplain - barrier-bar depositional environments grading upward, as progradation continued, into fluvio-deltaic depositional environments is inferred.

The sequence is broken into areally small fault blocks by both Basin and Range faulting and Rio Grande rifting. The faults, mainly normal faults, that bound the blocks may serve as conduits for descending uranium-bearing waters and also as conduits for ascending sour gas from fetid Lower Cretaceous limestones occurring at depth.

There is no visible organic trash preserved on outcrops of the sandstone beds. This does not preclude the possible presence of organic debris in the subsurface. Because coal beds and interbedded shales are present, disseminated organic trash is likely. Many sandstones that host large uranium deposits, such as the Westwater

Member of the Morrison Formation in the Grants (New Mexico) Mineral Belt, show no organic debris on weathered outcrops. It is abundant in the non-oxidized subsurface. Another likely reductant is sour gas ascending along faults. This mechanism has been used to explain the South Texas Tertiary deposits (Galloway, 1977; Goldhaber and others, 1978). The coal beds may serve as local reductants. Also, there are no preserved sulfides megascopically visible on outcrops.

Faulting, both by producing clay gouge and by juxtaposing permeable and relatively impermeable beds, furnished aquacludes that may help localize deposits.

There are no known uranium occurrences in the El Picacho - San Carlos sequence. However, near the Capote Mountain graben, Reeves and others (1979) reported "anomalously high" radioactivity, which they attributed to escaping radon. If this is so, a likely source of the radon might be uranium deposits in the Upper Cretaceous sequence. Rock samples from the sequence in the favorable area do not show any bleaching or megascopically visible alteration, but the qualification megascopically should be emphasized. Detailed petrographic study of numerous samples, precluded by time constraints in this study, may show that the feldspars are intensely altered. Also, ghosts of sulfides or minerals suggestive of a nearby deposit or mineralization front might be observed in thin-section. No redox boundary or paleo-water table was identified in this sequence.

HSSR ground-water data (Butz and others, 1979) are sparse, but reveal slightly elevated molybdenum, arsenic, vanadium, and uranium in a well on the McCutcheon Ranch 15 mi north of Candelaria. This is the only ground-water data point in the favorable area. Stream sediments (Butz and others, 1979), as expected, show high uranium values. Uranium in the stream sediments is mostly derived from the overlying

Vieja Group tuffs and tuffaceous sediments. Aeroradiometric data (LKB Resources, 1979) reveal one major anomaly (Anomaly 120) over the favorable area. This anomaly is "distinguished by strong equivalent uranium/equivalent thorium and equivalent uranium/potassium ratios," indicating a concentration of uranium relative to other radioactive elements. Scintillometer readings taken over the El Picacho - San Carlos sequence (250-300 counts per second) are uniformly five to six times those taken over the dense Lower Cretaceous limestones. The favorable area's radioactivity is about twice that of the lithologically similar Aguja Formation 80 mi (130 km) southeast in the Emory Peak Quadrangle. The radioactivity is about the same as that of the Marfa Basin, an intermontane basin filled largely with volcanic detritus.

Access to the favorable area is subject to nearly constant flooding by the Rio Grande and tributary arroyos. It was inaccessible during most of Phase II and an adequate sampling program was impossible without horses or burros. Three rock samples (MGE-123, MGE-124, MGE-125) show very low (average 2.5 ppm, App. B) U_3O_8 concentrations. The age-equivalent Aguja Formation, which crops out only in the Emory Peak Quadrangle, has been extensively sampled. Average U_3O_8 concentration is 4 ppm. The Aguja is almost identical lithologically to the El Picacho - San Carlos sequence, but it is unfavorable for uranium deposits, because it does not immediately underlie a tuff. There are no outcrops between Area A and the Aguja outcrop near Study Butte, nor is there sufficient subsurface information to establish facies or thickness trends that would improve the evaluation.

In summary, there are no known uranium occurrences in the favorable area, but the lithology of the El Picacho - San Carlos sequence is such that it would make an excellent host. Favorable lithology together with proximity to a possible source and favorable, although scant, HSSR and aeroradioactivity data lead us to conclude that the Upper Cretaceous continental and marginal marine sandstones in Area A are favorable.

Because little is known about this sequence, the entire outcrop, from Pilares, Texas, southward along the Rio Grande to the Candelaria area, is judged as favorable. There is also little information regarding subsurface extent or thickness of the favorable sequence. Thicknesses of 3,300 ft (1000 m) were reported by Barnes (1979b), but because of erosion and a presumed irregular lower contact, an average thickness of 1,650 to 2,300 ft (500 to 700 m) is reasonable.

Area A contains no towns or permanent residents. It is all privately owned. A dirt road parallels the Rio Grande on the U.S. side, but is often impassable due to wash-outs. Permission to travel on that road, and information on passability, may be obtained in Candelaria or in Pilares.

Detailed studies in the favorable area, particularly measurement and correlation of sections, would greatly enhance the evaluation. Such studies, extensive petrologic work, and more thorough geochemical sampling might help to delineate areas or targets of "greater favorability" within Area A.

BUCKSHOT IGNIMBRITE AND MAMMOTH MINE

The Mammoth Mine in the Buckshot Ignimbrite is one of the most significant uranium prospects in Trans-Pecos Texas. This fact alone suggests that the Buckshot should be considered a favorable environment. However, the origin of mineralization at the Mammoth Mine is uncertain; several hypotheses have been offered (Bilbrey, 1957; Nye, 1957; Anderson, 1975; Pilcher, 1978) and our alternative interpretation is not identical with any of these. Selection of a favorable environment on the basis of the Mammoth Mine is entirely dependent upon its presumed mechanism of formation. For this reason it is necessary to discuss the regional setting and possible mechanisms of mineralization in some detail.

Regional Setting

The Buckshot Ignimbrite is one formation of the Vieja Group, a 3,500 ft (1100 m) thick section of tuffaceous sediments, air-fall and ash-flow tuff, and lava flows and flow-breccias. The Vieja Group, including its stratigraphy, paleontology, diagenesis, and mineralization, is discussed in more detail by Bilbrey (1957), DeFord (1958), Wilson and others (1968), Twiss (1970), Anderson (1975), and Walton (1975). The Vieja Group overlies Upper Cretaceous sedimentary rocks; two basal units occur irregularly throughout the Sierra Vieja. A limestone conglomerate, the Jeff Conglomerate, fills channels cut into the Cretaceous rock. In the southern part of the Sierra Vieja, the Jeff or Cretaceous rocks are overlain by the Gill Breccia, a flow-breccia complex composed dominantly of trachybasalt porphyry (DeFord, 1958).

Most of the Vieja Group is composed of diagenetically altered tuffaceous sediments and air-fall tuff. Three sedimentary sequences are distinguished, primarily on the basis of intervening ash-flow tuffs or lava flows. From oldest to youngest, they are the Colmena Tuff (30 to 450 ft; 10 to 135 m thick), the Chambers Tuff (100 to 800 ft; 30 to 250 m thick) and the Capote Mountain Tuff (1,300 to 1,800 ft; 400 to 550 m thick). All include fluvially deposited tuffaceous siltstone, sandstone, and conglomerate, as well as subordinate air-fall tuff. The sediments are composed of glass shards and pumice (now largely destroyed by diagenesis), and rock and mineral fragments. Glass shards predominate in fine-grained sediment, whereas rock fragments are predominant in coarser deposits. The Colmena Tuff is separated in most places from the Chambers Tuff by the Buckshot Ignimbrite; the Chambers is in turn separated from the Capote Mountain Tuff by the Bracks Rhyolite. The Capote Mountain Tuff is capped by the Mitchell Mesa Welded Tuff. Although additional marker beds occur within the tuffaceous units, where the intervening volcanic rocks are absent, distinction between the different volcaniclastic units is difficult and they are not subdivided. The age of the Vieja Group ranges from Eocene (40 m.y. on the Gill Breccia) to Oligocene (31 m.y. on the Mitchell Mesa) (McDowell, 1979; Wilson and others, 1968).

The tuffaceous sediments have been diagenetically altered in an open hydrologic system to a subhorizontally-zoned assemblage of zeolites, montmorillonite, and silica minerals (Walton, 1975). Diagenetic mineral zones described by Walton "from top to bottom, are (1) montmorillonite - opal - glass, (2A) montmorillonite - opal - clinoptilolite, (2B) montmorillonite - quartz - clinoptilolite, (3A) montmorillonite - quartz - analcime, and (3B) analcime - quartz." Diagenesis occurred during deposition after a sufficient thickness (estimated by Walton to be several hundred meters) of sediment had accumulated. In addition to diagenesis, pedogenic alteration produced paleosoil horizons exhibiting calcite concretions and root mottling, particularly in the Chambers Tuff.

The entire Sierra Vieja is extensively cut by north- and northwest-trending normal faults having displacements up to 3,300 ft (1000 m). Faulting began approximately 23 m.y. ago (Dasch and others, 1969) and has continued to the present (Muehlberger and others, 1978). The Vieja Group and underlying rocks are broken into numerous individual fault blocks, tilted as much as 20°. Faulting was postdiagenesis (Walton, 1975).

All of the volcanic and volcaniclastic rocks contain high background concentrations of uranium. For example, hydrated vitrophyres of the Buckshot Ignimbrite commonly contain approximately 12 ppm U_3O_8. Concentrations in glassy and altered tuffaceous sediments range from approximately 3 to 15 ppm. Fission-track mapping shows that the uranium occurs predominantly in glass in glassy rocks and in various secondary minerals in devitrified or diagenetically altered rocks. Thus all the rocks constitute potentially good sources of uranium. Evidence as to whether or not uranium has been mobilized from any of these rocks is discussed below.

Reducing environments in the tuffaceous sediments to trap and concentrate uranium have not been observed. Channel sandstones containing organic debris or lacustrine beds containing lignite, such as are found in the Pruett Formation of the Emory Peak Quadrangle are not known to occur in the Vieja Group. Without an effective trapping mechanism, most of the tuffaceous sedimentary sequence is unfavorable for uranium deposits. However, other mechanisms to create reducing environments in the Vieja Group are possible and are discussed below.

The Buckshot Ignimbrite is a peralkaline ash-flow tuff emplaced as a single cooling unit. Its maximum thickness is about 100 ft (30 m), but average thickness is only about 70 ft (20 m). A basal vitrophyre is preserved in many places, but is invariably hydrated. The Buckshot is densely to moderately welded throughout its occurrence. An upper, non-welded air-fall tuff cited by Anderson (1975) is believed by us to be mostly a result of laminar flowage of the ash flow after deposition and partial consolidation. The Buckshot shows abundant evidence of a high volatile content and extensive vapor-phase activity. Anderson cites laminar-flow features, tumuli resulting from a form of fumarolic activity, and the presence of abundant cavities in devitrification spheres, rarely up to 15 cm in diameter.

