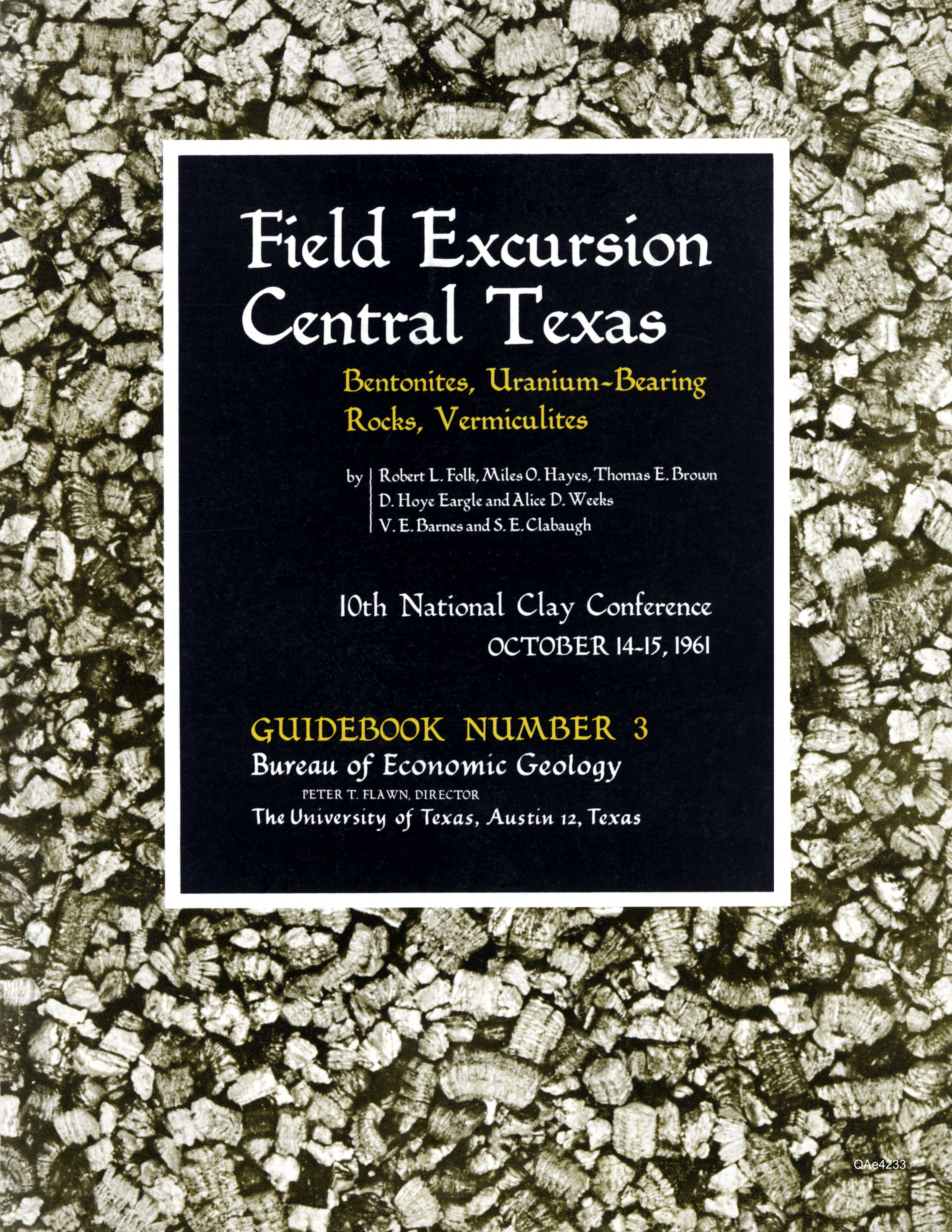

Field Excursion Central Texas

Bentonites, Uranium-Bearing Rocks, Vermiculites

by Robert L. Folk, Miles O. Hayes, Thomas E. Brown
D. Hoye Eargle and Alice D. Weeks
V. E. Barnes and S. E. Clabaugh

10th National Clay Conference
OCTOBER 14-15, 1961

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FOREWORD

This guidebook was prepared for field excursions planned in conjunction with the Tenth National Clay Conference held in Austin, Texas, October 14-18, 1961, and sponsored by the Committee on Clay Minerals of the National Academy of Sciences, National Research Council. Although the excursions were organized primarily for those concerned with the geology of clays, the guidebook deals with the general geology of the areas traversed, and it is to be hoped that it will be of general value to those interested in the geology of central Texas. For this reason, it is published as Guidebook No. 3 in the regular Bureau of Economic Geology series.

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ILLUSTRATIONS

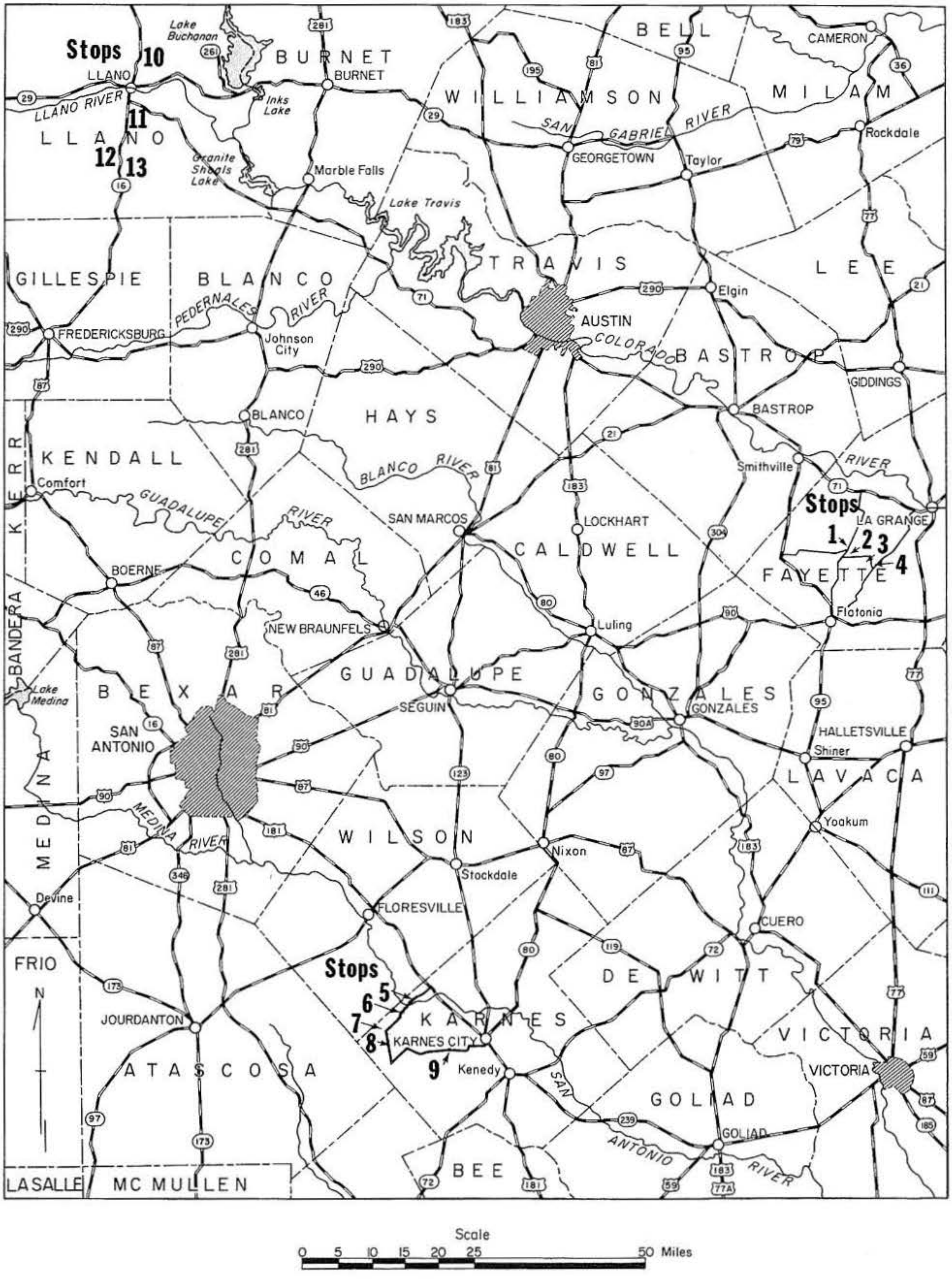

Figure 1. INDEX MAP SHOWING EXCURSION ROUTE AND LOCALITIES (STOPS 1-13).

TERTIARY BENTONITES OF CENTRAL TEXAS

Robert L. Folk,[1] Miles O. Hayes,[1] and Thomas E. Brown[1]

INTRODUCTION

The four stops of this field trip (fig. 2) are in the Upper Eocene (Jackson) and Oligocene volcanic ash and bentonite beds, which crop out about 50 miles southeast of Austin. In the road log, the geology of the area between Austin and these volcanic beds is only briefly noted.

In general, beds along the route dip about 1 or 2 degrees to the southeast, so that starting with the Upper Cretaceous Austin chalk, successively younger beds are encountered from Austin, Travis County, to Gonzales, Gonzales County. There are almost no folds, but there are two extensive fault zones; one, the Balcones, starts near Dallas, trends through the west part of Austin, and extends far west of San Antonio; the other, the Luling-Mexia fault zone, extends through Bastrop County. The area between these fault zones is a graben. Faults in Bastrop County have vertical displacements up to 600 feet.

Cretaceous marine limestones, chalks, and marls are succeeded by Eocene sands and clays, largely continental. The Wilcox and Claiborne divisions of the Eocene are very largely non-volcanic; the only evidences of volcanism are sporadic plagioclase, sphene, apatite, subhexagonal biotite, euhedral zircon, and phenocrysts of high-temperature quartz. In contrast, the Jackson (upper Eocene) and the Catahoula (?Oligocene) contain great thicknesses of bentonite, tuff, and volcanic sand.

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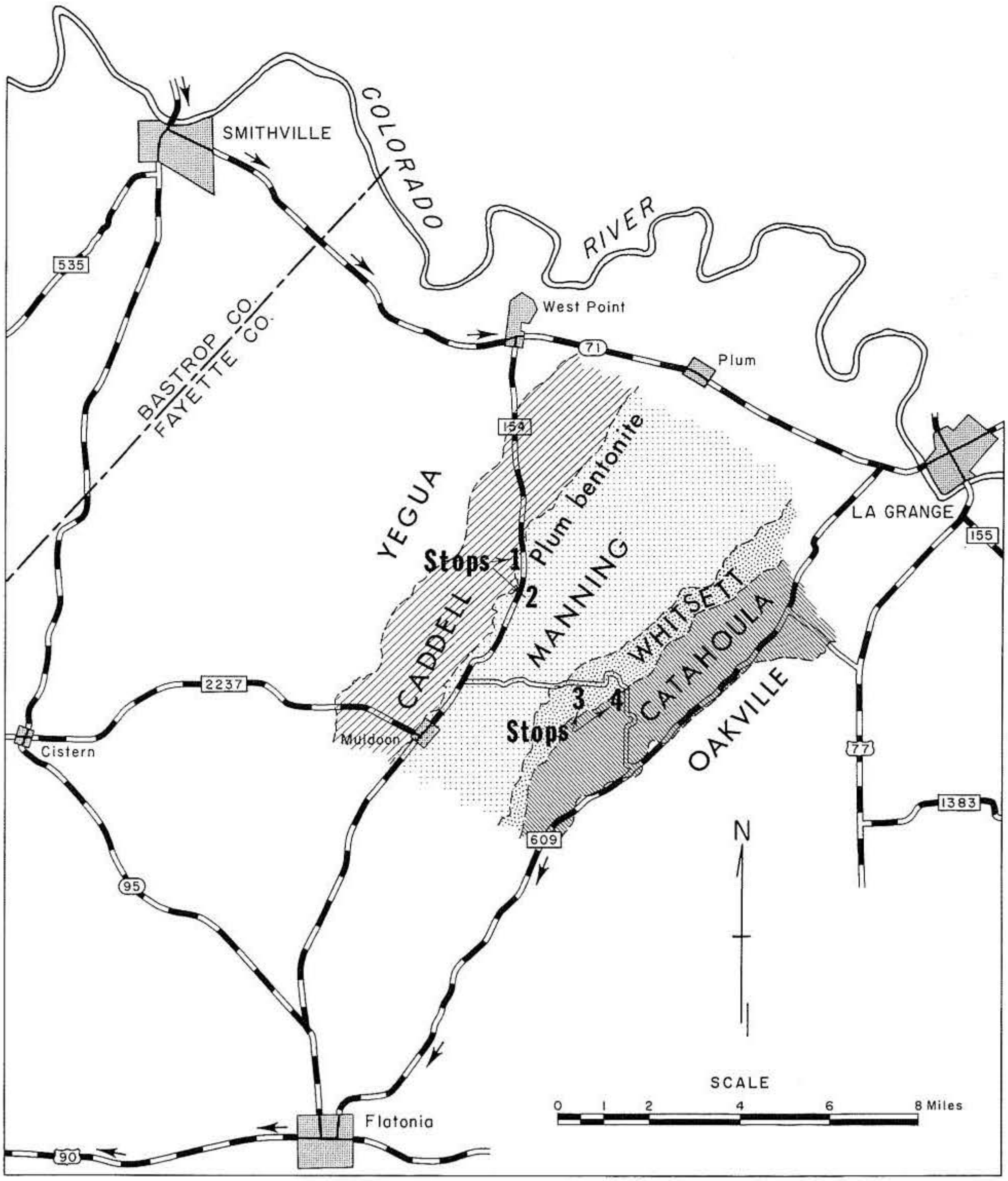

Figure 2. MAP OF FAYETTE COUNTY, TEXAS, SHOWING GEOLOGY AT STOPS 1-4.

