BUREAU OF ECONOMIC GEOLOGY
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Peter T. Flawn, Director

Report of Investigations — No. 63

Lithology and Petrology of the Gueydan (Catahoula) Formation in South Texas

By

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Lithology and Petrology of the Gueydan (Catahoula) Formation in South Texas

Earle F. McBride,[1] William L. Lindemann,[2]
and Paul S. Freeman[3]

ABSTRACT

The Gueydan Formation, which crops out south of the Colorado River in the Gulf Coastal Plain, is chiefly pastel-colored tuffaceous clay with lesser volcanic arenite and conglomerate, bentonite, vitric tuff, and a few beds of vitric ash. In Duval and McMullen counties the formation contains the coarsest volcanic rock detritus of any Tertiary unit in the Texas Gulf Coast.

The Gueydan rests unconformably on the Whitsett and Frio Formations (mid-Tertiary) and is unconformably overlain by the Oakville Formation (Miocene) to the north and Goliad(?) (Pliocene) to the south. The Gueydan has a maximum thickness of approximately 1,000 feet in Duval County and thins north and south to approximately 200 feet.

The age of the Gueydan is uncertain owing to the lack of indigenous datable fossils; it is probably Oligocene to early Miocene. Fossils found during this study are petrified wood, including questionable palm seeds, silicified plant roots, root-tube marks, animal burrows, turtle remains, unidentifiable bone detritus, and reworked marine fossils of Cretaceous and perhaps Tertiary age. The Gueydan is predominantly, if not entirely, nonmarine at the outcrop.

White to gray tuff is most common in the lower part of the formation, whereas pink tuffaceous clay is most abundant in the upper part. Sandstone, bentonite, and opalized tuff and clay occur throughout the formation, but sandstone and conglomerate are most abundant in the middle part in Duval and McMullen counties. Ash and clay beds were altered by weathering during the time of Gueydan deposition. Soil features formed include pisolites, beds devoid of internal stratification and having a random or uneven grain fabric, desiccation cracks, tubules of root scars, and opalized and calichified beds. The soils probably developed in a subhumid climate which had several months dry season each year. A climatic change was responsible for the differences between the lower part of the formation (slight devitrification, abundant zeolite, Ca-montmorillonite) and the upper part (argillized ash, scarce zeolite, Ca^{++} and Na^{+}-montmorillonite).

Ash and clay originally accumulated as air-fall, fluvial, and mudflow deposits. However, soil-forming processes have modified the depositional texture of most deposits, and the mechanism of deposition of most beds is uncertain.

Sandstone and conglomerate are fluvial bar and channel deposits. These rocks are composed largely of volcanic detritus (trachyte, trachyandesite, rhyolite, welded tuff) but locally have significant amounts of Cretaceous carbonate rock fragments or locally derived clay and tuff clasts. Conglomerate and sandstone beds are coarsest and richest in volcanic detritus in Duval County. The coarsest clasts are rounded boulders of amygdaloidal lava as large as 3 feet in diameter. The largest boulders are weathered out of clay in McMullen County.

Bentonite beds are composed of randomly oriented montmorillonite and are inferred to have formed in place by the argillation of glass dust, probably originally windblown deposits.

Evidence for the source location of the volcanic debris is inconclusive, but the

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sources were probably volcanoes and outcrops of lavas and tuffs located in Big Bend National Park and adjacent areas in northern Mexico and west Texas. Evidence for this distant western source includes petrologic similarity of rocks, probable west-to-east upper-level wind currents during Tertiary time, and a southeasterly direction of stream transport shown by crossbeds in Gueydan strata.

Complex diagenetic changes in texture and mineralogy include: argillation and zeolitization of glass; cementation of sand with zeolite (clinoptilolite), opal, and chalcedony; formation of glaebules (pisolites and lumps) in soils; formation of clay dikes along fractures in Gueydan strata; formation of zones of silicification and veins of calcite along faults; and calichification of porous strata.

INTRODUCTION

Tuff, tuffaceous sand and clay, bentonite, and sandstone containing abundant volcanic rock detritus are present in Gulf Coast Tertiary rocks ranging in age from Eocene to Pliocene. This report summarizes the results of a stratigraphic and sedimentologic study of outcrops of one unit of the sequence, the Gueydan (Catahoula) Formation, from south of the Colorado River, Texas, to the Rio Grande. It is one phase of a study of middle Tertiary volcanism in southern Texas and northeastern Mexico. The long-range purposes of this project are (1) to determine the petrogenesis and provenance of Gulf Coast Tertiary sedimentary rocks rich in volcanic rock detritus, and (2) to map, describe, and interpret previously unstudied Tertiary volcanic and hypabyssal rocks in northeastern Mexico.

The Gueydan Formation was chosen to be the first of the projected studies because (1) it contains the coarsest volcanic rock clasts in the Texas Gulf Coast, and (2) it is composed almost entirely of volcanic rock debris or the alteration products of volcanic rocks. Igneous rocks of gravel size in conglomerate are samples of the source rocks from which the fragments were derived and provide important clues to the source of the coarse fragments. Sedimentary structures in fluvial sandstone bodies enable determination of the directions of stream flow, and from this the paleoslope can be inferred. The fine-grained volcaniclastic detritus in the formation has undergone several types of post-depositional alteration to form a variety of new rock types: bentonite, opalized bentonite, caliche “limestone,” zeolitized tuff, and bentonitic tuff. Although study of the diagenetic products does not shed light on the source of the detritus, it yields information applicable to the petrogenesis of tuff and alteration products in other areas.

This report is based on contributions made as Master’s theses by the junior authors at The University of Texas under supervision of the senior author and on laboratory work subsequent to a geologic reconnaissance study of the Gueydan by the senior author. Lindemann (1963) mapped the Gueydan Formation in Duval County, emphasizing the stratigraphy and the sedimentologic aspects of the sandstone and conglomerate beds. Freeman (1966) mapped the tuff beds in the lower part of the formation in McMullen County and part of Live Oak County and studied relations of mudflow deposits, clastic dikes, siliceous knobs, and erratic rocks within the Gueydan. The senior author studied exposures of Gueydan along outcrop south of the Colorado River to the Rio Grande. The emphasis of field work was on clues to petrogenesis, relative abundance of rock types, and an attempt to record directional sedimentary structures to determine the paleocurrent pattern of sediment transport. Rock samples were collected and later studied by standard petrographic techniques to determine mineralogy, petrogenesis, and provenance. Field work was conducted at various times during 1962 and 1963 but chiefly during the summer months of June, July, and August of both years.

Sample localities of rocks mentioned in the report are shown in figure 1. Localities mentioned in the report are identified by a code letter and number that are enclosed in parentheses. The density of sample stations along the outcrop belt is unequal owing to more extensive study in Duval, McMullen, and Live Oak counties and also due to scarcity of outcrops in Jim Hogg, Webb, Gonzales, and Starr counties.

The manuscript was written by the senior author. Freeman does not agree with the origin proposed herein for some tuff beds, clastic dikes, and erratic rocks. He believes many of these rocks are intrusive and extrusive deposits emplaced during several episodes of sedimentary volcanism when high pressure gas forced tuff and erratic rocks at depth to the surface along

