Geology of the Oxidized Uranium Ore Deposits of the Tordilla Hill-Deweesville Area, Karnes County, Texas; A Study of a District Before Mining

GEOLOGICAL SURVEY PROFESSIONAL PAPER 765

Prepared on behalf of the
U.S. Atomic Energy Commission

Geology of the Oxidized Uranium Ore Deposits of the Tordilla Hill-Deweesville Area, Karnes County, Texas; A Study of a District Before Mining

By C. M. BUNKER *and* J. A. MACKALLOR

GEOLOGICAL SURVEY PROFESSIONAL PAPER 765

Prepared on behalf of the U.S. Atomic Energy Commission

A description of the lithologic and structural relations of shallow uranium deposits in denindurated sediments

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1973

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 72-600375

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock No. 2401-00292

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE OXIDIZED URANIUM ORE DEPOSITS OF THE TORDILLA HILL-DEWEESVILLE AREA, KARNES COUNTY, TEXAS; A STUDY OF A DISTRICT BEFORE MINING

By C. M. BUNKER and J. A. MACKALLOR

ABSTRACT

Shallow, oxidized uranium ore deposits in the Tordilla Hill-Deweesville area lie in a gently dipping, warped block between the Fashing and Falls City faults. These faults trend northeast, parallel to the regional strike, and may have acted as barriers to the normal downdip movement of ground water. Upward seepage of sulfurous gas through the fault systems may have provided the precipitant for uranium contained in ground water in the areas where fluid movement was hindered.

The Deweesville Sandstone Member of the Whitsett Formation (upper Eocene) is the most important host rock of the shallow, oxidized uranium deposits known at the completion of fieldwork, but not yet mined. The Deweesville commonly consists of tuffaceous sand, which grades into silt at the base; however, in the Tordilla Hill-Deweesville area in western Karnes County, its lithologic sequence changes significantly. Most of the important ore bodies are in, or updip from and adjacent to, a clay-filled channel cut deeply into or through the Deweesville. The channel roughly parallels the north to northeast strike of the Deweesville, is from 210 to 400 feet wide, and is about 25 feet deep. Adjacent and parallel to the mudstone channel, the Deweesville consists of a sequence of alternating sandstones, siltstones, and mudstones (mixtures of clay and silt-sized particles); in contrast, sand dominates elsewhere. The most important uranium deposits are in the lower part of the Deweesville in a sequence of varied lithology, rather than in the more permeable sandy facies; the uranium in the underlying Conquista Clay Member of the Whitsett Formation is generally of lower grade. The deposits are within or just below the zone of oxidation.

Many of the ore deposits are manifested on the surface by radioactivity anomalies updip from the deposits. However, the presence of a surface anomaly may not everywhere indicate an ore deposit.

INTRODUCTION

HISTORY OF INVESTIGATIONS

In the fall of 1954, uranium was discovered about 2 miles northeast of Tordilla Hill, western Karnes County, Tex. (fig. 1), by G. H. Strodtman, of Jaffe-Martin and Associates of San Antonio, while he was making an airborne radioactivity survey for oil structures. At about the same time, uranium minerals were found at the foot of the northernmost point of Tordilla Hill (fig. 1, Hackney deposit) by Carroll Ewers, of San Antonio, who was prospecting with a hand-portable counter. These discoveries of uranium, the first in the Gulf Coastal Plain province, led to intensive prospecting, leasing, and exploratory drilling, which soon established the existence of commercial quantities of uranium ore in the area. Most prospecting consisted of locating surface anomalies with radiation-detection equipment; this was generally followed by trenching or drilling. The intense search centered around, but was not confined to, the Tordilla Hill-Deweesville area. More than a dozen uranium occurrences were found in Gonzales, Karnes, and Atascosa Counties (Steinhauser and Beroni, 1955; Eargle and Snider, 1957, fig. 1). Before 1970, the largest known deposits were in the Tordilla Hill-Deweesville area.

From 1955 to 1957, the most extensive exploration and drilling program within the Tordilla Hill-Deweesville area was conducted by the Climax Molybdenum Co. (operating under the local name of the San Antonio Mining Co.), but the Continental Oil Co., the Texas Co., the Superior Oil Co., the Newmont Mining Co., and others were also active. The Nuhn deposit, on the Korzekwa, Lyssy, and Gembler tracts, and the Luckett deposit northeast of Deweesville, on the Lyssy and Neistroy tracts, as well as some smaller uranium deposits, were discovered. According to deVergie (1958, p. 23) more than 500,000 feet of exploration drilling was completed in

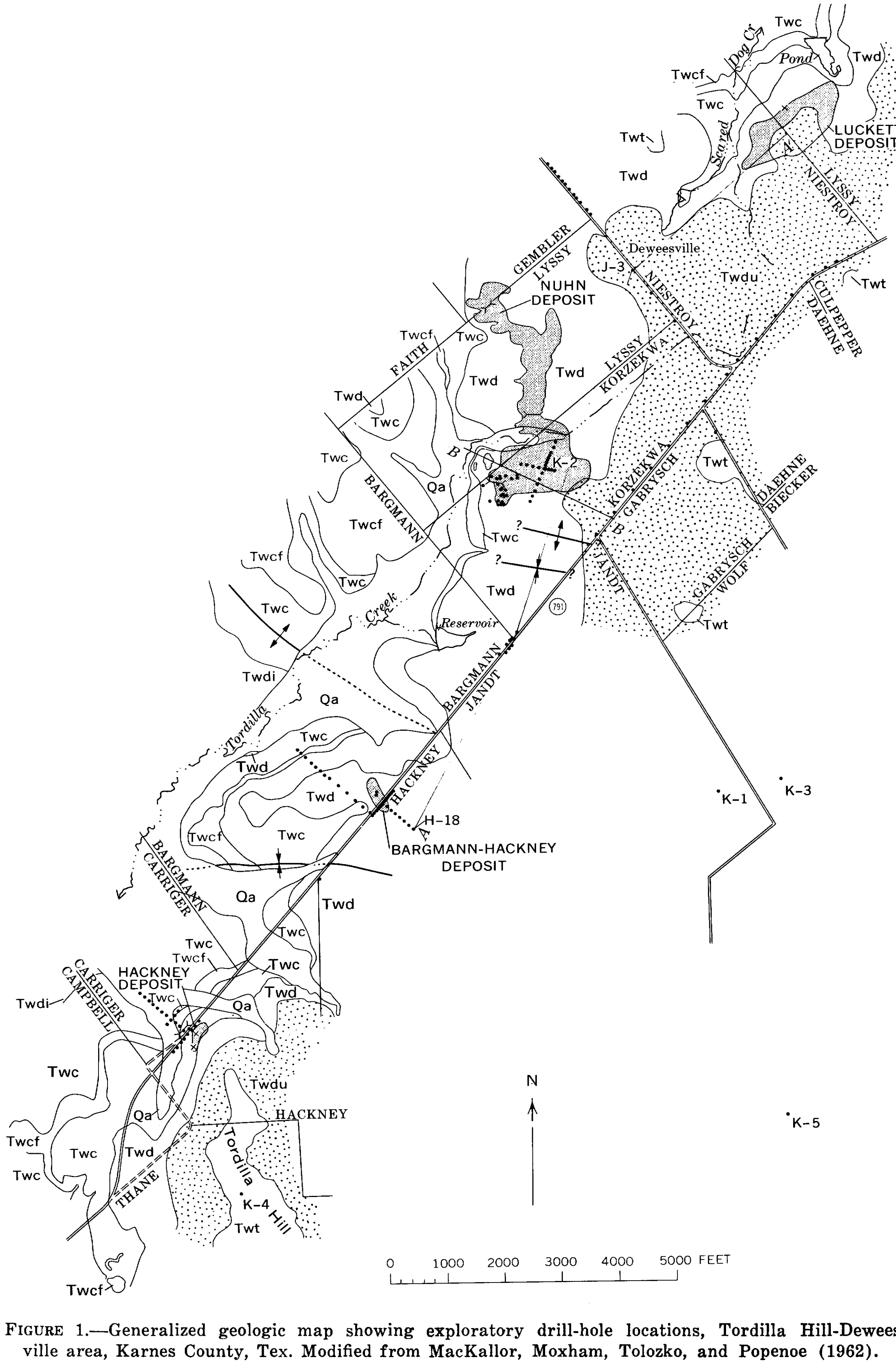


FIGURE 1.—Generalized geologic map showing exploratory drill-hole locations, Tordilla Hill-Deweesville area, Karnes County, Tex. Modified from MacKallor, Moxham, Tolozko, and Popenoe (1962).

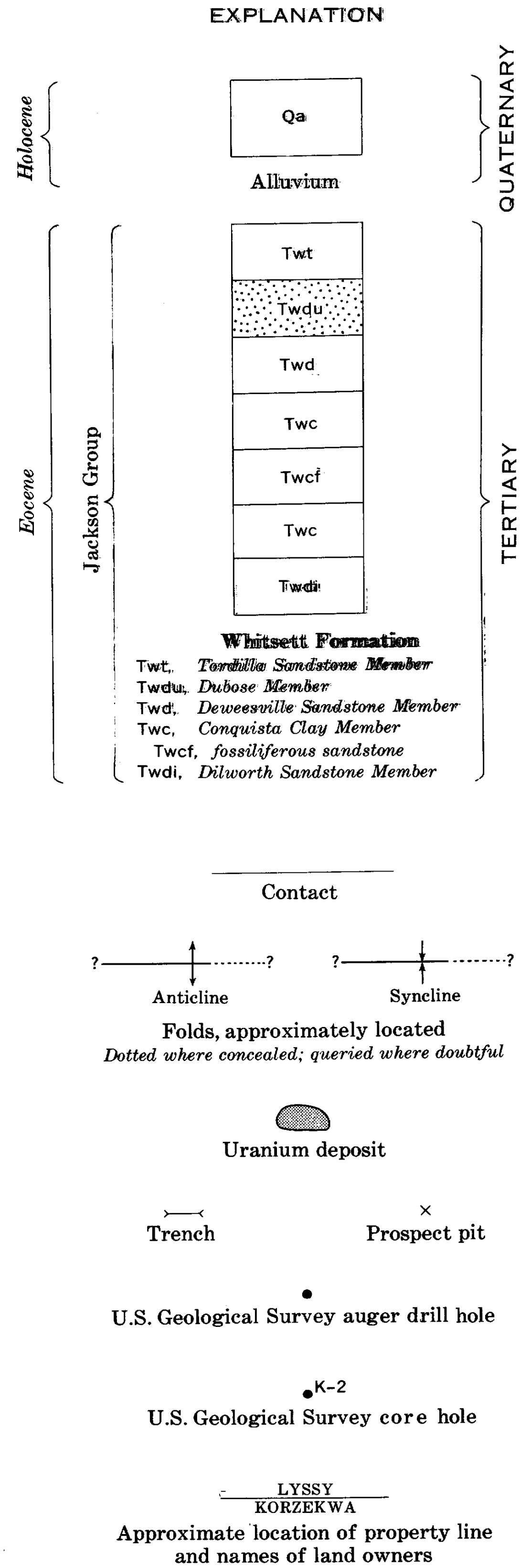


FIGURE 1.—Continued

Karnes County between the fall of 1954 and the summer of 1956.

Preliminary geologic investigations by the U.S. Geological Survey were begun in the Tordilla Hill-Deweesville area in the spring of 1955 (Eargle, 1955; Finch, 1955; Fix, 1955, 1956; Eargle and Snider, 1957). Geophysical studies were started in November 1955 with an airborne radioactivity survey of the area (Moxham and Eargle, 1961). These were followed by more comprehensive geological and geophysical studies of this area and by a much broader study in 1956 to 1959 to examine the relation between uranium deposits in a sedimentary environment and regional and local radioactivity, stratigraphy, lithology, and geologic structure (Moxham, Eargle, and MacKallor, 1957; Moxham, MacKallor, and Tolozko, 1957; MacKallor and others, 1958; Manger, 1958; Eargle, 1958; Moxham and others, 1958; Weeks and others, 1958; MacKallor and Bunker, 1958; Eargle, 1959a, b; Moxham and Eargle, 1961; Eargle and Weeks, 1961a, b; Brown, Eargle, and Moxham, 1961a, b; Eargle, Trumbull, and Moxham, 1961a, b, c; Trumbull, Eargle, and Moxham, 1961; Weeks and Eargle, 1963). One of the objectives of this work was to study unmined deposits and to survey a district before mining disturbed its radioactivity pattern and intensity and before the geology was revealed by mining, so that comparisons with still unmined undisturbed areas could be made. The studies described in this report were made from 1956 to 1958. Surface and subsurface geology and subsurface radioactivity were studied to determine how the geologic setting of the mineral deposits is related to ore depositional control and to mechanisms of ore origin. The area studied here extends from the Hackney deposit at Tordilla Hill to the Luckett deposit northeast of the old village of Deweesville. The area is about 5 miles long and is ½–¾ mile wide.

PHYSIOGRAPHY AND CLIMATE

The uranium deposits in Karnes County are in the Texas coastal plain between San Antonio and Corpus Christi. The topography ranges from gently rolling hills in the northern part of the coastal plain to very flat plains near the coast. In the area of this report, the lowest altitude, 350 feet above sea level, is on Tordilla Creek. The highest point, 520 feet above sea level, is on top of Tordilla Hill, a cuesta that has 120 feet of relief on the northwest side and is the most prominent landmark in the area. A series of low, rounded hills, northeast trending near Deweesville, separates the headwaters of Scared Dog Creek and Tordilla Creek. Scared Dog Creek drains northeastward into the San Antonio River, and Tordilla Creek drains southwestward into the Nueces River by the way of Borrego Creek and the Atascosa River.

The mean annual rainfall in Karnes County is about 30 inches, but yearly variations are large. Much of the land is used for grazing, but cotton and other crops are cultivated. Most of the cultivated land depends on natural rainfall, but some is irrigated. The county is between two belts of markedly different climates, subarid to the southwest and subhumid to the northeast. The climate of the county is characterized by long, hot summers and short, mild winters. To the southwest, caliche is forming at the surface, and vegetation is sparser than that to the northeast and is of a different type.

METHODS OF INVESTIGATION

The topography was mapped to provide an accurate base for surface and subsurface radioactivity studies of the uranium deposits, the enclosing bedrock, and the overlying soil. The area was mapped by planetable method from September 1956 to March 1958 by J. A. MacKallor, assisted by E. S. Santos, P. P. Popenoe, and others. A base line was established from two locations on the right-of-way of Farm Road 791, which had just previously been surveyed by engineers of the Karnes County office, Texas Highway Commission. Measurements of the attitudes of rock beds were usually determined by the three-point method, because the beds dipped gently and a few beds of hard rock were exposed. Attitudes thus determined are accurate within 5 feet per 1,000 feet and for strike within 20° to 30°. About 2,000 survey points were established within the area of approximately 5 square miles.

Exploratory drill holes provided (1) subsurface samples for lithologic determinations and for chemical and radiometric analyses and (2) access to subsurface strata for gamma-ray logging. A power auger was used to drill 130 drill holes about 4 inches in diameter and as much as 70 feet deep. The cuttings obtained with the auger were sampled at 1- to 5-foot intervals, depending on the complexity of the strata. Cuttings or sample descriptions from 200 holes drilled by the San Antonio Mining Co. were made available to and were used by the authors. Five holes (those with a "K" prefix) were drilled to depths of as much as 300 feet with a core bit and oil-base drilling fluid to obtain maximum recovery of unaltered and undisturbed cores that represented the natural state of the beds from which they were obtained and of the fluids they contained. These samples were sealed in plastic tubes to preserve their original physical and chemical properties until analyses could be completed. Physical properties of the cores and electric logs of the drill holes have been reported by Manger and Eargle (1967). All the samples were classified lithologically by visual examination.

Gamma-ray logs were made in all available drill holes to determine the depth, thickness, areal limits, and grade (percent equivalent uranium oxide, eU_3O_8) of radioactive rock. These data were used to study the relation between subsurface and surface radioactivity, lithology, and ore deposits. The logging system was calibrated in simulated uranium-ore bodies before this investigation and was standardized often to maintain the original calibration. Extensive laboratory and field studies showed the following accuracies of the interpreted data: thickness is within 0.1 foot for layers thicker than 0.8 foot, depth is within 0.5 percent, and values for grade of ore are within 20 percent. The gamma-ray logging equipment, calibration procedures, and data-interpretation methods are similar to those described by Bell, Rhoden, McDonald, and Bunker (1961).

ACKNOWLEDGMENTS

The technical assistance and suggestions of our many coworkers, especially R. M. Moxham, D. H. Eargle, and A. M. D. Weeks are gratefully acknowledged. Elmer S. Santos, Peter P. Popenoe, and Donald Peterson assisted with the geologic mapping. D. R. Cunningham aided with the drilling, sampling, and gamma-ray logging. Paul C. deVergie, of the U.S. Atomic Energy Commission, furnished information on the Luckett deposit and other uranium deposits outside the report area. D. H. Eargle furnished information on mining operations. Especially appreciated was the pleasant and helpful cooperation of the landowners and mining-lease holders who permitted mapping, drilling, and sampling on their properties and provided drill-hole location maps and samples from their exploration drilling programs. Chemical and radiometric analyses of uranium content of samples were made by J. W. Budinsky and B. A. McCall, of the U.S. Geological Survey.

This work was done on behalf of the Division of Raw Materials, U.S. Atomic Energy Commission.

GENERAL STRATIGRAPHY AND ENVIRONMENT

The regional stratigraphy of the southeastern Texas coastal plain is described by Eargle (1959a). The clastic sedimentary rocks (sandstone, siltstone, and clay) which underlie the Tordilla Hill-Deweesville area dip gently southeast and are a part of the thick homoclinal sequence of the Gulf Coastal Plain province. Time-equivalent rock units generally thicken and grade from north to south, changing from continental, through nearshore, to an offshore facies downdip toward the present Gulf of Mexico.

The formations exposed within the area of this report, with the exception of the alluvium, belong to the Jackson Group of Eocene age. Excluding the Tordilla Sandstone Member, which in most places is a moderately to highly silicified sandstone, the Whitsett Formation exposed in the area of this report (fig. 2) consists chiefly of sand, silt, and clay. The Dubose Member contains some beds of poorly indurated, friable sandstone and siltstone. Locally, some of the sands in the Deweesville Sandstone Member have been silicified into a well-indurated sandstone (MacKallor and others, 1962). Within the area many holes several tens of feet deep were drilled with a vehicle-mounted soil auger through sand, silt, and clay without piercing lithified rock such as sandstone or siltstone. Southeast and downdip from the uranium deposits several deep core holes (the "K" holes of fig. 1) did at depth penetrate beds of poorly to well-indurated sandstone. Most of the Dubose and Deweesville interval, as shown by the core holes, consists of friable, poorly indurated sandstone and siltstone and of sand, silt, and clay (Manger and Eargle, 1967).

The Catahoula Tuff of Miocene age overlies the Jackson; it is exposed a short distance southeast. Eargle (1959b, p. 2626; 1972) has divided the Jackson Group of south-central Texas from bottom to top into the Cadell Formation, Wellborn Sandstone, Manning Clay, and Whitsett Formation and has subdivided the Whitsett Formation into the Dilworth Sandstone, Conquista Clay, Deweesville Sandstone, Dubose, Calliham Sandstone and its equivalent, the Tordilla Sandstone, and Fashing Clay Members.