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ROAD LOG

Austin to Gonzales, Texas, and Vicinity
Stops 1-4
October 14, 1961

DEPART FROM VILLA CAPRI MOTOR HOTEL,
2360 Interregional Highway, Austin

Mileage Total	Mileage Interval	
0		Proceed south on access road of Interregional Highway.
0.5	0.5	Turn left (east) on East 19th Street. At 1.8 are mills which cut Precambrian granite from the Central Mineral region and Cretaceous limestone.
2.2	1.7	Turn right on Airport Boulevard. From here to the Colorado River, several terrace levels are crossed; these deposits have characteristic brown soil and abundant pebbles and boulders, some up to 4 feet long. The sand in the terraces is strongly arkosic, carrying about 30 to 40 percent microcline; this, together with the abundant hornblende in the heavy minerals, was carried by the Colorado River from the Central Mineral region. As shown by Bullard (1942), this mineral suite, unique for the area, is easily identifiable in Gulf Coast beach sands.
4.5	2.3	Intersection with U. S. Highway 183. Veer left after crossing the Colorado River bridge and continue on Highway 183. At 6.1, veer left on State Highway 71 toward Bastrop.
7.2	2.7	Bergstrom Air Force Base on the right, built on one of the Colorado River terraces. The terraces provide some of the best farmland in the area (note dairy to the left) and support beautiful live-oak trees.
8.5	1.3	Sand pit to the left is very unusual; it is a Pleistocene calclithite, i. e., a sandstone made almost entirely of fragments of reworked limestone, derived from nearby Cretaceous outcrops.

Mileage Total	Mileage Interval	
10.2	1.7	The bluff ahead is formed where Onion Creek cuts into the Navarro clay (uppermost Cretaceous). Mineralogy of the Navarro has never been studied; however, in this outcrop it is an unctuous, dark gray, conchoidally fracturing massive clay with abundant delicate pelecypods and other megafauna. The only thin section examined shows the clay to be very heavily churned and disoriented (presumably by burrowers), and it contains a small amount of pyrite and subhexagonal biotite, the latter indicating volcanic ash contributions. X-ray analysis of one sample showed the major constituent to be calcium montmorillonite with minor amounts of illite and kaolinite.
11.1	0.9	Cross Onion Creek and ascend onto the Navarro plain. The Taylor and Navarro clays are very heavily farmed along the entire outcrop from south of San Antonio to Dallas, and in early days they formed the best cotton land in the State, the so-called Blackland Belt. These rich clay (chernozem) soils are covered with mesquite, a small feathery tree with delicate green leaflets.
11.3	0.2	In the distance ahead and to the right can be seen low hills; these are a cuesta formed by basal Tertiary sandstone. The highway continues on Navarro clay, overlain by thin patches of Pleistocene terrace gravels; mesquite abounds and is always a good marker for a clay formation in this region of Texas. At 14.2, pass the settlement of Garfield, just beyond which the road drops off the Cretaceous and back onto almost perfectly level Colorado River terrace. At 16.3, Travis-Bastrop County line; the low hill immediately ahead is the poorly exposed outcrop of the Paleocene Midway formation.
17.9	6.6	Start ascending the cuesta that marks the base of the Eocene Wilcox group. The basal part of the Wilcox forms one of the most pronounced cuestas in this part of Texas and also is a sharp lithologic, vegetational, and cultural break. The Wilcox and all the beds above it (through the Pleistocene) include thousands of feet of dominantly continental sands and shales with scarcely a bed of limestone more than a few inches thick. Beds below the Wilcox are almost entirely marine clays and limestones with scarcely any sand until the basal Cretaceous. The Cretaceous is

Mileage Total	Mileage Interval	
		heavily farmed and covered with mesquite; the Eocene is largely forested with scrub oaks and has relatively poor soil, although there are some fertile strips in the clayey formations.
18.8	0.8	Blocks bulldozed by the side of the road are Seguin formation, basal unit of the Wilcox; the sandstone is cemented by calcite to form huge concretionary masses, extremely hard and thus responsible for the cuesta. Observe virtual disappearance of mesquite here. A mineralogical study of the Seguin by Rizvi (1958) revealed an abundance of garnet and epidote-zoisite, plus such volcanic indicators as subhexagonal biotite, sphene, and apatite. Rizvi concluded that part of the sand came from the Rocky Mountains and part from the Ouachita foldbelt in Okalhoma. Source of the volcanics is not at present known.
21.0	2.2	Typical lower and middle Wilcox vegetation occurs along this stretch of road; the land is sandy, almost worthless for farming, and virtually uninhabited save for a few families in roadside cabins. Black-jack and post-oaks and cedars dominate the scrubby woodland. A thin cover of Pleistocene gravel can be seen in places. Junction of Farm Road 1209 at 22.8 and State Highway 21 at 24.1. Monotonous Wilcox woods continue. To the north, at Elgin, several large brick plants utilize the Butler clay, a unit in the middle Wilcox that is not visible here.
27.0	6.0	Start descent off the Wilcox and onto the Colorado River terraces; several levels can be counted here. Good farmland again. Hills in the distance are formed by the Carrizo sand cuesta, capped by tall pines. At 29.8, cross Colorado River just above Bastrop. Outcrops of uppermost Wilcox Sabinetown sand can be seen in the river bank.
30.9	3.9	Contact between the Wilcox group and the Claiborne group, with its basal formation (Carrizo sand) supporting a thick growth of pines; outcrops of Carrizo, which are spectacular bluffs in most other localities, have been grassed by the State Highway Department. The Carrizo forms a deep, white loose sand soil and is an excellent aquifer in the subsurface in south Texas. The Carrizo, as shown

Mileage Total	Mileage Interval	
		by Todd and Folk (1957) is a subgraywacke containing about 10 to 40 percent slate and schist fragments and 5 to 10 percent feldspar; heavy minerals are overwhelmingly kyanite and staurolite, indicating that source area of the Carrizo was largely in the southern Appalachians, some 900 miles away. Kyanite and staurolite increase in grain size and abundance as the Carrizo is followed east into Louisiana and Mississippi (J. E. Webb, personal communication).
33.1	2.2	Quarry to the right exposes the contact between the Carrizo and the overlying Newby, a hematitic marine sandstone. The Newby also supports pines. Farther along the highway, thick Pleistocene terrace gravels obscure the outcrops.
36.6	3.5	Eddie's Dance Hall; Alum Creek, on the Marquez clay.
37.7	1.1	Bluff on the left is the Queen City sand, middle Claiborne (Eocene). According to Callender (1957), it is mostly marine (glauconite placers form dark streaks in the outcrop) and contains the same kyanite-staurolite suite present in the Carrizo but in somewhat less abundance. The sands bear evidence of slight and sporadic volcanic activity, containing rare beds rich in subhexagonal biotite, apatite, high-quartz phenocrysts, a few very thin bentonite beds, and local accumulations of pure alunite pebbles. Beyond the Queen City outcrop, the road drops down once again onto the Pleistocene terrace. Cotton, corn, maize and Johnson grass are the chief crops.
41.8	4.1	Cross Colorado River. The Weches claystone (oyster bed) crops out at the river level; glauconite in the Weches has been studied by Burst (1958). Veer left on State Highway 71 through Smithville. Smithville is the headquarters of the Tertiary field camp (for senior students) of The University of Texas; the students map the splendid geology between Bastrop and La Grange, north and south to the county lines, an area of more than 1,100 square miles. Continue east on Highway 71.

Mileage Total	Interval	
48.1	6.3	Steep bluffs on the left expose a series of sections of the Yegua formation, uppermost Claiborne group. The Yegua contains sand, clay, and lignite, and minerals which reflect an increase in volcanism. The sand contains common plagioclase and biotite, and the clays are often highly bentonitic; several 3-foot beds of waxy dark green bentonite occur north of the Colorado River. Petrified palm forests have been found in the Yegua, and silicified wood is very abundant.
51.3	3.2	West Point. Leave State Highway 71 and turn right on Farm Road 154 toward Muldoon. At 51.7, a bluff to the left shows the basal part of the Caddell formation, lowest unit in the Jackson group and the largest source of commercial bentonite. From here on (as far as the Miocene Oakville sand), the formations consist almost entirely of volcanic material--bentonites, tuffs, ash beds, and sands rich in detrital material of volcanic origin.
56.2	4.9	Just beyond the bentonite plant of The Texas Company, turn right across the railroad tracks onto a dirt road leading to the drying sheds and abandoned pit. Proceed to the pit and park. STOP 1. Abandoned bentonite pit of The Texas Company, in the upper part of the Caddell formation (Claiborne, Eocene). Most of the bentonite in this region of Texas is obtained from the Caddell formation; bentonite is the main economic support for the town of Muldoon, about 5 miles to the south. The Caddell is marine and has a few thin calcareous sands, but the bulk of the formation is bentonite and bentonitic clay. The quarry shows about 10 feet of bentonite and bentonitic clay, interbedded cream to light chocolate-brown color, unctuous, non-gritty, conchoidally fracturing, and containing some leaf fragments, jarositic nodules, and abundant gypsum plates. Sections can be seen in the gullies that cut the quarry banks. Much better sections occurring in active quarries to the southwest cannot be visited on this brief trip. X-ray study of one sample showed the major constituent to be calcium montmorillonite with minor amounts of illite and kaolinite.
56.9	0.7	Return to Farm Road 154 and turn right on that road.

Mileage Total	Mileage Interval	
57.4	0.5	Turn left off Farm Road 154 onto a dirt lane. Exposed in the creek is the Carlos sandstone, here beautifully jointed. The Carlos is a subarkose (15 percent orthoclase, sanidine, and plagioclase, and aphanitic volcanic rock fragments), cemented with opal. Although only 10 feet thick, it is an excellent mapping unit because of its hardness. It is used locally as a building stone, and huge blocks were also used in constructing the Galveston seawall. Continue on the dirt road to 57.7 and park.

STOP 2. (Sunglasses are advisable.) On the Bob Mattingly ranch is one of the best outcrops of the Plum bentonite, near the base of the Manning formation. The pit exposes about 12 feet of dazzling white, hard, conchoidally fracturing, and massively bedded bentonite. When fresh, it has the appearance and feel of ivory soap; some beds near the base of the quarry are a beautiful delicate purple. Underlying the bentonite is a cross-bedded sand, rich in plagioclase. As noted by Stenzel (1953), the Plum itself often shows erratic dips. The Plum bentonite, which has been studied by E. C. Jonas (personal communication), is a relatively pure calcium montmorillonite having a basal periodicity of 15.4 AU. It is fully expandable to 17 AU when ethylene glycol is applied.