Uranium Mineralization at the Mammoth Mine

The Buckshot at the Mammoth Mine crops out along the middle of a steep slope above Quinn Creek. Mineralization extends for a distance of about 170 ft (50 m) along the cliff face. The Buckshot at the Mammoth Mine is 35 ft (11.5 m) thick and in most respects is similar to the Buckshot throughout its area of outcrop (Anderson, 1975). Vitrophyre is not exposed right at the prospect, but does occur at several locations around the prospect, within about 300 to 700 ft (100 to 200 m). The rock is densely to partly welded, exhibiting a well-developed lithophysal zone.

Uranium mineralization is predominantly found in the densely welded zone, but minor amounts occur throughout the entire thickness of the Buckshot. The only uranium mineral positively identified is beta-uranophane, but both Nye (1957) and Anderson (1975) found another yellow uranium mineral, which Nye speculated could be a barium analog of uranophane. Uranophane occurs in cavities in devitrification spheres, in fractures in rock fragments, and in fractures in the Buckshot. Uranophane also occurs in minor amounts along fractures in the underlying Colmena Tuff. Uranium concentrations found in this study range up to 2750 ppm U_3O_8; Nye reported an average of 0.1 to 0.2% U_3O_8 with local concentrations up to 1%; Bilbrey (1957) reported an average assay of 0.27% U_3O_8.

Associated minerals found in cavities include secondary silica (quartz, chalcedony, and opal), calcite, and iron oxides. Limonite pseudomorphs after pyrite are common. The host rock is devitrified ash-flow tuff composed of quartz and feldspar. The rock is strongly bleached compared with typical red-brown Buckshot outcrops. Anderson also described this alteration and stated that it was a mixture of quartz and feldspar. The bleaching apparently has not significantly altered host rock mineralogy. Minor amounts of a soft, white mineral, possibly kaolinite, occur in some cavities. The bleaching might have resulted from acidic leaching resulting from oxidation of pyrite; in that case, greater alteration of feldspar and more development of kaolinite might be expected. Similar bleaching has not been found anywhere else in the Buckshot.

No other areas of mineralization are reported in the Buckshot. A second prospect, the McSpadden Prospect, occurs approximately 6 km southeast of the Mammoth Mine. We did not visit it during this study, but Bilbrey (1957) stated that no mineralization was observed and that radiation levels were typical of the Buckshot. An intensive gamma-ray spectrometer survey of part of the Buckshot by Anderson showed a moderate variation in total gamma radiation but no mineralization. Radiation was highest along a fault. Tumuli on the surface of the Buckshot were no more radioactive than undeformed parts of the surface.

<u>Origin of Mineralization</u>

Nye (1957) first advanced three general theories to explain the origin of uranium mineralization at the Mammoth Mine. More recent studies, although discussing various theories in greater detail and providing more evidence for and against different theories, have not added any general mechanisms of mineralization. Nye's theories are (1) concentration of uranium in vesicles by late-stage volatile components of the uranium-rich parent magma, (2) ground-water leaching from the Buckshot and overlying tuffaceous sediments and reconcentration in the Buckshot, and (3) introduction of uranium by a hydrothermal source.

Pilcher (1978) proposed the Mammoth Mine occurrence as an example of the hydroauthigenic uranium class (Class 530). He stated that mineralization was formed by "internal entrapment of released uranium-bearing volatiles and subsequent precipitation of uranophane." By this mechanism two sources of uranium-rich volatiles are conceivable. The first source could be gas released during initial eruption of the ash-flow and transported with it to the site of deposition and the second source could be gases released during cooling and devitrification of the consolidated ash-flow deposit.

We have doubts about this explanation for several reasons. Both volatile sources definitely exist, but if they were significant sources of uranium, mineralization ought to be widespread throughout the Buckshot. It is not. Pilcher (personal communication, 1979) suggested that the Buckshot at the Mammoth Mine is unusually thick and that this relationship accounts for uranium mineralization. However, according to Anderson (1975), the Buckshot at the Mammoth Mine is only about 35 ft (11.5 m) thick compared to an average Buckshot thickness of about 70 ft (20 m). Also, if a vapor phase is important, tumuli, resulting from the concentrated loss of volatiles, might be expected to show some evidence of uranium enrichment or mineralization. In fact, as noted above by Anderson and reinforced by the results of this study, tumuli are no more radioactive nor uranium-rich than the general Buckshot.

If gases released by devitrification were the source of uranium, then the unmineralized Buckshot near the Mammoth Mine ought to be highly depleted of uranium. However, uranium concentrations and thorium/uranium ratios of unmineralized rocks both at and near the Mammoth Mine are similar to concentrations and ratios throughout the Buckshot outcrop area. Also fission-track mapping of uranium distribution shows that uranium is disseminated uniformly throughout the ground mass of glassy and devitrified rocks both at and away from the Mammoth Mine. Devitrification does not appear to have mobilized measurable uranium.

An important factor is the association of uranium with limonite pseudomorphs after pyrite. To our knowledge pyrite has never been reported as a vapor-phase mineral in any ash-flow tuff. Its presence at the Mammoth Mine (and at no other localities in the Buckshot known to us) allows, but does not prove, an oxidation-reduction mechanism of concentration. The key to understanding the origin of the Mammoth Mine may be in understanding the origin of pyrite.

A hydrothermal source for uranium also seems unlikely. Although the area contains abundant volcanic and volcaniclastic rocks, no intrusive igneous rocks occur nearby. The nearest intrusive centers are in the Chinati Mountains, 30 mi (50 km) to the south, and the Van Horn and Eagle Mountains, about an equal distance to the north. There is geothermal activity in the area now, resulting from deep circulation of meteoric water along fault zones (Henry, 1979a). Similar activity probably occurred in the past. However, only geothermal water that has been in contact with the volcaniclastic rocks has moderately high uranium concentrations. A hydrothermal source for pyrite may be important, however.

Our postulated general mechanism for formation of the Mammoth Mine deposit involves (1) introduction of pyrite in the Buckshot by upward leakage of H_2S-bearing gas or water coming from underlying Cretaceous sedimentary rocks, (2) mobilization of uranium in glass in tuffaceous sediments by open-hydrologic-system diagenesis, and

(3) precipitation of reduced uranium minerals (probably coffinite) by reaction with pyrite and subsequent recent oxidation to form uranophane. Both good evidence and several problems are involved in this proposed mechanism.

1) Leakage of H_2S-bearing fluids from underlying Cretaceous rocks has not been documented in Trans-Pecos Texas and the area is not a producer of hydrocarbons. However, several deep wells have been drilled along buried Cretaceous structures to explore for hydrocarbons in the Mammoth Mine area (Bilbrey, 1957). Several of the wells encountered minor amounts of oil or gas. Two of the wells now produce hot water (approximately 80°C) containing H_2S and several hot springs in the area also produce H_2S (Henry, 1979a). A boulder of massive Lower Cretaceous limestone occurs in Quinn Creek near the mine; it is highly petroliferous. Its occurrence there is unusual, as Cretaceous rocks that crop out in the area are all Upper Cretaceous. Nevertheless, the petroliferous boulder implies that underlying Lower Cretaceous rocks could be a source of H_2S. This mechanism of pyritification and entrapment of uranium in major deposits is well documented in the Texas Coastal Plain uranium district (Goldhaber and others, 1978; Galloway and Kaiser, in press).

Two related questions relevant to this explanation are (1) why was pyrite formed only at the Mammoth Mine and only in the Buckshot? and (2) what conduits were available to conduct H_2S-bearing fluids into the Tertiary rocks? The first question is similar to the problem of why vapor-phase mineralization should occur only at the Mammoth Mine. Anderson (1975) noted an odd relationship between Cretaceous rock and probable Colmena Tuff at one locality in Quinn Creek near the mine. The rocks are conformable and oriented vertically; Anderson suggested that the vertical beds could have served as a conduit for hydrothermal uranium-bearing solutions. We disagree only in that we believe they could have provided a conduit for "hydrothermal" H_2S-bearing fluids. Because the Colmena Tuff is much thinner here (33 ft; 10 m thick) than at other Buckshot outcrops, the H_2S-bearing fluids may have reached the Buckshot more easily here than elsewhere. If this proposed mechanism is correct, pyrite and mineralization might also be expected to occur in the Colmena or Chambers Tuff near the Mammoth Mine. That it does not is a potential drawback in the mechanism. Nevertheless, the restriction of pyrite and uranium mineralization only to the Mammoth Mine argues for a genetic relationship between the two.

Basin and Range faults, although now serving as conduits for H_2S-bearing geothermal waters, probably did not act as conduits allowing H_2S-bearing fluids to produce pyrite at the Mammoth Mine. Basin and Range faulting did not begin until long after diagenesis (Walton, 1975), which we believe was the most favorable time for uranium mobilization from the tuffaceous sediments. However, diagenesis is not necessarily the only appropriate time for uranium mobilization. Ground water in tuffaceous sediments in Trans-Pecos Texas now contains high uranium concentrations. Thus pyrite formation and mineralization could have occurred after Basin and Range faulting; Anderson (1975) did find slightly higher radioactivity along fault zones in the Buckshot than elsewhere. Otherwise, the structure of underlying Cretaceous rocks may have been more important in localizing pyritification than Basin and Range structures.

2) During diagenesis, glass shards and pumice in the tuffaceous sediments were dissolved and all constituents of the glass, including uranium, went into solution. Thus diagenesis ought to be an ideal mechanism for releasing uranium and allowing it to migrate to form deposits. However, several different studies of the effectiveness of

uranium mobilization in the tuffaceous sediments of Trans-Pecos Texas indicate that this is not always the case. During open-hydrologic-system diagenesis of the Tascotal Formation, uranium appears to have entered solution but then migrated only a very short distance, possibly on the order of a few tens of meters before being trapped or precipitated (Walton, 1978). Other studies have contrasted the effect of diagenesis and of pedogenesis (soil-forming processes) on uranium release. Walton and others (in progress) argue that during pedogenesis, uranium is mobilized to migrate long distances, whereas during open-hydrologic-system diagenesis, released uranium is trapped and does not migrate far, possibly due to a lack of complexing agents in the ground water involved in diagenesis.

To test uranium mobilization in tuffaceous sediments of the Vieja Group, we have determined the uranium and thorium concentrations and thorium/uranium ratios in variously altered or glassy samples of tuffaceous sediments from the different formations. In addition we have made fission-track maps of some of the samples to determine the mineralogic locations of the uranium in the rock. Assumptions are that (1) the rocks have characteristic initial thorium/uranium ratios, (2) diagenesis could mobilize uranium as the soluble U^{+6} ion, but thorium would remain immobile, and (3) significant uranium mobilization would be indicated by greater thorium/uranium ratios than those found in unaltered rocks.