EOCENE

Field evidence is in agreement with the conclusions of Shepard and Rusnak (1957, p. 12) that the intercalated lenses and beds of tuffaceous sandstones, siltstones, and clays of the Jackson Group of Eocene age in the area were deposited under shallow-water nearshore marine or brackish-water conditions similar to those in present-day bays and lagoons between San Antonio Bay and Corpus Christi in the Gulf of Mexico. Evidence that supports the

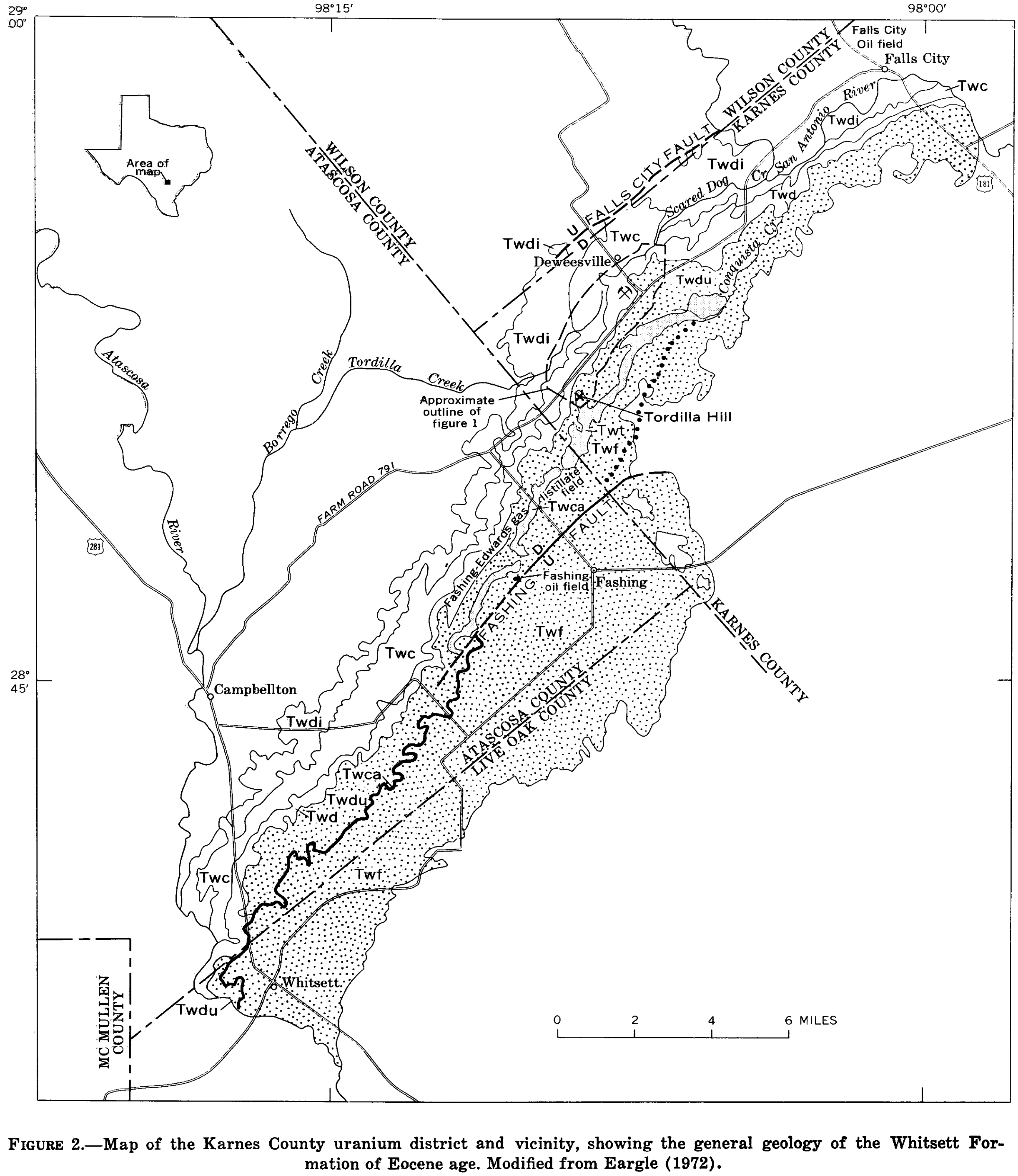
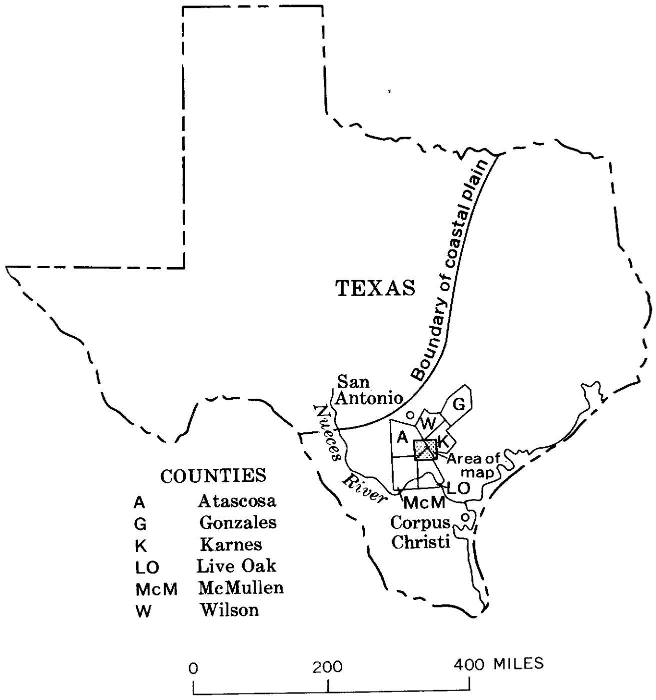
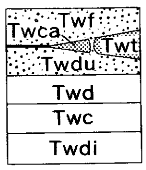


FIGURE 2.—Map of the Karnes County uranium district and vicinity, showing the general geology of the Whitsett Formation of Eocene age. Modified from Eargle (1972).



EXPLANATION



Whitsett Formation

Twf, *Fashing Clay Member*
Twca, *Calliham Sandstone Member*
Twt, *Tordilla Sandstone Member*
Twdu, *Dubose Member*
Twd, *Deweesville Sandstone Member*
Twc, *Conquista Clay Member*
Twdi, *Dilworth Sandstone Member*

Contact

U
D
Fault

Dashed where approximately located or inferred. U, *upthrown side;* D, *downthrown side*

Ore body   Ore roll

FIGURE 2.—Continued

conclusions reached concerning the depositional environment in this area includes personal observations and reports by others that (1) macrofossils (mostly gastropods and pelecypods) were found in Karnes and Atascosa Counties (F. S. MacNeil, written commun., 1958), (2) shallow-water Foraminifera were found in the immediate vicinity of the study area (Ellisor, 1933), (3) although *Textularia hockleyensis* was found in the Conquista Clay Member near the deposits (P. S. Morey, in Eargle and Snider, 1957), microfossils generally were scarce in the study area, (4) glauconite was not detected in the rocks near the uranium deposits, (5) *Ophiomorpha major*, a facies fossil that indicates brackish-water conditions, is common in sandstones of the Jackson Group, (6) a bed of oyster shells is found at the top of the Deweesville Member at the Luckett deposit, and (7) silicified wood is found in several units of the Jackson Group. Eargle (1959a) presented subsurface evidence that an offshore bar formed in Deweesville time about 10 miles downdip from the uranium deposits.

The rate of deposition or the length of time that the sediments remained exposed to the marine waters of the bays and lagoons may have been a major factor in the development of the uranium deposits. Shepard (1953) calculated that sediment at the rate of about 3 feet per century, which will form 1.5–1.8 feet of rock, is presently being deposited in Texas bays. Shepard's calculation is based upon an average depth change during 65 years determined from more than 20,000 observations made in all Texas bays and is corrected for an estimated 1.7 feet of submergence per century.

The present rate of sedimentation cannot be applied to the entire marine Tertiary of the Karnes County uranium area, because there have been times of little or no deposition. The rate, however, might be of value if modified and applied with caution to individual members. For example, the average thickness of the Deweesville Sandstone Member is about 45 feet in the area of the deposits; Shepard's minimum figure of 1.5 feet of rock per century would indicate that this member was deposited within a period of 3,000 years. The present rate of deposition probably is faster than the rate was in the preceding few centuries because cultivation of land has increased runoff and erosion and because dumping of sewage and industrial wastes into the rivers has increased their load. During Deweesville time, however, the rate of deposition almost certainly was faster than it was just before the settling of the Texas coastal plain, and probably was faster than the present rate. Volcanic ash was being deposited and provided additional material for an increased rate of accumulation. The presence of unaltered feldspar grains supports the idea of rapid deposition and burial. Therefore, it is estimated that the Deweesville Member was deposited between 2,500 and 3,000 years.

The following description of the composition, grain size, and shape of the detritals applies in general to all members of the Whitsett Formation of the Jackson Group exposed in the Deweesville-Tordilla Hill area and is not repeated in the discussion of the individual members.

Most of the sand-sized grains are fine to very fine, according to the classification of Wentworth (1922), and angular to subangular. Approximately 50 percent of the sand-sized particles are quartz, 25 percent are volcanic grains, which are probably of intermediate or acidic composition, and 25 percent are grains of almost unaltered feldspar, both orthoclase and plagioclase. Under crossed nicols, tiny microlites are visible in the volcanic grains. Glassy shards are locally common. A. M. D. Weeks of the U.S. Geological Survey (oral commun., 1962) has identified grains of chert, zircon, biotite, moonstone, pyrite, and clinoptilolite (zeolite) in thin section. A normal suite contains a small amount of rutile, ilmenite, garnet, and other common accessory heavy minerals. Cementing material, where present, consists of opal, chalcedony, or clinoptilolite. Crystals of gypsum, although not abundant, have been observed in silty and clayey beds of the various members. Gypsum is much scarcer below the zone of oxidization (as indicated by a change of color of the clay) than it is above.

According to A. M. D. Weeks (oral commun., 1962), spectrographic analyses show that the clay-sized material is dominantly clinoptilolite and montmorillonite.

WHITSETT FORMATION

DILWORTH SANDSTONE MEMBER

Only the top of the uppermost bed of the Dilworth Sandstone Member of the Whitsett Formation is exposed in the mapped area. The sandstone is gray to yellowish brown and very fine to fine grained; it is composed chiefly of quartz, moderately fresh fragments of volcanic rocks and feldspar, and silt-sized particles of tuffaceous material. Outcrops of white to light-gray silicified sandstone were observed northwest of Tordilla Creek on the Bargmann property.

Vertical, parallel, and nearly straight casts, $\frac{1}{16}$–$\frac{1}{4}$ inch wide and several inches long, that resemble plant roots are common. The upper few feet of the Dilworth, as determined by drill holes, is thin bedded and contains beds of maroon, brown, and gray mudstone (a mixture of clay- and silt-sized particles), in addition to sandstone, as at the Carriger property north of Tordilla Hill (fig. 1).

CONQUISTA CLAY MEMBER

In the mapped area the Conquista Clay Member is 75–90 feet thick. The clay or mudstone is reddish to grayish brown in the zone of oxidation, which extends to a depth of 30–35 feet below the surface, and dark gray to bluish black below the zone of oxidation. The depth of the base of the oxidized zone is generally related to the topography (section H–13 to B–24, pl. 1). The clay is tuffaceous, and the upper part is silty. Locally, the contact with the overlying Deweesville Sandstone Member is transitional. The upper 20 feet of the member contains a few small lenses of sandstone, and throughout most of the area the top is marked by a zone of calcium carbonate concretions as much as 3 feet in diameter. The member is carbonaceous and locally contains some silicified wood.

The contact between the oxidized and unoxidized zones is not as apparent in other rock types as it is in the Conquista Clay Member. In sandstone, the color change may not be readily apparent, and the contact instead of being sharply defined may be gradational vertically through several feet.

In the early exploration of the area, the oxidized (yellow or brown) clay and the unoxidized (medium-gray) clay, the "blue" clay of the drillers, were believed to be separate lithologic units. The base of the oxidized zone, however, approximately parallels the present topographic surface, except where overlying impermeable layers have retarded infiltration of oxidizing surface waters, and therefore the two color zones are now recognized to be one lithologic unit.

In most of the holes drilled, the anomalous radioactivity is confined to the oxidized zone and the radiation intensity generally decreases at or below the oxidized-unoxidized contact. For this reason the contact can often be identified on a gamma-ray log.

The Conquista Clay Member contains a sandstone unit 25–30 feet below the top. The sandstone has an average thickness of about 10 feet along the outcrop, but drill-hole data indicate that it pinches out downdip in the southeastern part of the area. The sandstone is gray to yellowish brown and fine-grained to very fine grained. It is composed mainly of quartz, moderately fresh feldspar, and fragments of volcanic rocks and is uniformly speckled with limonite. Casts of pelecypod and gastropod shells are common. Concretions of calcium carbonate found locally in the sandstone are similar to those at the top of the member. The sandstone unit contains two persistent silicified beds, each about 4 inches thick, that make excellent marker beds. The other sandstone strata of the unit are poorly indurated. The lowermost mudstone lies on the plant-root sandstone bed of the Dilworth and represents a change of environment, probably a slight deepening of the water.

The calcium carbonate concretions consist of a dense core and an outside zone of prisms or wedges of aragonite. These prisms are about 2 inches long and half an inch thick, and many are oriented radially, with the long axis pointed toward the center of the concretion. The concretions are slightly flattened along the general plane of bedding. Although exposures are poor and bedding is indistinct, the surfaces of the beds immediately below one of the better exposed concretions were observed to be slightly concave upward, and some of the beds appeared to be truncated along the sides of the concretion. In many places, even where bedrock is covered by as much as 2 feet of soil, the location of a carbonate concretion is marked by the presence of residual aragonite prisms.

The carbonate concretions apparently are syngenetic in origin, formed on the bottom of a bay, lagoon, or estuary under slightly arid climatic conditions. The calcite that replaced the shells and filled the intergranular spaces may have been penecontemporaneous, derived from the overlying calcareous nodules. The uranium deposits in the Karnes area are apparently unrelated to calcium carbonate, as Gott (1956) found to be true in the Black Hills, S.D.

DEWEESVILLE SANDSTONE MEMBER

The Deweesville Sandstone Member, the principal uranium ore-bearing rock in the area, consists chiefly of sand and silt but contains some siltstone and some sandstone and clay. The member contains calcium carbonate concretions, *Ophiomorpha major*(?), oyster shells, silicified tree stumps in situ, and casts of nearly vertical plant roots; silicified logs are common.

The Deweesville ranges in thickness from 20 to 50 feet and averages 40 feet. It forms a band of outcrop 250–300 feet wide in the mapped area. Local thinning is accompanied by thickening of the underlying

Conquista Member, and the combined thickness of the two members remains about constant.

The grain sizes of the sandstones in the Deweesville are similar to the grain sizes of other sandstones in the Jackson Group; the grains are predominantly fine to very fine and semiangular. Fine- to medium-grained subangular material is found occasionally throughout the member. The base of the member near the Hackney deposit is composed mostly of medium-grained sandstone, and many of the grains are semirounded to rounded.

The grains are principally quartz and fairly fresh fragments of volcanic rock and feldspar. In most sandstone beds, montmorillonitic clay forms a matrix for the grains (Eargle and Snider, 1957, p. 17).

Most of the sandstone is grayish to pale yellowish brown or buff and is locally stained with small amounts of limonite. At the Hackney deposit some of the outcrops of silicified sandstone and of unconsolidated sand are deep yellowish brown from intense impregnation of limonite; these outcrops contain conspicuous streaks of yellow uraniferous minerals. At other outcrops a few feet away, an equivalent bed is highly silicified and is dark gray to black.

Beds from 1 inch to 1 foot thick, predominantly of altered vo'canic ash, are randomly distributed in the Deweesville. At most outcrops these beds are white, hard, and silicified. At the Hackney deposit some of the silicified ash is pink and some chocolate colored; in places, color banding parallels the bedding. Below the surface the ash beds are soft, unsilicified, and purplish black. Impressions of leaf and stem fragments are abundant, but little organic material remains in the unsilicified parts of the beds. Thin sections of the silicified rock show numerous pinpoints of birefringent materials, brown streaks of plant material(?), and opal. According to A. M. D. Weeks (oral commun., 1962), spectrographic analyses of the silicified material show silica to be the only constituent present in quantities greater than 1 percent, and she identified only opal by X-ray analyses. In the field this type of rock has been called tuff, carbonaceous tuff, carbonaceous clay, ash, lignitic clay, and tuffaceous clay. The last name is the most descriptive, but is not diagnostic because it also applies to most of the other clays of the Jackson Group. Carbonaceous tuff is a good descriptive term, but the actual carbon content is low, even though impressions of stems and leaves are abundant. These beds probably were formed by alteration of extremely fine volcanic dust that fell into a Tertiary bay or lagoon. Some of the beds of tuff can be traced for a few thousand feet along the strike, but many pinch out within a few tens of feet.

The uppermost unit of the Deweesville is a zone of sandstone and clay. On the Niestroy and Bargmann properties, a zone of carbonate nodules, similar to those in the Conquista Clay Member, and a zone of oyster shells are at or near the top of the Deweesville (MacKallor and others, 1962). On the Hackney and Thane properties, the upper 2 feet of sandstone contains numerous casts of plant roots similar to those in the top beds of the Dilworth. Scattered carbonate nodules mark the top of the Deweesville at the Lyssy property. Between the Hackney and Lyssy properties, good marker beds are absent, but the upper sandstone bed contains some plant roots. On the Jandt property, about 10 feet below the top of the Deweesville, several silicified vertical tree stumps were observed, indicating that the trees had grown there. The characteristics of the upper Deweesville indicate that at the end of Deweesville time the bay was nearly filled with sediments and that deposition was probably proceeding at a slower rate.

In much of the area, the Deweesville Sandstone Member contains a zone 10 or more feet thick of clay and siltstone that divides the member into an upper and a lower sandstone unit. Near the Hackney deposit, the clay and siltstone zone is covered by a thin layer of soil and lies between two ledges of silicified sandstone. On the Korzekwa property, numerous drill holes have penetrated the clay and siltstone zone.

Silicified outcrops are common throughout the area of a sandstone bed near the base of the Deweesville that in many places contains *Ophiomorpha major*. In some places, this bed rests directly on the Conquista Clay Member; in others, the contact is transitional—predominantly silty sandstone or siltstone above and silty or sandy mudstone below. The location of the contact was chosen on the basis of grain size. The lensing and the channeling of the basal beds cause the contact to be irregular.

The lower part of the Deweesville and the upper few feet of the underlying Conquista contain all the uranium ore deposits shown in figure 1. Even where no ore is present, the radioactivity is greater in the lower few feet of the Deweesville and the upper few feet of the Conquista than in the rocks stratigraphically above and below (pl. 1).

The Deweesville Sandstone Member has been divided into three lithofacies units in the vicinity of the Nuhn deposit (fig. 3, section *A–A'*). Information from surrounding areas indicates that these units extend throughout the mapped area and probably beyond it.

A sandstone lithofacies as much as 50 feet thick consists entirely of sandstone except for siltstone and clay lenses in the basal 5–10 feet. The sandstone is mostly loose and unconsolidated; locally it is slightly indurated but, except for a few outcrops, is not silicified.

A second lithofacies (hereafter called the intercalated facies) consists of (1) a lower sandstone zone, 10–20 feet thick, that contains some claystone and siltstone lenses near the base, (2) a middle zone, 10–20 feet thick, of intercalated lenses of sandstone, siltstone, and clay, and (3) an upper zone, 10–20 feet thick, of sandstone. In most places this facies laterally adjoins a third, a clay-filled-channel, lithofacies, but where the intercalated facies is locally absent, the sandstone lithofacies adjoins the channel. Although available information is insufficient to delineate the exact boundaries of the intercalated facies, it undoubtedly extends, probably with only minor gaps, from the Luckett deposit southward to the Hackney deposit. All the uranium deposits are in or very near this intercalated facies.

The third lithofacies is a clay-filled-channel facies. The channel locally contains a few very small lenses of siltstone, sandstone, and tuff, and a 1- to 2-inch-thick bed of weathered tuff. Drill-hole samples of the clay cannot be distinguished from samples of the Conquista Clay Member, and where the channel intersects the Conquista, a definite boundary cannot be determined on the basis of lithology.

The channel occupies much of the Deweesville interval. A few feet of sandstone is usually above and below the clay, but in some places the channel base is near or cuts through the base of the Deweesville. Tongues of clay, which are transitional between the channel facies and the intercalated facies, locally extend outward from the top of the channel.