Return to Farm Road 154; mileage should read 58.0. Turn left and proceed south toward Muldoon.

59.9	2.5	Cross railroad tracks. Dip slope on Carlos sandstone visible to the right of the road.
60.5	0.6	Turn left onto dirt road and re-cross the railroad tracks. Carlos sandstone in the creek bottom. After crossing the creek, the route is on the Manning formation (Jackson, Eocene). Cross a small bridge at 61.4.
61.6	1.1	From here on, the stunted vegetation that has developed on the bentonite and acidic vitric tuff beds of the Manning formation is well displayed. Several badlands can be seen to the right of the road, with dwarfed trees hung with wispy lichen. Manning bentonites are characteristically chocolate colored, and lignite beds can be seen.

Mileage Total	Mileage Interval	
61.9	0.3	STOP 3. Badlands developed in the Manning formation. Section to be seen is as follows:

	Thickness (feet)
4. Fine sand (2.2 φ); moderately well sorted (δ = 0.5), light gray to light brown, soft, highly cross-bedded, with dips generally southeast. Sand contains considerable plagioclase and placers of white bentonite sand grains; it is also stained with limonite	5
3. Interbedded sandy clay and clayey sand; light gray; sand is very fine (3.5 φ); outcrop is riddled with limonitic tubules; some plant fragments and petrified wood. At the base is a 6-inch unit of rich chocolate-brown lignite	9
2. Vitric tuff, white, soft but coherent, forming a distinct ledge in the outcrop. Consists almost entirely of unaltered glass shards; contains numerous spiral burrows	0.5
1. Interbedded sand and clay; interbeds one-half to 3 inches thick, about 50 to 70 percent clay. Sand is very fine (3.5 φ), well sorted (δ = 0.35), light gray, very soft, appears to be mostly quartz. Clay is light gray to pale chocolate brown, bentonitic, unctuous, and contains some leaf fragments and limonite stains. The unit as a whole shows pronounced horizontal lamination.	8

The beds in this outcrop dip much more steeply than other Tertiary beds in this area. The vitric tuff bed strikes N. 70° E. and dips $2\frac{1}{2}$° SE. The cause of the dip is unknown; it may be a structural dip due to nearby faulting or may be a steep depositional dip. X-ray study of one clay sample showed the major constituent to be a calcium montmorillonite with a small amount of kaolinite.

Mileage Total	Interval	
		Continue east along the dirt road. At 62.1, a Manning lignite, and at 62.4, a good example of stunted spectral trees, covered with green lichens.
64.3	2.4	STOP 4. This stop is in a badlands exposing the upper Manning bentonites and clays, the Whitsett sand member of the Manning, and the Oligocene Catahoula formation. Note the peculiar vegetation. Section to be seen is as follows:

	Thickness (feet)
Catahoula formation--	
3. Interbedded bentonitic clay and sand, bedded at 1- to 6-inch intervals. Clay is cream colored to pale green, unctuous, and some of the beds are sandy. The sand is very fine, light gray, and soft, and entirely similar to the Whitsett sand below. Whitsett-type sand and Catahoula-type bentonite are interbedded over a span of some 10 feet so that the exact contact is a matter of judgment. The Catahoula shows some limonitic layers, traces of plant fragments, and some small-scale channeling. Its age is in dispute; some workers consider it Miocene	10+
Whitsett sand--	
2. Very fine sand (3.5-4.0 φ), very well sorted ($\delta = 0.3$), light gray, very soft, irregularly bedded with some clayey streaks. The outcrop is littered with plates of limonite and some jarosite. The sand here consists largely of quartz with some plagioclase and glass. Elsewhere in this region the Whitsett is as much as 50 feet thick, and at still other places it is absent. It is apparently not a single sand body but rather a series of separate channel sands occurring at different places	

	Thickness (feet)
in the stratigraphic section. Elsewhere it is highly cross-bedded (dip southeast), contains abundant petrified wood including large tree trunks, and is full of reworked bentonite cobbles. Some of the channel sands are mostly quartz, as is this one; others are mostly volcanic glass or are much richer in plagioclase. The heavy minerals here are chiefly euhedral zircon and magnetite	7
Manning formation--	
1. Bentonite, cream colored to pale green, unctuous, conchoidal fracture; occasional pelecypod molds are found; also contains limonite stains. If one continues to walk down the creek, he will come upon chocolate-colored bentonites and lignites that are more like typical Manning	5+

G. L. Thomas (1960), under the supervision of E. C. Jonas, has studied the clay mineralogy of the Catahoula from the Mexican border to Louisiana and found that in central Texas it is a calcium montmorillonite. Towards south Texas it is a sodium montmorillonite, and in east Texas it contains kaolinite. It is possible that this reflects a more humid climate in east Texas during Catahoula deposition, similar to the climatic situation which prevails today.

Continue along the dirt road over the Catahoula. Grotesque vegetation and lack of human habitation are readily apparent. At 64.9, the cuesta of the Miocene Oakville formation is visible on the horizon to the left. At 65.8, start ascending the Oakville cuesta, which marks one of the most pronounced lithologic and vegetational breaks on the Gulf Coast. The Catahoula bentonite, with its stunted post-oak and cedar trees, badlands, and very sparse population, contrasts sharply with the Oakville sandstone on which is developed a rich farmland, resembling the bluegrass district of Kentucky, with rolling hills supporting stately live-oak trees and thickly dotted with well-painted farmhouses and gothic-style churches. On a map showing culture, the contact is clearly visible owing to the marked change in density of houses and roads. The cause of this change is the mineralogy of the Oakville sandstone, which is a calclithite made up of over 90 percent fragments of reworked Cretaceous limestone and fossil fragments, derived from fluvial erosion of uplifted Cretaceous outcrops near Austin (Ragsdale, 1960). These form a very deep, rich, black chernozem soil. The Oakville, then, is a detrital fan of carbonate formed by Balcones faulting during the Miocene. Ely (1957) has shown that the reworked microfossils are dominantly Upper Cretaceous. J. A. Wilson (1956) dated the unit as Late Early Miocene, based on an extensive vertebrate fauna, particularly horse teeth. According to Ragsdale, the calclithite phase occurs only in central Texas; in south Texas, the Oakville is mostly volcanic rock fragments and plagioclase, and in east Texas it is largely quartz. Volcanic heavy minerals such as sphene and apatite increase in abundance, size, and euhedrism into south Texas.

At 66.8, turn right on State Highway 609 toward Flatonia. End of road log for this part of the field trip. Continue on Highway 609 to Flatonia (about 11 miles), turn right on U. S. Highway 90, and travel about 11 miles to Waelder; turn left on State Highway 97 and continue to Gonzales Courthouse (about 16 miles).

URANIUM-BEARING CLAYS AND TUFFS OF SOUTH-CENTRAL TEXAS [2/]

D. Hoye Eargle [3/] and Alice D. Weeks [3/]

INTRODUCTION

This field trip concerns itself with clays and tuffs of the Jackson group (late Eocene) in south-central Texas, approximately from the Colorado River southeast of Austin, Travis County, to Karnes County southeast of San Antonio.

The Jackson group is of interest because a large proportion of the sediments constituting these rocks is of volcanic origin, and the rocks show a wide range of alteration effects due to diagenetic and soil-forming processes. In Jackson time volcanic activity west and southwest of the Coastal Plain of Texas resulted in the deposition of much ash in swamps and bays along the coastline. The sediments are alternating marine and nonmarine with numerous thin lithologic units of nonmarine, feldspathic and lithic (volcanic) sandstone, tuffaceous sand, shardy ash, and lignitic clay, and marine fossiliferous, sandy clays. Some beds are almost entirely volcanic material but most are mixtures of tuffaceous and nonvolcanic detrital material. The volcanic activity began in pre-Jackson time and culminated in the Miocene with deposition of thick ash, tuffaceous sand, and volcanic conglomerate in the Catahoula tuff. In the Karnes County area the Catahoula unconformably overlaps part of the Jackson. Since the early Miocene, relatively smaller amounts of volcanic material were incorporated in the younger coastal plain sediments.

Participants on this trip not only will inspect some of the commercial deposits of clay but will also have an opportunity to consider the various diagenetic changes that have affected these highly reactive sediments. Changes have taken place both shortly after the sediments were laid down and more recently, as a result of weathering and soil-forming processes when the climate was more arid than it is at present. The origin of the shallow uranium deposits (one of which will be visited) in Karnes County is believed by some geologists and geochemists to be related to these diagenetic and soil-forming processes through the development of alkaline carbonate pore water, leaching of the tuffaceous sediments, and deposition of uranium under favorable climatic and geologic structural conditions and geochemical environment.

[2/] Publication authorized by the Director, U. S. Geological Survey.

[3/] U. S. Geological Survey, Austin, Texas, and Washington D. C.

The following discussions of the stratigraphy of the Jackson group and of the uranium deposits they contain apply to the Coastal Plain of south-central Texas south of Gonzales County, and particularly to Karnes, Wilson, Atascosa, and Live Oak counties.

STRATIGRAPHY OF THE JACKSON GROUP

A columnar section showing the stratigraphic divisions of the Jackson group and adjacent formations in south-central Texas (Eargle, 1959) is shown in figure 3. Also shown is the trace of a composite electric log from typical oil and core holes in the area. Following also is a brief lithologic description of the various stratigraphic units of the Jackson in south-central Texas.

Because the field trip of this conference also concerns the Jackson in east-central Texas, a comparison of formational names of that region with those in south-central Texas is given (fig. 4).

Jackson Group

Whitsett formation--

Fashing clay member--

Bentonitic clay, pale-yellow-brown to olive, and white tuff; contains thin coquinas of *Corbula*, banks of oyster shells, and septarian concretions.

Calliham sandstone member--

Sandstone, tuffaceous, fossiliferous, lenticular.

Dubose member--

Sandstone, tuffaceous, fine-grained, and bentonitic clay; contains some tuffaceous silt and white-weathering carbonaceous tuff; thin, impure lignite beds. Includes a marine sandstone, the Tordilla sandstone bed (of local usage), which caps Tordilla Hill in western Karnes County. The member contains a few small uranium deposits.

Stones Switch sandstone member--

Sandstone, fine- to medium-grained, tuffaceous, and carbonaceous siltstone; thin, bentonitic clay; locally fossiliferous near the top. The largest uranium deposits in western Karnes County occur near the base of this unit and locally extend into the underlying Conquista clay member of the McElroy formation.

McElroy formation--

Conquista clay member--

Clay, bentonitic, slightly carbonaceous, and tuffaceous silt and fine-grained fossiliferous sandstone. Impure lignite locally at base. Contains *Textularia hockleyensis* and *Massilina pratti*.