The results of the geochemical and fission-track studies suggest that no measurable uranium mobilization has occurred and that uranium in diagenetically altered rocks is commonly trapped by adsorption on Fe-Mn oxyhydroxides. Most thorium/uranium ratios average about 2 in both glassy and variously altered rocks. An immediate interpretation of these results is that insufficient uranium has been mobilized for major deposits to occur. Deposits such as the Mammoth Mine would be rare and of low tonnage. However, there is considerable scatter in the concentrations and ratios from sample to sample. Some uranium mobilization may have occurred. For example, mobilization of only 1 ppm of uranium from the rocks would be nearly impossible to detect because of uncertainties in the primary concentrations and ratios and in accuracy of the analyses. One ppm from a tuffaceous sedimentary source 660 ft (200 m) thick over an outcrop area of 36 m^2 (100 km^2) is approximately 1 million lbs (450,000 kg) of uranium. (Total volume of the Vieja Group is about 2 orders of magnitude greater.) Whether or not this would produce an ore deposit would depend on the effectiveness of entrapment. Nevertheless, the tuffaceous sediments constitute a more probable source of uranium than the Buckshot because the volume of tuffaceous sediments is so much greater. Henry and Duex (1980) discuss the application and significance of this approach in greater detail.

3) If the entrapment mechanism is reduction of U^{+6} to U^{+4} by reaction with pyrite, then the primary ore mineral ought to be a reduced mineral. Coffinite is most likely because the diagenetic waters have high silica concentrations and because the present ore mineral is uranophane, a U^{+6} silicate. Neither coffinite nor any other reduced uranium mineral has been found at the Mammoth Mine. However, the uranophane may have resulted entirely from postmineralization oxidation. Mineralization is exposed at the surface and known core drilling has been restricted to an area near the cliff face where mineralization is exposed. Thus any initial reduced minerals may have been entirely oxidized or simply not encountered by known drilling. Uranophane is reported from fractures within the underlying Colmena Tuff at the Mammoth Mine (Nye, 1957) and one sample (MGE-523) collected by us from an adit in

the Colmena contains 19 ppm U_3O_8. This could have resulted from downward leaching of uranium from the Buckshot during oxidation, but other explanations are possible. Determining the primary ore mineral would greatly clarify the origin of the deposit.

A major difficulty with the oxidation-reduction method of entrapment is the lack of enrichment in trace elements such as Mo, As, Se, and V, commonly associated with redox-type deposits. Mo occurs in moderately high concentrations (20 to 70 ppm) at the Mammoth Mine and shows some correlation with uranium ($R = 0.44$). However, Mo concentrations in unmineralized Buckshot samples from throughout its outcrop area show a similar range. The high concentrations in both mineralized and unmineralized samples are probably primary.

Also, Nye (1957) argued that ground water would have difficulty passing through the impermeable welded tuff. However, the Buckshot is highly fractured in all outcrops observed in this study; these fractures should provide sufficient permeability. In addition, lack of permeability would preclude any mineralization process involving a fluid phase. Nye favored a hydrothermal source of uranium; lack of permeability would negate this source. That permeability existed following consolidation and welding of the Buckshot is demonstrated by the presence of secondary silica and calcite in fractures and vesicles at the mine.

Conclusion--Exploration for Uranium in the Mammoth Mine Area

Both the vapor-phase and the oxidation-reduction involving pyrite mechanisms of mineralization have attractive attributes; both also have problems. The uncertainties stem from a lack of sufficient knowledge of the complete characteristics of the Mammoth Mine deposit. Better knowledge would allow resolution of the question of origin. Without an understanding of the origin of the deposit, both delineation of favorable areas and exploration for additional deposits is difficult. Exploration based on one model of origin would be totally ineffective if other mechanisms were responsible for mineralization.

Exploration based on the vapor-phase model requires understanding why some parts of the Buckshot concentrated vapor-phase uranium and why others did not. Exploration would be restricted to the Buckshot. Exploration based on the oxidation-reduction model requires understanding the controls of pre-ore pyritification. Mineralization would not necessarily be restricted to the Buckshot but would also occur in other parts of the Vieja Group. Possible target areas would be along Cretaceous structures, which could have controlled H_2S leakage, or along Basin and Range faults if pyrite formation is postdiagenesis.

As a compromise, we have designated almost the entire area of outcrop of the Vieja Group as favorable (Area B, Pl. I). Only intensely faulted areas, where the Vieja Group overlies Cretaceous rocks at shallow depths, are included. Unfaulted areas and the Vieja Group above the Bracks Rhyolite are generally not included. Also, those parts of the Vieja Group buried beneath bolson fill are not included, even though the favorable environment may extend beneath fill. Clearly not all of this area is truly favorable; the map should be interpreted accordingly. However, until the origin of the Mammoth Mine mineralization is better understood, more precise delineation of favorable areas is impossible.

ALLEN INTRUSIONS

Fracture zones in the Allen Intrusions, a group of rhyolite porphyry domes of probable Oligocene age, constitute a favorable environment for authigenic class deposits (Class 360 of Mathews, 1978). The Allen Intrusions occur along the southern border of the quadrangle and extend slightly into the Presidio Quadrangle. They are shown simply as undifferentiated Tertiary intrusions on the geologic map accompanying this report but are mapped separately by Amsbury (1958). Additional discussions of uranium mineralization in the Allen Intrusions are given by Amsbury (1958), Henry and Tyner (1978), and Reeves and others (1979).

The area of outcrop of the Allen Intrusions is only a few square miles. As the favorable environment consists of fracture zones within the intrusions, only a fraction of the total outcrop area is favorable. The fracture zones are probably a result of cooling of the intrusion. They dip steeply but irregularly and have irregular thicknesses up to approximately 15 ft (4 m). Mineralization was originally discovered at the surface, and drilling by Wyoming Minerals and Meeker & Co. found mineralized fractures to depths of at least 200 ft (60 m).

The Allen Intrusions are a group of shallow rhyolite domes with associated flows and breccias. They are contemporaneous with the Shely Group of rhyolite lava flows, ash-flow tuffs, and diagenetically altered tuffaceous sediments. Both groups of rocks are older than the rocks of the Chinati Caldera cycle (within the Presidio Quadrangle), but may be related to it or to an older caldera immediately east of the intrusions. All the major domes are rhyolite porphyries with quartz and alkali feldspar phenocrysts; plagioclase phenocrysts occur in some of the domes. Commonly the rocks are weathered or altered so that all ferromagnesian minerals and most feldspars are converted to oxides or clays. Vitrophyres associated with the porphyritic intrusions are rare, but two were found in this study (MGE-810 and MGE-811).

A second group of rocks associated with the domes includes nonporphyritic or sparsely porphyritic vitrophyres and perlites. They are probably remnants of flows associated with the domes.

Both groups of rocks are chemically similar. They are alkali-rich, high silica rhyolites with low Ca, Mg, and Fe concentrations. Aluminum is also low, but the rocks are not peralkaline, as shown by both the chemical analyses and by the presence of biotite in the two vitrophyre samples from the porphyritic group.

Evidence of favorability includes (1) the presence of abundant areas of uranium mineralization in fractures and (2) the similarity in overall geologic characteristics to those of the authigenic class (Class 360) of Mathews (1978). Mineralization occurs as uraniferous Fe-Mn oxyhydroxides and as secondary uranium minerals. Reeves and others (1979) reported autunite, metatorbernite and tyuyamunite. Anomalous uranium concentrations occur in many fracture zones throughout the porphyritic domes. Amsbury (1958) reported that 200 tons of ore averaging 0.34% U_3O_8 were extracted in the 1950's from one trench and stockpiled nearby. The highest grade found in this study was 1430 ppm U_3O_8 recovered from clay gouge along the trench (MGE-568). An Fe-Mn or Fe-Ti-Mn oxyhydroxide from the same trench contained 825 ppm U_3O_8 (MGE-545). Slightly lower concentrations were found associated with oxyhydroxides from several other fracture zones at the surface and were encountered in drill cores. Other elements enriched in the hydroxides are Cd, Be, Co, Cr, Cu, Ni, and V.

Our interpretation of the origin of the mineralization is adsorption from ground water of uranium and the other elements by amorphous Fe-Mn oxyhydroxide. Supergene weathering or crystallization of the amorphous hydroxides subsequently released the uranium. The released uranium then reprecipitated as secondary uranium minerals. Thus the highest grades should occur near the surface where secondary enrichment has produced an oxidized, supergene zone with both uraniferous hydroxides and secondary U^{+6} minerals. An alternative explanation is that pitchblende veins occur at depth and that both the oxyhydroxides and U^{+6} minerals are secondary. Drilling by Wyoming Minerals did not penetrate the water table so this interpretation cannot be tested. However, the fracture zones are generally smaller and of lower uranium grade at depth. This suggests that the presence of pitchblende veins is unlikely.

Probable sources of the uranium are the rhyolite porphyries themselves or the associated glassy rocks of the Allen Intrusions. Diagenetically altered tuffaceous sediments of the Shely Group are a third possible source. Primary uranium concentrations of the rhyolite porphyries may be as high as 23 ppm U_3O_8, the concentration found in the two vitrophyres (MGE-810 and MGE-811). All unmineralized surface samples contain lower concentrations ranging from approximately 5 to 15 ppm. Relatively unweathered and unfractured samples from drill cores contain variable concentrations closer to those of the vitrophyres. Thus surficial weathering, rather than crystallization of the magma or subsequent devitrification, is the most likely mechanism of uranium release.

Glassy samples of the nonporphyritic rocks contain 7 to 9 ppm U_3O_8, which is lower than the concentrations of the porphyritic vitrophyres, but which still makes them highly adequate source rocks. Diagenesis or weathering of these rocks could have released uranium to solution (Henry and Tyner, 1978).

An uncertainty is the timing of initial mineralization and temperature of the associated fluid. Mineralization may have occurred during initial cooling, involving moderately high-temperature waters. Alternatively, mineralization may have occurred a sufficiently long time after cooling, so that only cold ground water was involved. By either mechanism, supergene enrichment is probably a continuous process related to present-day weathering and erosion.

The geologic setting, alteration, and type of deposit agree well with the authigenic class of Mathews (1978). The rhyolite porphyry intrusions occur in a mobile belt and are postorogenic and epizonal. They are highly differentiated with high silica, alkali, and uranium concentrations and low calcium, magnesium, and iron concentrations. Mineralization occurs in fracture zones where uranium released by devitrification or weathering could be concentrated. Alteration is minor and consists primarily of the alteration of feldspar and mafic phenocrysts, argillic alteration along the fracture zones, and abundant limonitic staining and Fe-Mn hydroxides along the fractures.

There are no aeroradiometric anomalies associated with the Allen Intrusions. However, as discussed in the Procedures section, the aeroradiometric survey identified none of the known anomalies in the quadrangle. For that and several other reasons, the aeroradiometric survey is considered to be of no value. The hydrogeochemical survey of the Marfa Quadrangle is not available, but no anomalies were identified on the adjoining Presidio Quadrangle.