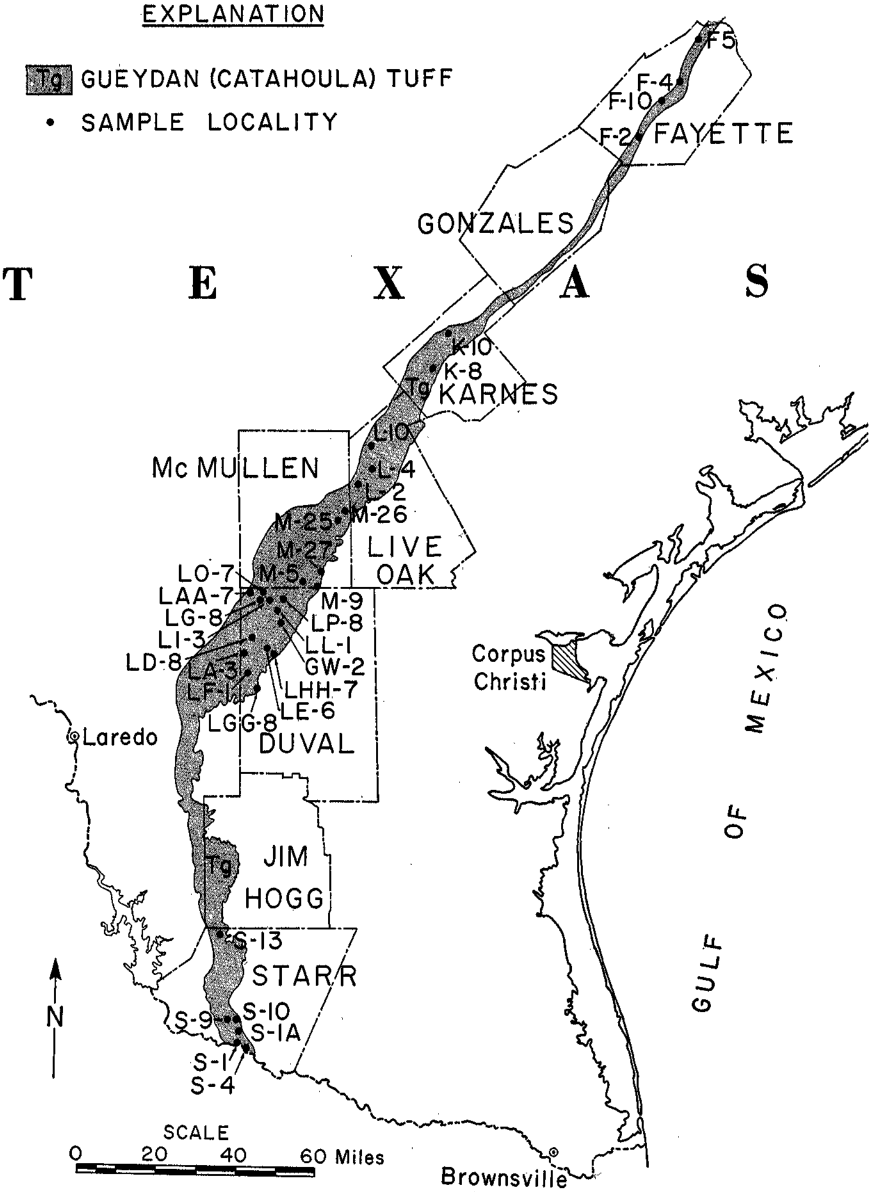

FIG. 1. Index map of sample localities. Labeled localities are those from which samples were collected or which are mentioned in the text. Gueydan outcrop from the Geologic Map of Texas (Darton, Stephenson, and Gardner, 1937).

faults. Evidence to support his hypotheses of origin is presented in his Master's thesis (Freeman, 1966) and is currently being prepared for publication; it is not presented here.

Preliminary reports on aspects of this study have appeared in abstracts by Lindemann (1962) and McBride (1966).

ACKNOWLEDGMENTS

Much of the cost of this investigation was borne by a grant from the National Science Foundation (G-19773) with P. T. Flawn and E. F. McBride as co-principal investigators. Flawn introduced the problem of the Gueydan to the writers and counseled them on many problems.

A grant from the Research Institute of The University of Texas to McBride provided time and supplies to implement the study.

The Bureau of Reclamation of the United States Department of the Interior permitted samples to be taken of cores from proposed dam-site locations in Live Oak County. Additional cores were examined at the Well Sample Library of the Bureau of Economic Geology, The University of Texas.

For helpful discussion on technical and geologic problems the writers are indebted to John A. Wilson, D. Hoye Eargle, Wilfred Portig, Lael Bradshaw, James W. Macon, Edward C. Jonas, Robert L. Folk, George Boyle, James Moberly, Jr., A. A. Meyerhoff, D. A. Barker, and J. A. Moore. Meyerhoff, Eargle, F. M. Bullard, Jonas, and W. L. Fisher reviewed the manuscript and made many improvements.

STRATIGRAPHY

NOMENCLATURE

The nomenclatural history of the rocks which form the subject of this report is, like that dealing with most rocks of the Gulf Coast Tertiary, nearly as complex as the rocks themselves. Most of this history is reviewed by Plummer (1933, pp. 710–713) and, more recently, by Stuckey and Woods (1954).

The rocks under consideration have generally been called Catahoula, although, for reasons stated later, the writers prefer the term Gueydan proposed by Bailey (1924). The term Catahoula was introduced by Veatch (1905) for strata exposed, and later described (Matson, 1917), in Catahoula Parish, Louisiana. Deussen (1914, pp. 68–70) applied the term to strata in east Texas, and Catahoula has subsequently been used to the Mexican border for strata similar either in lithology (in part) or in presumed age to strata in east Texas.

The rocks under consideration have been variously included within the Corrigan, Frio, Jackson, Oakville and Lapara, Reynosa, Fayette, Catahoula, and Gueydan Formations of previous workers. Catahoula gained acceptance in Texas following its use on the U. S. Geological Survey's geologic map of Texas (Darton, Stephenson, and Gardner, 1937), where Catahoula sandstone was used in east Texas and Catahoula tuff in south Texas. Catahoula tuff was accepted by the U. S. Geological Survey (Wilmarth, 1938) as the formation name.

Major stratigraphic details about the Catahoula in Texas appear in classic articles by Dumble (1918), Deussen (1924), Bailey (1926), and Renick (1936). Field work by these men and others has established that a belt of strata generally distinct from adjacent strata and characterized by pastel-colored tuffaceous and nontuffaceous clay and sandstone and other volcanic sediments can be traced across the Texas coastal plain. Whereas the clay in this stratigraphic unit apparently does not differ significantly along strike, the sandstone and associated strata do show pronounced differences.

Bailey (1926) was the first person to study and map systematically the rocks under consideration in this report over a large area (from the Rio Grande to Lavaca and Gonzales counties). He introduced the term Gueydan for rocks south of Gonzales County because he thought the strata were significantly different in lithology from strata (Catahoula) in the belt to the east that were examined by him or described in publications by others. The Catahoula strata in east Texas have not been studied with the detail and over as large an area as the Gueydan, so that knowledge of Catahoula lithology and stratigraphy is less than that for the Gueydan. However, the Catahoula is characterized by pastel clay and fine-grained sand and sandstone (Dumble, 1918, pp. 187–218). The term "rice sands" (Dumble, 1918, p. 188) has been applied as a field description to Catahoula sands because of the abundance of semi-polished grains of quartz of volcanic derivation and the scarcity of dark-colored grains. The Gueydan differs from the Catahoula in having a greater abundance of tuff and ash beds, coarser sand and sandstone that are rich in dark-colored volcanic rock fragments and iron ores, and, in Duval, McMullen, and Karnes counties, conglomerate beds with pebbles of lavas and other igneous rocks.

Eight years after introducing Gueydan, Bailey (1932) was willing to abandon the term in favor of Catahoula in deference to prevailing usage. The writers concur with his original conclusion that strata in south-central Texas, even though partly or entirely correlative to the Catahoula farther east, are sufficiently different in lithology to warrant a different name. Hence, Gueydan Formation is used in this report, realizing that the concept of "significantly different" is a subjective interpretation.

Bailey (1926, Pl. 1) mapped the Catahoula of east Texas as interfingering with the Gueydan in Gonzales County. In order to simplify terminology the writers refer to all outcrops which they studied as far north as Carmine, Fayette County, as Gueydan, even though the boundary established by Bailey is slightly south of this place. Additional mapping is needed to establish more accurately the boundary of the Catahoula-Gueydan.

Stratigraphic units for outcropping members of the Gueydan and of adjacent formations have been revised by workers subsequent to Bailey. They are summarized in figure 2.

The following have contributed interpretations on stratigraphic terminology involving the Catahoula-Gueydan in outcrop in Texas: Bailey (1924, 1932), Bowling and Wendler (1933), Cook (1932), Deussen (1924), Deussen and Dole (1916), Deussen and Owen (1939), Dumble (1894, 1903, 1924), Finch et al. (1931), Lahee (1932), Martyn and Sample (1941), Penrose (1890), Plummer (1933), Renick (1936), Thomas (1960), Trowbridge (1932), and Udden et al. (1916).

REGIONAL STRATIGRAPHY

The regional setting and stratigraphy of Texas Gulf Coast Tertiary strata were first outlined by Dumble (1918) and Deussen (1924) and were related specifically to the Gueydan by Bailey (1926). A more recent regional review is given by Murray (1961).

The Gueydan is part of a thick section of sedimentary rock of Tertiary age that fills the Gulf Coast geosyncline. Tertiary formations crop out in the gently sloping Gulf Coastal Plain in belts that generally are parallel with the present Gulf shoreline and dip gulfward from ½ degree to 2 degrees. Details of the surface stratigraphy of the Gueydan and adjacent formations are poorly known because of the scarcity of outcrops. The formations are largely weakly indurated rocks which weather easily to form deep soils and which offer few natural exposures.

As an aid to exploration for hydrocarbons in Gulf Coast Tertiary strata, considerable effort has been made to understand the spatial relations of Gueydan and adjacent stratigraphic units by using subsurface data. In spite of the wealth of information available, a confused nomenclature and stratigraphic picture exists because (1) facies relations are complex, and (2) correlations have been variously made on age, lithology, and fossils, frequently without realization that different parameters were used. An additional factor is that some rock-stratigraphic units named from the subsurface do not extend to the surface.