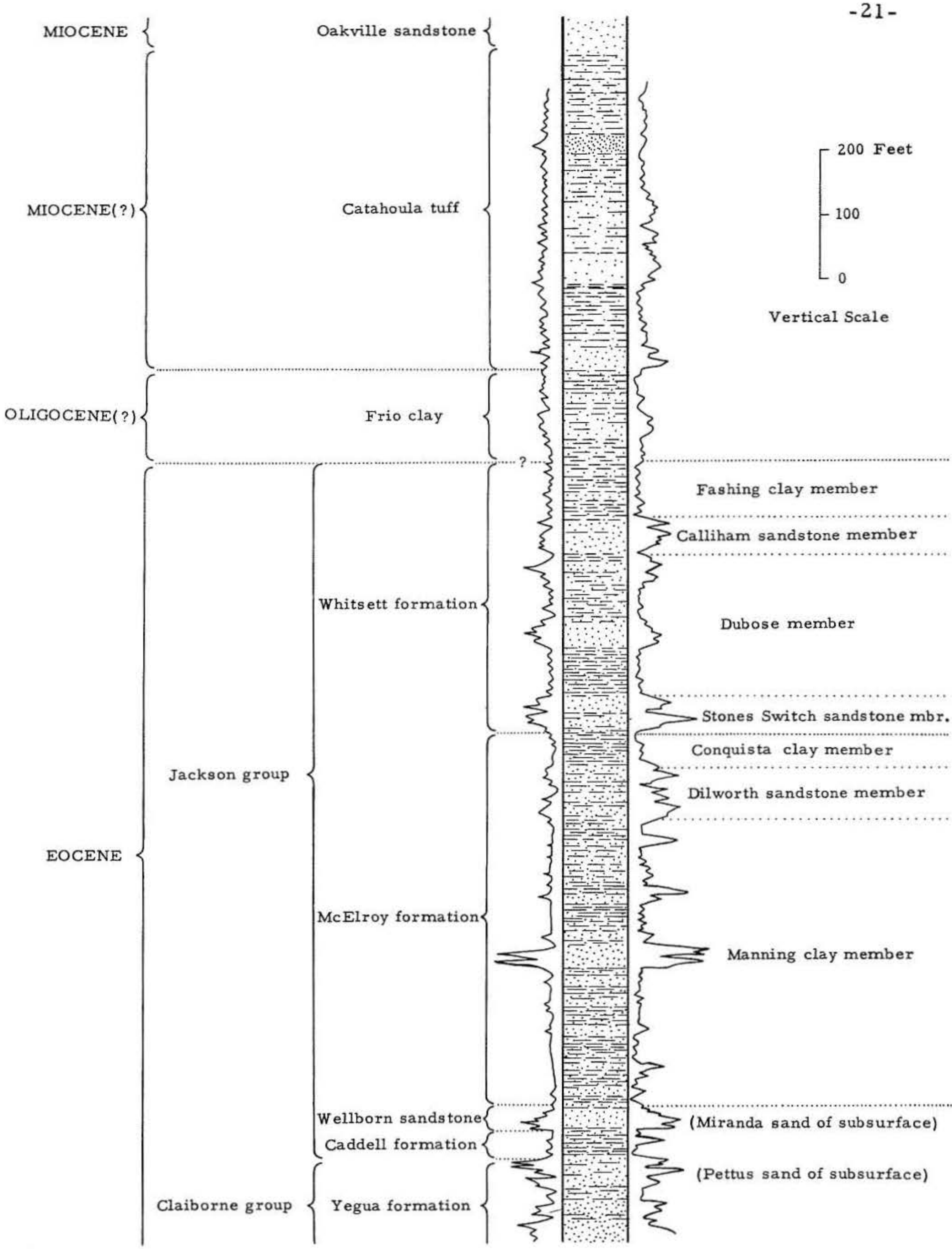

Figure 3. STRATIGRAPHIC UNITS OF THE JACKSON GROUP AND ADJACENT FORMATIONS, SOUTH-CENTRAL TEXAS.

McElroy formation (continued)--

Dilworth sandstone member--

Sandstone, bentonitic, carbonaceous, and locally fossiliferous. Contains some fissile, carbonaceous shales.

Manning clay member--

Clay, bentonitic, pale-olive to pale-yellow-brown, and fine-grained sandstone and carbonaceous tuff. Locally contains banks of oyster shells.

Wellborn sandstone--

Sandstone, fine-grained, tuffaceous. Locally contains marine fossils near base, silicified wood near top.

Caddell formation--

Clay, carbonaceous, and fine-grained glauconitic sandstone. Contains fossil shells and calcareous concretions near its base.

DIAGENESIS, WEATHERING, AND SOIL-FORMING PROCESSES IN THE KARNES COUNTY AREA

In these sediments the glass shards, grains of sanidine, zoned plagioclase, and biotite, and fragments of pumice and fine-grained trachyte and trachy-andesite are unstable and highly reactive chemically compared to the dominant quartz and clay minerals of many marine sandstones and lagoonal shales.

Diagenetic alteration of these sediments includes the development of montmorillonitic clays, heulandite (probably the variety clinoptilolite), authigenic feldspar overgrowths, opal, chalcedony and carbonate cements, manganese oxide seams, pyrite, marcasite, barite, and various nodules and concretions. The rocks have low permeability and the ground water has become alkaline and highly mineralized with sodium, calcium, silica, potassium, and other soluble constituents released from the alteration of the volcanic detritus.

Weathering and soil-forming processes conditioned by a hotter, drier climate in the past (perhaps middle Pleistocene) caused extensive caliche development and silica induration near the surface. At present the caliche is being eroded in the Karnes County area which is about the northeastern limit of a large caliche region extending southwest and south into Mexico, and also the northeastern limit of known commercial uranium deposits in the Texas Coastal Plain. Recent erosion has exposed many outcrops of silica-cemented sandstone ledges along the strike of the Jackson group in Karnes County and southeastern Atascosa County. At many of the uranium prospects the ore is in friable sand under a silicified cap. Some zeolotically altered tuffaceous sandstones are indurated and also form resistant ledges.

ELLISOR (1933)		RENICK (1936) (east-central Texas)		RUSSELL (1955, 1957) (east-central Texas)		THIS PAPER (south-central Texas)	
Fm	(Zone, member, or phase)	Fm	Member	Fm	Member	Fm	Member
Whitsett	Olmos sand	Whitsett		Whitsett		Whitsett	Fashing clay
	Fashing clay						
	Calliham sand						Calliham ss
	Dubose sands and clays	?	?				Dubose
	Stone's Switch sand	Manning	Yuma sandstone	Manning	Yuma sandstone		Stones Switch sandstone
	Falls City shales					McElroy	Conquista clay
	Dilworth sand		Dilworth sandstone		Tuttle sandstone		Dilworth sandstone
McElroy	Manning beds				Goodbread ss		Manning clay
	Wellborn sands	Wellborn	Carlos sandstone	Wellborn	Carlos sandstone	Wellborn ss	
	Wooley's Bluff clays		Middle Wellborn		Middle Wellborn sandstone		
					Middle Wellborn shale		
Caddell	Upper chocolate phase		Bedias sandstone		Bedias sandstone		
		Caddell		Caddell		Caddell	
	Lower marl phase		Basal sandstone				

Figure 4. COMPARISON OF STRATIGRAPHIC DIVISIONS OF THE JACKSON GROUP, according to several authors, and possible correlation of units of east-central Texas with those of south-central Texas (from Eargle, 1959, table 1, p. 2626).

STRUCTURAL SETTING OF THE KARNES COUNTY URANIUM DEPOSITS

The uranium deposits are in the upper Jackson sediments in an elongate area that lies in a graben-like structure in western Karnes County. On the northwest is a down-to-the-coast fault, the Falls City fault, and to the south and southeast are several less continuous up-to-the-coast faults, the Fashing and Hobson faults (Eargle, 1958). The rocks dip generally southeastward toward the Gulf of Mexico except for displacements along these faults. The faults seem to be part of the Mexia fault system and generally are en echelon along the trend, but individual faults may extend 5 to 25 miles along the strike. The faults apparently were initiated early in Late Cretaceous times and movement on some has been sporadic until at least Miocene times or later (A. W. Weeks, 1945, p. 1736). Local warping of beds along the faults produced several oil structures. Oil and gas are produced from Eocene beds at depths of a few thousand feet and gas and distillate from Cretaceous limestone at depths exceeding 10,000 feet. The possibility of a relation between the deposition of uranium and the reducing environment produced by H_2S gas from the petroleum has been considered (Eargle and Weeks, in press).

The uranium deposits in the upper Jackson are close to the unconformity with the Miocene(?) Catahoula tuff. The intervening Frio clay (Oligocene?) has been eroded, and the Catahoula rests on progressively older members of the Jackson toward the north.

URANIUM DEPOSITS

Discovery and Exploration

The highly radioactive anomalies associated with the Karnes County uranium deposits were discovered in the fall of 1954 by a pilot making a radioactivity survey for an oil operator on the theory that oil fields show slightly anomalous radioactivity.

At about the same time, uranium minerals were found at the northern foot of Tordilla Hill by a truck driver whose hobby was collecting and polishing opalized wood and who frequently carried a Geiger-counter. The uranium minerals were found in outcrops of silicified sandstone and in the soil profile barely beneath the organic-rich topsoil.

When these discoveries became known several months later, a scramble for leases and royalties and feverish prospecting set in. Most of the deposits known today were found in 1954-55. The localities discovered during this period extend from Fayette County on the northeast to Duval County on the southwest. By 1958 prospects were located in Starr County, near the

Rio Grande. Prospecting was carried on by air-, car-, and hand-borne scintillation- and Geiger-counters. Exploration was chiefly by drilling, logging with scintillation- or Geiger-counters, and by sampling. A number of pits, however, were excavated by bulldozer, and in these the relation of mineralization to lithology and bedding were studied, and the beds sampled more closely and exactly.

Following the first year of intensive exploration, it became evident that only a few of the surficial deposits were likely to contain commercial ore in large quantities. Some deeper drilling down the dip yielded only one large deposit--at a depth of about 325 feet at Palangana salt dome, Duval County (Weeks and Eargle, 1960). Because of the limited ore reserves found and because of the long haul to the nearest mill at Grants, New Mexico, and the unlikely prospect of a mill to be built in the area in the near future, most of the activity ceased a little more than a year after discovery. One shipment of about 9 tons of selectively mined ore from the Hackney (Boso) prospect in western Karnes County was made to Grants in 1958.

Plans for the building of a mill by Susquehanna-Western, Inc., were announced in 1959, and in July of 1959, stripping of overburden from the Jaffe, Martin, and Associates lease of the Climax Molybdenum Company, operating locally under the name San Antonio Mining Company, began on the Gembler, Lyssy, and Korzekwa properties, known collectively as the Nuhn lease, immediately west of the site of the abandoned village of Deweesville. Mining began a few months later, and 100,000 tons of ore, the reported amount called for in the contract of the company with the U. S. Atomic Energy Commission, was mined up to early in 1961.

Mining by Susquehanna-Western, Inc., on the Luckett lease (Lyssy and Niestroy properties), east of the site of Deweesville, began in the fall of 1960 and continued until the spring of 1961. Susquehanna-Western began building the mill for processing the ore of the district in the summer of 1960 and put it into operation in April of 1961.

Exact analyses of the ore removed from the mines of the district have not been released, but the average is reported to be in excess of 0.20 percent U_3O_8.

Uranium minerals have been found in tuffaceous sand and conglomerate, silt, or bentonitic clay in at least eight different stratigraphic positions ranging from the middle part of the Jackson (late Eocene) to the Goliad sand (Pliocene). They have been found in lignite in the middle Jackson in Fayette County, the basal sand of the Catahoula tuff in southern Gonzales County, from several positions in the middle and upper Jackson, and from the basal Oakville sandstone in Karnes County, from the upper Jackson in Atascosa and Live Oak counties, from the Catahoula, Oakville, and basal Goliad in Duval County, and from the Catahoula tuff in Starr County.

Uranium Ores

The ore in the Karnes County area is disseminated chiefly in tuffaceous sands and, to a lesser extent, as coatings and fillings along joint and bedding planes in the clay immediately underlying the sand. The principal ore-bearing sand has been correlated with a sandstone occurring along the Atascosa River about 20 miles to the southwest, termed by Ellisor (1933) the Stone's Switch sand, and the clay beneath it has been correlated with her Falls City shale of the Whitsett formation. These have been later redescribed by Eargle (1959) as the Stones Switch sandstone member of the Whitsett formation and the Conquista clay member of the McElroy formation. The ore deposits lie generally between 20 and 40 feet deep. Some zones of high radioactivity have been found in drill holes down the dip from the surface deposits, as deep as 100 feet or more below the surface. The deposits are only about a mile to a mile and a half north of the nearest outcrop of the Catahoula tuff, an overlapping formation of Miocene(?) age. Apparently the area of the deposits had been overlain by the Catahoula which, together with more than a hundred feet of intervening uppermost Jackson deposits, has been removed by erosion during late Tertiary, Pleistocene, and Recent times.

Other occurrences of uranium minerals in the area and, in some instances, of ore-grade mineralization, have been found in carbonaceous tuff, in unoxidized silty clay, in highly silicified sandstone, and as a caliche-like concentration of uranium minerals in the subsoil.

The minerals are chiefly varieties of yellow to greenish-yellow, oxidized uranium minerals. They include uranyl phosphates, arsenophosphates, 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.