The channel is 200–400 feet wide and from 20 to more than 40 feet thick in the middle; its sides slope about 20°. It trends southwestward, generally paralleling the strike of the beds, and has been traced from near Deweesville southward past the Nuhn deposit on the Lyssy and Korzekwa properties to a point about 400 feet southeast of the Bargmann-Hackney deposit. The only known outcrop is along Farm Road 791 about 3,500 feet east of the Bargmann-Hackney deposit. DeVergie (1958, fig. 3), who examined some drill cuttings of the Luckett deposit, did not find the typical clay-filled-channel facies around that deposit, but he did find a persistent zone of clay, lignite and lignitic clay, and siltstone, which corresponds closely to the intercalated facies of the Korzekwa-Lyssy area. DeVergie's work on the Luckett deposit suggests that the clay-filled channel terminates between Deweesville and the Luckett ore body but that the associated intercalated facies of the Deweesville continues to the northeast.

Inasmuch as the clay-filled channel and associated intercalated beds are a major ore control, consideration of the processes that could have produced these features is economically and scientifically important. The stratigraphic position of the channel (pl. 1; fig. 3) shows that the channel was formed and filled after the beginning of and before the end of Deweesville time, but the details of how it was formed are not easily determined.

The relatively great depth of the channel, without slumping of the sides of unconsolidated sand and clay, cannot be explained by the simple process of subaerial stream erosion and, during a later period of marine transgression, the filling of the eroded channel with clay. One possible origin of the channel is that it was cut subaqueously at the mouth of a delta-forming river and later filled with clay. A feature of the same magnitude, Joseph Bayou outlet of the Mississippi River, has been described by Russell (1936, p. 39). In 1896, Joseph Bayou was 100 feet wide and 26 feet deep; in 1907 it was 175 feet wide and 11 feet deep; and it is now 50 feet wide and less than 10 feet deep. Although the middle zone of intercalated clay, siltstone, and sandstone of the Deweesville Member could be deltaic, the evidence favors an origin other than deltaic, possibly lagoonal.

Additional evidence of scouring and channeling was observed by Eargle; he noted a coarse sand and clay-ball conglomerate fill exposed by mining operations in a pit on the Gembler property. The pit is described in the section of this report on the Nuhn deposit.

The scouring and channeling and the intercalation of sand, silt, and clay are suggestive of a tidal flat and strong tidal currents within the deeper channels. The environment during the deposition of clay and intercalated clays and sands probably was similar to that for the present tidal flats of the Wadden Sea area of the Dutch and northwestern German coasts. Van Straaten (1949; 1951) gave an excellent description of the Dutch Wadden Sea area, and Luders (1934) of the German area. These tidal flats have well-developed drainage systems consisting of large channels, approximately parallel to the shore, which drain smaller channels or prielen (Van Straaten, 1949, pl. 2; 1951, fig. 2). The remarkably

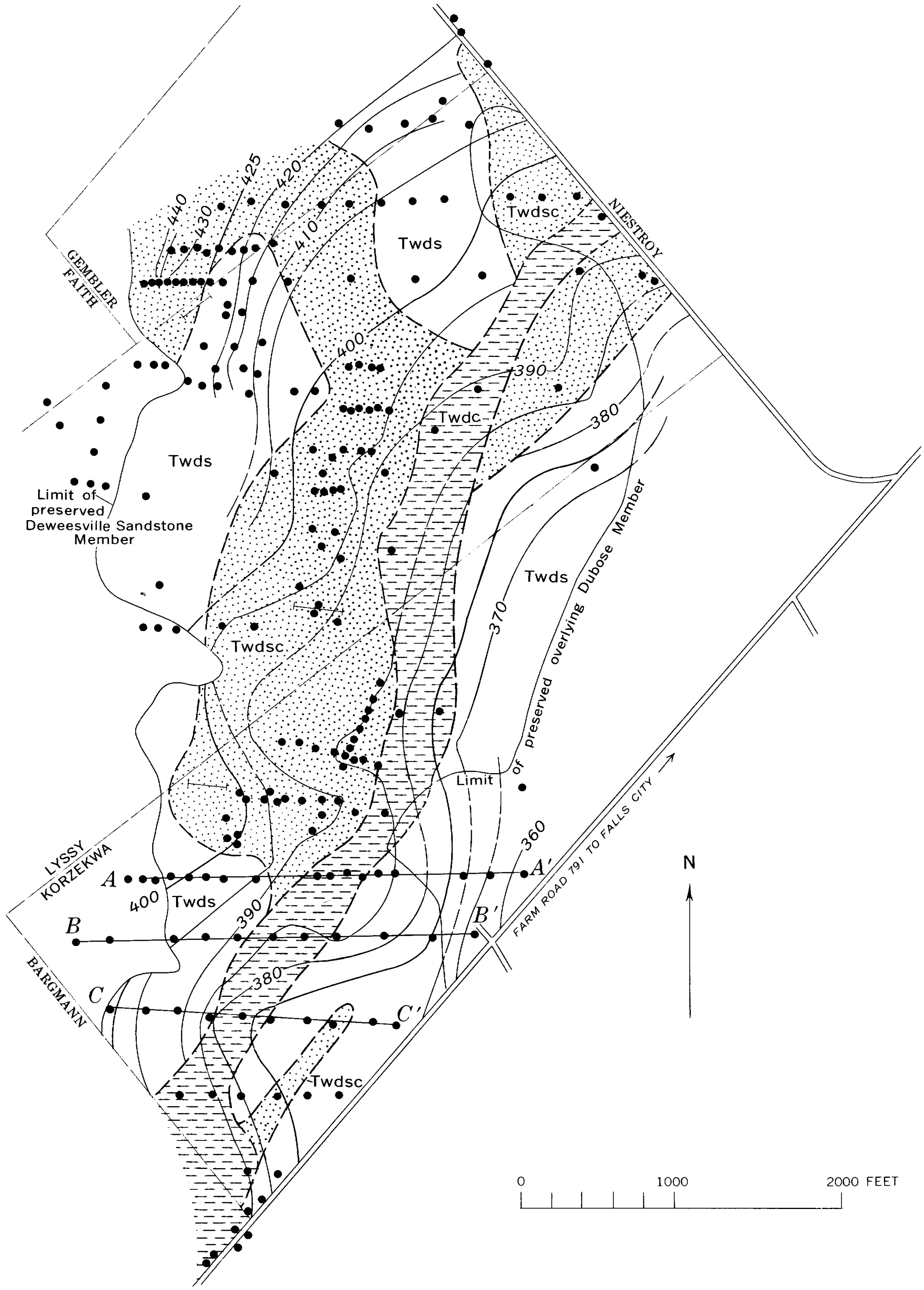
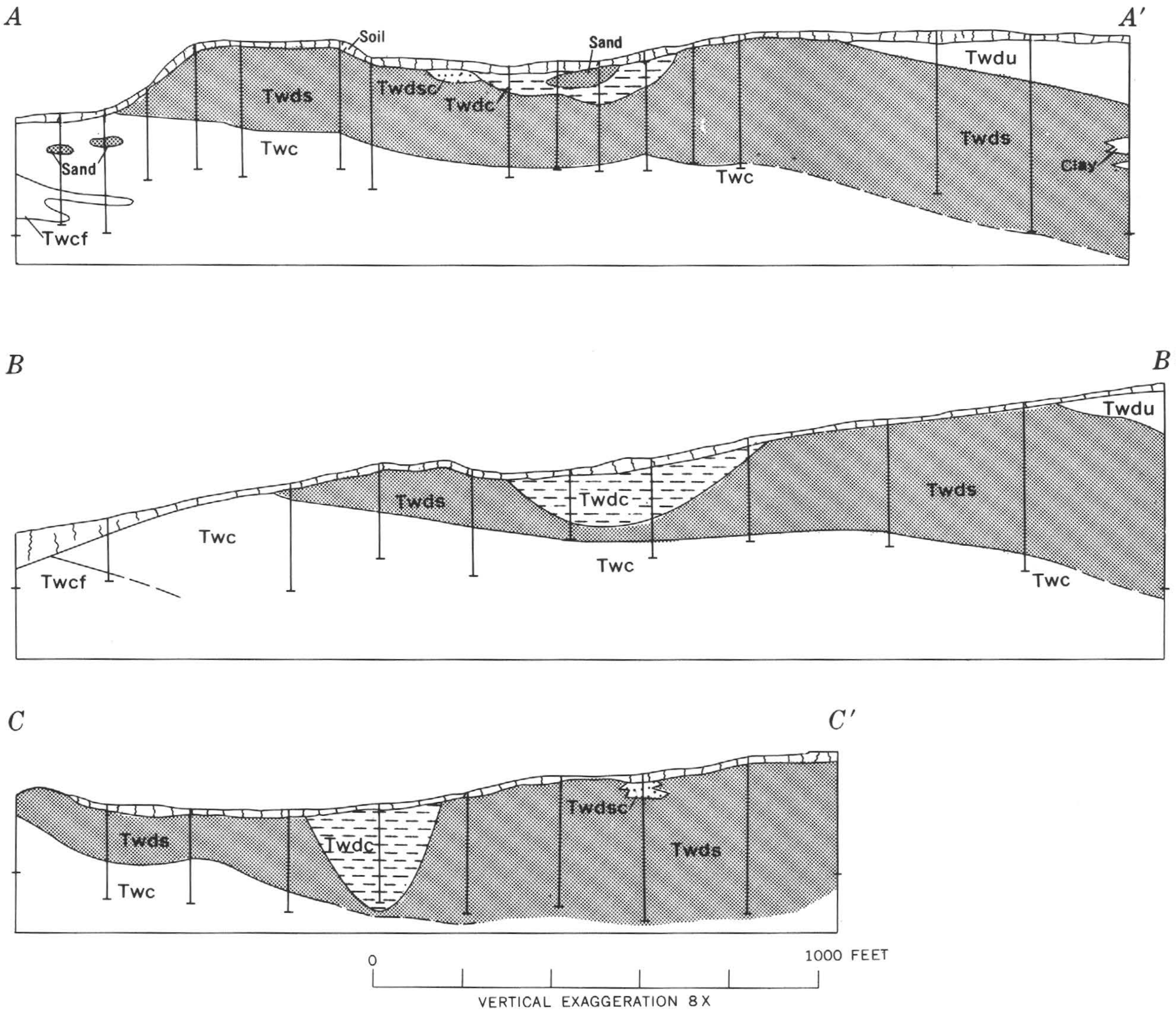


FIGURE 3.—Map and sections of the Nuhn deposit showing lithofacies of the Deeweesville Sandstone Member and structure contours drawn on its base.



EXPLANATION

WHITSETT FORMATION

Twdu, *Dubose Member*
Twd, *Deweesville Sandstone Member*
Twdc, *clay-filled-channel facies*
Twdsc, *intercalated sand-and-clay facies*
Twds, *sand facies*
Twc, *Conquista Clay Member*
Twcf, *fossiliferous sandstone*

Twdc — Clay-filled channel
Twdsc — Intercalated sand and clay
Twds — Sand

Facies of Deweesville Sandstone Member

Contact
Dashed where approximately located

400
Structure contour
Drawn on base of Deweesville Sandstone Member. Dashed where approximately located Contour interval 5 feet. Datum is mean sea level

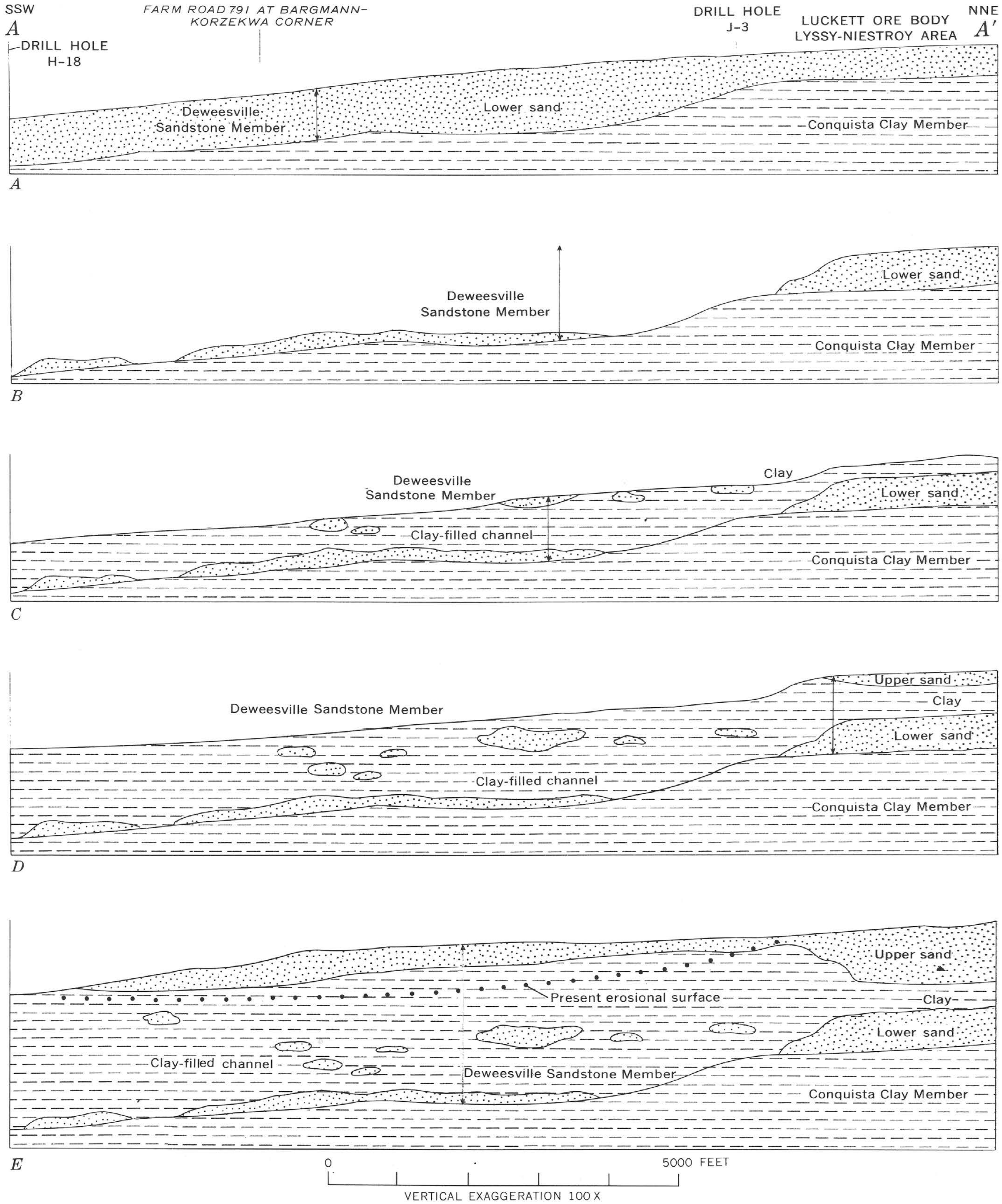
Lithofacies boundary
Short dashed where projected beneath Dubose Member

Trench exposing uranium

On map — On section
Drill hole

LYSSY
KORZEKWA
Approximate location of property line with names of land owners

FIGURE 3.—Continued


SSW
A
DRILL HOLE
H-18
FARM ROAD 791 AT BARGMANN-
KORZEKWA CORNER
DRILL HOLE
J-3
LUCKETT ORE BODY
LYSSY-NIESTROY AREA
NNE
A′
Deweesville
Sandstone Member
Lower sand
Conquista Clay Member
A
Deweesville
Sandstone Member
Lower sand
Conquista Clay Member
B
Deweesville
Sandstone Member
Clay
Lower sand
Clay-filled channel
Conquista Clay Member
C
Deweesville Sandstone Member
Upper sand
Clay
Lower sand
Clay-filled channel
Conquista Clay Member
D
Upper sand
Present erosional surface
Clay
Lower sand
Clay-filled channel
Deweesville Sandstone Member
Conquista Clay Member
E
0
5000 FEET
VERTICAL EXAGGERATION 100 X

straight courses of the large channels are in contrast to the meandering courses of the prielen, which according to Van Straaten (1949, p. 139) are comparable to rivers on land. The large channels are filled with water even during low tide, but the prielen run dry during low tide. As indicated by aerial photograph (Van Straaten, 1949, pl. 2), the large channels are of the same magnitude as the clay-filled channel of the Deweesville-Tordilla Hill area. Luders (1934) reported channels extending as much as 6 meters below mean sea level. The clay-filled channel of the Tordilla Hill-Deweesville area corresponds to the large channels of the Wadden Sea, and the numerous smaller channels (pl. 1; fig. 11) may correspond to the prielen. (For detailed description of lithology, fig. 11, see section entitled "Nuhn (Climax or Korzekwa-Lyssy-Gembler) deposit.")

MacKallor's interpretation of the development of the clay-filled channel within the Deweesville Member is shown in figure 4. After the lower sandstone was deposited throughout the area, strong tidal currents scoured out a channel in the loose sand. Then the clay zone, locally intercalated with sand and silt, was deposited throughout much of the area. During this time the large channel was receiving clay deposits, but the channel was not completely filled. The environment was similar to that of the present area of the Wadden Sea. After the period of scouring and the deposition of the middle zone of clay, calmer conditions prevailed, the channel was completely filled, and the upper sandstone unit of the Deweesville was deposited throughout the area.

DUBOSE MEMBER

The Dubose Member consists of 80–90 feet of intercalated clay, poorly indurated sandstones and siltstones, and carbonaceous tuff. Most of the beds are 2–5 feet thick. Sandstone is less common than siltstone or claystone; it is fine grained and is composed of quartz, feldspar, and volcanic rock fragments; it is only locally indurated. The sandstones are medium grained and are gray to yellowish brown, stained in various degrees with limonite. The carbonaceous tuff beds, which are less than 1 inch thick to several inches thick, contain abundant impressions of leaves and stems of plants, but the actual organic content is very low. Most of these beds are silicified at the outcrop and are white to pink. Where unsilicified, the beds are clayey and are chocolate brown to maroon. The tuffaceous clay and the siltstone are various shades of brown and green.

The Dubose contains abundant silicified wood and several beds of very carbonaceous tuff and clay. *Ophiomorpha major*, a facies fossil indicative of brackish-water conditions and a common fossil throughout the more massive Tordilla Sandstone Member above the Dubose, is not common in the Dubose.

The change from Deweesville to Dubose time was marked by increased volcanic activity, as shown by the greater number of thin ash beds. Although it is thought that both Deweesville and Dubose deposition took place in bays, the Dubose contains much more clay than the Deweesville,and its more variable lithology is indicative of multiple environments, and generally of fresh-water, rather than brackish-water, deposition, in contrast to the Deweesville below and the Tordilla above. The many thin lenses of sand and clay suggest that the Dubose may have been partially formed under deltaic conditions.

TORDILLA SANDSTONE MEMBER

Above the Dubose Member is a sandstone unit about 30 feet thick, the Tordilla Sandstone Member. The sandstone is gray to yellowish brown and is mostly fine grained; it is composed of quartz, moderately fresh feldspar, fragments of volcanic rock, and some tuffaceous material. The lower part of the Tordilla consists of thin platy beds of tuffaceous very fine grained sandstone and siltstone. Exposed surfaces are generally silicified but locally are poorly indurated. At Tordilla Hill, the sandstone is very hard, and it forms the caprock of this prominent topographic feature. It forms distinctive rubble of whitish plates and small blocks. This rubble and some bedrock cap small rounded hills or knolls on the Gabrysch and Culpepper tracts (MacKallor and

FIGURE 4.—Longitudinal diagrammatic sections showing development of clay-filled-channel facies of the Deweesville Sandstone Member. Line of section is shown in figure 1; map of clay-filled channel is shown in figure 3. *A*, After deposition of lower sand of Deweesville Member on Conquista Clay Member. *B*, After erosion of much of lower sand of the Deweesville in channel. Erosion of loose sand probably by tidal action but possibly by fluvial currents. *C*, After filling of channel in the Luckett area with clay and a few sand lenses. *D*, Beginning of deposition of upper sand of Deweesville Member in the Luckett area and the continuation of the filling of channel. Original channel has been filled, but tidal currents maintain a shallow channel in which sediments are being deposited in, at the sides of, and at the head of the channel. *E*, After deposition of all the Deweesville Sandstone Member and beginning of Dubose time.

others, 1962). Above the platy beds the sandstone appears massive, but it contains beds 1 foot or more apart and has some low-angle crossbedding.