The Gueydan, which is largely if not entirely nonmarine in outcrop, grades downdip into a thicker marine facies. Controversy exists over the names and ages of units correlated with the Gueydan (Catahoula). Summaries of usage are given by Martyn and Sample (1941) and Stuckey and Woods (1954). The latter authors, reporting the consensus of a study group of the Houston Geological Society, record that in the upper Texas Gulf Coast region most workers correlate Catahoula (surface) with the Frio and Anahuac Formations (Oligocene-Miocene) in the subsurface.

Although the term Catahoula has been applied to surface and subsurface units from Mississippi southward into Mexico (Murray, 1961), this report concerns only the Catahoula (Gueydan) in outcrop between the Rio Grande and Colorado River, Texas.

THICKNESS

The maximum thickness of the Gueydan is in Duval County, where values (calculated from outcrop width and average dip) of 850 feet (Bailey, 1926, p. 63) and 1,100 feet (Sayre, 1937, p. 39) are reported. Bailey (1926) calculated that the formation decreases in thickness north and south of Duval County and reported a thickness of only 190 feet in Gonzales County. The following approximate thickness values were obtained from wells spudded in near

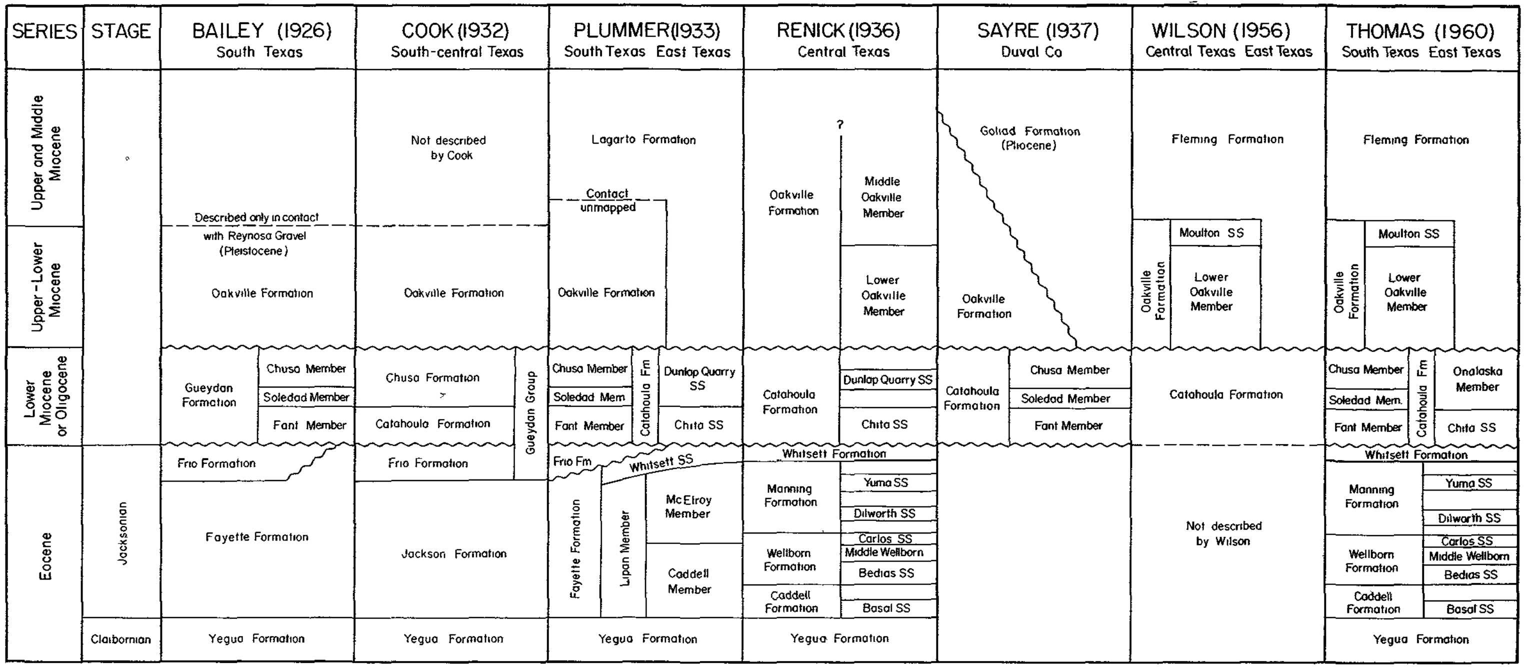

FIG. 2. Stratigraphic terminology of Gueydan and adjacent units. SS = sandstone.

the base of the overlying Oakville and which penetrated complete sections of Gueydan (D. H. Eargle, written communication, 1966) : eastern Karnes County, 500 feet; northern Live Oak County, 500 feet; central Live Oak County, 650 feet; north-central Duval County, 600 feet. Strata equivalent in age to the Gueydan increase in thickness eastward down the regional dip and grade laterally from nonmarine beds into marine beds; in Brazoria County, the Frio and Anahuac Formations have a total thickness in excess of 4,000 feet (Houston Geol. Soc. Study Group, 1954, cross-section A-A').

FORMATION BOUNDARIES

The Gueydan is underlain by the Frio Clay (Yeager Formation of Gardner and Trowbridge, 1931, and Murray, 1961, p. 399) (Oligocene?) in and south of Live Oak County and by the Whitsett Formation (Oligocene?) of the Jackson Group north of Live Oak County. This relation is the result of either a pinch-out by the Frio or overstepping of the Frio by the Gueydan in a northward direction. Basal Gueydan sandstone here rests on the Whitsett in stream-cut channel fills, although the length of the time represented by the erosion surface is unknown. Farther south the relations are more obscure. In Live Oak, McMullen, and Starr counties the base of the Gueydan is placed at the first prominent tuff bed above Frio Clay; the contacts apparently are conformable. In Duval, Webb, and Zapata counties, no exposures of the contact were recognized during this study.

The Gueydan is overlain unconformably by ancient stream-channel deposits along most of its outcrop. The formation to which the overlying rock units should be assigned has been disputed by previous workers. Bailey (1926) assigned the resistant sandstone unit which caps the Gueydan, and which forms an escarpment along much of the contact, to the Oakville (Miocene). Sayre (1937), who mapped Duval County only, showed the Oakville to be overlapped by the Goliad (Pliocene) in the southern part of the county so that Goliad rests on Gueydan. From recent mapping, D. H. Eargle (personal communication, 1964) also believes that the Goliad oversteps the Oakville south of the west-central part of Duval County. The controversy results from the fact that the rock units in question differ in lithology from the Goliad and Oakville Formations to the north, and these formations have not been mapped continuously to the southern exposures. In addition, datable vertebrate fossils have not been found south of Live Oak County.

FOSSILS

The most abundant fossils collected from the Gueydan are reworked Cretaceous foraminifers. Most foraminifers show effects of abrasion or are part of larger carbonate rock fragments. The most abundant genera are *Gumbelina, Globigerina,* and *Globotruncana. Planulina, Bulimina, Plectina, Anomalina,* and *Rotalia* are less common. These genera are all abundant in the Austin, Taylor, and Navarro Formations of Late Cretaceous age and were probably eroded from these rocks as exposed in what is now the Edwards Plateau.

Fossils found by the writers indigenous to the Gueydan include trace fossils (trails and burrows of worms or insects), fragment of a turtle shell (from tuff in southern McMullen County), petrified wood, and silicified beetlike cellular objects tentatively identified as parts of palm seeds. Sand-size bone fragments are recognized in several thin sections and heavy mineral mounts from sandstone beds, but the fragments may have been reworked from older formations. Cylindrical holes and tubules up to 2 mm in diameter, which probably were made by fossil roots, occur in many tuff beds. One calichified bentonite contains the silicified portion of a plant root.

MacNeil (1935) reported unidentifiable bones, leaves, lignite, and fresh-water mollusks from the Gueydan (Catahoula) in Fayette County. R. L. Folk (personal communication, 1964) also has found silicified shells in bentonitic clay in Fayette County, but they have not been identified.

A locality (S-10) of oyster-shell-bearing sandstone beds up to 20 feet thick (locally termed the Los Olmos sand member) was shown to McBride by George Boyle in 1962. Thin sections show that the shells are well rounded and occur with carbonate rock fragments; therefore, it is possible that they were reworked from older rocks.

MacNeil (1966, pp. 2353, 2359) reported reefs of *Ostrea blanpiedi* from the base of the formation in Karnes County and inferred them to be marine deposits.

An unusual occurrence of a single calcite plate of an echinoderm was found in a thin section of tuff from a shallow core in Live Oak County (Choke Canyon dam site). Although the tuff may be marine, the lack of supporting evidence of a marine origin in adjacent beds leaves the possibility that the fossil was reworked.

Trace fossils were identified with certainty in only three or four localities (beds with sparse burrows perpendicular to bedding occur at Loc. K-10; other fossils are trail casts). Abundant disturbed bedding structures in tuff beds described later (p. 19) also may be, in part, the result of burrowing animals.