Detailed study of the uranium-bearing Tordilla Hill-Deweesville area showed that the ores were concentrated slightly up the dip from a subsurface elongate clay- or mudstone-filled channel that trends roughly along the strike of the rocks (MacKallor and Bunker, 1958; and de Vergie, 1958). This channel is believed to have localized and perhaps hindered the flow of the ground water containing the uranium-bearing solutions, allowing the uranium minerals to precipitate in this area. It will be noted that the principal deposits are located near the divide of surface drainage between the San Antonio River, along Scared Dog Creek on the east, and the Atascosa River drainage along Tordilla Creek on the west.

Stratigraphy of the Deposits

The Stones Switch sandstone member, Whitsett formation, which contains the principal uranium deposits of the Karnes County area, consists of about 50 feet of strata, of which the upper and lower parts are chiefly sand and the middle section separating them is clay and carbonaceous siltstone. In the pits of the San Antonio Mining Company the upper sands and part or all of the clayey section have been locally cut out and replaced by a channel sand that contains large clay boulders and coarse sand. The clay layer that has been largely removed is a layer of bentonite (fig. 8). In the pits of Susquehanna-Western, Inc., the upper sandstone is fine grained and the clay contains large, conspicuous, calcareous concretions. Below the clay in both deposits is carbonaceous and tuffaceous siltstone, and below that, a fine-grained silty and tuffaceous sandstone. The ore is chiefly in the lower fine-grained sandstone.

The lower sandstone lies with sharp and undulated basal contact on a light-brown, slightly carbonaceous, tight clay of the Conquista clay member of the McElroy formation. Only the upper 6 or 8 feet of the Conquista is brown; this is the weathered or oxidized part of the underlying "blue clay" (medium-light-gray clay) of the miners. This brown clay below the sandstone contains some ore and generally the most conspicuous yellow to pale-green uranium minerals of the area. The minerals are coatings or segregations along bedding planes and, to a lesser degree, along joint planes in the clay. Beneath the deepest and richest of the deposits on the San Antonio Mining Company's property, a small area containing fine pellets of unoxidized ore (uraninite) was found in medium-gray clay that contains very thin lenses or mere dustings of silt or very fine sand. No ore has been found below the uppermost few feet of the Conquista, although a prospect pit in a fossiliferous sandstone, about 20 feet below the top of the Conquista on a lease adjoining the San Antonio Mining Company property to the southwest, showed some yellow uranium minerals filling fossil molds in the coquina-like sandstone.

A few prospects down the dip from the principal uranium deposits were in carbonaceous tuff and siltstone in the Dubose member overlying the Stones Switch member. Some of these carry a limited amount of ore, apparently in small patches. Although uranium of ore grade has not been found in the Catahoula or in overlying sediments in this area, it has been found in one prospect in southern Gonzales County to the northeast and in Duval and Starr counties to the southwest.

Origin of the Uranium Deposits

The origin of these deposits is related to a combination of geologic conditions such as favorable source rocks, a "built-in" solvent for uranium, permeability barriers, favorable climatic, structural, and geochemical conditions for concentration and precipitation of uranium from the solutions instead of dilution and dispersal. The source of the uranium and the associated phosphorus, arsenic, molybdenum, and traces of vanadium is thought to be the large quantity of tuffaceous material that is available in both the upper part of the Jackson group and the Catahoula tuff. Diagenetic alteration of the trachytic to andesitic ash released alkalies, silica, uranium and other trace elements through the development of alkaline carbonate pore water which is the "built-in" solvent. The graben-like area between the Falls City and the Fashing faults in the Karnes County region was a favorable basin of accumulation. The climate of the late Tertiary and Pleistocene was hot and dry enough at times for intense development of caliche, and at the same time concentration of uranium in solution probably as the uranyl tricarbonate $UO_2(CO_3)_3^{-4}$ or the uranyl dicarbonate $UO_2(CO_3)_2(H_2O)_2^{-2}$ complex ions. The thin lithologic units in the upper part of the Jackson range from moderately to slightly permeable and they contain local areas of reducing environment caused by lignitic ash, plant fragments, H_2S, or disseminated sulfide nodules. The uranium may be precipitated from the uranyl carbonate solutions either by reduction to fine-grained, low-temperature uraninite or by reaction with phosphate, arsenate, molybdate, vanadate, or silicate ions in the oxidized zone. An increase in CO_2 may take the minerals into solution again temporarily. The uraninite may be oxidized and migrate into another reducing environment possibly only a few feet away to be precipitated again. These shallow deposits are relatively unstable.

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ROAD LOG

Gonzales to Karnes City, Texas, and Vicinity
Stops 5-9
October 14, 1961

DEPART FROM GONZALES COURTHOUSE

Mileage Total	Interval	
0		Intersection of U.S. Highway 183 and State Highway 97. Proceed south on 183 and 97. San Marcos River terrace covers Cook Mountain--Yegua contact.
1.3	1.3	Guadalupe River crossing.
1.4	0.1	Historical marker. "On September 29, 1835, the Mexican government troops demanded return of the Gonzales cannon. After two days delay, awaiting recruits, the colonists answered, 'Come and take it.'"
2.0	0.6	Turn right on Highway 97 (leaving 183).
4.5	2.5	Farm Road 108 on left. Continue on Highway 97.
7.4	2.9	Sign indicating monument site where first shot was fired in the Texas Revolution on October 2, 1835, in the Battle of Gonzales. Route is on Cook Mountain formation; silty clay forms dark soils.
7.9	0.5	Village of Cost. Farm Road 1297 on right. Continue on Highway 97.
12.2	4.3	Outcrop of Cook Mountain formation in roadcut. Shows gray clay streaked with iron oxide and a thin highly fossiliferous layer; conglomeratic and sandy layer strongly cemented with iron oxide is probably terrace deposit.
13.1	0.9	Another outcrop of Cook Mountain formation.
14.6	1.5	Village of Bebe. Farm Road 1682 on right. Continue on Highway 97.
15.6	1.0	Although contact is obscure, sandy soil and oak trees indicate Sparta sand.

Mileage Total	Mileage Interval	
16.9	1.3	Sparta sand in small pit on left. Route approximately along the strike of the Sparta.
20.3	3.4	Sparta sand, ferruginous, with a little clay.
24.2	3.9	Join State Highway 80. Continue south on Highways 80 and 97 toward Nixon.
26.1	1.9	Farm Road 1117 on right.
26.7	0.6	Sand pit on left.
28.3	1.6	Town of Nixon. Cross U. S. Highway 87. Continue on State 80. Cook Mountain formation mostly clay, characterized by gently rolling slopes, absence of oak trees, and presence of mesquite vegetation.
32.5	4.2	Entering Karnes County at Wilson-Karnes County line. Now on Yegua formation.
32.9	0.4	Elm Creek crossing.
38. 1	5.2	Poor outcrop of Wellborn sandstone of Jackson group (late Eocene) in ditch on right. Gentle ridge of Wellborn sandstone.
38.4	0.3	Intersection with State Highway 119.
38.6	0.2	Turn right on Farm Road 887, leaving State 80, at town of Gillett.
38.8	0.2	Sharp left turn in Gillett.
40.6	1.8	Outcrop of Manning clay member of McElroy formation, Jackson group, on right.
41.0	0.4	Outcrop of Manning clay member on left. On right side of road a dirt lane leads 0.2 mile to a low ridge of indurated Wellborn sandstone. The sandstone has a dip of 7° to the southeast and is on the downthrown side of a down-to-the-coast fault. The Caddell formation (lowermost of Jackson group) is on the upthrown side of the fault.

Mileage Total	Interval	
43.3	2.3	Blocks of Wellborn sandstone, along both sides of road, were removed from roadbed during construction. Outcrops of Manning clay member, McElroy formation, chiefly altered tuff. Route follows a graben between a down-to-the-coast fault on north and an up-to-the-coast subsurface fault on south (fault does not crop out). In distance to left (south) is new Person oil field with production from deep Edwards limestone (Cretaceous) on the upthrown block of the fault which presumably dies out in the Midway (Paleocene).
47.8	4.5	Ridge on right is Wellborn sandstone.
49.5	1.7	Outcrop of Wellborn sandstone in ditch along left side of road. Many more outcrops and blocks of Wellborn in next 1.8 miles.
51.3	1.8	Cross State Highway 123 at Pawelekville and continue on Farm Road 887.
52.2	0.9	Crossing Cibolo Creek. Good exposure of Caddell formation (clay and sand) in creek bed below bridge. Just west of creek is the site of an old Spanish fort near historic Carvajal Crossing. The stone from the fort was used in construction of present house on right.
52.5	0.3	Wellborn sandstone well exposed in Krawietz quarry on hill on right. (Measured section by D. H. Eargle, in Guidebook of South Texas Geological Society Field Trip, December 5, 1958.) Falls City fault just northwest of quarry.
53.6	1.1	Farm Road 887 mostly follows Manning clay member. Good outcrop on right.
54.7	1.1	Falls City oil field on left. Production is from downthrown side of a down-to-the-coast fault; nine producing sands in about a 1,400-foot section of Wilcox group. In distance to left are the discovery wells of the new Panna Maria and Big John fields on south side of graben, producing from deep Edwards limestone (Cretaceous).
57.8	3.1	Turn left on U. S. Highway 181 in outskirts of Falls City at Somico camp.

Mileage Total	Mileage Interval	
58.7	0.9	Turn right on Farm Road 791 and continue on 791 (watch for several turns in the village).
60.1	1.4	On right is 100-yard outcrop of basal Dilworth sandstone member of McElroy formation with beds of tuff and sand containing glass shards overlying Manning clay member.
62.5	2.4	Turn left on dirt road to Conquista Bluff on San Antonio River (fig. 5).
63.3	0.8	STOP 5. Outcrop of Dilworth sandstone member in river bed provides means of fording river at historic Conquista Crossing of old Spanish road. Full section of Conquista clay member in bluff capped by part of Stones Switch sandstone member of Whitsett formation (fig. 6). Following is a description of the section exposed in the bluff.

Section in Conquista Bluff (measured from top down).

	Thickness (feet)
Whitsett formation--	
Stones Switch sandstone member--	
10. Sandstone, light gray, fine grained, indurated, thick bedded. Exposed, about	10
9. Covered	2
8. Sand, yellowish gray, very fine grained, laminated, unconsolidated; contains iron oxide streaks and caliche bands; 0.5-foot fossil plant layer at top	4
McElroy formation--	
Conquista clay member--	
7. Clay, light gray, pure to slightly silty, fissile; contains jarosite and iron-oxide staining . . .	28
6. Clay, chocolate, weathers to brownish gray; contains jarosite coating	6
5. Sand, argillaceous, varies to almost pure clay, light grayish brown, very fossiliferous (pelecypods and gastropods). Some layers almost coquinite. Much selenite	4
4. Clay, chocolate on fresh surface, grayish brown and fissile on weathered surface. Much jarosite and selenite on joints	6