The thick sandstone sequence of the Tordilla is very different from the variable lithologic sequence of the underlying Dubose, and there is nothing about the Tordilla to suggest a deltaic environment, although the presence of *Ophiomorpha* proves that the sandstone was deposited near shore under marine conditions.

QUATERNARY

Alluvium of Quaternary age that consists of silt, clay, and organic material occupies most of the valley bottoms; locally along Tordilla Creek, these deposits are covered by a thin veneer of gravel. The thickness of the alluvium ranges from about 4 to 10 feet. Most of the alluvium is covered with a dense, almost impenetrable, growth of thorny bushes. The surface remains muddy for weeks after a heavy rain.

STRUCTURE

The Tordilla Hill-Deweesville area (fig. 1) lies in the warped downthrown block between the ends of two normal, northeast-trending en-echelon faults (fig. 2; MacKallor and others, 1958, fig. 20). The Falls City fault, north and northeast of the deposits, beyond the limits of the area of figure 1, is downthrown to the southeast; the Fashing fault, south and southwest of the deposits, is downthrown to the northwest. Both of these major faults have associated oil and gas fields; the Falls City field (Crutchfield and Bowers, 1950) produces oil from the Wilcox Group of Eocene age and the Fashing field produces oil from the Carrizo Sand of Eocene age and gas distillate from the Edwards Limestone of Cretaceous age (Knebel, 1957). No faults were observed within the area by geologic surface and subsurface mapping nor were any detected by seismic and resistivity surveys, but the lenticularity of the beds prevents detection of faults that have only a few feet displacement either by geologic or by geophysical methods.

The beds within the area of the deposits strike generally north-northeast, but in the immediate vicinity of Tordilla Hill, the beds locally strike north or even a little west of north. In the northeastern part of the area, the strike is east-northeast. The beds within the area depicted in figure 1 dip to the southeast from 20 to 60 feet per thousand (1°–4°), which is less than the regional dip of the Jackson beds for most of the coastal plain. Apparent local variations in the attitude of the beds are the result in part of very gentile anticlinal and synclinal flexures and in part of irregularities in the thickness of sand units.

On the Bargmann property (fig. 1) an anticlinal axis and a synclinal axis trend perpendicular to the regional strike. Interpretations of the structure-contour map drawn on the base of the Deweesville Sandstone Member (fig. 3) include (1) the presence of two possible folds on the Korzekwa property (fig. 1), (2) the local thickening and extension down into the Conquista Clay Member by the Deweesville, and (3) a lesser possibility of the presence of faults. The fold axes (or the local thickenings of the Deweesville) may extend southeastward from the Korzekwa property through the Jandt and the Gabrysch properties (fig. 1).

Many silicified outcrops have one or two, rarely three, well-developed sets of almost vertical joints. The joints of any one set at a single outcrop are straight and within a few degrees of being truly parallel. Individual joints normally are from about 1 to 3 feet apart. The strike of the most common and best developed set is north-northeast to east-north east, parallel to the regional strike of the beds; a second conspicuous set of joints strikes perpendicular to the strike of the beds. A third well-developed set of vertical joints intersects the other two sets at approximately 30° and 60° angles, but this set was observed only near the Hackney deposit (MacKallor and others, 1962). In a few places, poorly developed nonplanar vertical joints from 4 to 8 feet apart intersect the two major joint sets. Because the difference in strike of individual joints, or even of the strike along the same joint, was as much as 30°, these poorly developed, irregular joint sets were not plotted. Where the local strike of the beds deviates from the regional strike, as on the Lyssy property east of Deweesville, the strike of the two major joint sets continues to parallel the regional strike and the dip direction of the beds.

In agreement with the conclusions by McKinstry (1948, p. 291–295) and Billings (1946, p. 101–103) regarding the structural interpretation of joints and shears, the joint system in the area (MacKallor and others, 1962) indicates horizontal, rather than vertical forces. By being in a downthrown block, the area would have been subjected to horizontal compressive forces by either horizontal or vertical movement along the Falls City and Fashing faults.

SILICIFICATION

Patches of well indurated silicified sandstone and carbonaceous tuff are spotty but widespread throughout the area of uranium deposits (MacKallor and others, 1962). Attention was given to silicification in both the large-scale and quadrangle mapping programs because of the proximity of silicified sandstone to most of the uranium deposits.

Highly silicified sandstone is extremely hard, breaks across the grain, gives a ringing sound when struck with a hammer, and has a shiny luster; less hardened sandstone and tuffaceous material are classified as indurated. Induration by silica is common; but according to A. M. D. Weeks (oral commun., 1960), zeolitic alteration is responsible for much of the moderate induration. Most of the sandstone in the area is friable, and some sandstone is as nonindurated as recent beach sand. Silicified siltstone was rarely observed.

Thin sections of silicified fine-grained sandstone and tuff show the cementing material to be opal; no uranium minerals were observed. In highly silicified sandstone that contains secondary uranium minerals, bands of opal and chalcedony are intercalated; those bands in contact with the sand grains are opal. The cement of medium-grained sandstone that does not contain uranium minerals consists of opal bands only. A tentative conclusion is that the formation of chalcedony, rather than opal, is in some way related to the deposition or occurrence of secondary uranium minerals.

Within the report area (figs. 1, 2), silicified rock is found within all exposed members of the Eocene Whitsett Formation. The upper plant-root bed of the Dilworth and two thin beds, one at the top and one near the base of the fossiliferous sandstone unit of the Conquista, are silicified at every outcrop. Some outcrops of the Deweesville are silicified. The lower, middle, and upper parts of the Deweesville are all locally silicified, but the entire section is not silicified in any one place. Most outcrops of the Tordilla are silicified. The Dubose contains mostly mudstone and siltstone, rocks that are not favorable for silicification, but the few sandstone beds and thin tuff beds in this part of the section are silicified at some outcrops.

In outcrops, silicified sandstone grades downward within a few feet to poorly indurated nonsilicified sandstone, and the contact between silicified and nonsilicified sandstone is irregular and cuts across bedding. Excellent examples of the relationship between silicified and nonsilicified sandstones of the Tordilla are visible along the rim of Tordilla Hill (MacKallor and others, 1962). Several small outcrops of well-silicified Deweesville Sandstone Member just north of Tordilla Hill on the Hackney property have been removed by mining operations. The silicified rock was only a foot or two thick and was underlain with slightly indurated sandstone or unconsolidated sand. The layer of silicified sandstone did not extend downdip under soil and bedrock at the Hackney workings, although an exploration trench did expose silicified ribs (fig. 5). Some of the sandstones of the Tordilla and Deweesville contain nodules which have a ⅛-inch-thick rim of grayish, punky, poorly indurated sandstone enclosing a shiny, hard, bluish-gray silicified core. In some places prongs of poorly indurated sandstone extend into the silicified sandstone along joints. An interpretation, suggested by D. H. Eargle (oral commun., 1958), is that the silica cement is now being removed because of climatic conditions.

Inasmuch as the auger drill could not penetrate a silicified layer even a few inches thick, no auger holes were started on silicifed sandstone; but many holes were started near silicified outcrops. The drill seldom encountered silicified rock in these holes. A very few holes had to be abandoned at a depth of about 30 feet because of a silicified layer perhaps no more than 2–3 inches thick. Silicification below the surface is scarce and spotty—one hole may contain a thin silicified layer and adjoining holes at the same interval may be unsilicified. In the five core holes (K–1 to K–5), only a few scattered small stringers of silicified rock were found below the zone of oxidation.

The evidence from outcrops, trenches and pits, and drill holes is that most silicification occurs in the oxidized zone at or within a few feet of the surface. After examining the distribution of silicified sandstone near Tordilla Creek, the authors concluded that the present drainages existed at the time of silicification but that they have been widened and deepened since that time. The large patch of silicified sandstone just north of the Korzekwa trench in the Nuhn deposit (fig. 1; MacKallor and others, 1962) apparently forced Tordilla Creek to make a big loop around the resistant rock and confined it to a narrow valley in this area.

Another type of silicification, the replacement of wood by silica, probably occurred before the silicification of the rocks just discussed. Silicified logs and tree stumps have been observed in the Conquista Clay, Deweesville Sandstone, and Dubose Members of the Whitsett Formation. The logs retain their

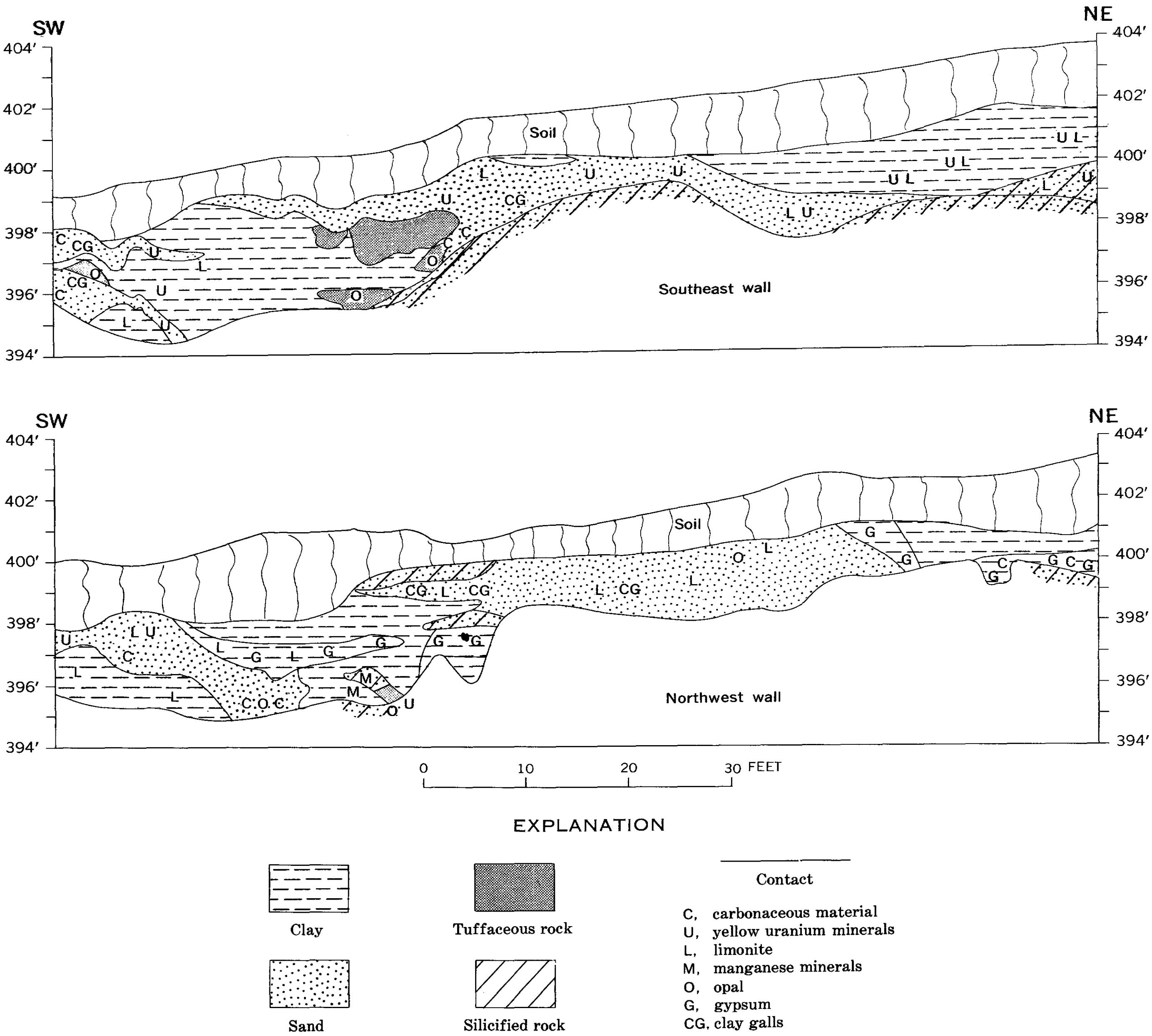


FIGURE 5.—Geologic sections along southeast and northwest walls of trench in the Hackney deposit.

original shape in cross section, which suggests that silicification took place shortly after deposition and burial of the logs. If the logs had been silicified after a few hundred feet of overlying sediments was deposited and after a considerable lapse of time, the cross section of the logs would have been modified by the compressive force of the overlying sediments. Outside of the study area of figure 1, a few silicified logs contain small encrustations of yellow uranium minerals on the outside and in small cracks, but the logs do not approach ore-grade material.

The conclusion is that the spotty silicification, confined almost entirely to 5 feet of the present surface, is of recent geologic age (that is, Pleistocene), preceding only the late deepening of stream valleys. The lack of deformation of silicified wood, however, indicates early penecontemporaneous replacement. Therefore, silica has been in the sediments and water since the early deposition of ash.

URANIUM DEPOSITS

Uranium minerals in Texas have been found in the Oakville Sandstone (Miocene), in the Catahoula Tuff (Miocene), and in several members of the

Whitsett Formation (Eocene). The significant deposits in the Tordilla Hill-Deweesville area occur where the permeable Deweesville Sandstone Member lies on the relatively impermeable Conquista Clay Member (fig. 6). The uranium minerals occur mostly within the lower 10 feet of the Deweesville, but almost invariably extend down into the upper few feet of the Conquista; and where the upper part of the Conquista is unusually silty, the uranium concentration may be greater below than above the contact. The host rocks in the vicinity of the deposits are characterized by diastems, channels, crossbedding, and intercalated lenses of sandstone, clay, and siltstone. Furthermore, the largest deposits occur within a few hundred feet updip from a major clay-filled channel (fig. 3).

The larger deposits either crop out at or extend to within 20 feet of the surface, but economically important deposits may exist at greater depths. Although the nearness to the surface affects the mineralogy of the deposits, it is not an ore control.

Downdip from the principal ore bodies, three of the cored holes penetrated areas of anomalous radioactivity at depths below 100 feet. K–1 had an anomaly of 0.12 percent equivalent uranium oxide (eU_3O_8) from a depth of 157.6 to 158.8 feet; K–3 an anomaly of 0.22 percent eU_3O_8 from 140.2 to 141.8 feet; and K–5 anomalies of 0.12 and 0.15 percent eU_3O_8 from depths of 103.0 to 104.2 feet and from 112.1 to 113.0 feet, respectively. Equivalent uranium oxide is the amount of U_3O_8 that would have contained enough uranium to decay to the amount of daughter products that emit the measured radioactivity. The chemical uranium in the cores was considerably less than the equivalent uranium. The anomalies in K–5 were in the Tordilla Sandstone Member; the other anomalies were in the lower part of the Deweesville Member (Manger and Eargle, 1967). The radioactivity anomaly in hole K–5 was later shown to be on the updip fringe of the largest uranium deposit in the region (D. H. Eargle, written commun., 1969). No discrete uranium minerals were identified in the cores, and inasmuch as the radioactivity was disseminated in the light fraction of the rock, the radioelements may be absorbed on the clay minerals (A. M. D. Weeks and A. H. Truesdell, written commun., 1959).

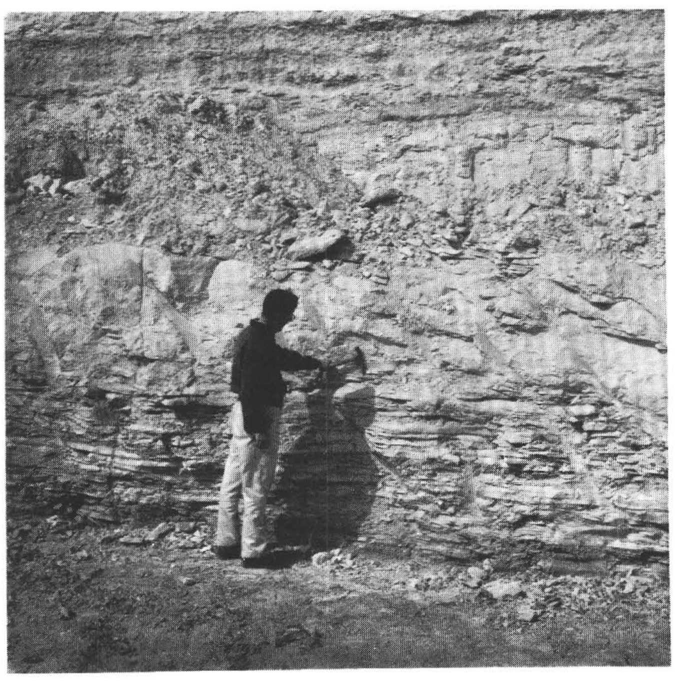


FIGURE 6.—Principal ore-bearing zone of the Tordilla Hill-Deweesville area straddles the contact (to which the man is pointing) between the Deweesville Sandstone Member and the underlying laminated Conquista Clay Member of the Whitsett Formation and extends upward to the surface. Trench is in the northwestern part of the Windmill deposit on the Gembler property. Photograph by D. H. Eargle, 1960, after mining began in the area.

The uranium deposits are, in general, tabular; their shape was determined from the results of the fieldwork and verified by subsequent mining. The interpretation of horizontal shape (fig. 1 and plate 1) is based on data from the ground radioactivity study by L. R. Tolozko (in MacKallor, 1962), gamma-ray logs, and outcrops and exposures in pits. The general dimensions of the Luckett deposit were obtained from deVergie (1958, fig. 2) and from the pattern of drill-hole locations noted during plane tabling of the area. Although the exact shapes of ore bodies are not shown on detailed maps made by mining companies, the maps do show the larger ore bodies to be elongated along the strike of the beds. Small protuberances parallel with and perpendicular to the general strike of the beds coincide with the orientation of the most conspicuous joint systems.

MINERALOGY

The deposits contain a great variety of high-valent uranium minerals, many of which are unstable. On the Gembler property, uraninite occurs in the Conquista Clay Member below the zone of oxidation but forms a very minor part of the deposit. Eargle and Weeks (1961a, p. 26) stated,

> The minerals are chiefly varieties of yellow to greenish-yellow, oxidized uranium minerals. They include uranyl phosphates, arseno-phosphates, silicates, phospho-silicates, molybdates, and vanadates. Locally in silty clays beneath the thickest and richest deposit a small amount of uraninite ore has been found. The uranyl phosphate minerals, autunite or meta-autunite, are the most abundant.

In general, the mineralogy resembles more the oxidized near-surface deposits in the Tertiary of Wyoming than it does those of the Colorado Plateau which are high in vanadium and contain carnotite as the dominant mineral. The Karnes County area ores are low in vanadium content, but traces of the uranyl vanadates, carnotite and tyuyamunite, are widely distributed.

Most of the uranium minerals are oxidized because the deposits are within or just below the zone of oxidation. In addition to the one occurrence of uraninite, A. M. D. Weeks (unpub. data) reported one other mineral that may be in part low valent—an unidentified purplish-black uranium molybdate found in an outcrop of highly silicified sandstone at the Hackney deposit.

MacKallor systematically collected 33 samples from a prospect trench (fig. 1) on the Korzekwa property at the south end of the Nuhn deposit for chemical and equivalent uranium analyses and for semiquantitative analyses of other elements. A. M. D. Weeks (oral commun., 1958) compared the results with the composition of average sandstones and found that the MacKallor samples showed considerable to slight enrichment in uranium, molybdenum, arsenic, vanadium, and lead. She believed that a moderate enrichment of these elements was caused by volcanic debris in the sandstone.

J. N. Rosholt, of the U.S. Geological Survey, made radiochemical analyses of three suites of samples, two from a shallow trench on the Korzekwa property and one from a depth of about 40 feet from an ore body along the Gembler-Lyssy property line. The samples have a wide range of disequilibrium, and Rosholt interpreted the radiochemical analyses as indicating considerable migration of uranium within the last 250,000 years (Rosholt, 1963).

Uranium minerals occur as thin layers along bedding planes and joints and are disseminated throughout the host rock, coating grains and filling interstices. Some uranium minerals have replaced volcanic rock fragments and feldspar grains along cleavage cracks. Ore-grade material has been found from the surface to a maximum depth of about 40 feet.