Prospects in the Allen Intrusions are abundant and several are of high enough grade to be economic. However, the total tonnage of currently known deposits is small and may be a limiting factor on development. Minor uranium concentrations also occur in secondary silica within parts of the nonporphyritic group of the Allen Intrusions. The uranium concentrations in silica are both very low grade and low volume and are not of economic significance.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

SUMMARY

Many environments in the Marfa Quadrangle are considered unfavorable for uranium deposits. They are (1) Precambrian rocks, (2) Paleozoic rocks, (3) most Mesozoic rocks, (4) mafic rocks, including lava flows and small intrusive bodies, (5) most silicic and intermediate lava flows, ash-flow tuffs, and intrusions, (6) plutonic rocks, (7) most tuffaceous sediments, and (8) fluorite deposits in the Eagle Mountains. Most of these environments are considered unfavorable because they contain no mechanisms to trap uranium. However, some could serve as source rocks for uranium deposits in other units where trapping mechanisms are present.

PRECAMBRIAN ROCKS

Although the Precambrian rocks in the Marfa Quadrangle include a wide variety of meta-igneous and meta-sedimentary rocks, they have uniformly low uranium concentrations (highest uranium = 6.5 ppm, MGE-206, App. B). Furthermore they lack the physical conditions for trapping or concentrating uranium and are not associated with aeroradiometric anomalies. Therefore, these rocks are considered unfavorable environments for uranium deposits.

PALEOZOIC ROCKS

Permian rocks (for nomenclature, see Fig. 3) directly overlie the Precambrian at the surface and in the shallow subsurface. Although there is some uranium mineralization associated with Tertiary intrusions near the Chinati Caldera (Dietrich, 1965), there is no uranium mineralization in Paleozoic rocks in the area. Permian rocks are, however, age equivalent to argentiferous limestones at Shafter (Presidio Quadrangle). Several samples from Permian units in Pinto Canyon occurring in the Presidio Quadrangle (MGF-362 and MGF-363) yield low concentrations of U_3O_8, and exhibit few characteristics judged favorable for uranium deposits. There are no HSSR and aeroradioactivity anomalies over the Paleozoic outcrop. Subsurface Paleozoic rocks are either unfavorable by analogy to outcrops or are too deep to be evaluated here.

MESOZOIC ROCKS

No Triassic or Jurassic rocks crop out within the quadrangle. No Triassic rocks and only thin, possible Jurassic rocks were recognized on well logs in this study. The Malone Mountains, where the only known Jurassic rocks in Texas crop out, are 30 miles north of the quadrangle, in the Van Horn Quadrangle. There is no reason to believe that the Jurassic rocks, even if present in the shallow subsurface of the Marfa Quadrangle, would be favorable for uranium. Rocks that do crop out in the Malone Mountains are marine limestones, and extensive studies of outcropping and subsurface Mesozoic rocks in Chihuahua (Haenggi, 1966) have not revealed Triassic or Jurassic rocks, except for a thick sequence of evaporites, usually considered Cretaceous, but possibly Jurassic. Triassic and Jurassic rocks, even if present in the shallow subsurface, would very likely be unfavorable.

The Cretaceous Yucca, Bluff Mesa, Finlay, Espy, Loma Plata, and Borracho and Buda Formations are unfavorable for uranium deposits, as they are mainly dense marine limestones, do not contain a suitable reductant, and exhibit no radiometric (airborne or ground) anomalies or chemical anomalies.

The Cox, Benevides, and Del Rio Formations, chiefly siliciclastic units, are likewise unfavorable because they lack reductants. Their radiometric signature (average 50-70 counts per second) hardly warrants further study.

Upper Cretaceous rocks have largely been eroded from the Marfa Quadrangle. They are preserved in two places: (1) Chispa Summit, the pass between the Sierra Vieja and the Van Horn Mountains, where an extensive area of Boquillas Formation crops out and (2) the area west of the Vieja Rim, where Upper Cretaceous sandstones are favorable. The Boquillas in the first area has a radiometric signature (150 counts per second) that is about three times that of the dense Lower Cretaceous limestone. The elevated radiometrics are due to bentonite beds in the Boquillas that, while slightly uraniferous, do not approach favorability, as they lack a concentrating mechanism.

TERTIARY ROCKS

Mafic Rocks

Mafic lava flows in the Marfa Quadrangle considered unfavorable for uranium deposits include (1) the Petan Basalt (MGE-921, 0.5 ppm U_3O_8), (2) mafic units in the Garren Group (MGE-968, 2.5 ppm U_3O_8), (3) the Pantera Trachyte (MGE-997, 7.3 ppm U_3O_8), (4) the basalt lentil of the Hogeye Tuff (MGE-992, 1.3 ppm U_3O_8), and (5) mafic rocks in the Davis Mountains. These units are judged unfavorable on the basis of surface rock sampling because they have generally low uranium concentrations and contain neither evidence of uranium enrichment nor known mechanisms for trapping uranium.

Silicic and Intermediate Rocks

Numerous rhyolitic to intermediate lava flows, ash-flow tuffs, and small intrusive bodies in the Marfa Quadrangle are judged to be unfavorable for uranium deposits. These units include lava flows and ash-flow tuffs in the Shely, Garren, and Vieja Groups, and most units in the Davis Mountains. Geochemical (rock) sampling and inspection of aeroradiometric data indicate that these units have low to moderate uranium and total radioelement concentrations. Inspection of a known aeroradiometric anomaly in the Davis Mountains (Mt. Livermore anomaly, Reeves and others, 1979) revealed low to moderate concentrations of uranium in the rocks sampled (highest uranium = 21.0 ppm U_3O_8, MGE-938, App. B). No process or mechanism capable of concentrating uranium was observed in these units. However, they are potentially favorable sources of uranium to form epigenetic deposits elsewhere.

Plutonic Rocks

Large intrusive masses of generally felsic composition are considered to be unfavorable environments because of low uranium content and lack of any indication of a primary magmatic deposit. These plutons are the Eagle Peak Syenite (highest uranium content = 5.5 ppm, MGE-812, App. B) in the Eagle Mountains, quartz microsyenite and quartz trachyte in the Davis Mountains (highest uranium content = 9.7 ppm, MGE-733, App. B), the quartz monzonite of Canning Ridge (uranium = 2.8 ppm, MGE-867, App. B), and the Ojo Bonito "Laccolith" north of the Chinati Mountains (uranium content = 3.8 ppm, MGE-794, App. B). In addition, no aeroradiometric or geochemical anomalies are associated with these rocks. Similar to the silicic flow rocks, these rocks could be potential sources of uranium.

Tuffaceous Sediments

Most tuffaceous sediments of the Vieja Group, Garren Group, Shely Group, Buck Hill Group, and Davis Mountains are unfavorable for uranium deposits because they lack reductants or other trapping mechanisms. Channel sandstones containing organic debris or lacustrine deposits containing lignites are not known to occur in any of the above rocks in the Marfa Quadrangle. These types of reducing environments, which occur in the basal Pruett Formation of the Emory Peak Quadrangle may also occur in that part of the Pruett Formation in the subsurface in the Marfa Quadrangle. That formation is not exposed in the Marfa Quadrangle, however, and thus cannot be evaluated. Epigenetic reductants, such as those postulated for the Mammoth Mine uranium occurrence, may exist in lower parts of the tuffaceous sedimentary sequence, especially in the Vieja Group. This environment is considered along with the Buckshot Ignimbrite.

Clinoptilolite, a common constituent of the tuffaceous sediments, has been found to concentrate uranium in at least two other areas of tuffaceous rocks, the Tono Mine of Japan (Katayama and others, 1974) and the Reese River Valley of Nevada (Basinski and Larson, 1979). However, fission-track mapping of uranium distribution in the tuffaceous sediments of the Marfa Quadrangle shows that clinoptilolite and another zeolite, analcime, are depleted in uranium. Reasons for this difference are not known. Nevertheless, no trapping mechanisms have been identified in tuffaceous sediments of the above formations. Therefore, these are considered unfavorable.

Although the tuffaceous sediments are considered unfavorable because they do not contain environments suitable to concentrate uranium, they are potentially excellent uranium sources. All tuffaceous sediments examined by us in the Marfa Quadrangle have been diagenetically altered. Diagenesis may have released uranium to solution, to be concentrated elsewhere. A brief discussion of this possibility is presented above in the section on the Buckshot Ignimbrite and Mammoth Mine.

Fluorite of the Eagle Mountains

Fluorite deposits associated with rhyolitic intrusive bodies in the Eagle Mountains have low uranium concentrations; the highest uranium content in fluorite from the Eagle Mountain fluorospar district is 4.5 ppm (MGE-850, App. B). This is in contrast to fluorite deposits in the Christmas Mountains (Emory Peak Quadrangle), which have anomalously high uranium (Daugherty and Fandrich, 1979). The variable uranium content of fluorite from these two areas can be attributed to a difference in composition of the associated rocks. The igneous rocks of the Eagle Mountains are less alkalic than those of the Christmas Mountains (Barker, 1977). The mechanism for concentrating uranium in fluorite is apparently related to the alkalinity of the associate igneous rocks. Thus the fluorite deposits in the Eagle Mountains are classified as unfavorable environments because of low uranium content and association with unfavorable rock types.

UNEVALUATED ENVIRONMENTS

BOLSON-FILL DEPOSITS

Bolson-fill deposits within Presidio, Hueco, and Red Light Bolsons, Eagle Flat, and Lobo Valley - Ryan Flat are classified as unevaluated. Although several lines of evidence suggest that the fill, especially in Presidio Bolson, could be favorable, other evidence suggests that it is unfavorable. Information to draw a final conclusion is not available.

Geologic Setting

The bolsons are filled with detritus, shed from adjacent highlands and composed of either Tertiary volcanic and intrusive rocks or Cretaceous or older sedimentary rocks. Deposition began with initiation of faulting, about 23 m.y. ago (Dasch and others, 1969). Deposition continued in closed basins until the Pleistocene when integration of the Rio Grande drainage system allowed through-going drainage of the basins along the Rio Grande. Bolson fill there is now being dissected, and several different terrace levels are developing as the Rio Grande cuts downward. Lobo Valley and Eagle Flat are not part of this drainage system but drain into Salt Basin, a closed basin in the Van Horn Quadrangle to the north.

Groat (1972) divided basin fill in Presidio Bolson into conglomerate, sandstone, and mudstone lithosomes, depending on the dominant lithology. His model is probably appropriate to the other basins, although, because most are not as dissected as Presidio Bolson, basin fill deposits are either poorly exposed or not exposed at all. The fill is zoned and the coarsest material is adjacent to major basin-bounding faults along the mountain fronts. Fill adjacent to the mountain front was deposited in alluvial fans. The material fines basinward into the mudstone lithosome, although conglomerate and sandstone lenses compose as much as 10% of the mudstone lithosome. During closed basin sedimentation the center was occupied by a playa lake; evaporite beds containing gypsum occur within the mudstone lithosome in several locations. Groat considered the alluvial fan, gypsum, and playa deposits as being similar to deposits associated with playas in the Mojave Desert.

Thickness of the fill ranges from greater than 4,000 ft (1200 m) in several locations along the center of Presidio Bolson down to areas of pinch-out along the margins of the basin. However, thickness changes abruptly at faulted margins where basin fill is displaced against older rocks. Thickness of fill in the other basins is comparable to that in Presidio Bolson.