AGE

The age of the Gueydan and its northern extension, the Catahoula Tuff, is uncertain because of the lack of indigenous fossils and dispute over the formation to which datable fossils belong. The Gueydan Formation may range in age from Oligocene to early Miocene. It rests on Oligocene? (Frio) rocks and is overlain, in part, by Miocene (Oakville) strata.

Berry (1917, pp. 227–230) dated the Catahoula in East Texas, Louisiana, and Mississippi as Oligocene from its plant content; Matson (1917, p. 209) did similarly on the basis of stratigraphic position.

Deussen (1924, p. 98) reported a middle or late Miocene rhinoceros from Washington County to be from the Oakville; however, A. W. Weeks (1933, pp. 456–457) placed the fossil-bearing bed in the Catahoula. Later work shows the rhinoceros to be late Oligocene or early Miocene (Wood and Wood, 1937) in age. Weeks likewise assigned to the Catahoula (Gueydan) a bed in Starr County that yielded a fragment of *Protohippus sejunctus* Cope of late Miocene to early Pliocene age. Bailey (1926), however, mapped the bed as Oakville. The fossil, however, is younger than the Oakville Formation (Wilson, 1956, fig. 1).

Alice Weeks of the U. S. Geological Survey reported that a lead-alpha age determination of zircons from the lower part of the Gueydan in Live Oak County yielded an age of 24 m.y. ± 1 m.y. (written communication to Lindemann, 1963). This age is early or middle Arikareean (Evernden et al., 1964), a stage of the early Miocene. The Gueydan has been correlated by most investigators with the Frio and Anahuac Formations in the subsurface. Sufficient doubt exists about the age of the latter formations, so they are generally considered Oligocene-Miocene in age (Houston Geol. Soc. Study Group, 1954, fig. 3). Akers and Drooger (1957, p. 658) believed the Anahuac is unquestionably Miocene.

LITHOLOGY AND FIELD RELATIONS

In the study area the Gueydan in outcrop is estimated to be 82 percent tuffaceous clay, 9 percent sand or sandstone, 1 percent conglomerate, 5 percent bentonite, and 3 percent vitric tuff; there are a few beds of ash and limestone (caliche) of diagenetic origin. All gradations occur between tuffaceous clay and tuff, and all these deposits are composed largely of vitroclastic debris or their alteration products. These estimates of abundance of rock types are based on inference from soil type in addition to study of outcrop sections.

Bailey (1926) divided the Gueydan into three members, which he mapped between Webb and Karnes counties: a lower tuff (Fant), a middle sandstone (Soledad), and an upper tuffaceous clay (Chusa). Detailed mapping in Duval County (Lindemann, 1963) showed that the Soledad Member is a series of discontinuous volcanic sandstone beds and conglomerate lenses interbedded with tuffaceous clay. Sandstone lenses are also common in the lower part of the formation, though less resistant and containing more carbonate rock fragments than volcanic rock fragments. The prominent tuff exposed in the type area of the Fant in Live Oak County does not extend into Duval County. Thus, detailed mapping shows that the stratigraphy is more complex than Bailey indicated. Reconnaissance in other counties indicates that three members cannot everywhere be distinguished, and hence member names have not been applied in this study.

Details of the stratigraphy of the Gueydan are known only where several feet are exposed in escarpments, meager road cuts or borrow pits, oil-well sites, or well cores. Measured sections are presented in Appendix A to illustrate local details and rock types. Reasons for the complexity of the stratigraphy are twofold: (1) The formation is composed of fluvial deposits, and possibly mudflow deposits, air-fall and windblown deposits, all of which are lenticular in shape and variable in texture, and (2) most beds have been modified by soil-forming processes or ground-water alterations and now differ from their original state. It is apparent from this study and even cursory inspection of Tertiary stratigraphic units in the Gulf Coastal Plain that detailed geologic maps are needed before even first-order stratigraphic details of the Gueydan and other Tertiary formations will be known. Useful descriptions of local details or maps are given by Bailey (1926), Bowling and Wendler (1933), Cook (1932), Lonsdale and Day (1937), Deussen and Owen (1939), Renick (1936), Ripple (1951), Sayre (1937), Thomas (1960), Moxham and Eargle (1961), Ferguson (1958), and A. W. Weeks (1933, 1937). The Gueydan (Catahoula) is shown in detailed maps of Karnes and adjacent counties based on work by D. H. Eargle and co-workers (published as U. S. Geological Survey Geophysical Investigations Maps GP-247, 248, 250–253).

PETROGRAPHY OF CLAY, TUFF, AND ASH

The Gueydan is characterized by monotonous exposures of pastel-colored tuff and tuffaceous clay. However, the formation includes a variety of rock types that are distinctive in either mineralogy, or texture, or both. Excellent descriptions of these rock types, including several measured sections to illustrate stratigraphic details, are given by Bailey (1926, pp. 67–95). In the following two sections descriptions are given of rock types related by genesis rather than by stratigraphic position. For each rock type described a reference in parenthesis is given to Bailey's descriptions so that comparisons can be made. Bailey also is the only author who gives detailed interpretations of the origin of specific rock types in the Gueydan; hence a comparison of his interpretations with those of the writers are made also.

TUFFACEOUS CLAY

This tuffaceous clay (Chusa Member of Bailey, 1926, pp. 91–92) is a soft, crumbly white, light gray to pink, unstratified to crudely bedded rock (Pl. 19A) in which shards are either subordinate to clay or absent. It is the most abundant lithologic type in the Gueydan, and outcrops of it have been found throughout the study area. Pink tuffaceous clay is the most abundant; it predominates in Starr County and in the upper third of the formation in McMullen and Duval counties (Bailey's Chusa Member). A well in Starr County (drill hole No. 5, Los Olmos dam site) penetrated 205 feet of pink tuffaceous clay in which only slight differences in texture exist.

Tuffaceous clay lacks internal bedding; generally only a foot or two is exposed in outcrop with the result that the thickness of beds is generally not known. Beds in the core in Starr County are several inches to 2 to 3 feet thick. The rock owes its softness to the presence of montmorillonite and amorphous clay. Sufficient shards are present, however, to give the rock a slightly rough feel and to be gritty when chewed.

Some beds contain hard, elliptical particles of irregular shape sparsely scattered through the rock. These particles are mostly between 2 to 10 mm in diameter but reach diameters of 3 cm. The objects are generally similar in texture but slightly darker than matrix clay. Bailey (1926, p. 91) called the smaller objects pisolites and the larger ones concretions. Unlike pisolites in tuff described later (p. 13), most of those in the clay are structureless and unlaminated. Well-developed pisolitic and concretionary texture is illustrated in tuffaceous clay in the bluffs of Loma Novia, 3 miles northeast of Freer, Duval County. Here the top of the Gueydan has been extensively calichified where it is overlain by conglomerate of the Oakville(?) Formation.

In thin section (Pl. 2) the rocks are characterized by shards with a random or swirl orientation, nodular masses with textures different from host rock, abundant montmorillonite, and generally more crystal fragments than are present in the tuff beds. The clays show considerable differences in mineral content, but most have compositions within the following range: 35–60 percent shards, 40–50 percent clay (montmorillonite and amorphous swelling clay), 1–15 percent crystal fragments, and a trace to 15 percent rounded tuff and clay clasts. Biotite and heavy minerals are present in trace amounts. Bailey (1926, p. 89) found a few beds with pumice pebbles, and the writers found one bed with trachyte fragments up to 2 mm in diameter. Although the presence of tuffaceous clay and volcanic rock clasts shows that the beds were deposited from aqueous media, the clasts are very poorly sorted; clasts up to 3.0 mm are scattered randomly among smaller clasts, shards, and matrix clay. Some clay clasts are coated or pervaded by manganese-oxide stain.

Some beds of tuffaceous clay contain irregular pods, wisps, or blebs of brown (iron-oxide-stained) montmorillonite. The clay masses are not rounded; they were soft when introduced because they are embayed by crystal fragments and shards. Some show a prominent mass-extinction effect between crossed polarizers resulting from the parallelism of clay platelets.

Calcareous clay beds are present locally. They are abundant in and south of Karnes County, where they appear to be the product of calichification. Calcareous beds are also common near the top of the Gueydan. At several localities where the Oakville or Goliad(?) Formations rest unconformably on pink tuffaceous Gueydan clay, the clay has a peculiar vertical pattern of tubes and fingers (Pl. 23B) that extend several feet below the contact. This is best shown in Loma Novia, 3 miles northeast of Freer, Duval County, just east of U. S. Highway 59. Beneath a resistant Oakville(?) conglomerate is a pink rough-feeling earthy unit 8 feet thick that is now almost entirely caliche. Tubes and fingers (20% of rock) of clay with a few percent quartz and feldspar sand grains have closely spaced joints and a smooth texture. Montmorillonite particles form a random brush-heap texture but are tangentially aligned around sand grains (simple embedded grain argilans of Brewer's (1964) terminology). Tubes and fingers have uneven widths from 1/8 to 2 inches wide but extend vertically for several feet. Twelve feet lower in the section is another pink caliche bed that has scattered clay clots and pisolites up to 1/4 inch wide.Thin sections show the clots to be remains of the original tuffaceous clay bed and the pisolites are caliche particles that differ from host caliche in grain size and fabric of calcite.