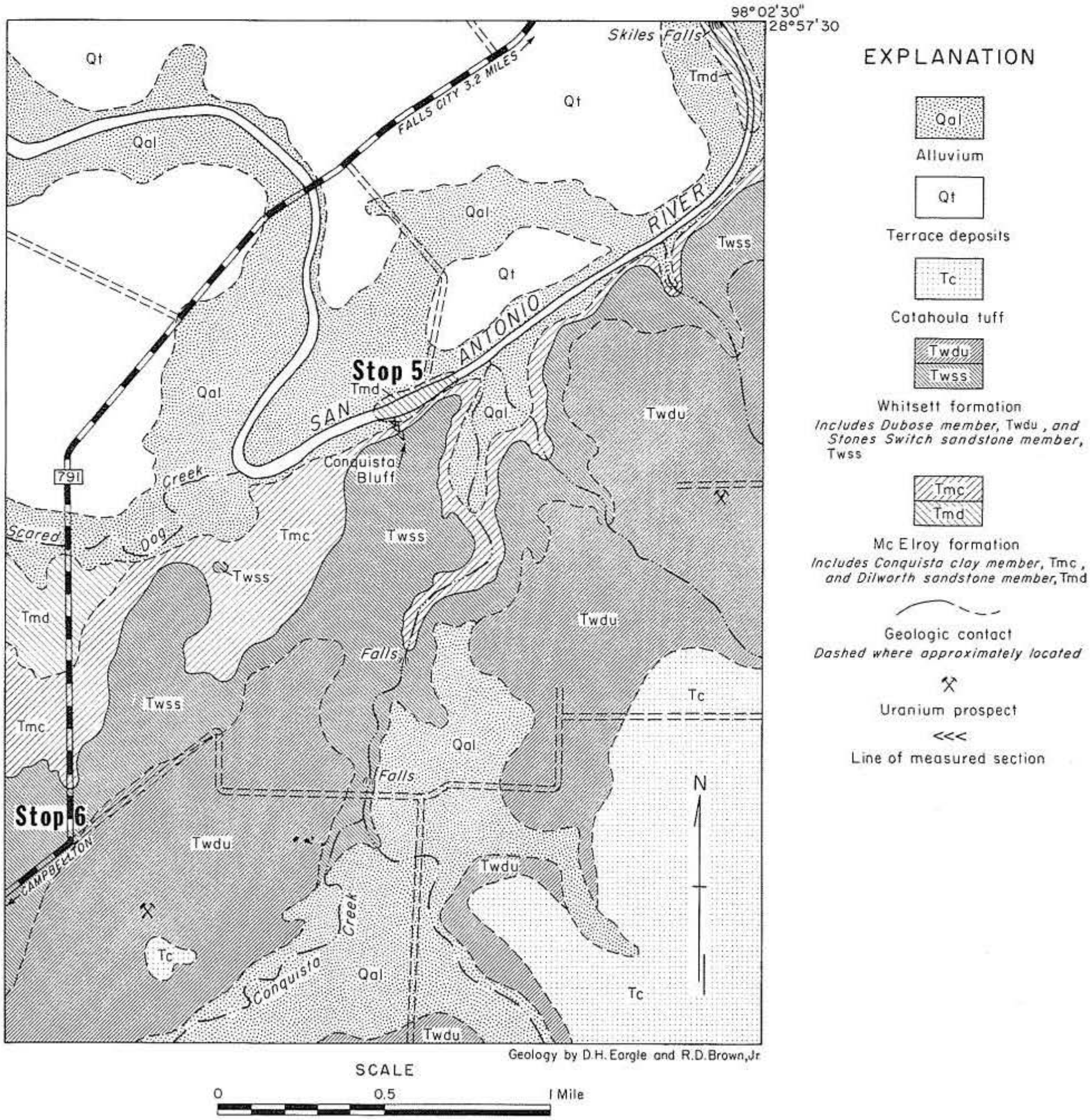


Figure 5. GEOLOGIC MAP OF VICINITY OF CONQUISTA BLUFF, KARNES COUNTY, TEXAS.

	Thickness (feet)
McElroy formation (continued)--	
Conquista clay member (continued)--	
3. Clay, sandy, light brown, breaks into irregular blocks with platy selenite and jarosite coating on joints	6
2. Clay, chocolate, grades up into gray-streaked silty clay toward top; fissile. Bedding planes coated with jarosite	14
Dilworth sandstone member, upper bed--	
1. Sandstone, indurated, medium gray, very fine grained, with matrix of clay. Contains white plant-root impressions. Dip about 2° SE., strike N. 35° E. on this bed. Strong parallel joints trending N. 35° to 40° E.	2+

Section in bed and walls of Conquista Creek, 0.75 mile south of Conquista Bluff on Pawlik farm (measured from top down).

	Thickness (feet)
Jackson group--	
Whitsett formation--	
Stones Switch sandstone member--	
13. Sandstone, indurated, gray, fine grained; upper 4 feet locally layered and ripple marked, elsewhere not visibly bedded; contains *Ophiomorpha major* borings; overlies 1-foot bed of nodular less indurated sand; overlies 1-foot bed of massive to faintly cross-bedded hard sandstone . .	6
12. Sand, silty, soft, light gray to pale yellowish brown, fine grained, high percentage of dark grains, well bedded. Sharp basal contact	14
Conquista clay member--	
11. Clay, weathers light yellowish brown, laminated, bentonitic. To bed of creek	4

Beds 11-13 of Conquista Creek are correlated with beds 8-10 (see numbered beds in fig. 6). Farther upstream and in nearby gullies the Stones Switch sandstone member consists of about 60 feet of silty and slightly clayey, generally soft, sand and contains coquinas of fossil pelecypods and abundant *Ophiomorpha* borings and, near the top, fossil plant impressions and opalized wood fragments. Contact with clays of the overlying Dubose member is sharp.

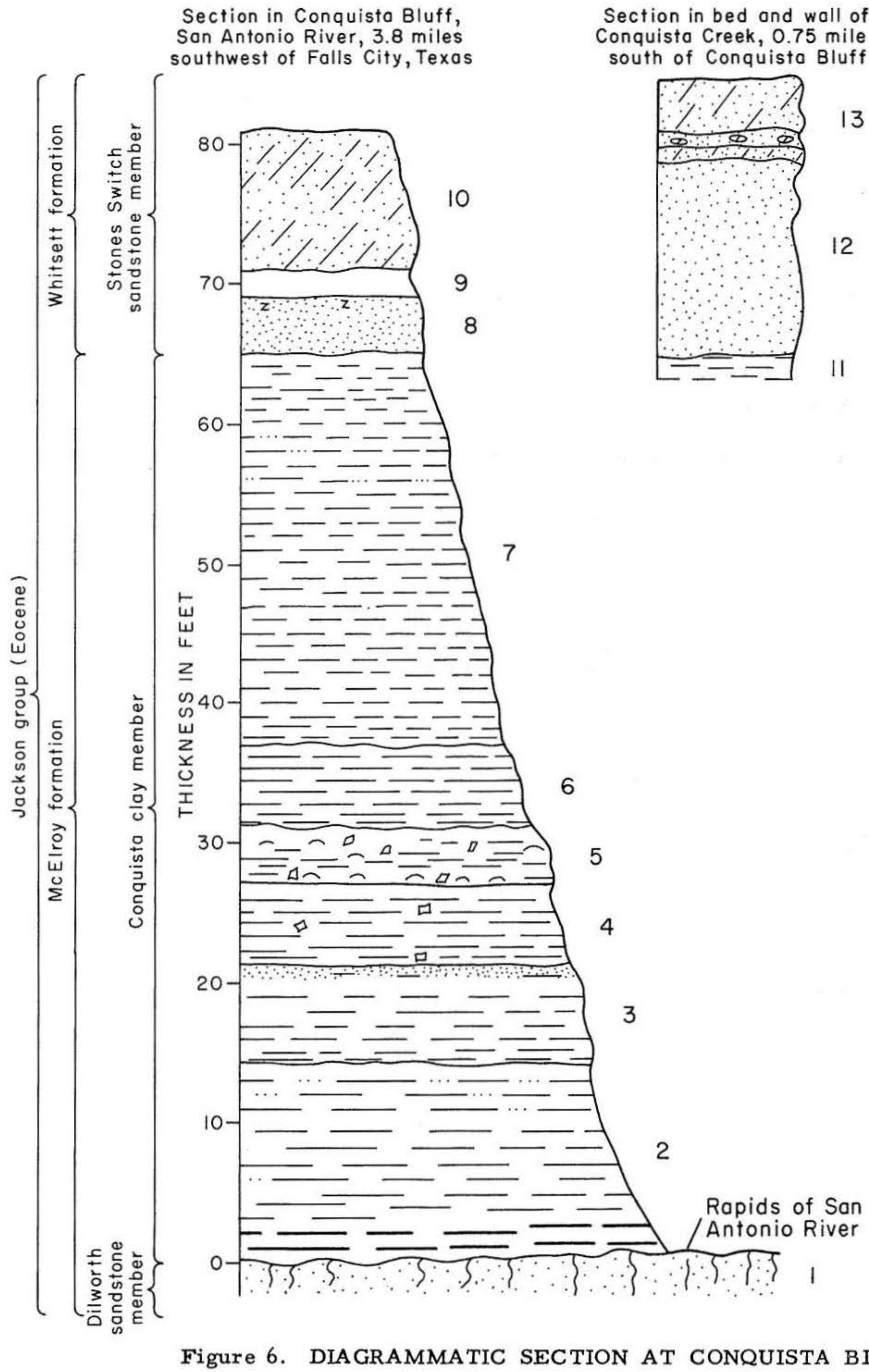


Figure 6. DIAGRAMMATIC SECTION AT CONQUISTA BLUFF,

SAN ANTONIO RIVER, KARNES COUNTY, TEXAS.

Philip B. King (1940, p. 178), discussing the economic uses of clays in Texas, has the following remarks concerning the clays at Conquista Crossing: "According to H. B. Parks (letter June 1934), 'during the Civil War an attempt was made to make sugar at Falls City. There still remains the ruins of a sugar mill. The reason that the sugar mill was located there was the presence of fuller's earth, which allowed them to bleach the sugar.' J. R. Martin states, however, that the clays of the deposit are of inferior bleaching power, although they might be of use for ceramics. The deposit was only briefly examined by the writer [King] and no samples were taken."

Mileage Total	Mileage Interval	
64.1	0.8	Return to Farm Road 791 and turn left on that road.
64.3	0.2	Cross San Antonio River.
65.9	1.6	Outcrop of Dilworth sandstone member on right side of road.
66.3	0.4	STOP 6. Outcrop of Stones Switch sandstone member of Whitsett formation, upper formation of Jackson group, on left side of road. Indurated sandstone at top, grading into soft, tuffaceous sandstone below. Fine-grained, highly feldspathic and lithic sandstone with zeolitic cement (heulandite) at top. Trachytic texture in lithic grains in soft sand.
68.9	2.6	Along next 0.3 mile, on both sides of Farm Road 791, are outcrops of nonmarine interbedded silt, carbonaceous clay, and sand of Dubose member, Whitsett formation (fig. 7).
69.8	0.9	Turn right at Susquehanna-Western, Inc., sign. Ahead was formerly the community of Deweesville, in recent years abandoned, now the site of Susquehanna-Western's uranium mill.
70.6	0.8	Turn right at gate to mine (Lyssy-Niestroy property, Luckett lease, of Susquehanna-Western, Inc.).
71.3	0.7	STOP 7. Open-pit uranium mine. Following is description of section.