PRODUCTION AND RESERVES

In 1958, after the period of intense prospecting but before any mining operations were begun, the U.S. Atomic Energy Commission (S. R. Steinhauser, oral commun., 1958) estimated the reserves of uranium in Karnes, Atascosa, and Gonzales Counties, Tex., to be 280,000 tons of ore which would average 0.22 percent U_3O_8.

The first production of uranium ore from the southeastern Texas coastal plain was from the Hackney deposit in December 1958, when a few tons of selectively mined ore containing 2.16 percent uranium was trucked to the uranium mill at Grants, N. Mex.

In July 1959, preparation for open-pit mining was begun by the San Antonio Mining Co. on the Nuhn deposit (Maxwell, 1962, p. 123); and by April 1961, the company had fulfilled its contract to deliver 100,000 tons of ore containing about 0.2 percent U_3O_8. By July 1961, Susquehanna-Western Inc. had mined about 80,000 tons of ore containing about 0.2 percent U_3O_8 from the Luckett deposit (Maxwell, 1962, p. 126). The same company mined the Bargmann-Hackney (formerly Rare Metals) deposit in 1963, greatly enlarged the Korzekwa mine in 1964, and reopened the Hackney deposit and mined about 10,000 tons of ore in 1965 (D. H. Eargle, written commun., 1969). In 1968, production from Susquehanna-Western's mill at Deweesville was about 1.2 million pounds of U_3O_8 (Eargle, 1970).

SUBSURFACE RADIOACTIVITY STUDIES

COMPARISON BETWEEN CHEMICAL AND RADIOMETRIC ANALYSES OF DRILL-HOLE SAMPLES

Gamma-ray log interpretations are based on the assumption that the uranium is in equilibrium with its daughter products; therefore, it was necessary to determine whether the radioactive material in the report area fulfilled that condition.

Samples from auger cuttings and drill cores were analyzed chemically for uranium content and radiometrically for equivalent uranium content. The results of these analyses may not agree, because of secular disequilibrium, statistical error, or error in both chemical and radiometric analyses.

Disequilibrium can be caused by normal geologic processes. Because the parent and daughter radioelements have different chemical characteristics, they can be separated by ground-water movement. Either the parent or the daughter products may predominate in a uranium deposit.

Disequilibrium may also occur through radon loss during the grinding process preceding radiometric analysis either because the gas is driven off by frictional heat or because it escapes from pore spaces in the rock as a result of fracturing of the pores. Unless the sample is allowed to stand for several days after grinding to regain equilibrium, as was done here, the measured radioactivity may be less than that required for a true radiometric analysis.

Statistical error is inherent in all radiometric analyses and is a function of the total number of events or counts observed. The error can be minimized in laboratory analyses by increasing the measurement time interval for samples of low activity. For count-rate meters used with gamma-ray logging equipment, the magnitude of the fluctuation from an average value depends on the count rate and the time constant of the instrument.

The relation between chemical and radiometric analyses of drill-hole and pit samples was established by plotting the uranium data obtained by the two methods (fig. 7). All the chemical analyses are assumed to be correct, though some errors believed to be relatively insignificant undoubtedly exist, particularly in analyses of low-grade material. The results show a wide range (about 0.5–2.0) in ratios between chemical and radiometric analyses, especially for values less than 0.05 percent chemical uranium. Above this value, the range is not as wide, and the chemical uranium analyses are about 1½ times higher than the radiometric analyses. The radiometric analyses are generally higher than the chemical analyses in the range of 0.001 to 0.01 percent U. Some of the discrepancy in the two sets of data in this range may be the result of the contribution of radioactivity from the natural radioisotope of potassium, K^{40}. The gamma-radioactivity emitted by K^{40} in a sample containing 1.5 percent K is equivalent to the radioactivity from 0.001 percent U (J. N. Rosholt, U.S. Geological Survey, oral

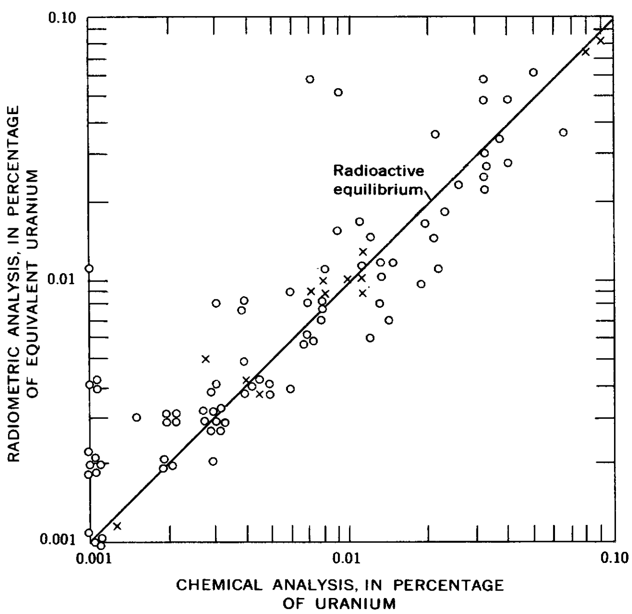


Figure 7.—Relation between chemical and radiometric analyses for uranium content of drill-hole samples. o, auger sample; x, diamond-drill core sample obtained with oil-base mud.

commun., 1958). Semiquantitative spectrographic analyses by A. M. D. Weeks show that rocks of the Deweesville Sandstone and Conquista Clay Members of the Whitsett Formation range from 1 to 3 percent K (D. H. Eargle, written commun., 1964).

A comparison of equivalent uranium and chemical uranium analyses was made by A. M. D. Weeks on more than 530 samples ranging from high-grade ore down to a content of 0.001 percent U. The results indicated that the average equivalent uranium is about 5 percent higher than the average chemical uranium (Weeks and Eargle, 1963), though ratios from individual samples vary widely.

EFFECT OF RADON ON GAMMA-RAY LOG INTERPRETATION

Gamma-ray logs obtained from a few drill holes, especially those on the Korzekwa property, exhibited excessively high anomalous radioactivity through several tens of feet of drill hole. Data from most holes in the area indicated that the maximum thickness of mineralized zones was a few feet; therefore, contamination of the few holes by radon gas was suspected. During drilling, radioactive cuttings and dust are sometimes transported up the hole by drilling fluid or air and are deposited along some finite interval of the hole. In contrast, radon gas is usually distributed throughout several tens of feet within the drill hole. The effects of radon contamination on the gamma-ray logs in the Tordilla Hill-Deweesville area are similar to those observed in other areas in the United States (Hilpert and Bunker, 1957).

To test the inference that radon contamination was present, drill hole B–39 (fig. 8), suspected of being highly contaminated, was used for an experiment. The hole had been logged immediately after it was drilled, and the log exhibited anomalously high radioactivity throughout its length (fig. 8, log A). Twelve hours later the hole was relogged. Except for a few feet at each end of the hole, the radioactivity had increased significantly (fig. 8, log B). The radioactivity in a zone about 10 feet thick between the depths of 40 and 50 feet, and just below the uranium ore, had increased by a factor of two. The hole remained uncapped for an additional 48 hours and was logged again (fig. 8, log C). The radioactivity in the bottom of the hole had decreased to less than the amount found immediately after drilling. The radioactivity between the depths of 40 and 50 feet had decreased to about 50 percent more than was observed immediately after the time the hole was drilled. Although no meteorological data were kept,

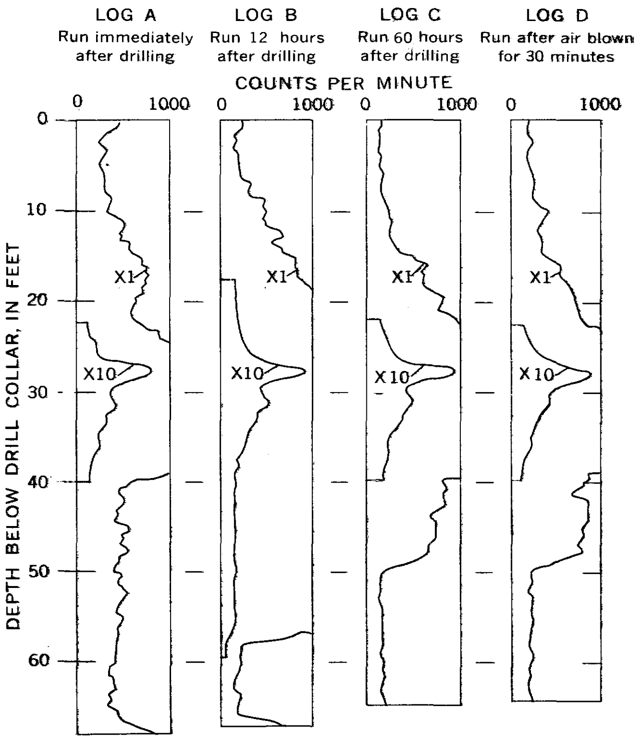


FIGURE 8.—Gamma-ray logs of drill hole B-39 in the Nuhn deposit showing radon contamination and effects of time and of air flushing. Curve × 1, read direct; curve × 10, multiply reading by 10.

the authors believe that the radon gas was evacuated from the drill hole by an increase in barometric pressure and wind velocity (Hilpert and Bunker, 1957). An air hose was lowered to the bottom of the hole, and air was pumped into the hole at a rate of about 600 cubic feet per minute for 30 minutes. Subsequent logging indicated no significant change in the radioactivity (fig. 8, log D). The lack of change in radioactivity between the depths of 40 and 50 feet probably indicates that a predominant source of the radioactivity here was radioisotopes lead-214 and bismuth-214 adhering to the walls of the drill hole.

On drill-hole logs that were recognizably contaminated by radon, only major anomalies were interpreted for grade. For these, the instrument readings were reduced by the amount of contamination, doubtlessly causing an underestimation of equivalent-uranium content in some zones of lower grade mineralization.

RELATIONS BETWEEN SURFACE AND SUBSURFACE RADIOACTIVITY

Airborne (Moxham, 1958, 1964; Moxham and Eargle, 1961) and carborne radioactivity surveys in the Texas coastal plain indicate that the gross regional radioactivity ranges from about 6μr (microroentgen) per hour to about 9 μr per hour. The Tordilla Hill-Deweesville area is surrounded for many square miles by an aura of slightly anomalous radioactivity ranging from about 10 to 15 μr per hour (Moxham, Eargle, and MacKallor, 1957, p. 449; MacKallor and others 1962). The Tordilla Hill-Deweesville area is completely within the aura; therefore, most of the lowest surface radiation intensities shown (fig. 9; MacKallor and others, 1962) are higher than the regional radiation intensity.

The uranium deposits are reflected by surface anomalies directly over them in some places, especially where the uranium is near the surface. An intense surface anomaly overlies the Hackney deposit at the north foot of Tordilla Hill. Both the surface and the subsurface radioactivities extend downslope (northwest) from the deposit. A surface anomaly of 5,000 μr per hour was measured in this area and is probably related to a surface accumulation of mechanically dispersed ore from the Hackney deposit. Elsewhere, the surface anomalies are found updip from the uranium deposits at the location where the ore-bearing geologic units are exposed at the surface.

SIZE AND SHAPE OF RADIOACTIVE LAYERS

The sizes and the shapes of the radioactive layers are as varied and complex as those of the lithologic units. The thickness of the layers that show anomalous radioactivity ranges from a few inches to several tens of feet; the thickness of the high-grade (0.5–0.99 percent eU_3O_8) layers is limited to a few feet. In cross section the layers range from ellipsoids to long stringers. The width of the layers ranges from a few feet to a few hundred feet; the width of the high-grade layers is not more than 100 feet.

The higher grade zones are surrounded by halos of lower grade uranium. Similar halos in the Colorado Plateau were reported as early as 1950 (A. S. Rogers, U.S. Geol. Survey, written commun., 1950). In the Karnes County area, where the mineralized zones are several feet below the surface, the halos follow the topographic slope. The halos generally extend farther downdip than updip from the locus of mineralization.

The edges of the horizontal layers in cross section are very irregular. Many layers split into multiple layers at the edges; this splitting is especially noticeable in the low-grade (0.01–0.049 percent eU_3O_8) deposits.

The shape of the layers is also very irregular in plan view. Some of the apparent irregularity may be

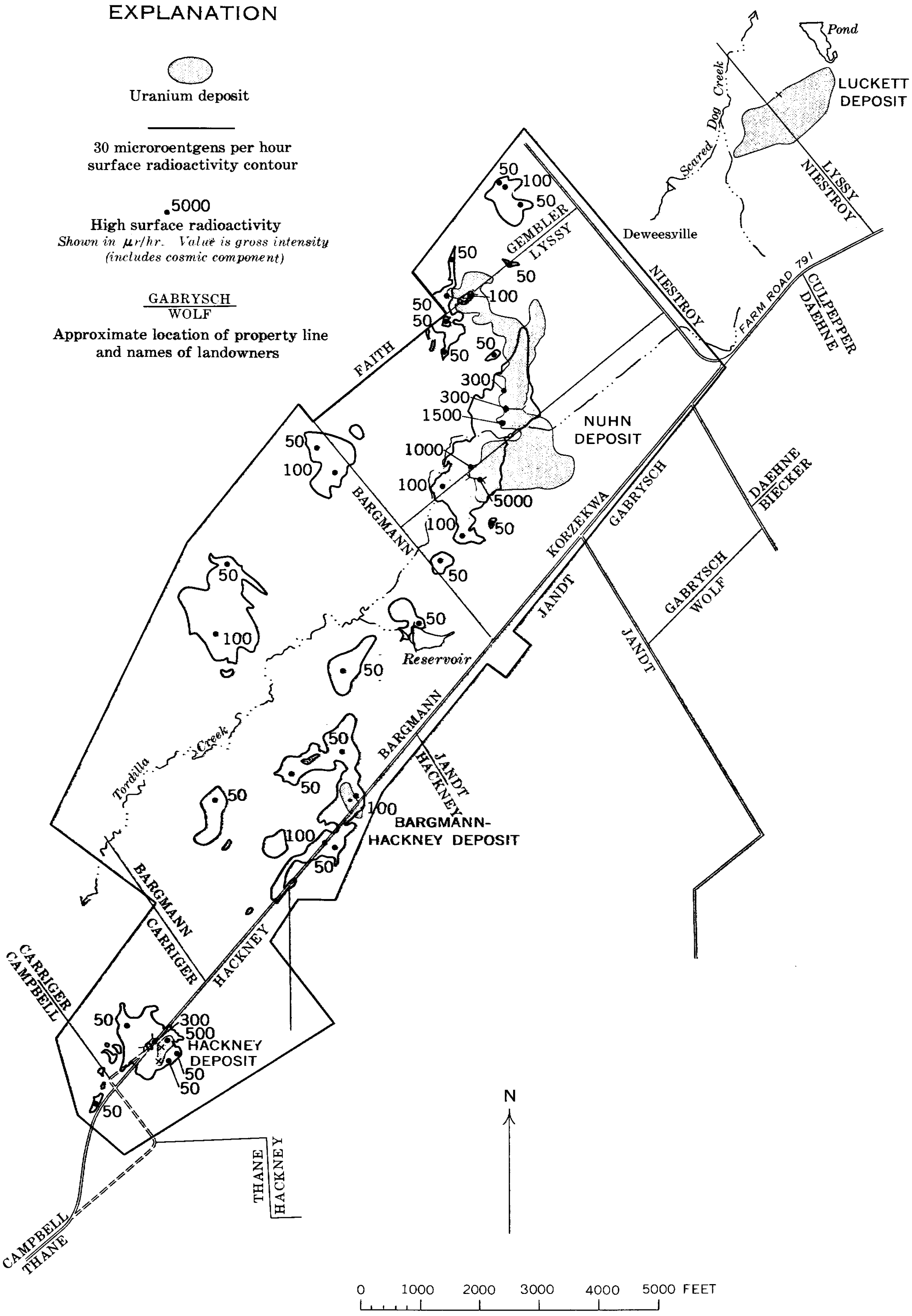


FIGURE 9.—Ore deposits and generalized surface radioactivity contours in the Tordilla Hill-Deweesville area. Modified from MacKallor, Moxham, Tolozko, and Popenoe (1962).

caused by the pattern of the drill holes and by the subjective interpretation of the radioactivity data. However, in some areas that are pierced by many drill holes, for example, the Korzekwa property, the horizontal limits of the radioactive layers are defined reasonably well. The radioactivity in this area follows a meandering southerly trend within which are elliptical deposits of high-grade uranium.

INDIVIDUAL DEPOSITS

Figure 1 shows the landowners and the names being used in 1958 for the important deposits in the Tordilla Hill-Deweesville area. The Nuhn (Climax) deposit is a collective name for three somewhat separate ore bodies: Korzekwa, Lyssy, and Gembler-Lyssy (or Windmill). During this study, the Nuhn deposit was also known as the Climax or San Antonio Mining Co. deposit. The Luckett deposit was also known as the Continental and as the Susquehanna-Western deposits. These two deposits extend across property lines; where a precise location is needed, the name of the landowner follows the name of the deposit in parentheses. The Bargmann-Hackney deposit, also known as the Superior-Rare Metals deposit, is divided by the highway.

HACKNEY (BOSO) DEPOSIT

The Hackney (Boso) deposit at the foot of Tordilla Hill was one of the first deposits of uranium minerals to be discovered in the southeastern Texas coastal plain. The mineral lease of part of the Hackney tract, including the uranium deposit, was acquired by the late Dr. Fred M. Boso, of San Antonio, shortly after the discovery of uranium mineralization there (1954).

After the upper few feet of material around the deposit was bulldozed, between 8 and 9 tons of selected ore, containing 2.16 percent U_3O_8, and 1.4 percent lime, was trucked to the mill at Grants, N. Mex., in December 1958. The deposit was mined later, in 1965, by Susquehanna-Western, Inc.

The Hackney deposit is the only one in the Tordilla Hill-Deweesville area in which highly silicified sandstone contains uranium. At the time of this survey, three silicified outcrops within the uranium deposit had been destroyed by bulldozer operations. These three outcrops were part of the sandstone bed of the Deweesville Sandstone Member and lay just above the silty clays of the Conquista Clay Member of the Whitsett Formation.

One of the small outcrops was unusual in that the exposed rock had a dark-yellowish-brown ferruginous stain; yellow uranium minerals were abundant. The exposed sandstone was slightly less than 1 foot thick and lay just above a 1-inch-thick bed of opalized tuff. This thin bed of tuff, exposed in a nearby prospect pit, also contained abundant yellow uranium minerals. Although float from this tuff was found for several hundred feet along the contact, no mineralized material was found away from the deposit.

The northern outcrop of the deposit, a light-gray fine-grained sandstone, contained a few specks of yellow uranium minerals. In the southern outcrop, the sandstone is highly silicified and is smoky to very dark gray. The southern outcrop is predominantly medium grained; in contrast, most of the other outcrops are fine grained. The cementing material consists of alternate bands of chalcedony and opal. In a small prospect pit here, visible uranium minerals were scarce, but the mineralogy is unusual. At this outcrop, and no place else, A. M. D. Weeks (oral commun., 1960) identified iriginite, a yellow uranyl molybdate, and a newly discovered purplish-black uranium molybdate mineral, as well as two molybdenum minerals, jordisite and ilsemannite.

The yellow uranium minerals found in the Hackney deposit were mainly autunite, carnotite, and tyuyamunite. Carnotite was more abundant at this deposit than at the other deposits in the area.

In addition to the uranium minerals, the deposit locally contained small amounts of disseminated fine-grained pyrite and marcasite. A. M. D. Weeks (oral commun., 1961) observed these minerals as microscopic subhedral grains in interstitial bands of opal and as replacements of detrital volcanic grains. Limonite stains are common throughout the deposit in both sandy and clayey material. Manganese oxides, occurring locally as BB-sized pellets and stains, are common, but elsewhere are scarce or absent.

In a trench on the Hackney property (fig. 5), which was bulldozed during mining operations, yellow uranium minerals were seen to be scattered throughout the sandstone and clays, but were very scarce in the silicified sandstone. The uranium minerals commonly were concentrated along bedding planes in streaks less than 1 cm thick, and several very thin streaks were locally seen within an interval of a few inches. The uranium minerals coat the sand grains and partly fill the interstices with a fine yellow powder. In clay, the minerals form conspicuous yellow coatings along bedding planes and minute, nearly vertical, partings or cleavage fractures. Uranium minerals were observed as partial replacements of grains of feldspar and volcanic material in thin sections of silicified rock. Limonite, both yellowish brown and reddish brown, is more widespread than uranium minerals and imparts the characteristic colors to some streaks of sand. In the trench, selenite is common above the silicified sandstone and below the soil and occurs as platy aggregates from less than 1 inch to several inches in diameter.