TUFF AND ASH

Lumpy pisolitic tuff (Fant Member, type 1, Bailey, 1926, pp. 66–69)

This is a moderately well-indurated, massive-bedded, generally porous, grayish-white tuff that is characterized by a lumpy or pisolitic texture (Pls. 3, 4). The rock is devoid of bedding in outcrop and hand specimen, and no bedding can be detected in X-radiographs of thin, sawed slabs of the tuff. Thin sections show that shards have a peculiar non-uniform distribution; in some areas they have a random orientation, whereas in others, long axes are aligned along zones a few millimeters wide that curve in swirling patterns. Beds range from a few inches to 2 feet thick and cannot be traced more than several hundred yards. Beds of lumpy pisolitic tuff have been found only in Live Oak, Duval, and McMullen counties in the lower part of the formation, but it is not a common rock type. Pisolitic clays are more abundant.

The upper surface of some lumpy pisolitic tuff beds displays prominent vertical polygonal desiccation cracks (Pl. 3B) that extend deep enough into the beds (6–18 inches) to produce columnar jointing. Polygons range from 3 to 12 inches across and generally have case-hardened borders that stand above the floor of the polygons because of the more resistant nature of the borders. The lumpy and pisolitic texture of the tuff is its most diagnostic feature.

Pisolites are spherical objects that are mostly between 1 to 5 mm in diameter but range from 0.2 to 10 mm in length (Pls. 4 and 5). Many have a crude to well-formed concentric layering (Pl. 4B, C), whereas the remainder are structureless. The largest pisolites are more irregular in shape and grade into lumps.

Lumps are irregular-shaped masses of tuff (Pls. 3A, 4A, B) that range from approximately 5 to 30 mm in long dimension. They generally have no concentric banding, but some have a crude preferred orientation of shards aligned spirally (swirl-pattern) or concentrically with the periphery of the particle. Lumps are best developed on strongly weathered surfaces, and generally lose their identity several inches from the surface. Pisolites range from incipient forms visible only in thin section to prominent objects in hand specimen that comprise up to 30 percent of a rock. In tuff with well-developed lumpy texture, lumps comprise essentially the entire rock.

Pisolites differ from their matrix in that they contain either more or less shards or crystal fragments than the matrix, or have undergone a different manner of alteration (Pl. 4C), or both. In rocks with the best developed pisolitic texture, the pisolites have a black, nearly opaque rind (Pl. 4C). In polarized light they appear as a feebly birefringent mosaic of devitrification products in contrast to the matrix, which shows higher-order interference colors caused by platelets of montmorillonite oriented parallel with the edge of shard and crystal fragments (Pl. 5C). The feebly birefringent mosaic in the pisolites appears to be largely montmorillonite platelets that have a random orientation. Pisolites have been noted that have better oriented montmorillonite but these are rare. As a rule, individual pisolites are uniform in texture and style of alteration. The dark rind is white in reflected light and cryptocrystalline; it probably is clay with a coating of leucoxene or manganese oxide. Pisolites that have more or less shards than the matrix (Pl. 5) are not as common as those that only show a different type of alteration. Some pisolites are compound and made of two or three accreted small forms. A few examples of concentric laminae (Pl. 4C) that appear to be growth bands were noted.

Lumps and poorly formed pisolites show features that are critical to interpreting their origin. Some pisolites are well outlined from their matrix by textural or compositional differences along half their boundary but elsewhere grade imperceptibly into the host rock. This feature suggests that this type of pisolite (or lump) is formed by *in situ* alteration, as will be supported later.

Pisolitic tuffs have a distinctly porous[4] texture caused by tiny irregular cavities and cracks. Most cavities are pinpoint in width, but the large ones reach 1 to 2 mm in diameter. The pinpoint cavities appear to be cross sections of sinuous irregular-shaped cavities. However, a few pores are tubular-linear forms that can be traced several inches across sawed slabs. The latter large tubular pores grade into hairline cracks, which are visible only in thin sections. The hairline cracks are less than 0.1 mm wide and are visible in most slides. Thin sections show that most cavities are lined or filled by montmorillonite (stained brown by iron oxides). The montmorillonite platelets are generally aligned parallel with the walls of the pores such that the mass of clay shows sweeping extinction when the slide is rotated under crossed polarizers (and circular pores show a pseudo-uniaxial cross). In some highly porous rocks, montmorillonite patches comprise 30 percent of the thin section to produce a striking texture. Parts of most slides have groups of montmorillonite platelets randomly arranged in a patchwork pattern.

Before devitrification and alteration, the pisolitic tuff consisted of 30 to 60 percent glass shards, 1 to 3 percent crystal fragments (sanidine, anorthoclase, and quartz), and the remainder glass dust. The glass dust and some small shards have undergone devitrification. The microscope reveals that these products include abundant montmorillonite, small (2 to 20 μ in diameter), spherical isotropic grains of what is apparently opal (index below C.B.), and trace amounts of zeolite as laths up to 20μ long. X-ray diffraction patterns show the presence of montmorillonite in all samples, and zeolite (clinoptilolite) in most samples. No cristobalite or tridymite were detected.

Bailey (1926, pp. 118–119) found the index of refraction of glass in the tuffs to range from 1.495 to 1.517, with most between 1.499 to 1.505. The indices are slightly higher than those of average rhyolite glass and lower than average trachyte or andesite glass (*cf.* George, 1924).

Tubular-porous tuff (included in rock type 1 of the Fant Member of Bailey)

This type of tuff is white to gray white, non-pisolitic to slightly pisolitic, and is characterized by (1) its strong induration, (2) abundance of tubular pores, and (3) columnar jointing (Pl. 6). The tuff is similar to lumpy-pisolitic tuff because of massive bedding, random (Pl. 7B) and swirl-orientation of shards, presence of tubular pores, and, in some beds, presence of columar joints that probably are desiccation cracks. It differs from the lumpy pisolitic

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[4] Bailey used the term vesicular, but because this implies the cavities were formed by gas, the writers prefer a non-genetic term.

tuff, however, in that the tubular pores are more abundant (Pl. 6B), or at least more prominent, because they have fewer pinpoint pores; tubules are lined not only by waxy pale-green to cream montmorillonite but also by zeolite (clinoptilolite) crystals (Pl. 7A, 16B). The tubules trend in all directions but are predominantly vertical. Well-formed pisolites are scarce in this tuff. The tuff occurs in units up to 30 feet thick that have poorly formed bedding planes from 6 inches to 3 feet apart. Vertical columnar joints are prominent in many beds of this tuff (Pl. 6A) and form crude polygonal talus blocks in beds that have prominent bedding planes. The joint surfaces are highly uneven and have a distinct vertical grain produced by tubules and edges of intersecting small-scale joints.

Before alteration and devitrification, tubular-porous tuffs probably had the same texture and composition as the lumpy pisolitic tuffs, although a few have as much as 15 percent crystal fragments. The chief difference in mineralogy is that tubular tuffs now have far less montmorillonite-lined pinpoint pores, slightly more clinoptilolite in the matrix, and prominent clinoptilolite-lined tubules. Zeolite laths from 2 to 10μ long project inward from pore walls (Pl. 16B) and certainly have grown into the cavities. Montmorillonite coatings preceded zeolite formation where both are present in a tubule.

Tubular-porous tuff is best exposed in Live Oak and McMullen counties where it is interbedded with the lumpy pisolitic tuff in the lower part of the formation. The tubular-porous tuff is several times more abundant than the lumpy pisolitic tuff.

Friable bedded tuff (Fant Member of Bailey, type 3)

This rock is white to light gray or yellowish-gray tuff that is characterized by its friability and faint horizontal bedding planes (Pl. 8). The tuff is so friable that it may be crushed easily between fingertips yet is cohesive enough to form vertical walls 6 feet high in Lang Creek, Live Oak County (Loc. L-14). The tuff is distinguishable from other types at a distance by faint bedding planes spaced from 3 to 18 inches apart; the tuff is non-pisolitic and lacks tubules or pinhole pores. Close examination reveals that the bedding planes which appear distinct from a distance are actually a thin zone of several horizontal laminae along which the beds part. Closer scrutiny shows that additional faint bedding planes can be discerned, commonly where layers of tuff of slightly different grain size are in contact. Beds with horizontal laminae predominate over beds with small-scale cross-bedding (1 to 3 inches thick). A few beds fill shallow channels.