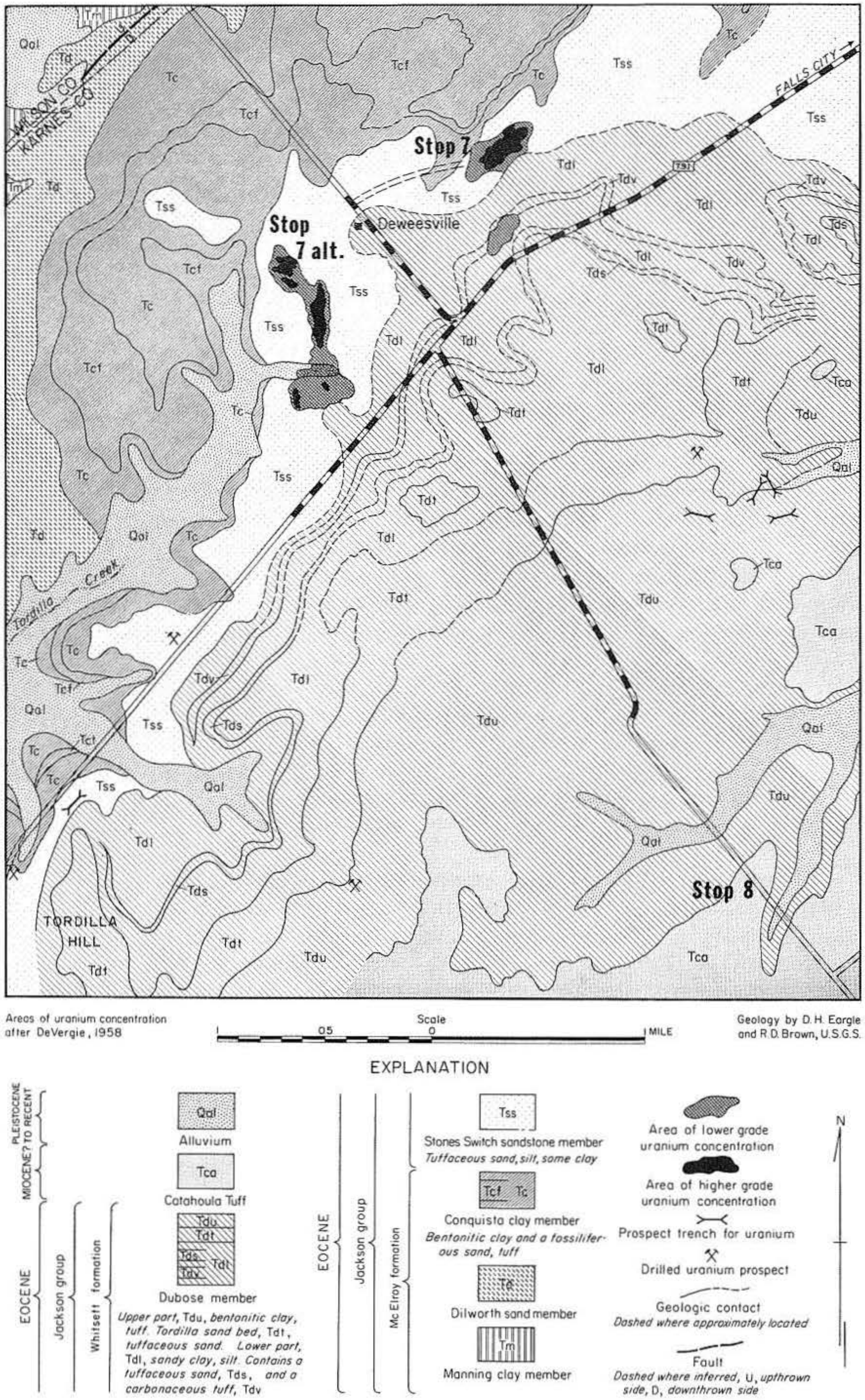


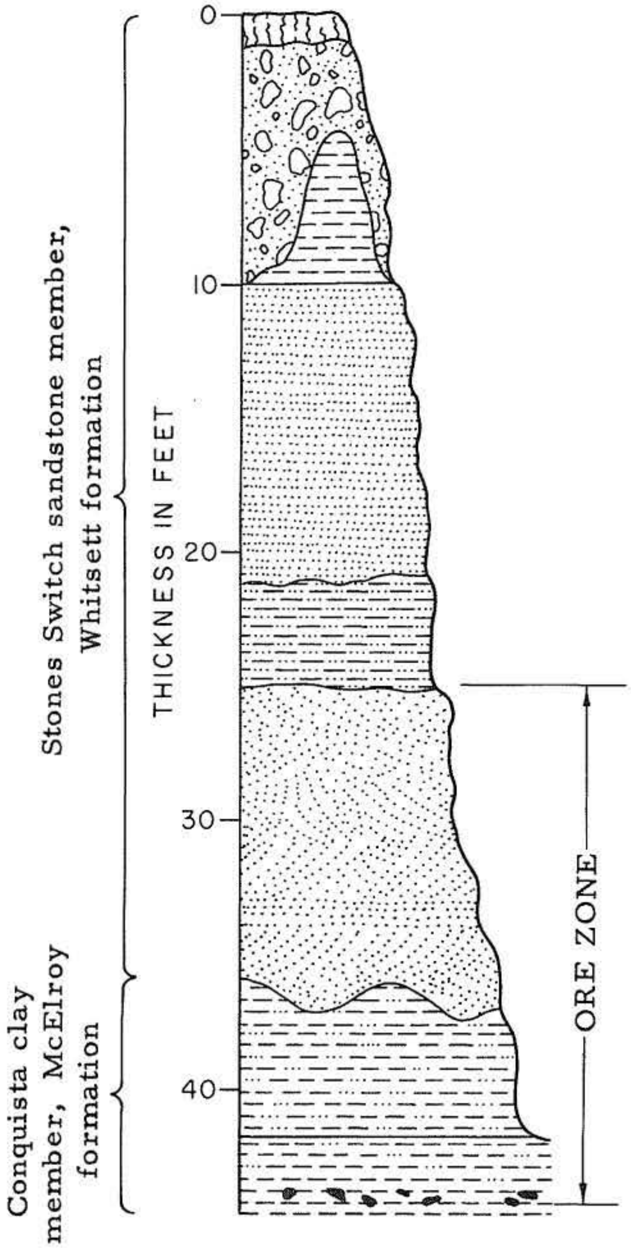
Figure 7. GEOLOGIC MAP OF VICINITY OF DEWEESVILLE,

KARNES COUNTY, TEXAS.

Section of Stones Switch sandstone member in open-pit uranium mine of Susquehanna-Western, Inc. (measured from top down).

	Thickness (feet)
Soil	2
Sandstone, fine to medium grained, tuffaceous, silty, and clayey. Irregular, crumbly structure. Near base are impressions of small pelecypods	6
Clay, with zone of 2 to 4 feet of calcareous concretions slightly above the middle of zone. Concretions are dense limestone; each is wider than high and has mammillary surface. Clay between concretions is light gray, smooth, dense, slightly brittle, and has conchoidal fracture. Near bottom of 8 feet of clay is a second zone of calcareous concretions 1 to $1\frac{1}{2}$ feet in diameter, developed locally in mine	8
Tuffaceous shale, somewhat sandy, fissile to slabby, brittle, and abundant plant impressions; pinkish gray	3
Sandstone, medium grained, hard, gray to pinkish gray, with plant impressions. Grades into soft sand below	2 to 3
Sand, fine grained, friable, clayey, finely cross-bedded. This is the ore-bearing sand with uranium ore irregularly distributed in it. The principal uranium mineral is autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 10H_2O$, with small amounts of uranyl vanadate. Under the Stones Switch sandstone member the top of the Conquista clay member is exposed locally in the floor of the pit. It is massive to faintly bedded, tuffaceous silty clay, weathering to irregular lumps. Pinkish gray. Plant fragment impressions . .	6 to 9

Mileage Total	Mileage Interval	
72.0	0.7	Return to Deweesville road at gate of mine road. Alternate trip (STOP 7, alt.) to uranium mill and/or exposure of Stones Switch sandstone member in Gembler open-pit mine half a mile from road and directly behind the uranium mill. This pit shows a similar section of sandstone (fig. 8), except that the sandstone is locally highly silicified at the surface of the north wall of the pit. It shows more irregular channeling of sand and clay and lacks the



Soil, sandy, dark gray

Conglomerate, clay fragments, and boulders, coarse sand matrix, very irregular base

Clay, bentonite, very light gray, smooth, very irregular fracture

Sandstone, silty, very light olive gray, fine grained, tuffaceous, laminated; finely divided organic matter; upper part contains Ophiomorpha borings

Siltstone, pale-chocolate to yellowish-orange-brown; highly carbonaceous, laminated

Sandstone, very light gray, fine grained, silty, soft, finely cross-bedded, faintly laminated, abundant secondary minerals filling interstices between grains. Irregular base

Clay, silty, pale-brown, carbonaceous, laminated, abundant autunite along bedding and joint planes

Clay, medium-gray, laminated, silty streaks. Black vermiculate mottling of sooty pitchblende locally in silty layers

Figure 8. DIAGRAMMATIC SECTION ALONG NORTH WALL OF PIT

IN WINDMILL ORE BODY,

Gembler tract, Nuhn lease of San Antonio Mining Company,

Karnes County, Texas.

Mileage		
Total	Interval	
		large, dense, calcareous concretions. The floor of this pit is also on the Conquista clay member which is relatively impermeable and prevents the draining of rain water. Locally, the Conquista clay member is dark blue-gray with fine-grained pyrite and plant fragments and contained uraninite. This is the only low-valent or reduced uranium found thus far in the Karnes County area.
72.8	0.8	Return to T junction on Farm Road 791; turn right.
72.9	0.1	Turn right (south) on county road.
73.8	0.9	On left side of road, a pit in sand of Dubose member of Whitsett formation.
75.7	1.9	STOP 8. A sequence of outcrops in ditches along both sides of road is as follows, from the north and top of the sequence:

Catahoula(?) tuff--

4. Tuff, very light gray (N8), very fine-grained glass shards with some very fine-grained quartz and feldspar; the shards are of two types--(1) clear platy and (2) fluted; index of refraction in range of 1.495 to 1.505; and they are partly altered to montmorillonite. This tuff is much less altered than the white tuff beneath as indicated by its higher content of alkalies (see spectrographic analyses in table 1) and by less clay alteration.

3. Tuff, white, very fine grained, considerably altered to montmorillonite. Thin section shows faint outline of shards in plain light but chiefly fine-grained, birefringent clay with crossed-nicols. This sample is about 5 feet stratigraphically below gray tuff sample and not more than 25 feet above base of tuff.

Whitsett formation, upper part--

2. Nodules at top of bed just below altered tuff.

1. Clay, brittle, compact, light olive-gray. Uniform, massive, cryptocrystalline clay in thin section, shows no banding, shard texture, or sand grains. X-ray diffraction pattern shows opal, montmorillonite, and quartz. Silica released from alteration of (3) has formed the siliceous nodules of (2) and opal in top of clay bed.

TABLE 1. Composition (semiquantitative spectrographic analyses). Joseph Haffty (spectrography), Joseph Budinsky (chemical U), and B.A. McCall (equivalent U), analysts, U.S. Geological Survey.

Percent	Gray tuff (AW-344)	White tuff (AW-343)	Olive-gray clay (AW-346)
> 10	Si	Si	Si
10.	Al	Al	Al
3.	Na K	-	Fe
1.	Fe Ca	Fe Mg Ca	Mg Ca K
.3	-	Na	Na Ti
.1	Mg Ti	Ti	-
.03	Ba Ce	B	Ba
.01	Mn La Sr Y Zr	Ba Sr Zr	Mn B Sr V Zr
.003	Ga Sc	Mn Ga La Ni Sc	Cr Cu Ga La Ni Sc Y
.001	Cu Mo Nb Pb	Co Cr Cu Nb V Y	Co
.0003	Be Yb	-	Yb
.0001	-	Be Yb	Be
.00001	-	-	Ag
Chem. U (%)	.001	< .001	.001
Equiv. U (%)	.002	< .001	< .001

Sensitivity approximately 0.1 percent for K.

Mileage Total	Interval	
75.9	0.2	Approximate contact of Catahoula tuff (Miocene?) with underlying Jackson group (Eocene).
76.2	0.3	Turn left (northeast) on county road.
77.1	0.9	Good outcrop of Catahoula tuff with many thin stringers of caliche.
78.6	1.5	Turn right on (paved) Farm Road 1144 toward Karnes City.
82.7	4.1	Road to left to Hobson oil field (Carrizo sand production). Continue on Farm Road 1144. Catahoula tuff outcrops with caliche cap and many veinlets.
83.6	0.9	State Highway 81 on left. Continue on Farm Road 1144.

Mileage		
Total	Interval	
84.0	0.4	STOP 9. Outcrop in long roadcut of Catahoula tuff covered with caliche showing various stages of working down into the altered tuff. A thin section of the tuff shows no remains of shardy texture; the tuff is mostly altered to clay and contains a little quartz. The caliche contains some montmorillonite and, from the spectrographic analyses (table 2), seems to have infiltrated the tuff and chiefly diluted the constituents.

TABLE 2. Composition of pink tuff and caliche from semiquantitative spectrographic analyses. Joseph Haffty, analyst, U. S. Geological Survey.

Percent	Tuff (AW-341)	Caliche (AW-342)
> 10	Si	Ca Si
10.	Al	-
3.	Fe	Al
1.	Mg Ca Na K	Fe K
.3	Ti	Mg Na
.1	-	Ti
.03	Mn Ba Sr Zr	Ba Sr
.01	V B	Mn
.003	Co Cr Cu Ga Ni Sc Y	Cr Cu Y Zr
.001	Nb Pb	Co Ga Ni Sc V
.0003	Yb	-
.0001	Be	Yb

Mileage		
Total	Interval	
86.7	2.7	On left is pit with gravel from Catahoula tuff used for road material.
87.9	1.2	Base of Oakville sandstone is indicated by sandy soil. It rests on pale-pink tuff of Catahoula.
88.9	1.0	Intersection of Farm Road 1144 with U. S. Highway 181, half a mile west of Karnes City. Continue to State Highway 123 in Karnes City and turn left on 123 to Austin, about 108 miles distant.