The original ore shipment was obtained from a small area north of the trench—around the small outcrop and prospect pit—and west of the easternmost outcrop. Although the excavations extended to Conquista, the ore came only from the basal few feet of the Deweesville. This basal sandstone ranges from completely unindurated to indurated and highly silicified. In many places no gradation occurs between highly silicified and unindurated sandstone; in some places from a few inches to as much as 1 foot of indurated, slightly silicified sandstone separates highly silicified from unindurated sandstone. The highly silicified sandstone is smoky to dark gray. The normal color of the slightly silicified and unindurated sandstones is light gray to pale brown; where these sandstones are heavily impregnated with limonite, the color is dark brown. The limonite on the outcrops was a dark yellowish brown, but much of the limonite below the surface was reddish brown. Mottled bright yellow and brown limonitic pockets that are as large as a few cubic feet and that consist almost entirely or only partly of high-grade ore were observed only in unindurated and in slightly silicified sandstone.

The digging of a trench, now filled, on the Carriger property just across the road from the Hackney deposit uncovered uranium minerals in the Conquista Clay Member. Such occurrences undoubtedly were similar to those visible along the highway cut between this trench and the Hackney deposit, where uranium minerals occur uncommonly along bedding planes and cleavage fractures. Directly below the mined-out area, in the upper 2 feet of the Conquista, yellow uranium minerals are conspicuous, but even this material does not approach ore grade.

The two unmineralized outcrops on the Hackney property are part of the plant-root bed, which is in the uppermost sandstone of the Deweesville. The interval between this sandstone bed and the basal sandstone bed consists of unindurated sandstone and clay. At this deposit, the Deweesville is only 20 feet thick, whereas the average thickness in the Tordilla Hill-Deweesville area is 40–50 feet. The local thinning of the sandstone is a result of the depositional environment. The difference in thickness of the permeable Deweesville between this area and adjacent ones certainly affected the rate of ground water movement and may have been an important ore control.

The beds on the Hackney and adjacent properties dip gently southeast except for a local area on the Hackney property, opposite the Bargmann-Carriger property line, where they locally dip northeast. A north-trending fault, not observable on the surface, may be present in this region.

BARGMANN-HACKNEY (SUPERIOR-RARE METALS) DEPOSIT

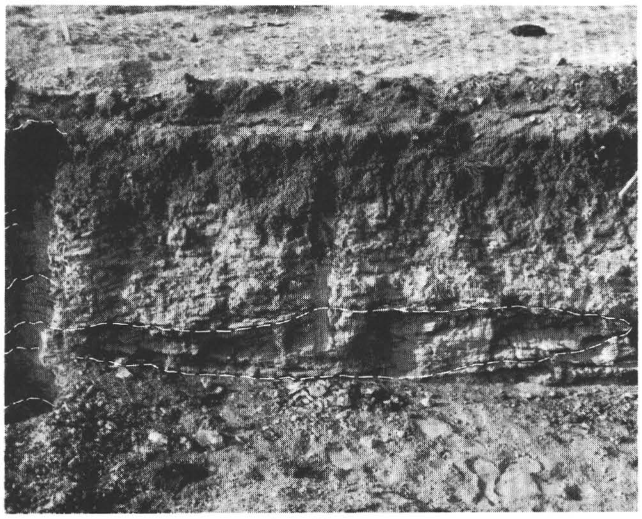
Closely spaced drill holes on the Bargmann property near a surface radioactivity anomaly indicate the probable extent of a deposit found by the Superior Oil Co., mineral leasees of the tract. Several holes were drilled by the U.S. Geological Survey near the road on both the Hackney and the Bargmann properties, and some mineralized material containing less than 0.1 percent eU was found beyond the deposit, as shown in figure 1. The amount of higher grade material apparently is minimal (pl. 1) and is confined to the Deweesville Sandstone Member. The upper few feet of the Conquista Clay Member contains a considerable amount of radioactive material that is less than 0.05 percent eU (holes H–13 to B–24, pl. 1). The uranium deposit lies a few hundred feet updip from a deep clay-filled channel, a major ore control of the area.

NUHN (CLIMAX OR KORZEKWA-LYSSY-GEMBLER) DEPOSIT

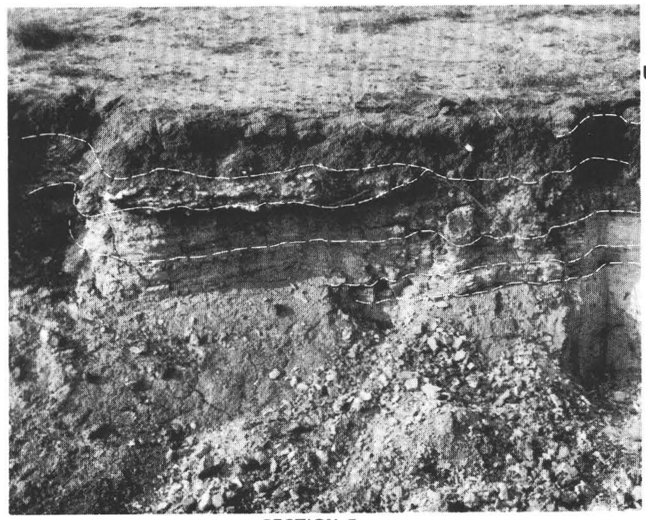
One large deposit, containing several distinct ore bodies, occurs on the Korzekwa, Lyssy, and Gembler tracts, known collectively as the Nuhn lease. The deposit was mined by the Climax Molybdenum Co. operating under the name of the San Antonio Mining Co.

During the U.S. Geological Survey's airborne radioactivity survey in the Texas coastal plain, the ore bodies showed one large anomaly (Moxham and Eargle, 1961); this anomaly was perhaps the principal one discovered during the airborne survey by Jaffee-Martin and Associates that started the uranium rush in the southeast Texas coastal plain.

The Climax Molybdenum Co. systematically drilled these three tracts and discovered two small high-grade ore bodies on the Korzekwa property, a larger one on the Lyssy property, and another partly on the Gembler tract and partly on the Lyssy tract. Mining operations did not commence until 1959, after fieldwork for this report had been completed, and as a result figure 1 does not show the location of the open-pit mines. By April 1961, the San Antonio



SECTION *A*
East end of trench



SECTION *G*
West end of trench

Unit	*Lithology*	*Thickness* (ft)
1	Soil.	
2	Silty clay subsoil; caliche	0.9
3	Sand, fine; caliche	.4
4	Sand, fine; limonitic caliche	1.2
5	Sand, fine to medium, lignitic, limonitic; caliche	.9
[1]6	Sand, fine	.4
7	Lignite and sand	.6
8	Sand, fine to medium, very limonitic, at top; autunite(?)	.4+

[1] Unit 6 illustrates the discontinuous nature of the individual lithologic units.

Unit	*Lithology*	*Thickness* (ft)
1	Soil.	
2	Subsoil, sandy	1.0
3	Sand, yellow to buff, very fine; clayey streaks of reddish-brown limonite	.8
4	Sand, light-gray above yellow-brown, very fine to fine, tuffaceous, clayey	.5
5	Clay, chocolate to maroon, lignitic	.4
6	Sand, light-gray to pale-yellow, very fine, tuffaceous; clayey streaks; yellow uranium minerals	.4

FIGURE 10.—Detailed lithology of the localities fro which channel samples A and G were taken from the south wall of the Korzekwa trench, south end of the Nunn deposit. Photographs by J. A. MacKallor, 1957.

Mining Co. had produced 100,000 tons of ore containing about 0.2 percent U_3O_8 from this deposit.

One of the small ore bodies on the Korzekwa property, the Orchard, near the center of the tract was tested by two perpendicular lines of holes drilled by the U.S. Geological Survey (pl. 1). Plate 1 shows that the mineralized zone is not controlled by the present land surface but by the Conquista-Deweesville contact. Although most of the uranium is in the sandstone above the contact, some is in sandy and silty clay below.

Another ore body on the Korzekwa property was originally exposed by a shallow trench (figs. 1, 10) near the Korzekwa-Lyssy property line. Gamma-ray logs made by the U.S. Geological Survey in holes drilled by the Climax Molybdenum Co. show the ore body to be elongated parallel to the strike of the Deweesville.

The section exposed in the trench was from 10 to 15 feet above the base of the Deweesville and clearly showed the small-scale scouring, crossbedding, and lensing within thin units of intercalated fine-grained sandstone and claystone. Such intercalations are characteristic of the lowest few feet of the Deweesville and to a lesser extent of the upper few feet of the Conquista, the zone that contained all the known oxidized uranium deposits in the Tordilla Hill-Deweesville area at the time of this survey.

In the sandy material of the trench, bright yellow uranium minerals occur as streaks along bedding planes and as irregularly scattered blobs. The uranium minerals coat and fill the interstitial space between sand grains. In the clayey beds, uranium minerals from coatings along bedding planes and along minute, nearly vertical, partings or cleavage fractures. A. M. D. Weeks (oral commun., 1961) has identified the yellow to greenish-yellow uranium minerals autunite, carnotite, tyuyamunite, and poseyite from the Korzekwa trench.

Each small unit (fig. 10; see section on "Mineralogy") was spectrographically assayed for uranium and other elements. Unit 8 of channel sample C contained 0.3 percent U, which was the highest assay obtained from the south side of the trench. One small pocket of high-grade ore was observed just below the soil on the north side of the trench. This pocket contained a little more than 1 cubic foot of ore and may be a result of the upward movement of ground water by capillary action.

Gypsum is very scarce, but stringers and small nodules of caliche are abundant throughout the uppermost few feet of section exposed in the Korzekwa trench. In contrast, in the Hackney trench caliche is scarce, but gypsum is abundant.

Limonite is common throughout the beds and occurs both as small specks scattered throughout the sandstone and as streaks along bedding planes. The distribution of limonite and uranium in the beds is apparently unrelated.

A large ore body near the center of the Lyssy property belonging to the Nuhn deposit (fig. 1) is elongated parallel to the strike of the beds. A deep trench at the south end of the deposit exposed 10–15 feet of mineralized material, some above and some below the Conquista-Deweesville contact. The exposed Conquista section consists of slightly silty clay that underlies a zone of clayey silt. The basal 5–10 feet of Deweesville consists of intercalated sandy and silty beds very similar to those exposed in the Korzekwa trench. Above the basal intercalated zone of Deweesville is a 2- to 3-foot bed of sandstone covered by soil.

Uranium minerals are commonly visible in the sandstone and siltstone of the lower part of the Deweesville and in the clayey siltstone at the top of the Conquista. The occurrences of uranium minerals, caliche, and limonite in this deposit are similar to those described for the Korzekwa tract. Several closely spaced thin seams of manganese oxide could be traced for several feet along the wall of the Lyssy trench. The seams occur within the ore zone and are either parallel with the bedding planes or cut across them at a low angle.

During its drilling program, the Climax Molybdenum Co. discovered the Windmill ore body along the Gembler-Lyssy property boundary. At the time of field mapping, the only surface evidence of this deposit was a filled-in trench, drill holes, and an intense surface-radioactivity anomaly. After the fieldwork was completed, this ore body was mined by open pit, and geologic sections of the pits and other geologic observations were made by D. H. Eargle as mining progressed. This ore body was the first to be mined by the San Antonio Mining Co. and furnished much of the total production from the Nuhn deposit.

Beside the usual yellow, high-valent uranium minerals, the Windmill ore body contains, at a depth of about 40 feet, an appreciable quantity of sooty pitchblende. Figure 11 and the following columnar section furnished by Eargle show the stratigraphic position of the pitchblende.

Section of the Whitsett Formation in north wall of pit of the San Antonio Mining Co. Windmill ore body, Gembler property, Nuhn deposit, 9 miles airline southwest of Falls City, 2,000 feet west of Deweesville, Karnes County, Tex.

[Beds 1–3 constitute the ore zone. Measured by D. H. Eargle.]

	Feet
Deweesville Sandstone Member:	
7. Clay-conglomerate (channel-fill); coarse-grained sandstone matrix; clay blocks and boulders as much as 2 ft long, jumbled; sandstone lenses, some sandstone loose, some silicified after deposition; sharp very irregular lower contact, with as much as 4 ft of relief. Maximum thickness to top of cut	9
6. Clay, bentonite, very light gray; weathers white with irregular conchoidal fracture and smooth surface; faintly laminated, hackly, brittle; sharp contacts on top and bottom, bottom contact regular, manganese dioxide stains along top and bottom. Thickness varies with depth of scour preceding deposition of overlying bed	0–5
5. Sandstone, silty, very light olive gray, very fine grained, tuffaceous, laminated; contains fragments and some impressions of finely disseminated plant fragments; upper 1 ft contains manganese dioxide stains; *Ophiomorpha;* lenticular, slightly ferruginous, silicified at base, unit averages 6 inches in thickness, but varies 4 in. in thickness in 6 ft laterally	11
4. Siltstone, tuffaceous, carbonaceous, pale-chocolate to yellowish-orange-brown, clayey, very finely interlaminated with very fine grained sand; very carbonaceous 1.5–2.4 ft below top; lower contact wavy	4.5–7
3. Sandstone, very light gray, fine-grained, silty, soft, finely crossbedded, faintly laminated; basal contact sharp but wavy, with about 6 in. relief in 6 ft laterally; oxidized uranium minerals fill interstices between grains	10–12
Total Deweesville Sandstone Member exposed	34.5–39
Conquista Clay Member:	
2. Clay, silty, pale-brown, contains finely disseminated carbonaceous matter; upper 3 ft thin bedded, beds averaging 1–2 in. in	

Section of the Whitsett Formation in north wall of pit of the San Antonio Mining Co. Windmill ore body, Gembler property, Nuhn deposit, 9 miles airline southwest of Falls City, 2,000 feet west of Deweesville, Karnes County, Tex.—Continued

Conquista Clay Member—Continued

	Feet
thickness, maximum of 3 in.; vertically jointed; brown (ferruginous) staining and abundant autunite and other oxidized uranium minerals locally along bedding and joint planes; oxidized zone of bed below	4
1. Clay, medium-gray, laminated; contains silty streaks and lenses; locally, along bedding-plane surfaces of clay and in thin silty laminae, are smears, or vermiculate mottlings, of somewhat irridescent black mineral matter containing sooty uraninite	2
Total Conquista Clay Member exposed	6

All the deposits on the Nuhn lease lie along the Deweesville-Conquista contact updip from a deep clay-filled channel in the Deweesville Member (fig. 3). The other two facies of the Deweesville are also present within the Nuhn lease.

Where not eroded, the Deweesville Sandstone Member is 40–50 feet thick within the Nuhn lease. The beds strike from about N. 20° E. to N. 60° E. and dip southeast from 20 to 60 feet per thousand, but the slight change in attitude has no apparent effect on the distribution of ore minerals.

LUCKETT (CONTINENTAL OR LYSSY-NEISTROY) DEPOSIT

The Continental Oil Co. acquired the mineral lease for the Lyssy and Neistroy tracts northeast of Deweesville (fig. 1) from A. J. Luckett, of New Braunfels, Tex., trustee for the mineral rights. The Continental Oil Co. drilled several holes to explore a large surface radioactivity anomaly and discovered a sizable deposit, which was mined by Susquehanna-Western in 1961–62.

Cuttings from the drill holes were examined by Paul deVergie, of the U.S. Atomic Energy Commission, and much of the following description is based upon his work (deVergie, 1958). The maximum dimensions of the deposit, extended to include much low-grade material, are about 2,000 feet long, 800 feet wide, and 10 feet thick; the long dimension parallels the strike of the beds. The uranium ore is confined to a sandstone and siltstone zone of irregular thickness between the clay of the Conquista and an overlying clay zone within the Deweesville. Although this clay zone is wider and more sheetlike than the clay-filled channel (figs. 3, 4), the two features undoubtedly are closely related. The scouring and the lensing within the lower part of the Deweesville in the immediate vicinity of this deposit are similar to these features within the Deweesville at other deposits.

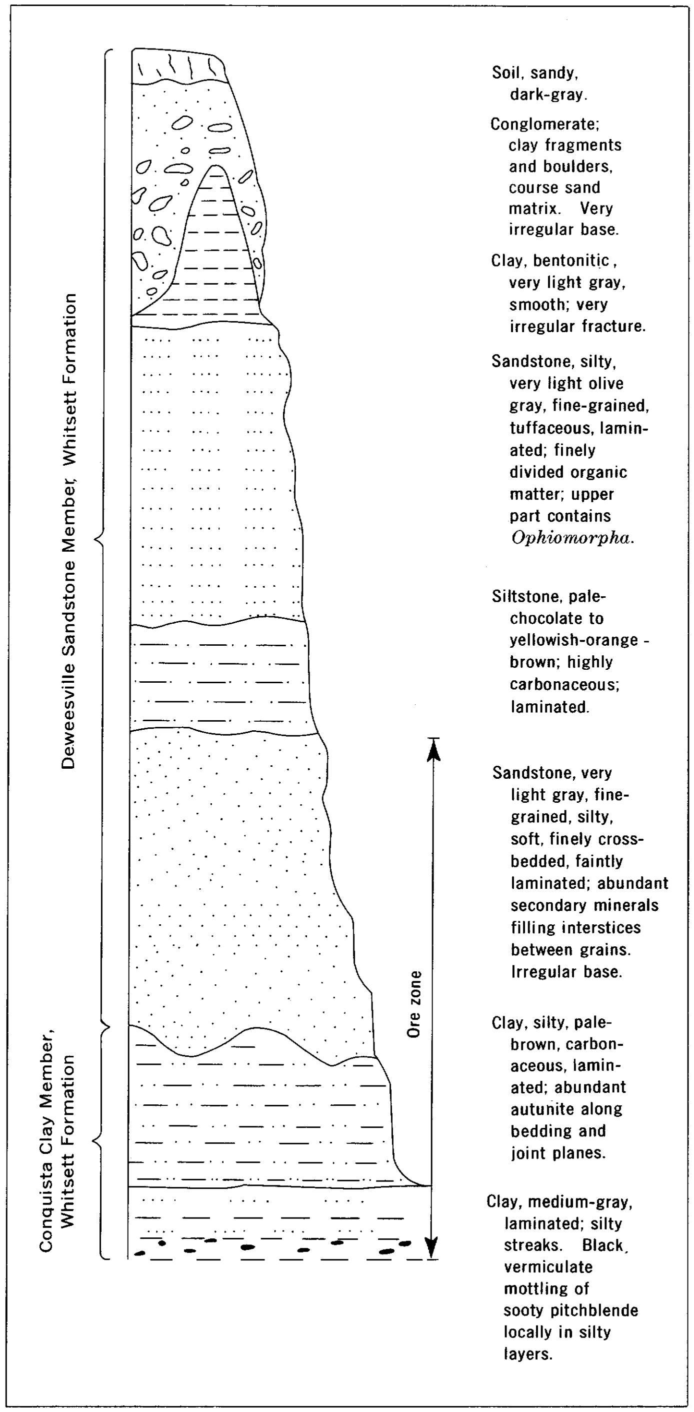


FIGURE 11.—Diagrammatic section, on north wall of pit in Windmill ore body, Gembler property, Nuhn deposit. Note channeling and scouring. Section by D. H. Eargle. Not to scale.

ORE CONTROLS

The most obvious factors that controlled uranium deposition are lithology, structure, and stratigraphy. In the Tordilla Hill-Deweesville area all the important known deposits occur near the Conquista-Deweesville contact. Most of the ore is within the lower part of the Deweesville Sandstone Member, which is fine grained to very fine grained sandstone with intercalated lenses of sandstone, silt, and clay. In some deposits an appreciable amount of uranium occurs locally where beds in the upper several feet of the Conquista Clay Member are mainly silt.