Friable bedded tuff has been found only in Live Oak and McMullen counties, where it is not a common rock type. It occurs in the lower part of the formation (Bailey's Fant Member). Good exposures are in the walls of Lang Creek (Pl. 8) (Loc. L-4) and on the northwest side of the Nueces River, 0.75 mile northwest of Simons, where a bed 10 feet thick is exposed in a bluff (Bailey, 1926, p. 70).

Bailey called this rock type "sand-tuff" (p. 70) because it is composed predominantly of glass shards of fine to coarse sand-size in a matrix of fine material, largely montmorillonite.

Thin section examination shows that in addition to shards, beds contain rounded clasts of clay, ragged flakes of biotite, and, in some beds, placers of opaque minerals (leucoxene and magnetite). Beds are composed of from 40 to 60 percent shards, 5 to 25 percent tuffaceous clay clasts, and the remainder of montmorillonite matrix (Pl. 9). Feldspar, quartz, biotite, and heavy minerals comprise only trace amounts. Shards attain lengths of 0.8 mm and clay clasts attain diameters of 2.0 mm. Shards show a preferred orientation of long axes parallel with bedding, although the degree of preferred orientation varies considerably. A distinctive feature seen in thin sections is the abundance of long shards that appear to be lined athwart, even perpendicular to, the major preferred direction. Many such spurious shards are in fact bladelike spurs of shards whose long directions parallel bedding, but whose long dimensions are not seen in the plane of section of the slide.

Heavy minerals extracted from the bedded tuff are opaque iron oxides, small euhedral zircon, and trace amounts of apatite and sphene.

Ash

Although some tuff beds are weakly indurated, they are too hard to be called ash. However, a few beds of pure ash are exposed in a road cut in the lower part of the formation in Live Oak County (Loc. L-10). The cut is through a conical hill approximately 12 feet high in which a variety of tuff and ash types are exposed, a few of which have not been found elsewhere in the formation (Pl. 1A). In the lower part of the hill the tuff and ash beds are of uneven thickness because they were deposited on channeled surfaces. Stratification in a clayey ash on the left side of the hill has variable dips toward the west (right) and locally abuts an erosion surface. On the right side of the hill an ash bed in contact with clay has fingers and apopheses of ash within the clay; this structure developed by soft-sediment deformation.

The stratified ash bed on the left is composed entirely of silt- and clay-size glass and was apparently water laid. The finest fraction has devitrified to a mixture of feebly birefringent irresolvable constituents. X-ray diffraction patterns of powdered ash have a broad hump between 10–14° 2θ but an absence of peaks; hence, devitrification products are present in amounts too small to be detected.

The ash on the right has a porosity of 30 percent and is composed of 80 percent glass shards up to 0.03 mm long and the remainder of glass dust which shows only incipient devitrification. This bed has numerous accretionary lapilli 3.0 to 5.0 mm in diameter and a striking geopetal fabric; glass dust occurs in conical piles on top of flat shards oriented parallel with bedding (Pl. 10B).

Accretionary lapilli (Pl. 10A) have a core of coarse shards (maximum length, 0.5 mm) that makes up 80 percent of the cross-section area of the lapilli. The core grades outward into finer shards and farther out into glass dust to form a distinctive graded texture. A few lapilli in the ash bed have altered diagenetically to bright green concentrically layered grains. X-ray diffraction patterns of powdered material and oriented samples of the less than 2μ fraction of this ash have a low hump with a maximum intensity at 10° 2θ but no sharp peaks. Glass masks whatever devitrification products are present. No peaks occur on patterns of the green lapilli in spite of their waxy appearance that suggests the presence of montmorillonite.

OPALIZED TUFF AND CLAY

These rock types (Fant Member, type 2, Bailey, 1926, pp. 69–70) occur as elongate nodules up to 6 inches long and as thin beds in tuff and tuffaceous clay. The rocks are hard, break with conchoidal fracture, generally are pink or white, and commonly have a few small, irregular pores that are lined with bluish botryoidal opal.

Thin sections of opalized tuff (Pl. 12A) have a brownish color in ordinary light and show only lowest-order gray colors under crossed polarizers. Opal has replaced all or most glass and whatever clay was present. The ghosts of only a few shards are detectable where opal with fibrous axiolitic texture replaced the shards. Crystal fragments (from 2 to 15 percent) remained unaltered. Up to 30 percent of the opal occurs as spherical and doughnut-shaped particles less than 0.2 mm in diameter.

A sample of opalized tubular porous tuff from a core at a proposed dam site (Choke Canyon) on the Nueces River west of Three Rivers has approximately 3 percent clinoptilolite laths in the rock where the crystals fill or line clay-coated pores.

Opalized tuff and clay have been noted only in Live Oak, McMullen, and Duval counties where the most extensive work was done. Its abundance elsewhere is unknown.

BENTONITE

Bentonite (Fant Member, type 5, bentonitic clay, Bailey, 1926, p. 71) is a soft to medium-hard compact clay that breaks into smooth-faced surfaces with conchoidal fracture. Pink predominates, but pale green, mottled pink and pale green, and cream colors have been found. In only a few places are beds of pure bentonite thicker than a few inches, but bentonite beds may predominate in sections of interbedded bentonite and tuffaceous clay that attain thicknesses of 16 to 20 feet. Bedding is not visible in outcrop, and no laminations are visible in thin sections. Samples grade from those that do not swell and become only slightly softer to the finger-nail after being wetted, to those that develop a loose slippery film upon being wetted.

Sawed surfaces of some bentonite samples show vertical tubes, irregular pockets, and fingerlike zones that are filled with sandy bentonite. The tubes and pockets are interpreted to be animal burrow-fillings because of their similarity to burrows in Recent sediments. The irregular fingers, which generally taper to a thin edge and then pinch out, are of uncertain origin. They may be desiccation-crack fillings or possibly material injected during soft-sediment deformation.

Thin sections (Pl. 11) show the bentonite is free of any traces of bedding and is from 85 to nearly 100 percent montmorillonite.[5] Beds have from a trace to 15 percent glass fragments smaller than 15µ that are visible only on thin edges of the slides under high magnification. The glass particles are straight laths or spherical blebs and lack the odd bifurcate curved forms of coarser shards. Crystal fragments make up less than 1 percent of the bentonite and are generally less than 5µ in diameter. Feldspar, quartz, and zircon are the chief fragments. Most montmorillonite occurs as a mosaic of grains smaller than 3µ. The grains have a random orientation because there is no mass extinction between crossed polarizers. Some rocks have, in addition, aggregates of grains up to 0.1 mm long that have a random brush-heap texture. These aggregates (Pl. 11B) have a fibrous texture and may be montmorillonite pseudomorphs of zeolite.

Roberson (1964) studied eight Gueydan bentonite samples collected from Fayette, McMullen, and Duval counties. All are characterized by poorly crystallized Ca^{++} and Na^{+} montmorillonite; one sample each had small amounts of illite and kaolinite, and one sample had cristobalite. Roberson noted that the bentonite in east and southwest Texas contains more quartz, feldspar, and more clay minerals in addition to montmorillonite than do those of central Texas.

Thomas (1960) studied clay minerals in various Gueydan and Catahoula rocks, including bentonite, along the entire outcrop in Texas. He reported Ca^{++} montmorillonite typical of the lower part of the Gueydan (Fant Member), mixed-layer $Ca^{++}–Na^{+}$ montmorillonite as typical of the upper part (Soledad and Chusa Members), and kaolinite to be common, but not typical, in the Catahoula in east Texas.

X-ray studies were made on only four samples during this study. Bulk powder and oriented slides were examined. Two samples (K-10E, DH-8M) are poorly crystallized Na^{+} montmorillonite (broad peaks at 12.5 and 13.0A, respectively), one (LA-13) is well-crystallized Na^{+} montmorillonite (peak at 12.3A), and one contains quartz and montmorillonite so poorly crystallized that it yields a broad hump at 4°–7° 2θ. The first three samples gave only montmorillonite peaks.

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[5] E. C. Jonas (personal communication, 1964) reported that bentonite from various formations studied by him which appears to be entirely clay in thin section generally has several percent glass that is detectable by special X-ray diffraction technique.

PETROLOGY OF CLAY, TUFF, AND ASH

The fine-grained sedimentary rocks under consideration are interpreted to have been deposited as continental sediments on a coastal plain not far from the shoreline. Many of the present characteristics of the strata are the product of soil-forming processes that operated during deposition of the Gueydan, although some calichification at the top of the formation and at the present surface is younger. Soil-forming processes have strongly modified the original depositional texture of most beds, so that an interpretation of the manner of deposition of individual beds is strongly conjectural. Some tuff beds are clearly stream deposits, some tuff and ash beds are air-fall deposits, some tuff beds may be mudflow deposits.