VERMICULITE DEPOSITS NEAR LLANO, TEXAS

V. E. Barnes [4/] and S. E. Clabaugh [5/]

INTRODUCTION

At least three genetically and mineralogically dissimilar types of vermiculite are found in Precambrian metamorphic rocks in central Texas. The most distinctive variety is pearly white magnesian vermiculite which occurs sparingly in weathered marble at an abandoned magnesite mine about 4 miles southeast of Llano. The second type is green to brown vermiculite associated with soapstone and serpentine. It is best developed in the Carl Moss deposit about 8 miles south of Llano, where it appears to be a hydrothermal mineral. The third and most abundant variety is brown vermiculite formed by the weathering of biotite in mica-amphibole schist. A small amount of this type has been mined for commercial use from the Bush deposit about 5 miles northeast of Llano.

For additional information, the reader is referred to "Vermiculite in Central Texas," by Clabaugh and Barnes, issued in 1959 by the Bureau of Economic Geology as Report of Investigations No. 40. The road log which follows does not duplicate maps and information in that Report of Investigations. Instead, the reader is advised to supplement the log with a copy of the Report.

[4/] Bureau of Economic Geology, The University of Texas.

[5/] Department of Geology, The University of Texas.

ROAD LOG

Austin to Llano, Texas, and Vicinity
Stops 10-13
October 15, 1961

DEPART FROM VILLA CAPRI MOTOR HOTEL,
2630 Interregional Highway, Austin.

Mileage Total	Mileage Interval	
0		Proceed south on access road of Interregional Highway to East 19th Street.
0.5	0.5	Turn right (west) on East 19th Street, passing, to the left, the "Little Campus," which houses the Bureau of Economic Geology, the Division of Extension, and several other branches of The University of Texas. The main campus of the University lies ahead and to the right, centered about the conspicuous tower. In a small park on the north (right) side of East 19th Street is an unusual and appropriate monument, an old oil well rig brought here from the first producing well--Texon Oil Company No. 1 Santa Rita--drilled on University land in the western part of the State. The University system now possesses an endowment of about a third of a billion dollars obtained chiefly from oil leases and royalties on land grants. Income from the endowment helps operate Texas A. and M. College and its branches, several medical schools, Texas Western College, and the main University in Austin.
1.9	1.4	Turn left (south) on Lamar Boulevard.
3.2	1.3	Bridge over the Colorado River; continue straight ahead on South Lamar. The Colorado River of Texas is a small stream by comparison with its big relative, the Colorado River of the West, which carved the Grand Canyon. The Colorado River of Texas was once a wilder stream capable of producing muddy floods that reached into the business district of Austin and wreaked havoc in the farmlands adjoining the river between Austin and the coast. During the past 30 years, seven dams have been built on the Colorado within 75 miles of Austin, creating more shoreline in central Texas than on the Gulf Coast of the State! Some of the lakes may be seen as this route is traversed.

Mileage Total	Mileage Interval	
9.9	6.7	Pass through the small community of Oak Hill. In this vicinity the main branch of the Balcones fault system is crossed; this separates the low-lying coastal plain, underlain by soft Upper Cretaceous and Tertiary sedimentary rocks, from the central Texas "highlands" or Edwards Plateau, underlain by harder Lower Cretaceous rocks. Most of the land ahead is used for ranching, whereas much of that to the southeast is farmland.
11.2	1.3	Highway intersection; keep to the right on State Highway 71.
23.7	12.5	Two small landslides have occurred here in sandy marl where roadcuts weakened the hillside. Both are still active and debris must be removed from the road at intervals of a few months. We have been traveling through hills cut in Glen Rose limestone. As the Llano uplift is approached, where granite and metamorphic rocks were being eroded in Cretaceous time, the Glen Rose limestone becomes more sandy and marly, finally giving way to near-shore sediments consisting of sandstone, shale, and reef limestone.
25.6	1.9	View of Lake Travis on the right (north) in the valley of the Colorado River.
28.8	3.2	Pale Face store on right and Pedernales River bridge ahead. The river is actually an estuary of Lake Travis at this place. The cliffs bordering the river are reef limestone (Cow Creek limestone) through which the stream had incised its course into underlying shale. The Pedernales River has recently attained minor fame as the site of Vice-President Lyndon Johnson's ranch, located about 20 miles upstream (southwest). The name of the river is the Spanish word for nodules of flint or chert, which are abundant along the stream. It was a favorite haunt of Indians for at least the last 7,000 years, as shown by radiocarbon dating of charcoal associated with artifacts and bones in shelters in the limestone cliffs near the bridge.

Mileage Total	Mileage Interval	
35.3	6.5	Ahead lies a small area of farmland in which the small town of Spicewood is situated. A few beds of Glen Rose limestone crop out in low hills to the left, but the farms are located on outcrops of Hensell and Sycamore sandstones, the near-shore Cretaceous sandstones. This isolated patch of fertile (but semi-arid) farmland is part of a discontinuous belt of outcrop of sandstone on the southern margin of the Llano uplift. It is also a strip of country which German colonists wisely selected for intensive settlement more than a century ago, and the present residents are nearly all of German extraction.
37.4	2.1	The two-story house clearly visible to the left on a low hill is typical of the dwellings built by the German colonists throughout this region. Continuing northwest along Highway 71, we pass rapidly out of the sandy farmland to rocky ground on lower Paleozoic formations.
44.6	7.2	Intersection with U.S. Highway 281. Continue straight ahead on Highway 71. The town of Marble Falls and a major granite quarry are located about 5 miles to the north. The quarry supplied granite for the Texas Capitol building, the Los Angeles County Courthouse, the Leif Erickson Memorial in Iceland, and a multitude of other structures. Marble Falls takes its name from outcrops of unmetamorphosed, siliceous Pennsylvanian limestone in the bed of the Colorado River.
48.9	4.3	In this vicinity Granite Shoals Lake may be glimpsed to the north in the valley of the Colorado River.
50.8	1.9	Roadcut in brecciated Ordovician limestone followed by outcrops of Precambrian metamorphic rock. The two are in contact along a high-angle fault with more than a thousand feet of vertical displacement.
56.0	5.2	Bridge over Sandy Creek. The roadcut ahead exposes weathered hornblende schist.
58.3	2.3	The mountain on the right is Packsaddle Mountain. It is chiefly Upper Cambrian sandstone and limestone resting on Precambrian metamorphic rocks.

Mileage Total	Interval	
61.8	3.5	Bridge over Honey Creek. Graphite schist is exposed in the roadcuts ahead. The largest operating graphite mine in the United States is located nearby in the vicinity of Burnet.
65.6	3.8	Roadcut in Cambrian sandstone.
71.4	5.8	Roadcuts in this vicinity expose Precambrian metasedimentary rocks. The prominent hills on both sides of the highway are granite.
74.5	3.1	Highway intersection at outskirts of Llano. Turn right toward center of town.
75.3	0.8	Llano County Courthouse on left; continue straight ahead (north).
75.5	0.2	Bridge over the Llano River, a tributary of the Colorado. Continue straight ahead (north) on State Highway 16 through the highway intersection at the north edge of town.
80.0	4.5	Turn right on unpaved road to T. K. Bush house and vermiculite deposit.
80.9	0.9	STOP 10. Pit on right (south) side of road about 0.1 mile beyond Bush house. This is the locality from which 6,000 tons of vermiculite-bearing rock was mined in 1946. The deposit is described more fully and shown on a geologic map in Report of Investigations No. 40, pages 11-13. Chemical analyses follow.

Chemical analyses of samples from Bush pit, Llano County, Texas. C. O. Ingamells (Samples 1 and 3) and Eileen H. Oslund (Sample 2), analysts, Minnesota Rock Analysis Laboratory, Minneapolis.

	Sample 1	Sample 2	Sample 3
SiO_2	38.96	33.99	37.55
Al_2O_3	14.11	14.23	10.86
TiO_2	0.87	0.69	0.22
Fe_2O_3	3.00	0.91	3.96
FeO	8.79	9.58	0.18
MgO	18.71	20.11	25.63
MnO	0.15	0.13	0.06
NiO	--	0.19	--
CaO	0.14	0.34	0.50
Na_2O	0.34	0.14	0.08
K_2O	9.39	0.06	0.05
Rb_2O	0.03	--	--
H_2O+	3.90	8.61	9.10
H_2O-	0.40	10.69	11.16
F	0.15	0.05	0.09
Cl	0.04	--	--
BaO	0.07	--	--
Cr_2O_5	0.45	--	--
	99.50	99.72	99.44
Less O = F and Cl	0.07	0.02	0.04
	99.43	99.70	99.40

Sample 1. Unweathered biotite from the floor of the pit.
Sample 2. Brown vermiculite from the wall of the pit.
Sample 3. Large yellowish flakes from the southwest corner of the pit.

Mileage Total	Mileage Interval	
86.5	5.6	Return to Llano and continue south on State Highway 16, passing the Courthouse at this mileage.
88.5	2.0	Turn left (east) on unpaved road marked Riley Mountains.
90.0	1.5	Turn right on unimproved ranch road and continue about 0.5 mile.

Mileage		
Total	Interval	
90.5	0.5	STOP 11. The abandoned Texas Mines magnesite quarry is located in the adjoining pasture to the west. To reach it, a barbed wire fence must be crossed. (Easiest method: Forget dignity and crawl under; it is a conveniently high fence.) From this locality was obtained a highly magnesian vermiculite which appears to have been produced by the weathering of phlogopite. An analysis of the vermiculite follows. NOTE: If interest in weathered phlogopite is keen, and if time allows, a second locality may be visited. It is located exactly 3 miles west of the Llano Courthouse on the road to Castell in a low roadcut in marble on the north side of the road east of a small creek.

Chemical analysis of vermiculite from area of Texas Mines magnesite quarry, Llano County, Texas. Eileen H. Oslund, analyst, Minnesota Rock Analysis Laboratory, Minneapolis.

	Percent
SiO_2	35.36
Al_2O_3	13.61
TiO_2	0.26
Fe_2O_3, FeO	0.24
MnO	0.01
NiO	0.00
MgO	27.48
CaO	0.37
Na_2O	0.05
K_2O	0.10
H_2O+	10.36
H_2O-	10.74
F	0.51
CO_2	0.44
	99.53
Less O = F	0.21
	99.32

Mileage Total	Mileage Interval	
92.5	2.0	Return from the Texas Mines magnesite quarry to the intersection of the Riley Mountains road with State Highway 16. Proceed south on Highway 16.
98.6	6.1	STOP 12. Park vehicles beside the highway and enter the Carl Moss ranch through an old gate on the right (west) side of the highway. Walk about 500 yards west to the vermiculite, soapstone, and serpentine occurrences. This deposit is shown on geologic maps and described in Report of Investigations No. 40, pages 19-23. Analyses of two collected samples of vermiculite follow.

Chemical analyses of vermiculite samples from the Carl Moss ranch, Llano County. C. O. Ingamells (Sample 1) and Doris Thaemlitz (Sample 2), analysts, Minnesota Rock Analysis Laboratory, Minneapolis.

	Sample 1	Sample 2
SiO_2	35.19	34.95
Al_2O_3	12.73	12.85
TiO_2	0.75	0.13
Fe_2O_3	3.52	3.09
FeO	0.46	0.57
MnO	0.05	0.03
MgO	26.85	29.25
CaO	0.24	0.00
Na_2O	0.02	0.02
K_2O	0.01	0.03
H_2O+	10.77	10.87
H_2O-	9.00	7.55
F	0.15	0.38
Cl	0.04	--
	99.78	99.72
Less O = F and Cl	0.07	0.16
	99.71	99.56

Sample 1. From veinlet near top of old inclined shaft.
Sample 2. From bottom of same shaft at least 50 feet underground.

Mileage Total	Interval	
		Return to vehicles and continue south on State Highway 16.
100.55	1.95	Turn left (east) from Highway 16 on unpaved road beyond the spreading live-oak tree.
103.1	2.55	Turn right on ranch road at sign marked Thomas Gregory.
103.5	0.4	STOP 13. A series of pits in soapstone in which vermiculite occurs is about 100 yards west of the Gregory house. This deposit is described on pages 23 and 24 of Report of Investigations No. 40. The shaft has been filled, but part of the face of the open cut shown in the sketch is still exposed.