The spatial relationship of the three lithofacies of the Deweesville Member is an important local control. The deposits occur in or near the sandstone-silt-clay facies of the Deweesville, or lie within the clay-filled channel, or are found updip on the outer flank of a leveelike structure adjacent to the channel. The relation of the deposits to the channel suggests that the levee restricted the movement of uranium-bearing solutions through the relatively permeable Deweesville and that the resultant change in velocity contributed to the uranium precipitation. The channel and the uranium deposits lie in a north-trending belt. The higher grade uranium is in or slightly updip from the channel; no uranium was found nearby on the downdip side. Elsewhere, however, such as in sections B–60 to B–39 (pl. 1), where the levee is only slightly higher than the base of the Deweesville, the levee has no apparent effect on the deposition of the uranium. The lack of influence is emphasized by the extension of the radioactive zone through the clay which forms the levee.

The Nuhn deposit on the Lyssy-Korzekwa properties is a few hundred feet updip from the clay-channel facies (fig. 12) and has been emplaced mainly within the sandstone-silt-clay facies. The Bargmann-Hackney deposit is a few hundred feet updip from the clay-filled channel facies and probably is in the sandstone-silt-clay facies, though this relationship has been obscured by erosion. Much of the uranium in the Hackney deposit is in a medium-grained sandstone of the sandstone-silt-clay facies. The clay-filled channel facies has not been detected near the Hackney deposit, but a clay zone, exposed by exploration, may be related to the channel.

The channel and the sandstone-silt-clay facies apparently extend northeastward from Deweesville through the area of the Luckett deposit. Work by deVergie (1958, fig. 3) shows in the middle part of the Deweesville Member a 10- to 20-foot-thick zone of clay and silt that corresponds to the sandstone-silt-clay facies described herein. In the area of the Luckett deposit, the channel filling becomes siltier, thinner, and wider, grading laterally into the sandstone-silt-clay facies.

The deposits are in beds that are transitional (both vertically and horizontally) between strata of moderate permeability and strata of relatively low permeability.

The relation between uranium grade (percent eU_3O_8) and rock type was examined statistically (fig. 13). Uranium in the grade range of 0.010–0.049 percent eU_3O_8 is about evenly distributed in sandstone, sandy clay, and clay. Layers of uranium minerals cross lithologic contacts, thereby indicating no apparent lithologic control over their deposition for this grade.

Uranium minerals in the grade range 0.05–0.099 percent eU_3O_8 are found in all three lithologies but occur less in clays; thus their deposition may have been controlled to some extent by decreasing permeability below the layers of uranium. In some places depositional control is the base of the oxidized zone (pl. 1, section B–56 to B–50); elsewhere, layers of

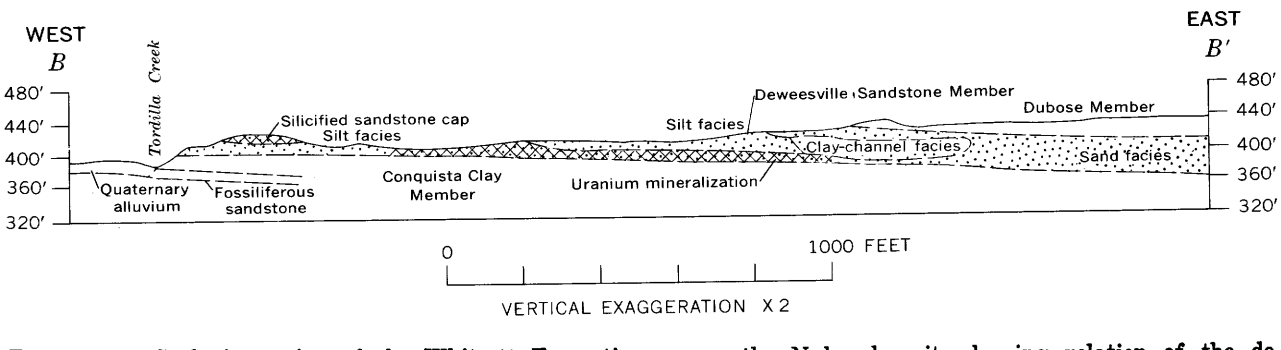


FIGURE 12.—Geologic section of the Whitsett Formation across the Nuhn deposit, showing relation of the deposit to the clay-channel facies and to the sand-silt-clay facies. Deweesville Sandstone Member is shown by dot pattern; uranium mineralization by crosshatch. Line of section shown on figure 1. Modified from MacKallor, Moxham, Tolozko and Popenoe (1962).

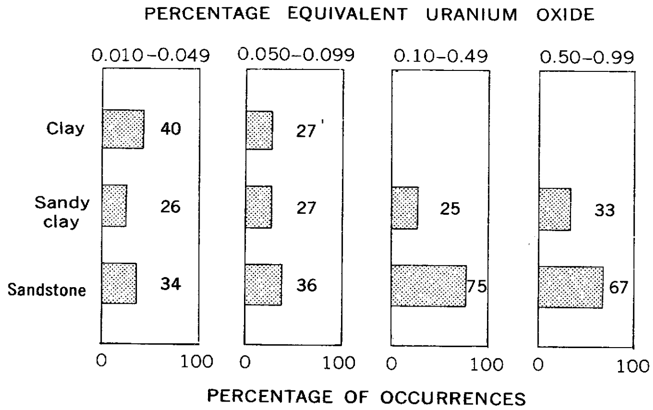


FIGURE 13.—Relation between uranium grade and rock type.

this grade cross lithologic contacts with no apparent depositional control.

Uranium above 0.10 percent grade is found only in sandstone and sandy clay, thereby indicating lithologic control. In sections B–60 to B–39 and B–56 to B–50 (pl. 1), the uranium is in a fairly continuous zone that follows the general dip of the beds. The zone is apparently unaffected by local undulations in the vertical position of the stratigraphic contact. In section B–56 to B–50 the uranium in the grade range 0.10–0.49 percent eU_3O_8 occurs mainly in sand but intersects undulations in an underlying sandy clay. Uranium in the highest grade range, 0.50–0.99 percent eU_3O_8, occurs in discontinuous zones in sandstone and sandy clay, but does not occur in clay.

The extent of structural control of ore deposition is not easily assessed. Vertical jointing had some minor influence in determining the exact shape of the deposits, and the strike of the beds in most instances coincides with the direction of elongation of the deposits. The clay channel that cuts through the Deweesville Member probably impeded or diverted the movement of ground water in a manner that favored a strike-oriented trend for major ore deposition. The concentration of deposits in the warped block between the ends of the Falls City and Fashing faults may also reflect the control of ground-water movement on mineral deposition.

In the Tordilla Hill-Deweesville area and in the central coastal plain area as a whole, the principal known uranium deposits are in the basal part of the Deweesville Sandstone Member and the upper part of the Conquista Clay Member of the Whitsett Formation. Evidently the rocks laid down during this geologic interval provided the environment required for a uranium host, and it is in this sense that the term "stratigraphic control" is used. Perhaps more correctly, such stratigraphic control represents a summation of favorable lithologic factors and the necessary geochemical environment for the formation of uranium deposits.

ORIGIN OF THE URANIUM DEPOSITS

Volcanic tuff was deposited in a terrestrial or shoreline environment during Jackson time. Glassy material of this sort is fairly unstable, particularly if exposed to alkaline carbonate ground water similar to that now existing in the coastal plain area. It is postulated that uranium and silica were released from the glass during diagenetic processes, as evidenced by widespread devitrification of the glass, silicification, and zeolitic alteration.

The uranium in the interstitial fluid was transported to a favorable depositional environment, apparently provided in part by permeability traps and by reducing agents—perhaps organic material, hydrocarbons, hydrogen sulfide, and pyrite in the host rocks or hydrogen sulfide originating in the Edwards Limestone (associated with the Fashing-Edwards gas-distillate field). The depositional environment would tend to minimize loss of uranium to the open sea.

Tertiary volcanic material provides a source of uranium. A theory of leaching of uranium from tuff has been presented by Waters and Granger (1953) and by McKelvey, Everhart, and Garrels (1955, p. 499–501). Denson and Gill (1965, p. 67) concluded that uranium was leached from Oligocene and Miocene volcanic ash, transported laterally and downward, and then precipitated in carbonaceous rocks (lignite) in the southwestern part of the Williston basin of the northern Great Plains. The Eocene and Miocene rocks of the Texas coastal plain contain a considerable amount of tuff and other volcanic debris (Eargle, 1959b).

On the basis of a study of idiomorphic zircon, Callender and Folk (1958) stated that volcanism was more pronounced during deposition of the Eocene Yegua Formation (at the top of the Claiborne Group) and younger formations than during deposition of the Eocene Sparta Sand (near the middle of the Claiborne Group) and older formations. Their study supports the theory that most of the uranium was leached from the Jackson (younger than the Yegua) and younger rocks, rather than from rocks stratigraphically below the ore-bearing Jackson Group.

Although chemical analyses of weathered and unweathered rock outside the mineralized area are not available, an assumption that about 5 ppm U was leached from the more tuffaceous units of the Tertiary sediments is reasonable. Denson and Gill (1956, p. 417) stated that the Arikaree Formation and the White River Group of eastern Montana and the Dakotas contain an average of about 0.0015 percent (15 ppm) uranium, which is 12 times the average for sedimentary rocks. According to Larsen and Phair (1954, p. 75), Denson and Gill (1965, p. 58), Doe (1967, p. 62), and Rosholt and Noble (1969), 6–7 ppm U is a more realistic maximum concentration for silicic glassy igneous rocks. Larsen and Phair (1954, p. 80) stated that as much as 40 percent of the uranium in most fresh-appearing igneous rocks is readily leachable.

If the tuffaceous rocks of the Texas coastal plain originally contained 6–7 ppm U and if from ⅓ to ½ of that uranium were in a state available for leaching, about 3 ppm U could be leached from the tuffaceous sediments and would be available to form a uranium deposit.

The tuffaceous rocks of the Texas coastal plain are a quantitatively adequate source for the uranium contained in the deposits in the Tordilla Hill-Deweesville area. Consider a slab of sandstone of the Deweesville 40 feet thick (the average thickness), extending about 20,000 feet along the strike from the base of Tordilla Hill to the Luckett deposit (fig. 1) and extending updip for 5,000 feet. If the rock averages 14 cubic feet per ton and if 3 ppm U is readily leached, this one slab would make available more than 840 tons of the element uranium, which is considerably more than the uranium contained in the 250,000 tons of inferred ore (Moxham, 1958, p. 816) for the Karnes County–Atascosa County area. Admittedly, the quantity of uranium in nonore grade rock may be several times as large as the quantity of uranium within the deposits, but the source material was not confined to the Deweesville, and much of the leached uranium well may have moved more than 5,000 feet downdip before redeposition.

A magmatic theory was considered, but there are no known igneous intrusions to support such a theory, and an aeromagnetic survey made at the same time as the aeroradioactivity survey (Moxham and Eargle, 1961) did not indicate buried igneous rocks. If uranium were introduced into the Jackson rocks by solutions coming from a deeply buried unknown magmatic source, one might find evidence of the pathways or channels traversed by the magmatic solutions. The Falls City and the Fashing faults are logical pathways, and if they served such a purpose for uraniferous solutions, one would expect to find at least a slight contrast in radioactivity on opposite sides of the faults. Neither these nor any other major faults in the immediate area can be detected from the radioactivity pattern (Moxham and Eargle, 1961); but several radioactive anomalies, including a small uranium deposit in Live Oak County to the south, occur along faults. These occurrences may be due to the coincidence of faulting and the retardation of ground water plus seepage of a precipitant along the faults.

TRANSPORTATION AND DEPOSITION OF URANIUM

Much of the present ground water in the area is of an alkaline carbonate type (Anders, 1960, table 7), which is an excellent leaching and transporting agent for uranium. The water probably became alkaline by the leaching of volcanic material in the Tertiary rocks, and similar alkaline carbonate waters would have existed in the past.

Regardless of the original source of the uranium, it eventually was added to alkaline carbonate ground water, probably as a uranyl ($U^{+6}O_2$) ion. As the ground water migrated downdip, the uranium precipitated in chemically and physically favorable reducing environments. According to A. M. D. Weeks (oral commun., 1958), some reducing agent is needed to trigger precipitation of uranium. Although reduced carbonate content of the ground water may have been an important factor in determining the general area in which uranium was deposited, the actual site of deposition requires the presence of a reducing agent. Carbonate can be lost if by release of pressure, carbon dioxide gas escapes; such loss would cause calcite precipitation, even if the solubility were decreased by the loss of sulfate and carbonate radicals. Hydrogen sulfide in natural gas will produce the reducing environment required for precipitating uranium.

In the southern Black Hills, Gott (1956, p. 8) found that uranium occurred in carbonate-poor sandstones marginal to sandstones that were well indurated with calcium carbonate cement. This relationship suggests (Gott, 1956, p. 3–4) that solutions that precipitated calcium carbonate also precipitated uranium. In the Tordilla Hill-Deweesville area, however, no calcium carbonate cement was observed in the ore deposits, and only very small stringers of caliche occur near the surface. Calcium carbonate cement was observed in outcrop only in the sandy, fossiliferous unit of the Conquista Clay Member and was not observed in the ore zone, the Deweesville Sandstone Member. If precipitation of calcium carbonate was a factor in uranium deposition in the Karnes County area, precipitation of the calcium carbonate would have occurred generally updip from the uranium deposits in part of the Deweesville now removed by erosion. Any calcium carbonate deposited near the uranium deposits in beds not yet eroded might have been removed by meteoritic water, just as caliche in the Catahoula Tuff a few miles from the deposits is now being destroyed. A few of the deeper sandy cores from the "K" holes, downdip from the uranium deposits, did contain a few stringers of fibrous calcite and calcium carbonate cement; mainly from depths greater than 150 feet.

A significant quantity of reducing material is required to form an ore deposit. Tests show that natural gases, principally those that contain hydrogen sulfide, but maybe hydrogen to a lesser extent, will precipitate uraninite at the gas-liquid interface (Sims and Smith, 1956). Hydrogen sulfide undoubtedly was an important reducing agent for the Karnes County deposits. A possible source is the Fashing-Edwards field, which produces a sour-gas distillate from the Edwards Limestone of Cretaceous age. This field is only about 1 mile downdip from the deposits but is at an elevation of —10,380 to —9,780 feet (Pinkley, 1958, p. 40). Sour gas from this field may have migrated up the Fashing fault zone and then updip in permeable beds such as the Deweesville Member.

D. H. Eargle (written commun., 1971), however, believes this is an unlikely source of the reducing agent and says,

> Although migration upward from the Edwards Limestone in the Fashing gas field has been postulated, it is not likely that this was the source of the hydrogen sulfide. The principal argument against this source is that the same fault traps sweet gas in the Carrizo Sand 7,500 feet higher in section. Apparently enough hydrogen sulfide is generated in the higher beds to create the reducing environment necessary to precipitate the uranium.

Hydrogen sulfide may have been generated locally from organic matter in the clayey parts of the Jackson Group rather than brought into the ore beds from the Fashing-Edwards gas field. Either or both sources of hydrogen sulfide are geologically feasible. A strong odor of hydrogen sulfide was detected coming from a shallow water well a short distance downdip from the deposits. The presence of the well in the Whitsett Formation strengthens the idea that hydrogen sulfide played an important role in forming the deposits.

Organic derivatives of either animal or vegetable material may have been reducing agents. Garrels and Christ (1956, p. 300) stated, "It appears that most materials derived from wood are effective precipitants of uranium from migrant solutions * * *." The evidence is that wood, per se, was not an important reducing agent in the Karnes County area. Although silicified wood occurs in most of the Jackson beds, it rarely contains anomalous amounts of uranium, and the occurrence of uranium mostly in cracks indicates deposition after silicification. Most of the deeper cores (from five holes drilled by the U.S. Geological Survey) of silt and clay contained organic derivatives, indicated by a petroliferous odor. A partial explanation for the occurrence of the uranium deposits in sand and silt overlying clay is that reducing fluids formed in the clay, which was comparatively rich in organic material, and migrated upward into permeable sands, where they precipitated uranium from ground water in those sands.

In addition to the previously mentioned gas-distillate field, there are two oil fields, one producing from the Wilcox Group of Eocene age along the same fault zone and another producing from the Wilcox along the Falls City fault. No evidence has been found, however, that petroleum, per se, was an important factor in formation of the uranium deposits, either as a transporting medium or as a reducing agent. Two of the samples collected by Climax Molybdenum Co. from its drill holes near uranium deposits contained grains of a black vitreous substance that burned with a smoky flame. This asphaltite, probably a petroleum residue, contained no anomalous radioactive elements.

Scattered small grains of pyrite, a good reducing agent for uranium, were observed with a hand lens at the Hackney deposit and in many of the clayey and silty cores from the "K" holes. Although pyrite is widespread, the percentage of pyrite in the occurrences observed is too low for the pyrite to have been the major reducing agent for the Karnes County deposits. Locally, where concentrations are high, pyrite might have been an important reducing agent—at the Hackney deposit, for example. Although only an insignificant amount of pyrite is now in the rocks there, some of the high-grade material, both silicified and nonsilicified, is heavily coated with deep-yellowish-brown limonite, which may be an alteration product of pyrite.

A. M. D. Weeks (oral commun., 1959) suggested that uranium might be removed from ground water by adsorption on clay, but it is difficult to see how this process alone could form a significant deposit in silty or sandy rocks.

GEOLOGIC DEVELOPMENT OF THE DEPOSITS

The source of the Eocene sediments must have been a combination of erosional debris from olde sedimentary rocks to the northwest or west (D. H. Eargle, written commun., 1969) and of clastic volcanic material. The sediments locally contained considerable organic material, as evidenced by lignitic material, molds of plant remains, silicified wood, small round masses of asphalt, and thin coquinas of *Corbicula, Ostrea,* and gastropods. Volcanic activity to the west and southwest, chiefly in northern Mexico and western Texas, contributed much ash and sand-sized volcanic material to the area. Some of this material fell directly into shallow bays and estuaries, but most of it was deposited on land. The fine unconsolidated volcanic debris was quickly picked up by streams and, along with other detrital sediments, quickly transported to the shallow marine environment where it was deposited before fresh water had a chance to leach the volcanic material. Rapid burial prevented uranium from being leached by the sea water. Slight transgressions and regressions of the sea in Jackson times, as well as the very nature of shallow-water nearshore deposits, resulted in intercalations of sand, silt, and clay.

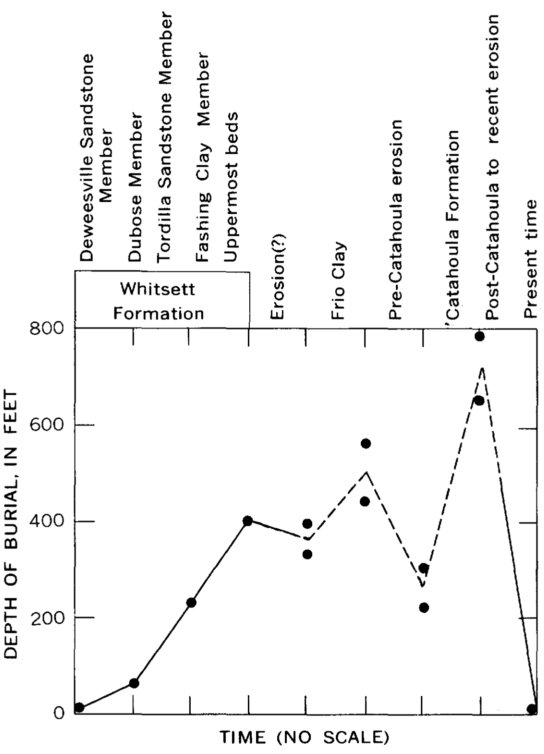


FIGURE 14.—Depth of burial of basal part of the Deweesville Sandstone Member from the start of Deweesville time to the present in the Tordilla Hill-Deweesville area. Graph line dashed where drawn between two possible depths as shown by heavy dots.

In Oligocene time, conditions were more stable than during Jackson time, and the dominant sediment deposited was clay. Ash in the upper part of the Oligocene(?) Frio Clay is evidence of some volcanic activity. At the end of Frio deposition, the Deweesville Sandstone Member of the Jackson Group was covered by approximately 600 feet of sediments (fig. 14). Fresh water began to enter the Jackson rocks at about this time, probably shortly before deposition of the Catahoula Tuff.