Evidence that the fine-grained Gueydan strata represent paleosoils comes from both textural and compositional features. Textures in Gueydan strata that are typical of soils (as described by Brewer, 1964) include pisolites, lumps, tubular pores, clay skins on detrital grains, poor sorting, lack of internal bedding, and randomly oriented clasts. Although no Recent example of soil that is identical to Gueydan strata has been described, there is considerable similarity between the composition of Gueydan strata and soils forming on volcanic ash in Indonesia described by Mohr and van Baren (1954, pp. 300 – 331). The chief controlling factors there are composition of the ash, elevation, climate, and the milieu of weathering with respect to the water table and ground-water migration. Variations in these factors are responsible for producing a wide range of soil types. Lithologic types in the Gueydan that are similar in part to various Indonesian soils include caliche, siliceous clay and tuff, pisolitic and concretionary beds, montmorillonite-rich clay, and gray and pink clay. The best overall reconstruction of the conditions of soil formation during Gueydan deposition is that of a tropical climate with high rainfall but with a 2- to 3-month hot, dry season. Poor circulation of ground water resulted in incomplete flushing of metal cations, and montmorillonite was the clay formed. The montmorillonite in turn helped to retard water circulation. Ground water percolated downward during wet months but upward during dry months when evaporation exceeded infiltration. The Gueydan soils developed largely by weathering of fresh ash and reworked soils to attain a juvenile or early virile stage. Moberly (1960) described more mature paleosoils in the Cloverly and Sykes Mountain Formations that also formed when ash weathered under an inferred savannah tropical climate.

Bailey is the only author that previously offered detailed interpretations on the mode of deposition and diagenesis of specific rock types of the Gueydan. Hence, a comparison with his interpretations is presented below.

TUFFACEOUS CLAY

Bailey (1926, p. 90) interpreted the tuffaceous clay to be largely material reworked from older Gueydan strata and mixed with small amounts of non-volcanic detritus by streams. However, the lack of internal stratification and the poor sorting of the clay are not typical of stream deposits. It is more probable that the tuffaceous clay formed by alteration of ash-rich sediment in the A and B soil horizons. Repeated swelling and contraction during wetting and drying plus the action of plant roots could have produced the unsorted texture and random fabric of clasts in the clay. Pisolites are typically formed at the base of the A horizon in the examples described by Mohr and van Baren (1954). The lack of tubules produced by plant roots in the clay is peculiar, in view of their prevalence in the tuff. Possibly the tubules were closed during compaction of the non-indurated clay, or perhaps the present texture of the clay developed below the zone of root penetration.

The manner of deposition of the tuffaceous clay must remain conjectural because almost no primary texture is preserved. Bailey's interpretation that the clay is largely stream deposits cannot be ruled out. The general scarcity of grains of sand size or coarser suggests that much of the ash may have been air-fall deposits. The occurrence of scattered large boulders of lava weathering from tuffaceous clay suggests that some beds may have been deposited as mudflows. Whatever the mechanisms of deposition, the great thickness of tuffaceous clay deposits suggests an equilibrium between rate of deposition and rate of alteration.

Why there is more clay in the tuffaceous clay beds than in the tuff presents a problem. The clay may have been transported as clay minerals, it may be glass dust that altered in place, or it may be an authigenic pore-filling. At least some clay is the product of *in situ* alteration of previous glass fragments, because inspection of thin sections under high magnification shows that small shards and, in places, large shards have undergone partial replacement or alteration to clay. It is possible that the chief reason for the ultimate difference between the tuff and clay is that they were weathered under different climatic conditions, a suggestion that is supported also by the occurrence of different types of montmorillonite in the tuff (lower part of the formation) and clay (upper part).

The caliche and tubular structure present at the top of the Gueydan (*see* p. 13) in tuffaceous clay apparently formed as a soil zone during post-Gueydan but pre-Miocene (Oakville) or pre-Pliocene (Goliad) time.

LUMPY PISOLITIC TUFF AND TUBULAR-POROUS TUFF

Bailey (1926, pp. 66–69) interpreted what the writers call lumpy pisolitic tuff and tubular-porous tuff to be mudflow deposits. Bailey's interpretation of a mudflow origin for the tuff beds was based on the lack of bedding, apparent uneven thickness of beds, presence of "vesicular" texture, lumps of tuff similar to host rocks, desiccation cracks (he used the terms dehydration or sun cracks), and the existence of one bed of tuff whose surface has a ropy structure (p. 67) ". . . exhibited by some types of pahoehoe lava." Bailey's concept of the origin and character of the mudflows is not clear, but he stated (p. 67) that "these indurated tuff beds were deposited as mudflows from one or more volcanic vents," and that tubular cavities (tubules) probably were channels along which steam and other vapors—originally included in the mudflow—escaped. He apparently envisaged the tuff to have been mobilized on the flanks of a volcano by the condensation of steam emitted from subsidiary vents. Pisolites and tuff lumps were interpreted to be pieces of the drier, crusty part of the flow that were brecciated and rounded as they were over-ridden and incorporated in the flow.

The writers do not dispute the possibility that the tuff beds under discussion may have been deposited as mudflows. However, from evidence cited later (p. 36), it is believed that the source volcanoes were several hundred miles distant. Hence, if ash were transported as mudflows, the writers believe it more likely that they were generated when rain fell on ash-covered terrane far from the volcanoes.

Evidence cited by Bailey to support a mudflow origin can be explained equally well by soil-forming processes; some evidence is better explained by these processes. Because the geometry of the beds is unknown, the most useful piece of evidence to check either hypothesis is lacking.

Soils typically are poorly sorted mixtures of sand- and clay-size particles, lack internal bedding, and lack a preferred orientation of clasts because of repeated disturbance by plant roots and repeated expansion and contraction following water saturation and dehydration. Desiccation cracks may form in any soil but are most pronounced in montmorillonite-rich soils. The tubular pores present in both tubular-porous and lumpy-pisolitic tuffs are identical to scars left by plant roots. In addition, the vertical grain and jointing of some tubular-porous tuff resemble the exposed vertical faces of loess exposed in the Mississippi River Valley. Plant roots probably produced this grain in the tuffs in the same manner they did in loess.

The chemically active environment around the roots probably hastened a more rapid alteration of the tuff, with the result that some root tubules were enlarged by leaching in the Gueydan soil zone. Tubules (Pl. 6B) have been found in cores[6] of tubular-porous tuff in Live Oak County to depths of 68 feet; hence the structures are not the product of Recent plant growth.

The more common irregular and nontubular cavities that characterize the lumpy-pisolitic tuffs are of uncertain origin. If the cavities were formed by gas bubbles, as suggested by Bailey, they should have smooth spherical walls. Instead, most walls and shapes are irregular. It is suggested that most pores are solution cavities of material dissolved or mechanically removed during weathering in the Gueydan soil zone or by ground water. The fact that most pores now are lined partly or completely by clay that has either filtered in or been precipitated in place, suggests that solution is not now an important process.

The pisolites pose several problems. They have features in common with both soil pisolites and with accretionary lapilli that have undergone alteration. As an alternate hypothesis on the origin of pisolites and lumps, Bailey (1926, p. 68) noted that they might originate by the cohesive action of raindrops as described by Lacroix (1904, p. 420). According to this process, raindrops falling through an ash cloud accrete pisolitelike bodies almost as large as 1 cm. Moore and Peck (1962) more recently have reviewed the general problem of origin of spherical accretionary lapilli in volcanic rocks and concluded that most form by the accretion of moist ash in an eruptive cloud and fall as mud-pellet rains. Lapilli studied by them are pea-size structures that decrease in grain size from core to rim. An example of accretionary lapilli with such texture (Pl. 10A) occurs in one ash bed in Live Oak County (Loc. L-10). The bed is probably an air-fall ash that contains scattered lapilli up to 5 mm in diameter (Pl. 10A). Shards in the pisolites are oriented with flat surfaces parallel with the outer surface and must have accreted one at a time while the drop was in motion. Pisolites in the tuff beds are composed largely of devitrification or alteration products and do not now have ghost shards. The possibility that pisolites may be altered accretionary lapilli was suggested by J. G. Moore (letter to McBride, 1966), who favors this origin for the pisolites shown in Plate 10.

However, because pisolites can form entirely by soil-forming processes the problem remains unsolved. Gueydan pisolites have textural similarities with various types of soil glaebules[7] described by Brewer (1964, pp. 264–282), with calcite pisolites in caliche (Swineford et al., 1958), and with gibbsite pisolites in bauxite (Harder, 1952; Mackenzie et al., 1958). The presence of pisolites that have well-formed rinds on half the particle, but which grade imperceptibly into the matrix elsewhere, is evidence in favor of *in situ* development.