Faulting has continued to the present; recent fault scarps cut several terraces developed since integration of the Rio Grande drainage. Recent fault scarps also occur along the west side of Lobo Valley (Muehlberger and others, 1978). Although the largest faults are along basin margins, numerous additional faults occur within the basins, especially in the northern part of the dissected Presidio Bolson. Faults within the other basins are also likely but most are probably buried beneath recent sediments.

Uranium Favorability

Epigenetic uranium deposits, the most likely type to form in the bolsons, require the appropriate interaction of three factors: (1) a source rock that has released uranium, (2) a transporting medium, and (3) trapping and concentrating mechanisms and locations. All three factors may exist within the bolsons, but the actual existence or effectiveness of them has not been completely evaluated.

Source Rocks. Much of the detritus composing the basin fill and much of the adjacent highlands that drain into the basins are composed of Tertiary volcanic, volcaniclastic, or intrusive rocks having relatively high primary uranium concentrations. In highland areas where nonvolcanic Cretaceous or older sediments are now exposed (for example the Quitman Mountains, and parts of the Eagle Mountains, Van Horn Mountains, and Wylie Mountains), volcanic rocks initially capped the sediments but have since been eroded. Thus basin fill in these areas may be at least partly composed of igneous or igneous-derived rocks. Uranium concentrations in basin fill and in volcanic rocks of the highlands typically range from a few ppm to about 15 ppm, making them more than adequate sources of uranium. Analyses of stream sediments within Presidio Bolson show similar concentrations (Union Carbide, 1978b). Uranium mineralization within the Allen Intrusions could also be a potential source of uranium for basin fill in the northern Presidio Bolson. Less certain is whether or not significant amounts of uranium have been released from any of these rocks. Release would have to be by weathering rather than by any process of devitrification or diagenesis. High-temperature devitrification would have occurred before basin formation; open-hydrologic-system diagenesis of tuffaceous sediments would also have occurred before basin formation, because diagenesis occurred soon after initial deposition of the sediments (Walton, 1975). Also, tuffaceous sediments do not occur within basin fill because tuff-producing volcanism ceased before formation of the basins.

Nevertheless, weathering may be an effective mechanism of uranium mobilization from volcanic rocks. Results from this study, from evaluation of the Emory Peak and Presidio Quadrangles, and from previous work in the Chinati Mountains bordering Presidio Bolson (Henry and Tyner, 1978) indicate that weathering can release 50% or more of the primary uranium content of some rocks. Probably sufficient amounts of uranium have been released from potential source rocks to form significant deposits if a concentrating mechanism exists.

Migration. Surface and ground-water flow, both during basin filling and since integration of the Rio Grande, was from high areas along basin margins towards the basin center. While the basin was closed, all water and any dissolved uranium was trapped within the basin. After integration, uranium-bearing waters could reach the Rio Grande and be removed from the system. Permeability of the basin fill probably varies greatly, from very high permeability in the basin-margin conglomerate lithosome to very low permeability in the basin-center mudstone lithosome of Groat (1972). Sandstone lenses do occur even within the mudstone lithosomes, so beds having sufficient permeability to transport ground water to the basin center do exist.

Entrapment. A possible mechanism of entrapment is the most poorly evaluated of the three factors needed for uranium deposits. The most likely entrapment mechanism is by reduction, either (1) by organic material (or pyrite generated from the organic material) deposited in channels in conglomerate or sandstone lithosomes or as lignite beds in the basin center, or (2) by pyrite generated by postdepositional reduction by discharge of H_2S-bearing waters from underlying Cretaceous or Permian sedimentary rocks. The first mechanism is unlikely; evidence for or against the second is meager.

Neither lignitic beds nor organic material of any kind has been found in the basin fill. Although lignite is common in closed basins formed during early Tertiary time (for example, the Pruett Formation of the Emory Peak Quadrangle), the climate may have been considerably drier during deposition of basin fill. Thus organic formation may have been negligible during deposition; any organic material that did form may have been oxidized immediately. Playa-lake deposits of the Mojave Desert are commonly highly oxidized (W. E. Galloway, personal communication, 1979).

Postdepositional reduction by H_2S leaking along faults cutting basin fill is entirely theoretical. The general mechanism and evidence for such reduction are discussed above in the Buckshot Ignimbrite section. Faults cutting through basin fill provide conduits for the rise of thermal water for hot springs, particularly along the Rio Grande. A similar process conceivably could lead to reduction of sediments in basin fill adjacent to fault zones.

If neither reduction mechanism exists, other concentrating processes are still less likely. Formation of calcrete deposits or adsorption of uranium by secondary amorphous silica or hydroxides are possible processes. However, it is more likely that without reduction, uranium in water entering the playa would simply be dispersed throughout playa sediments without being concentrated. Reeves and others (1979) reported uranium mineralization associated with the Quebec Siding anomaly. Aeroradiometric data do show a radioactivity anomaly in that area (LKB Resources, 1979) but our investigation suggests that this results from the presence of detritus moderately rich in U, Th, and K, rather than from mineralization.

Information to Improve Evaluation of Bolson Fill

Factors 1 and 2 required for the formation of epigenetic uranium deposits have probably been operative, so the limiting factor is factor 3, the existence of reducing environments to concentrate uranium. With this uncertainty, the environment is classified as unevaluated. Ground-water analyses from basin fill are sparse, because wells are sparse in the relatively unpopulated bolsons. The few reported concentrations (Union Carbide, 1978b) are relatively low (less than 10 ppb). However, because there are so few analyses, characterization of present day ground-water concentrations is not possible. Also no measurements of oxidation-reduction status were made, so the existence of reducing environments within basin fill cannot be established. More complete sampling emphasizing oxidation-reduction status of existing wells or of wells drilled expressly for uranium exploration in basin fill could resolve this uncertainty.

RECOMMENDATIONS TO IMPROVE EVALUATION

Specific recommendations regarding individual favorable, unfavorable, or un-evaluated environments are discussed above under the appropriate environment. Recommendations given in this section are of a more general or generic nature. Of particular importance is understanding the processes that could lead to uranium ore formation, either in Tertiary igneous rocks or in other rocks where uranium released from the Tertiary rocks is concentrated. The tuffaceous sediments constitute an immense potential source of uranium. A preliminary attempt has been made in this study to understand the effect of diagenesis or other alteration processes on uranium mobility. However, uranium mobility is poorly understood and the conclusions of this report are tentative, at best. Further study of diagenesis, pedogenesis, or other types of alteration and their effects on uranium mobility would greatly enhance evaluation not only of the Marfa Quadrangle but also of all other areas where volcanic or volcaniclastic rocks are potential uranium sources.

The genesis of many types of uranium deposits is extensively debated. Exploration methods are commonly dependent upon theories of genesis. Methods applicable to one ore formation model would be useless for another model. Although information on genetic models would aid evaluation, such studies are beyond the scope of NURE.

Aeroradiometric data were of little use in evaluation. A followup study at a closer spacing has been done but is not yet available. The results of this later study may aid evaluation. The preliminary hydrogeochemical study is also of uncertain significance. High concentrations of uranium and several trace elements exist in ground water in almost all the tuffaceous units of Trans-Pecos Texas (Union Carbide, 1978a and b). Whether these are indicative of mineralization or simply indicate a high regional background level is uncertain. A more complete hydrogeochemical survey, including determination of the oxidation state of ground water, would aid in interpretation of results and exploration for sandstone-type deposits.

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URANIUM OCCURRENCES IN THE MARFA QUADRANGLE

Location . Rng. (W)	Lat. (N)	Long. (W)	Host rock formation/member	Deposit class or sub-class (no.)	Production#	Reference
	30 26 42	104 48 30	Buckshot Ignimbrite	Hydroauthigenic? (530)*	a	Nye, 1957; Anderson, 1975; Pilcher, 1978
	30 00 30	104 29 55	Allen Intrusion	Authigenic(360)**	a	Amsbury, 1958; Reeves and others, 1979

a (no uranium production reported from these occurrences).

URANIUM OCCURRENCES IN THE MARFA QUADRANGLE

ocation			Host rock formation/member	Deposit class or subclass (no.)	Production#	Reference
. Rng. (W)	Lat. (N)	Long. (W)				
	30 26 42	104 48 30	Buckshot Ignimbrite	Hydroauthigenic? (530)*	a	Nye, 1957; Anderson, 1975; Pilcher, 1978
	30 00 30	104 29 55	Allen Intrusion	Authigenic(360)**	a	Amsbury, 1958; Reeves and others, 1979

O_8 (no uranium production reported from these occurrences).

MA[illegible] GEO[illegible]ICAL [illegible]AMP[illegible] (pp[illegible] [illegible]xcep[illegible] [illegible]K)

eU	eTh	cU_3O_8	Ag	Al	As	B	Ba	Be	Ca	Co	Cr	Cu	Fe	La	Li	Mn
		1	<10	80,000	<200	10	700	<10	7,000	<10	20	<10	50,000	<20	20	1,5
		<1	100	5,000	<200	10	>10,000	50	1,000	50	100	70	10,000	<20	70	>10,0
	17±2.3	4	<10	50,000	<200	<10	1,000	<10	5,000	<10	10	<10	20,000	<20	15	3,0
	7±1.6	3	<10	30,000	<200	<10	300	<10	10,000	<10	50	<10	30,000	<20	5	2,0
	±2.1	3	<10	50,000	<200	10	500	<10	50,000	<10	20	<10	20,000	<20	15	[illegible]
	2.9	2	10	50,000	<200	10	50	<10	5,000	<10	10	<10	50,000	<20	30	[illegible]
	2.8	1	<10	50,000	<200	10	500	<10	10,000	<10	10	<10	7,000	<20	15	2
		75	<10	50,000	<200	10	150	<10	700	<10	20	<10	20,000	<20	20	1,0
	)±0.7	<1	<10	500	<200	<10	<20	<10	500	<10	10	<10	5,000	<20	<5	1,0
	)±1.0	<1	<10	30,000	<200	<10	500	<10	10,000	<10	20	<10	20,000	<20	150	7
		1	<10	7,000	<200	50	<20	20	500	10	10	<10	20,000	<20	5	1,0
	-2.0	<1	<10	7,000	<200	<1	<20	<10	500	10	15	10	20,000	<20	5	1,5
		<1	<10	100,000	<200	20	100	<10	20,000	30	50	150	100,000	100	10	
		<1	<10	30,000	<200	10	500	<10	500	<10	100	<10	50,000	50	5	5
		<1	<10	50,000	<200	10	1,000	<10	10,000	<10	5	<10	30,000	<20	10	1,0
		4.9	<0.5	70,000	<200	10	150	30	15,000	5	10	<10	30,000	150	<100	5
		3	<.5	70,000	<200	10	700	<1	30,000	5	30	7	15,000	50	<100	5
		3	1	60,000	<200	<10	5,000	<1	50,000	30	150	50	30,000	70	<100	1,0
		3	<.5	70,000	<200	<10	1,500	5	7,000	<5	100	7	30,000	150	<100	7
		4	<.5	70,000	<200	<10	1,000	2	10,000	<5	150	7	30,000	70	<100	3
		4	3	10,000	<200	<10	20	<1	20,000	<5	20	7	1,500	<20	<100	
		2														
		2														
		3														
		2														
		3														
		6														