Shallow ground waters flowed laterally toward streams, but deeper ground water flowed downdip, leaching elements from the volcanic material. The waters moving downdip were locally diverted, guided by clayey aquicludes and retarded by permeability barriers where there were facies changes and structural anomalies. Sodium was added by a process of base exchange (Renick, 1924). Eventually a sodium carbonate ground water, containing small amounts of uranium, molybdenum, and other elements, was developed. This ground water was under sufficient hydrostatic pressure to replace some of the connate water. Although most of the movement of ground water was downdip, there was some movement between units. For example, some water in the Dubose Member may have entered the sandstone of the Deweesville by flowing from one lens of sandstone to other contiguous, but lower, lenses until it reached the Deweesville; and the ground water in the Catahoula Tuff of Miocene age may have moved into lower stratigraphic units (fig. 15).

Upon passing through a physically and chemically favorable environment, uranium and other elements were precipitated. Inasmuch as most of these favorable environments were below the water table, some of the uranium was precipitated as pitchblende and other minerals in which the uranium has a valence of +4; some of the uranium, however, may have been absorbed by clay. Except in rare cases, the deposited uranium was widely scattered in small quantities.

Although the water table fluctuated during climatic cycles, the overall tendency was for it to drop in relation to the stratigraphic units, as a result of the lowering of the land surface by erosion. When the water table dropped below the precipitated uranium, the minerals were unstable in the oxidizing environment, and new oxidized minerals were formed. Because vanadium was scarce, mostly water-soluble

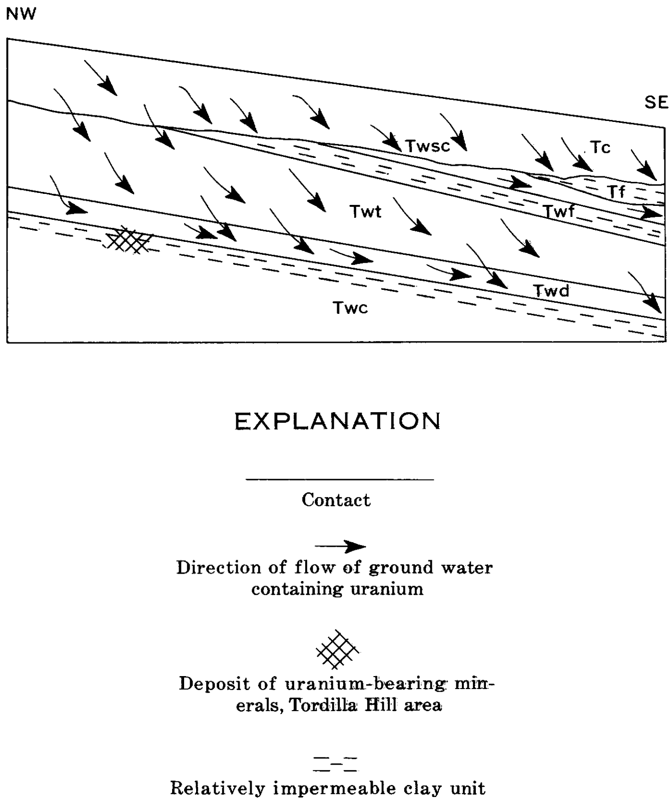


FIGURE 15.—Diagrammatic section along the southwest boundary of Karnes County at the end of Catahoula time, showing movement of ground water. Tc, Catahoula Tuff. Tf, Frio Clay. Whitsett Formation: Twsc, upper sandstone and claystone; Twf, Fashing Clay Member; Twt, Tordilla Sandstone Member; Twd, Deweesville Sandstone Member; Twc, Conquista Clay Member.

minerals, rather than carnotite, were formed. These newly formed minerals may have been taken into solution and almost immediately reprecipitated, either as a result of evaporation of the vadose water or by chemical reaction with a nearby reducing material. Sooner or later, however, the uranium was carried by vadose water back to the ground water where it was again reprecipitated, and another cycle was completed.

Under certain conditions uranium was lost or permanently removed from this cycle of temporary deposition and solution. Such a loss is occurring today in the Karnes County area. When the land surface is lowered faster than uranium in the oxidized zone is added to the ground water, some of the uranium eventually reaches the surface to form an outcrop and is then eroded and carried away by surface water.

The slower the rate of erosion, the more time a favorable reducing zone had to deposit or "trap" uranium from migrating ground water. Eventually, however, erosion lowered the surface so that the deposited uranium minerals were in the zone of oxidization above the water table. Under these conditions the uranium minerals were unstable and were eventually taken into solution and redeposited in another favorable reducing environment downdip from the previous site. The trend is for the later deposits to be larger and richer than the first ones formed, for the first ones had a source of uranium only from the tuffaceous material. Later deposits had an additional source of uranium from the preexisting concentrations or deposits.

An arid climate results in less vadose water to carry the uranium to the ground water; if evaporation were greater than precipitation, capillary action would move the uranium toward the land surface rather than toward the water table. This has been happening in the Karnes County area, where a high-grade pod of yellow uranium mineral (autunite?) has formed just below the surface at the Korzekwa trench. Isotopic analyses by Rosholt (in Weeks and Eargle, 1963) also show that near-surface uranium recently has been moving.

The climate of the last few thousands of years has been such that uranium in the oxidized zone has not been moving down as fast as erosion has lowered the surface. Consequently, some uranium is being carried out of the area by both Tordilla Creek and Scared Dog Creek. A water well on the Korzekwa property a short distance downdip from the deposit contains 96 ppb (parts per billion) uranium, which indicates that some of the uranium is being removed by ground water from the deposit.

The data (pl. 1, section H–13 to B–24) show some evidence that the radioactive minerals have been deposited recently and that they are probably in transit at present. Between holes B–24 and H–4, the layer of anomalous radioactivity intersects at least two lithologic contacts, including the contact between the Deweesville and the Conquista Members. The base of the radioactive layer parallels that contact and is restricted to the oxidized zone. Between drill holes H–9 and H–11 the radioactive layer parallels the topographic slope instead of the stratigraphic dip; this relationship suggests that surface water is leaching radioactive minerals from the area near H–9 and that the minerals are being redeposited at present in the vicinity of hole H–10.

Evidence of leaching of uranium minerals from a deposit by ground water movement is illustrated at drill hole H–7 (section H–13 to B–24, pl. 1). A depression in the base of the Deweesville may cause an accumulation of surface water, thereby permitting a greater quantity to enter the underlying Conquista at this location than elsewhere. The leached minerals appear to have moved downward from the depression into the Conquista and to have proceeded from there downdip.

The relative permeability of the host rock and of the underlying rock may have been a controlling factor in the deposition of the uranium minerals. The base of most uranium layers follows an inclined plane which sometimes follows a distinct lithologic contact. In many locations the uranium occurs in a relatively permeable sandy layer underlain by a less permeable clayey layer.

Another example of uranium minerals being leached from a deposit and moved down the topographic slope instead of following the geologic dip is shown in section S–40 to B–28 (pl. 1). The Hackney deposit is about 200 feet east of hole B–28 beyond the left end of the illustrated section. The high-grade ore is in the basal part of the Deweesville Sandstone Member and the lower grade material extends into the Conquista Clay Member. The ore is near the surface of the ground, at an elevation higher than that of the drill collar of hole B–28. Erosion along the topographic slope has truncated the strata that crop out along the section. Fragmental debris from the outcropping strata has been transported by surface water westward and redeposited down the slope. The waterborne uranium leached from the Hackney property follows the surficial alluvium lying on the truncated layer of impermeable clay between holes B–28 and S–29. Between S–29 and S–30 the uranium apparently entered the permeable sandstone of the Conquista, and its movement along the topographic slope virtually terminated at hole S–30. The layer of anomalous radioactivity that parallels the topographic surface at a depth of about 10–15 feet between S–27 and S–31 seems to originate locally from the fossiliferous sandstone between holes S–27 and S–28. This origin suggests strongly that the uranium has moved downdip from the radioactive layer at the surface along the contact of the fossiliferous sandstone unit and the clay of the Conquista Member between drill holes S–29 and S–28.

REFERENCES CITED

Anders, R. B., 1960, Ground-water geology of Karnes County, Texas: Texas Board of Water Engineers Bull. 6007, 107 p.

Bell, K. G., Rhoden, V. C., McDonald, R. L., and Bunker, C. M., 1961, Utilization of gamma-ray logs by the U.S. Geological Survey, 1954–53: U.S. Geol. Survey open-file report, 89 p.

Billings, M. P., 1946, Structural geology (second printing): Prentice-Hall, Inc., 473 p.

Brown, R. D., Jr., Eargle, D.H., and Moxham, R.M., 1961a, Preliminary aeroradioactivity and geologic map of the Falls City NW quadrangle, Atascosa, Karnes, and Wilson Counties, Texas: U.S. Geol. Survey Geophys. Inv. Map GP–249.

———1961b, Preliminary aeroradioactivity and geologic map of the Falls City NE quadrangle, Karnes and Wilson Counties, Texas: U.S. Geol. Survey Geophys. Inv. Map GP–250.

Callender, D. L., and Folk, R. L., 1958, Idiomorphic zircon, key to volcanism in the lower Tertiary sands of central Texas: Am. Jour. Sci., v. 256, no. 4, p. 257–269.

Crutchfield, J. W., and Bowers, E. F., 1950, Performance of the Lower Pawelek Reservoir, Falls City Field, Karnes County, Texas: Am. Inst. Mining Metall. Engineers Trans., v. 189, p. 335–344.

Denson, N. M., and Gill, J. R., 1956, Uranium-bearing lignite and its relation to volcanic tuffs in eastern Montana and North and South Dakota, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 413–418.

———1965, Uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston basin—a regional study: U.S. Geol. Survey Prof. Paper 463, 75 p.

deVergie, P. C., 1958, Some developments in uranium ore studies in Karnes County, Texas, *in* South Texas Geol. Soc., Fall Field Trip Dec. 1958, p. 23–29.

Doe, B. R., 1967, The bearing of lead isotopes on the source of granitic magma: Jour. Petrology, no. 8, pt. 1, p. 51–83.

Eargle, D. H., 1955, Stratigraphy [Karnes County, Texas]: U.S. Geol. Survey Rept. TEI–540, p. 135–139.

———1958, Regional structure and lithology in relation to uranium deposits, Karnes County area, Texas [abs.]: Econ. Geology, v. 53, no. 7, p. 919.

———1959a, Sedimentation and structure, Jackson Group, south-central Texas: Trans. Gulf Coast Assoc. Geol. Soc., v. 9, p. 31–39.

———1959b, Stratigraphy of Jackson group (Eocene), south-central Texas: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 11, p. 2623–2635.

———1970, Recent developments in uranium in south Texas: South Texas Geol. Soc. Bull., v. 10, no. 6, p. 3–6.

———1972, Revised classification and nomenclature of the Jackson Group (Eocene), south-central Texas: Am. Assoc. Petroleum Geologists Bull., v. 56, no. 3, p. 561–566.

Eargle, D. H., and Snider, J. L., 1957, A preliminary report on the stratigraphy of the uranium-bearing rocks of the Karnes County area, south-central Texas: Texas Univ., Bur. Econ. Geology, Rept. Inv. 30, 30 p.

Eargle, D. H., and Weeks, A. D., 1961a, Uranium-bearing clays and tuffs of south-central Texas, *in* Field excursion, central Texas, October 1961: Texas Univ. Bur. Econ. Geology Guidebook 3, p. 19–30.

———1961b, Possible relation between hydrogen sulfide-bearing hydrocarbons in fault-line oil fields and uranium deposits in the southeast Texas coastal plain, *in* Short papers in the geological and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D7–D9.

Eargle, D. H., Trumbull, J. V. A., and Moxham, R. M., 1961a, Preliminary aeroradioactivity and geologic map of the Floresville SE quadrangle, Karnes and Wilson Counties, Texas: U.S. Geol. Survey Geophys. Inv. Map GP–246.

———1961b, Preliminary aeroradioactivity and geologic map of the Stockdale SE quadrangle, Karnes, De Witt, and Wilson Counties, Texas: U.S. Geol. Survey Geophys. Inv. Map GP–248.

———1961c, Preliminary aeroradioactivity and geologic map of the Karnes City NW quadrangle, Karnes County, Texas: U.S. Geol. Survey Geophys. Inv. Map GP–251.

Ellisor, A. C., 1933, Jackson group of formations in Texas, with notes on Frio and Vicksburg: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 11, p. 1293–1350.

Finch, W. I., 1955, Karnes County, Texas: U.S. Geol. Survey Rept. TEI–540, p. 134–135.

Fix, P. F., 1955, Uranium in natural waters: U.S. Geol. Survey Rept. TEI–540, p. 200–202.

———1956, Uranium in natural waters: U.S. Geol. Survey Rept. TEI–620, p. 279–280.

Garrels, R. M., and Christ, C. L., 1956, Field studies on the origin of primary uranium ores in the western United States, *in* Semiannual progress report for June 1 to November 30, 1956: U.S. Geol. Survey TEI–640, p. 300–301, issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Gott, G. B., 1956, Inferred relationship of some uranium deposits and calcium carbonate cement in southern Black Hills, South Dakota: U.S. Geol. Survey Bull. 1046–A, 8 p.

Hilpert, L. S., and Bunker, C. M., 1957, Effects of radon in drill holes on gamma-ray logs [N. Mex.]: Econ. Geology, v. 52, no. 4, p. 438–445.

Knebel, R. M., 1957, Deep Edwards reservoir in shallow country: Oil and Gas Jour., v. 55, no. 1, p. 166.

Larsen, E. S., Jr., and Phair, George, 1954, The distribution of uranium and thorium in igneous rocks, *in* Faul, Henry, ed., Nuclear geology: John Wiley & Sons, Inc., p. 75–89.

Luders, Von K., 1934, Uber das Wandern der Priele: Abh. Naturwiss., verein zu Bremen, 29, p. 19–32.

MacKallor, J. A., and Bunker, C. M., 1958, Ore controls in the Karnes County uranium area, Texas [abs.]: Geol. Soc. American Bull., v. 69, no. 12, pt. 2, p. 1607.

MacKallor, J. A., Eargle, D. H., and Moxham, R. M., 1958, Texas Coastal Plain geophysical and geologic studies—semiannual progress report, June 1 to Nov. 30, 1958: U.S. Geol. Survey Rept. TEI–750, p. 78–87.

MacKallor, J. A., Moxham, R. M., Tolozko, L. R., and Popenoe, P. P., 1962, Radioactivity and geologic map of the Tordilla Hill-Deweesville area, Karnes County, Texas: U.S. Geol. Survey Geophys. Inv. Map GR–199.

McKelvey, V. E., Everhart, D. L., and Garrels, R. M., 1955, Origin of uranium deposits, *in* Part 1 *of* Bateman, A. M., ed., Economic geology, 50th anniversary volume, 1905–55: Urbana, Ill., Economic Geology Pub. Co., p. 464–533.

McKinstry, H. E., 1948, Mining geology: Prentice-Hall, Inc., 680 p.

Manger, G. E., 1958, A comparison of the physical properties of uranium-bearing rocks in the Colorado Plateau and Gulf Coast of Texas [abs.]: Econ. Geology, v. 53, no. 7, p. 922–923.

Manger, G. E., and Eargle, D. H., 1967, Physical and associated properties of uranium-bearing rock in five drill holes in Karnes County, Texas: U.S. Geol. Survey open-file report, 19 p.

Maxwell, R. A., 1962, Mineral resources of south Texas—Region served through the Port of Corpus Christi: Texas Univ. Bur. Econ. Geology Rept. Inv. 43, 140 p.

Moxham, R. M., 1958, Geologic evaluation of airborne radioactivity survey data, *in* United Nations Survey of raw material resources: U.N. Internat. Conf. Peaceful Uses of Atomic Energy, 2d, Geneva, Sept. 1958, Proc., v. 2, p. 814–819.

———1964, Radioelement dispersion in a sedimentary environment and its effect on uranium exploration: Econ. Geology, v. 59, no. 2, p. 309–321.

Moxham, R. M., and Eargle, D. H., 1961, Airborne radioactivity and geologic map of the Coastal Plain area, southeast Texas: U.S. Geol. Survey Geophys. Inv. Map GP–198.

Moxham, R. M., Eargle, D. H., and MacKallor, J. A., 1957, Texas Coastal Plain geophysical and geologic studies—semiannual progress report, Dec. 1, 1956 to May 31, 1957: U.S. Geol. Survey Rept. TEI–690, p. 445–457.

———1958, Texas Coastal Plain geophysical and geologic studies—semiannual progress report, Dec. 1, 1957 to May 31, 1958: U.S. Geol. Survey Rept. TEI–740, p. 217–227.

Moxham, R. M., MacKallor, J. A., and Tolozko, L. R., 1957, Radioactivity surveys and their relation to geologic features, Texas Coastal Plain [abs.]: Geol. Soc. Am. Bull., v. 68, no. 12, p. 1770.

Pinkley, G. R., 1958, Geologic studies, surface and subsurface, Fashing field area, Atascosa County, Texas, *in* South Texas Geol. Soc., Fall Field Trip Dec. 1958, p. 30–41.

Renick, B. C., 1924, Base exchange in ground water by silicates as illustrated in Montana: U.S. Geol. Survey Water-Supply Paper 520d, p. 53–72.

Rosholt, J. N., 1963, Uranium in sediments: U.S. Geol. Survey open-file report, 211 p.

Rosholt, J. N., and Noble, D. C., 1969, Loss of uranium from crystallized silicic volcanic rocks: Earth and Planetary Sci. Letters, v. 6, no. 4, p. 268–270.

Russell, R. J., 1936, Lower Mississippi River delta, *in* Reports on the geology of Plaquemines and St. Bernard Parishes: Louisiana Geol. Survey Geol. Bull. 8, 453 p.

Shepard, F. P., 1953, Sedimentation rates in Texas estuaries and lagoons: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 8, p. 1919–1934.

Shepard, F. P., and Rusnak, G. A., 1957, Texas bay sediments: Inst. Marine Sci. Pub., v. 4, no. 2, p. 5–13.

Sims, H. M., and Smith, F. L., 1956, Studies regarding the role of Wyoming natural gas in precipitating uranium minerals from pregnant solutions: RME–3143, issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn., 58 p.

Steinhauser, S. R., and Beroni, E. P., 1955, Preliminary report on uranium deposits in Gulf Coastal Plain, southern Texas: U.S. Atomic Energy Comm. Rept. RME–1068, 43 p., issued by Tech. Inf. Service, Oak Ridge, Tenn.

Straaten, L. M. J. U., van, 1949, Quelques particularité du relief sous-marin de la mer des Wadden (Hollande): Comptes du Congres de Sediment. et Quat. en France, p. 139–145.

———1951, Texture and genesis of Dutch Wadden Sea sediments: Proc. 3d Internat. Cong. Sedimentology, Nederlands, p. 225–244.

Trumbull, J. V. A., Eargle, D. H., and Moxham, R. M., 1961, Preliminary aeroradioactivity and geologic map of the Stockdale SW quadrangle, Karnes and Wilson Counties, Texas: U.S. Geol. Survey Geophys. Inv. Map GP–247.

Waters, A. C., and Granger, H. C., 1953, Volcanic debris in uraniferous sandstones, and its possible bearing on the origin and precipitation of uranium [Colorado Plateau]: U.S. Geol. Survey Circ. 224, 26 p.

Weeks, A. D., and Eargle, D. H., 1963, Relation of diagenetic alteration and soil-forming processes to the uranium deposits of the southeast Texas Coastal Plain, *in* Clays and clay minerals, Natl. Conf. clays and clay minerals, 10th, 1961, Proc.: New York, Macmillan Co., p. 23–41.

Weeks, A. M. D., Levin, Betsy, and Bowen, R. J., 1958, Zeolitic alteration of tuffaceous sediments and its relation to uranium deposits in the Karnes County area, Texas [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1659; also Econ. Geology, v. 53, no. 7, p. 928–929.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, no. 5, p. 377–392.