BFEC EST NO. 102356 — BENDIX FIELD ENGINEERING CORPORATION — PAGE 1

[illegible] STIP W. P. HILBERT — GEOCHEMICAL ANALYSIS DEPARTMENT

DATE 80/01/14. — EMISSION SPECTROSCOPY — PROJECT 12737288

SEMI-QUANTITATIVE ANALYSIS

JULIAN RUN DATE [illegible] — CONCENTRATION IN PPM

	55557 MGE-0123	55558 MGE-0124	55559 MGE-0125	55560 MGE-0126	55561 MGE-0127	55562 MGE-0128	55563 MGE-0129	55564 MGE-0354	55565 MGE-0355	55566 MGE-[illegible]
[illegible]	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
[illegible]	[illegible]	94100	55300	8620	< 100	62600	68600	5400	57900	62100
[illegible]	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
B	36	55	11	< 10	< 10	26	18	20	59	33
BA	242	253	109	330	< 100	371	785	315	222	[illegible]
BE	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
BI	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
CA	14300	26500	53300	> 100000	> 100000	53700	> 100000	59300	49300	35300
CD	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
CE	< 10	36	< 10	23	< 10	< 10	< 10	< 10	22	[illegible]
CR	71	170	40	16	14	11	11	54	29	[illegible]
[illegible]	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
FE	[illegible]	34200	19200	27500	28100	17400	22300	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	20400	13900	15300	16300	26900	26400	[illegible]	[illegible]	[illegible]
LA	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
LI	< 3000	< 3000	< 3000	< 3000	< 3000	< 3000	< 3000	< 3000	< 3000	< 3000
MG	[illegible]	[illegible]	3900	2320	3300	4680	2870	5050	[illegible]	[illegible]
MN	[illegible]	[illegible]	1140	677	134	371	1300	307	[illegible]	[illegible]
MO	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
NA	[illegible]	31200	20600	5320	< 100	25000	29100	[illegible]	[illegible]	[illegible]
NB	< 100	< 100	< 100	698	1030	< 100	194	< 100	[illegible]	< 100
NI	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
P	[illegible]	[illegible]	464	951	< 100	1050	877	770	1250	[illegible]
PB	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40
SB	< 5000	< 5000	< 5000	< 5000	< 5000	< 5000	< 5000	< 5000	< 5000	< 5000
[illegible]	< 3	5	< 3	11	35	< 3	9	< 3	< 13	< 3
[illegible]	[illegible]	[illegible]	263000	52700	[illegible]	296000	301000	334000	229000	315000
[illegible]	[illegible]	< 10	17	70	17	< 10	< 10	< 10	[illegible]	[illegible]
[illegible]	125	191	124	575	546	810	627	194	404	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1190	731	2270	2110	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	178	[illegible]	341	199	245	214	[illegible]	[illegible]
[illegible]	< 100	< 100	< 100	565	496	< 100	< 100	< 100	< 100	< 100
[illegible]	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40
[illegible]	< 100	179	< 100	560	900	< 100	238	< 100	[illegible]	< 100
ZR	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	51	[illegible]

*** INDICATE CURRENT LIMITS OF ANALYSIS

[illegible]

Li	Mn	Mo	Na	Nb	Ni	Pb	Sb	Sc	Sn	Sr	Ti	V	W	Y	Zn	Zr
20	1,500	<10	20,000	20	10	20	<100	<10	<10	300	3,000	150	<100	20	200	200
70	>10,000	200	500	<20	20	5,000	200	<10	<10	2,000	150	500	5,000	<10	<200	<10
15	3,000	<10	10,000	<20	10	10	<100	<10	<10	500	2,000	100	<100	30	<200	200
5	2,000	<10	10,000	<20	10	<10	<100	<10	<10	200	2,000	50	<100	<10	<200	150
[illegible]	[illegible]	<10	15,000	<20	<10	10	<100	<10	<10	200	2,000	50	<100	20	<200	200
[illegible]	[illegible]	<10	20,000	20	10	<10	<100	<10	<10	<100	2,000	20	<100	20	<200	500
[illegible]	200	<10	15,000	<20	10	<10	<100	<10	<10	500	700	20	<100	<20	<200	50
20	[illegible]	<10	20,000	20	20	10	<100	<10	<10	<100	1,500	20	<100	100	<200	700
<5	1,000	<10	300	<20	20	<10	<100	<10	<10	<100	50	<10	<100	<10	<200	100
[illegible]	700	50	1,000	<20	20	10	<100	<10	<10	<100	1,000	<10	<100	50	<200	200
5	1,000	<10	20,000	20	20	10	<100	<10	<10	<100	300	<10	<100	50	<200	200
5	1,500	<10	20,000	20	20	20	<100	<10	<10	<100	700	<10	<100	50	<200	200
[illegible]	[illegible]	<10	30,000	20	200	50	<100	<10	<10	100	10,000	200	<100	10	<200	100
5	500	<10	1,000	<20	20	<20	<100	<10	<10	<100	7,000	70	<100	10	<200	700
[illegible]	1,000	<10	20,000	<20	10	10	<100	<10	<10	1,000	2,000	50	<100	<10	<200	200
[illegible]	500	<10	40,000	50	<10	50	<100	5	15	<100	2,000	10	<100	20	<200	500
[illegible]	500	<5	30,000	<10	10	<30	<100	5	<10	300	1,500	50	<50	30	<200	200
[illegible]	1,000	<5	30,000	<10	70	20	<100	15	<10	700	3,000	100	<50	20	<200	50
[illegible]	700	5	40,000	20	7	50	<100	10	10	100	3,000	30	<50	70	<200	200
[illegible]	300	<5	40,000	<10	7	70	<100	5	<10	300	2,000	20	<50	50	<200	300
[illegible]	150	<5	3,000	10	<5	10	<100	<5	<10	200	200	20	<50	10	<200	<10

APPENDIX C.

Uranium-occurrence reports

URANIUM-OCCURRENCE

REPORT

Quad Name A90< Marfa >

Quad Scale A100< 2,5,0,0,0,0 >

Deposit No. B40< 1 >

Deposit Name A10 < Mammoth Mine >

Synonym Name(s) A11 < >

District or Area A30 < Sierra Vieja >

Country A40 <U S> U S   State Texas

State Code A50 <4 8> 4 8   County A60 < Presidio >
(Enter code twice from List D)

Position from Prominent Locality A82 < 6 miles SSW of Gettysburg Peak >

Field Checked G1 <7 8 0 9> By G2< Henry , Christopher D. >
Yr Mo   Last name   First   Initial

Latitude A70 <3 0 - 2 6 - 4 2 N>   Longitude A80 <1 0 4 - 4 8 - 3 0 W>
Deg Min Sec   Deg Min Sec

Township A77 < > N/S   Range A78 < > E/W   Section A79 < >

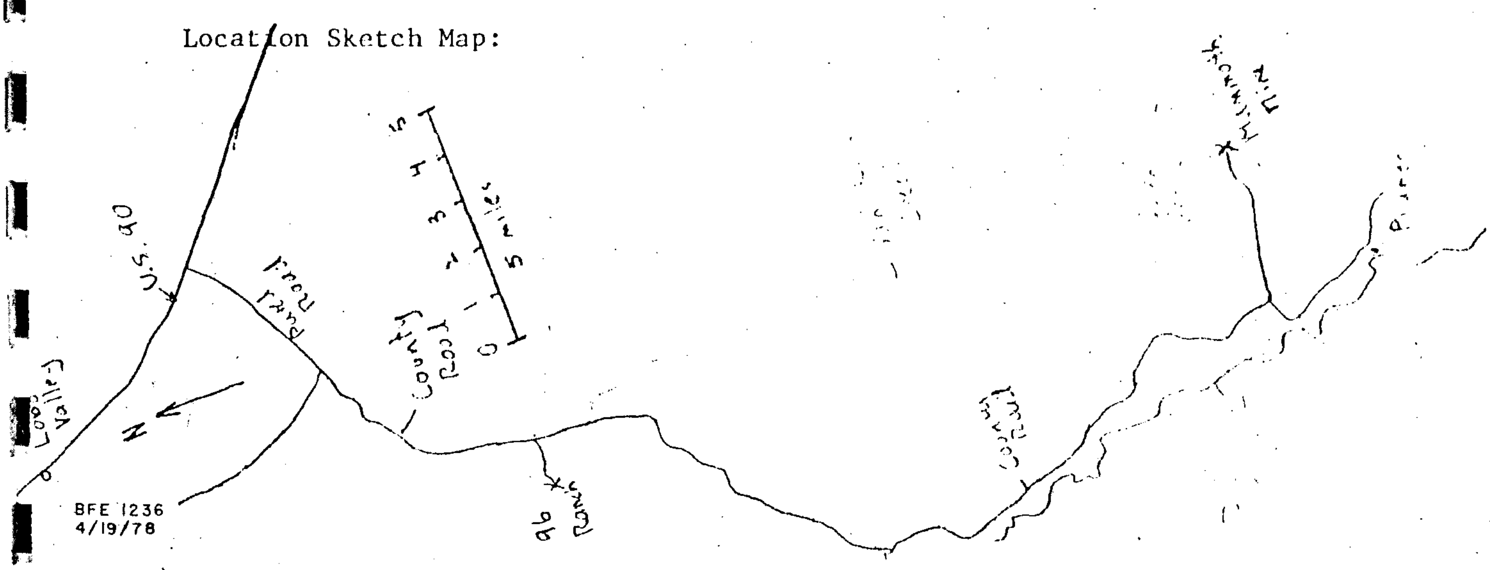
Meridian A81 < >   Altitude A107 < > FT/M

Quad Scale A91 < >   Quad Name A92 < >
(7½' or 15' quad)

Physiographic Province A63 <1 2> Basin and Range >
(List K)

Location Comments A83 < >

Location Sketch Map:



BFE 1236
4/19/78

URANIUM-OCCURRENCE REPORT

Quad Name Marfa

Deposit No. 1 -

Commodities Present:

C10 <U >

Commodities Produced:

MAJOR < > COPROD < >

MINOR < > BYPROD < >

Potential Commodities:

POTEN <U > OCCUR < >

Commodity Comments C50 < >

Status of Exploration and Development A20 < 3 >
(1 = occurrence, 2 = raw prospect, 3 = developed prospect, 4 = producer)

Comments on Exploration and Development L110 < Sporadic exploration since 1954 Presently under active investigation >

Property is A21 (Active) A22 (Inactive) (Circle appropriate labels)

Workings are M120 (Surface) M130 (Underground) M140 (Both)

Description of Workings M220< Three shallow adits, approximately 15 old drill holes; present drilling uncertain >

Cumulative Uranium Production PROD YES NO SML MED LGE (circle)

DH2 accuracy thousands of lb. years grade

G7<U> G7A< > G7B<LB> G7C< > G7D< % U308>

Source of Information D9 < Anderson, W.B., 1975 - Uranium mineralization >*

Production Comments D10 < >

Reserves and Potential Resources

EH accuracy thousands of lb. year of est. grade

E1<U> E1A< > E1B<LB> E1C< > E1D< % U308>

Source of Information E7 < >

Comments E8 <

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URANIUM-OCCURRENCE REPORT

Quad Name Marfa

Deposit No. 1

Deposit Form/Shape M10 < Irregular Dissemination in ~~cavities & fractures~~ >

Length	M40 < >	FT/M M41< >	Size M15 (circle letter):
Width	M50 < 50 >	M51< M >	lb U308
Thickness	M60 < 5 >	M61< M >	A 0 - 20,000
			B 20,000 - 200,000
Strike	M70 < N 30 E >		C 200,000 - 2 million
			D 2 million - 20 million
Dip	M80 < 8 degrees NW >		E More than 20 million

Tectonic Setting N15 < Mobile Belt >

Major Regional Structures N5 < Southern part of Basin & Range within major graben north of Presidio Bolson >

Local Structures N70 < Within area of intense normal faulting and minor tilting; nearest fault approximately 300m to west >

Host-FM. Name U1 < Buckshot Ignimbrite > Member U2 < >

Host Rock K1 < OLIGO | | | | | | B | Welded ash-flow tuff
(Age) (Rock type, texture, composition, color,

Strike and dip same as deposit
alteration, attitude, geometry, structure, etc.) >

Host-Rock Environment U3 < Volcanic, postorogenic, ignimbrite >
(Sed. dep. environ., metamorphic facies, ign. environ.)

Comments on
Associated Rocks U4 < Overlain and underlain by unmineralized tuffaceous sediment >

Ore Minerals C30 < β-uranophane 90%, unidentified yellow uranium mineral >

Gangue Minerals K4 < iron oxides, secondary silica (quartz chalcedony; opal), calcite, limonite after pyrite, all found in cavities in * >

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4/19/78

URANIUM-OCCURRENCE REPORT

Quad Name Marfa

Deposit No. 1

Alteration N75 < Buckshot at this location is highly oxidized but mineralogy other than uranium similar to other locations >

Reductants U5 < Pyrite present > 1%, all now occurs as limonite >

Analytical Data (General) C43 < Highest grade U found 2750 ppm U_3O_8 Mo concentrations about 20 to 70 ppm but no greater than in unmineralized Buckshot >

Radiometric Data (General) U6 <
(No. times background and dimensions)
>

Ore Controls K5 < Origin of deposit speculative: 2 mechanisms possible 1) vapor phase crystallization of uranophane during devitrification of glass 2) reduction of uranium-bearing groundwater by pyrite. Pyrite now replaced by limonite. Origin of pyrite uncertain. Primary ore mineral may have been coffinite now oxidized to uranophane
1) Deposit class= 530 Hydroauthigenic 2) None >

Deposit Class C40 < See K5 > Class No. U7 <| | | >

Comments on Geology N85 < See discussion in text for geologic setting and possible origin of deposit >

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4/19/78

URANIUM-OCCURRENCE REPORT

Quad Name Marfa

Deposit No. 1

Uranium Analyses:

Sample No.	Sample Description	Uranium Analysis
M6E-514	altered, welded ash-flow tuff	2750 ppm U_3O_8
M6E-509	altered, welded ash-flow tuff	1550 ppm U_3O_8
M6E-517	altered, welded ash-flow tuff	960 ppm U_3O_8
M6E-519	Vitrophyre, unmineralized, near Mine	12.4 ppm U_3O_8

Geologic Sketch Map and/or Section, with Sample Locations:

References:

F1 < Nye, 1957: The Mammoth Mine, Tierra Vieja Mtns, Presidio County, TX: U.S. Atomic Energy Commission now reprinted by U.S. DOE as DAO-4-TM-10

F2 < W.B.Anderson, 1975: cooling history and uranium mineralization of the Buckshot Ignimbrite, Presidio and Jeff Davis Counties, * >

F3 < R. C. Pilcher, 1978: Volcanogenic uranium occurences, in D.G.Mickle & G. W. Mathews eds: Geologic characteristics of * >

F4 < >

BFE 1236
4/19/78

URANIUM-OCCURRENCE

REPORT

Quad Name Marfa

Deposit No. 1

Continuation from p. 1-5:

Label

D9 < Buckshot Ignimbrite

F2 Texas, University of Texas at Austin, M.A. Thesis, 134 p.

F3 environments favorable for uranium deposits

U.S. Dept. of Energy GJBX-67(78) p. 181-220

(Gangue Minerals K4) devitrification spheres.

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PETROGRAPHIC DESCRIPTION

PROJECT: Marfa 12-78-7283 REQUEST: 101979 FIELD NO: MGE-118 AASSN:

ROCK NAME: Unconsolidated Sand PETROLOGIST: MJE

MINERAL/COMPONENT	%	COMMENTS
Carbonate	23	Fine to medium sand sized grains; mostly micrite but many sparite grains also. Some are fossiliferous (looks like globigerina but fragments are too small to be sure).
Sediments Rock Fragment	22	Granule and smaller sizes; sandy carbonates. Strongly weathered, no tuffaceous fragments visible as in MGD-933.
Volcanic Rock Fragments	8	Altered basaltic and other more felsic fragments.
Quartz	17	Includes small amount of chert. Mostly fine sand sized angular grains.
Clay	9	Fine clumps occur throughout and are sometimes mixed with micrite.
Plagioclase	8	Fine sand sized cleavage fragments. Alteration is quite variable.
Glass	2	Devitrified blocky & rounded fragments. No shard-like fragments were found.

TEXTURE:

This sample consists of sand grains and other detritus, without a matrix. Grain size varies from granule to very fine sand, mostly fine sand. Alteration is stronger than in MGD-933 and features of the grains are less distinct.

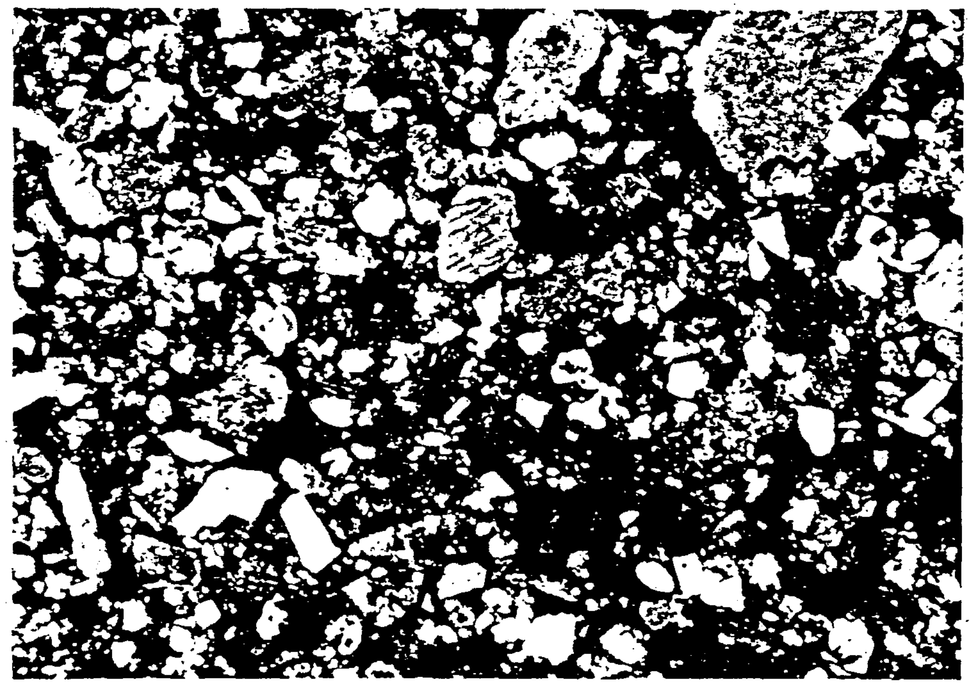
PETROGRAPHIC DESCRIPTION-continued

PROJECT: Marfa 12-78-7283 REQUEST: 101979 FIELD NO: MGE-118 AASSN:

ROCK NAME: Unconsolidated Sand PETROLOGIST: MJE

MINERAL/COMPONENT	%	COMMENTS
Hornblende	tr	
Sphene	tr	
K-feldspar	tr	Microcline.
Opaques	tr	
Biotite/Muscovite	tr	
Glauconite	tr	
Zircon	tr	

PHOTOMICROGRAPH OF SAMPLE MGE-118



General view of sand consisting of carbonate (micrite), rock fragments, quartz, etc. Glauconite pellet and hornblende grains are near center. 40X, crossed polarizers.

PETROGRAPHIC DESCRIPTION

PROJECT: Marfa 12-78-7283 REQUEST: 101979 FIELD NO: MGE-122 AASSN:

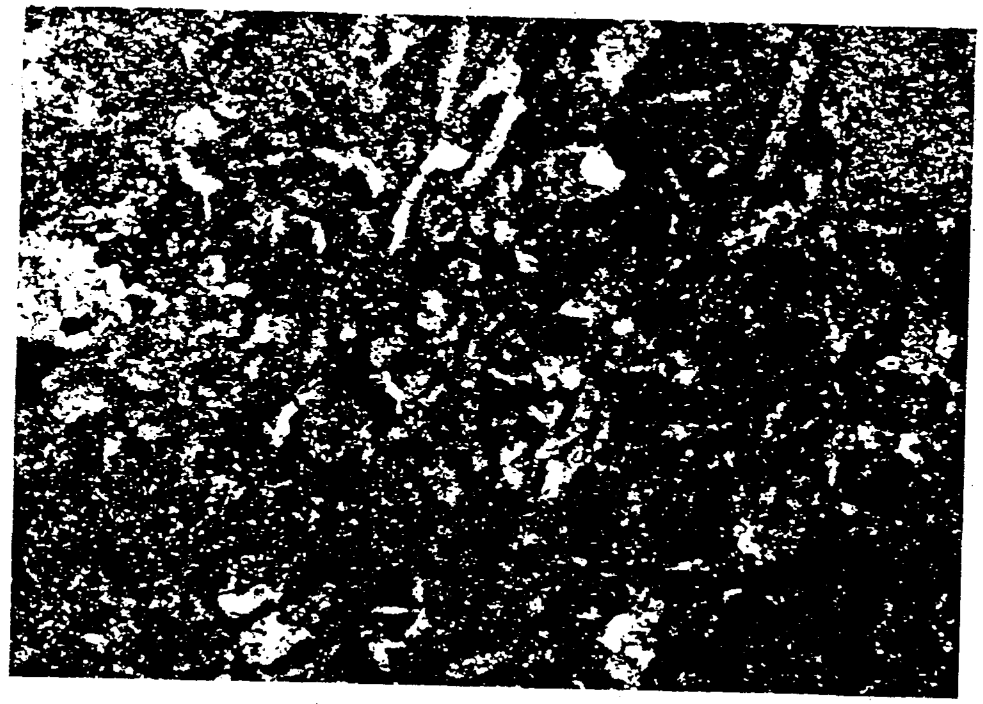
ROCK NAME: Dismicrite PETROLOGIST: MJE

MINERAL/COMPONENT	%	COMMENTS
Micrite	90	
Sparite	10	As curved veinlets, possibly shrinkage crack fillings, etc. Also replaced fossils?
Chalcedony	tr	

TEXTURE:

Dismicrite was chosen for a name because the origin of most of the larger grains in the rock seem to be from disturbance of the sediment causing filling of cracks and possibly burrows or slumping. There are some features that may be fossils.

PHOTOMICROGRAPH OF SAMPLE MGE-122



General view of dismicrite with sparite fillings and fossils. 40X, crossed polarizers.

URANIUM-OCCURRENCE

REPORT

Quad Name A90 Marfa

Quad Scale A100< 2 5 0 0 0 0

Deposit No. B40< 2

Deposit Name A10 < Shely Prospect >

Synonym Name(s) A11 < Organ Pipe Hill Prospect >

District or Area A30 < Pinto Canyon >

Country A40 <U S> U S State Texas

State Code A50 <4 8> 4 8 County A60 < Presidio >
(Enter code twice from List D)

Position from Prominent Locality A82 < From Marfa, TX 32 miles SW on to end of pavement, then approx 6 mi on unpaved county road to Organ Pipe Hill. Prospect is on side of hill 200 yds south of road. >

Field Checked G1 <7 8 | 9> By G2< Henry, Christopher D. >
Yr Mo Last name First Initial

Latitude A70 <3 0 | 0 0 | 3 0 N> Longitude A80 <1 0 4 | 2 9 | 5 5 W>
Deg Min Sec Deg Min Sec

Township A77 < > Range A78 < > Section A79 < >
N/S E/W

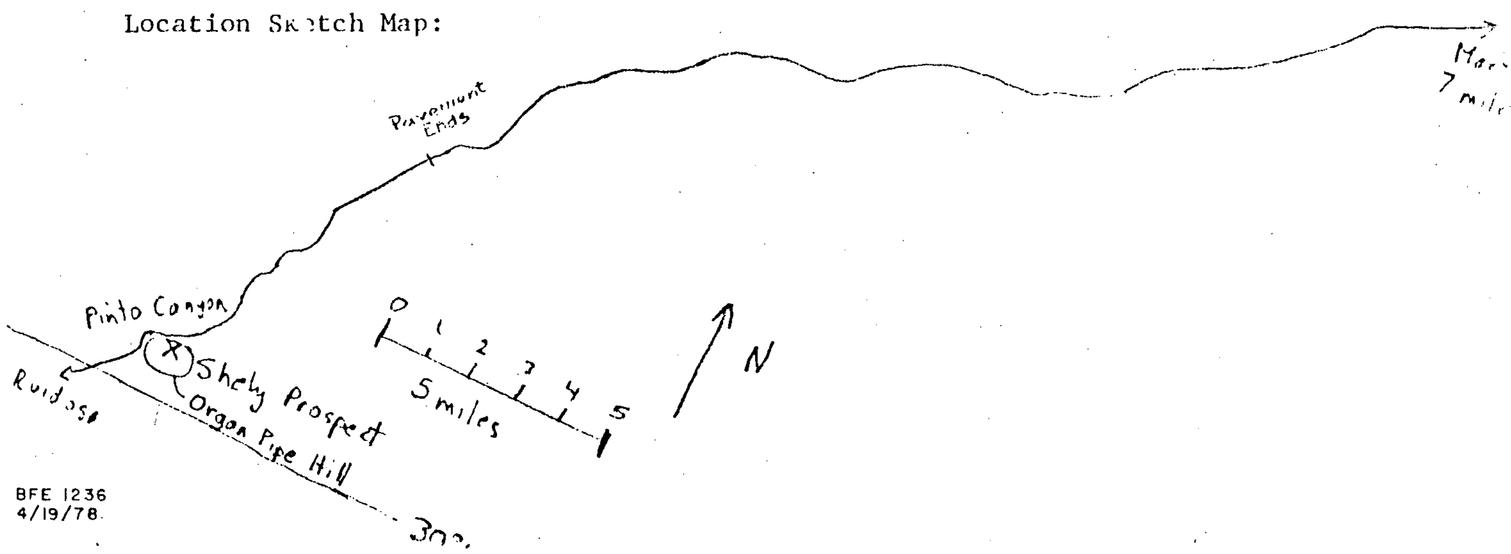
Meridian A81 < > Altitude A107 < 4800 FT > FT/M

Quad Scale A91 < 2 4 0 0 0> Quad Name A92 < >
(7½' or 15' quad)

Physiographic Province A63 <1 2> Basin and Range >
(List K)

Location Comments A83 < >

Location Sketch Map:



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URANIUM-OCCURRENCE REPORT

Quad Name Marfa

Deposit No. 2

Commodities Present:
C10 <U >

Commodities Produced:
MAJOR < > COPROD < >

MINOR < > BYPROD < >

Potential Commodities:
POTEN <U > OCCUR < >

Commodity Comments C50 < >

Status of Exploration and Development A20 < 3 >
(1 = occurrence, 2 = raw prospect, 3 = developed prospect, 4 = producer)

Comments on Exploration and Development L110 < shallow trench in late 1950's; extensive drilling 1975-1976 >

Property is A21 (Active) A22 (Inactive) (Circle appropriate labels)

Workings are M120 (Surface) M130 (Underground) M140 (Both)

Description of Workings M220< One trench ≈ 30m x 3m along fracture zone from 1958; approximately 12 drill holes from 1975 work >

Cumulative Uranium Production PROD YES NO SML MED LGE (circle)

DH2

accuracy	thousands of lb.		years	grade
G7<U>	G7A< >	G7B<LB>	G7C< >	G7D< % U308>

Source of Information D9 < Amsbury, D.; 1958, Geology of the Pinto Canyon >

Production Comments D10 < Tons of ore, average grade 0.34% U_3O_8 was stockpiled but not shipped in 1950's >

Reserves and Potential Resources

EH

accuracy	thousands of lb.		year of est.	grade
E1<U>	E1A< >	E1B<LB>	E1C< >	E1D< % U308>

Source of Information E7 < >

Comments E8 < >

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URANIUM-OCCURRENCE

REPORT

Quad Name Marfa

Deposit No. 2

Deposit Form/Shape M10 < Irregular fracture zone

Length M40 < 1000 > M41< FT > (FT/M)

Width M50 < 8 > M51< FT >

Thickness M60 < > M61< >

Strike M70 < N80°E >

Dip M80 < 50°N >

Size M15 (circle letter):

lb U3O8

A 0 - 20,000
B 20,000 - 200,000
C 200,000 - 2 million
D 2 million - 20 million
E More than 20 million

Tectonic Setting N15 < Mobile Belt >

Major Regional Structures N5 < Southeastern Basin & Range; east of NE edge of Presidio Bolson; approximately two miles north of wall of Chinati Caldera >

Local Structures N70 < Mineralization is in fracture zones in rhyolite domes at north edge of Chinati Caldera; Domes are older than Chinati Caldera but may be related to older caldera cycle >

Host-FM. Name U1 < Allen Intrusion > Member U2 < >

Host Rock K1 < O L I G O ? | Rhyolite porphryry intrusion; porphyritic,
(Age) (Rock type, texture, composition, color, alteration, attitude, geometry, structure, etc.)

white to grey, rhyolite with phenocrysts of quartz and alkali feldspar (commonly kaolinized). Intrusion is one of several flow-dome complexes in 5 mile^2 area >

Host-Rock Environment U3 < Hypabyssal intrusion >
(Sed. dep. environ., metamorphic facies, ign. environ.)

Comments on
Associated Rocks U4 < Related rocks are rhyolite lava flows, breccias, and tuffaceous sediments >

Ore Minerals C30 < Primary uranium-bearing mineral is probably amorphous Fe-Ti-Mn hydroxide; secondary minerals include autunite and tyuyamunite

Gangue Minerals K4 < Fe-Ti-Mn hydroxides; montmorillonite; both as fracture fillings >

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URANIUM-OCCURRENCE REPORT

Quad Name Marfa

Deposit No. 2

Alteration N75 < Host rock is weathered and kaolinized to considerable depth; gouge along fracture is altered to montmorillonite; fracture filled with Fe-Ti-Mn hydroxides >

Reductants U5 < None known >

Analytical Data (General) C43 < Highest grade U found = 1430 ppm; trace elements concentrated with U in minor amounts include Cd, Be, Co, Cr, Cu, P, Ni, V. Fe, Ti and Mn enriched in hydroxides >

Radiometric Data (General) U6 < >
(No. times background and dimensions)

Ore Controls K5 < U was probably adsorbed by amorphous Fe-Ti-Mn hydroxides from downward moving groundwater; secondary U minerals probably a result of crystallization of hydroxides; hydroxides and permeability are largely restricted to fracture zones in rhyolite domes and mineralization occurs in many such fractures. Source of U is probably the rhyolite dome itself or associated rocks of U4 >

Deposit Class C40 < Authigenic > Class No. U7 <3610>

Comments on Geology N85 < Temperature of formation of deposit unknown; Mineralization could have been by heated ground water soon after intrusion or cold ground water long after intrusion >

URANIUM-OCCURRENCE — Quad Name: Marfa

REPORT — Deposit No. 2

Uranium Analyses:

Sample No.	Sample Description	Uranium Analysis
M6E568	Clay gouge in fracture zone	1430 ppm U_3O_8
M6E545	Fe-Ti-Mn hydroxide in wall of fracture	825 ppm U_3O_8
M6E544	Altered rhyolite host rock; wall of fracture	83 ppm U_3O_8
M6E 856		110 ppm U_3O_8
M6E 860		200 ppm U_3O_8
M6E 864		440 ppm U_3O_8

Geologic Sketch Map and/or Section, with Sample Locations:

References:

F1 <Amsbury, D., 1958, Geology of the Pinto Canyon area, Presidio County Texas; The University of Texas at Austin Bureau of Economic Geology>

F2 <Reeves, C.C., Kenney, P., Wright, E., 1979, known radioactive anomalies and uranium potential of Cenozoic sediments, Trans-Pecos Texas:

F3 <
>

F4 <
>

BFE 1235.
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URANIUM-OCCURRENCE REPORT

Card No. Marfa

Page No. 2

Continuation from p.

Label

D9 area, Presidio County, Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map. No. 22.

F1 Geologic Quadrangle Map 22.

F2 The University of Texas at Austin Bureau of Economic Geology Guidebook 19, p. 127-136.

RFE 1230
4/12/78