The process by which pisolites are formed in caliche and bauxite is unknown, although the geologic conditions under which they form have been inferred (Swineford et al., 1958; Harder, 1952; Mackenzie et al., 1958). Both caliche and bauxite form above the water table. Bauxite forms in a moist sub-tropical climate, but the origin of caliche is uncertain. Some caliche forms in a semi-arid temperate climate, but it may also form in a tropical climate when carbonate-rich ground water is drawn to the surface by capillary pressure and evaporated during dry seasons (Charles, 1948; Vageler, 1933, pp. 72–73; Jackson and Sherman, 1953, p. 260). Under the latter circumstances, dissolved material may be expected to pass alternately downward during percolation of rain water and upward during dry periods, and segregation of mineral constituents

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[6] Descriptions of the cores are given in the report by Cabrera and Redfield (1964).

[7] Glaebules is Brewer's term for sub-spherical objects that have formed essentially in place in soil.

could result. A process such as this could have operated during Gueydan deposition. The bentonite beds interbedded with the tuff, if they were bentonite at this time, probably prevented rapid loss of water by percolation and thus retarded removal of soluble constituents. Brewer (1964, p. 278) attributed the concentric fabric of soil glaebules to accretionary growth during alternating wet and dry conditions, or possibly to a process related to the formation of Liesegang rings.

The mode of origin of the lumps is uncertain. Most appear to form during Recent weathering, but the pattern of differential weathering is controlled by original internal textures. One possibility is that lumps formed by the breakup of crusty, weakly indurated ash beds during movement of mudflows; they may be internally brecciated clasts. During subsequent movement the clasts become rounded but never sorted, and concentric patterns of shards formed where some domains underwent circular motion. Another possibility is that they are irregular-shaped soil glaebules.

A stream-deposited conglomerate containing compound pisolites crops out in Live Oak County (Loc. L-10). The pisolites have clearly been reworked from older strata. If the pisolites are altered accretionary lapilli, this fact is not important. However, if the pisolites are soil features, it indicates some pisolites formed during the time of Gueydan deposition.

FRIABLE BEDDED TUFF

Bailey (1926, p. 70) interpreted this tuff type to be an air-fall deposit. However, the abundance of tuffaceous clay clasts and the presence of some cross-bedding indicate that the beds were current-deposited. The clasts are identical with tuff and tuffaceous clay types in the Gueydan and are obviously reworked from these strata. It is possible that some beds are windblown deposits, but only a few beds are sorted well enough to support this idea. The overall texture and bedding types favor deposition by streams.

With either interpretation, the presence of montmorillonite matrix in the rock is anomalous with respect to the otherwise moderately well-sorted character of the tuff sand framework. Because of this, it is suggested that the montmorillonite is a diagenetic mineral that was not present at the time of deposition. The clay is present as minute crystals that form feebly birefringent mosaics between shard and tuff clasts and is presumed to have been precipitated from water that migrated through the once-permeable sand. The mosaic texture of the montmorillonite is unlike the well-oriented aggregate masses in the pisolitic tuff that is inferred to have formed by the accretion of clay that filtered in particle-by-particle.

ASH

The scarcity of ash beds in the Gueydan compared to tuff and clay attests to the ease with which ash is altered. The ash beds exposed in Live Oak County must be considered accidents of preservation.

The ash bed with accretionary lapilli is interpreted as an air-fall deposit. The excellent orientation of flat shards parallel with bedding in the outcrop, lack of internal stratification, and random distribution of the lapilli favor this interpretation. The geopetal fabric of piles of glass dust on flat shards could have formed either during deposition of the bed or post-depositionally by percolating ground water.

Moore and Peck (1962) noted that accretionary lapilli can form by (1) accretion on the ground of fresh ash around nuclei blown by wind or rolling downslope; (2) absorption by fresh ash of water or fallen raindrops during light rain; or (3) accretion of moist ash in an eruption cloud to form mud-pellet rains. Lapilli studied by them are graded in the same manner as the Gueydan lapilli and were interpreted to form in the air during volcanic eruptions. The occurrence of accretionary lapilli in the ash with geopetal fabric shows that the lapilli formed in the air prior to deposition, but whether this was in an eruption cloud is uncertain.

The stratified tuff associated with the tuff with accretionary lapilli was water-laid. The absence of particles other than glass or clay suggests the detritus moved only a short distance and was derived from an air-fall ash.

OPALIZED TUFF AND CLAY

Silicified tuff lenses are present in some Indonesian soils developed on ash (Mohr and van Baren, 1954, pp. 311, 315, 326). Although the character of the silification is not described by the authors cited, the field characteristics resemble the opalized beds in the Gueydan. The Indonesian examples form generally at the base of the soil profile.

BENTONITE

Bailey (1926, p. 72) interpreted the bentonite to be stream-deposited material "... derived from the erosion of older Gueydan tuff beds and of Frio Clay and older formations." The implication is that the clay particles, derived at least in part from altered ash, were deposited as clay to form bentonite beds. An alternate explanation is that beds of fine volcanic glass, largely dust, came to rest and were later argillized in place. The latter explanation is considered to be more likely, because the montmorillonite particles do not have a preferred orientation and the rocks have no internal bedding. If the clay had settled from aqueous suspension, the platelets should have formed a preferred orientation parallel with bedding, as in fact do most clay particles in marine and fluvial shales. However, O'Brien (1964) has argued that unbedded, randomly oriented kaolinite underclays develop by slow dewatering of flocculated detrital clay. Roberson (1964) inferred that the Gueydan bentonite studied by him was re-deposited bentonitic material because it had considerable amounts of shards, quartz, and feldspar grains and had poorly crystallized montmorillonite. In contrast, bentonite free of quartz and feldspar commonly had well-crystallized montmorillonite.

Although some bentonite in Gulf Coast Tertiary strata has ghosts of large shards, no such relic textures are visible in Gueydan bentonite beds. Inasmuch as the largest of the tiny glass shards in tuff show only incipient argillation, the bulk of the bentonite studied by the writers is inferred to have formed from very fine-grained glass dust. The few small glass plates detectable in some bentonite beds presumably escaped argillation because of their relatively large size as compared with the dust. In the absence of bedding, it is uncertain whether the glass dust beds were deposited in water or subaerially, but the high degree of sorting that the beds originally must have had suggests that the dust was wind-transported.

An unusual feature in thin sections of some bentonite samples is that, in addition to the mosaic pattern of small clay platelets, there are narrow zones in which montmorillonite particles are oriented parallel with one another, producing a mass-extinction effect. Zones of such oriented grains up to 0.1 mm long form the borders of polygonal blocks in which clay has the common mosaic pattern. In ordinary light these odd patches cannot be distinguished from normal bentonite texture (Pl. 11). The cause of the feature is also conjectural; perhaps the zones are areas where the glass dust was burrowed before argillation.

If the bentonite formed by the alteration of glass dust beds, as is believed by the writers, the question of time of argillation is important. Argillation could occur in soil profiles during accumulation of Gueydan sediments or diagenetically by ground water after burial. The abundant clay (bentonite) clasts in tuffs and tuffaceous sandstones in the Gueydan show that bentonite was available to streams during deposition; hence some argillation occurred prior to burial of more than a few feet.

Bentonite occurs along the entire outcrop belt studied, but because it does not form good outcrops, its relative abundance is unknown.

CALCITIC TUFF AND "LIMESTONE"

Mention has been made previously about the calcitic (calichified) tuff and clay beds that occur at the present surface of weathering and below the unconformity with overlying formations. A few highly calcareous beds also occur within the Gueydan.

One type of highly calcerous rock from the lower part of the Gueydan is a calcite-cemented, white, bedded tuff (Fant Member, type 3, of Bailey) from the floor of Lang Creek (Loc. L-2). Sparry calcite occurs as a pore filling and comprises 35 percent of the rock. Other tuff beds in the section are cemented by authigenic montmorillonite. There is no evidence that the calcitic tuff ever had a clay cement.

Bailey (1926, p. 86) described a ". . . dense-textured, rather soft, somewhat conglomeratic, unfossiliferous limestone" from the lowermost part of the formation that he interpreted to be a fresh-water limestone. The writers did not find such a rock during their study, although several hard, compact beds and nodules of "limestone" that are probably caliche and which break conchoidally were seen. A thin section of a pink "limestone" bed 6 inches thick (Loc. L-2), mistakenly collected as a silicified clay because of its compactness, hardness, and conchoidal fracture, is 65 percent calcite, 34 percent montmorillonite, and 1 percent shards, crystal fragments, and chalcedony pore fillings. The calcite occurs chiefly as grains of micrite (less than 5μ in length), but grains of coarse spar occur as tubule-pore fillings and scattered patches in the rock. Although the rock may be a fresh-water limestone, the texture fits equally well the interpretation that it is a calcitized or calichified bentonite. One tubule pore has a 3.0 mm-long segment of a plant root (Pl. 12B) that is now chalcedony and opal. This feature, however, is not a clue to the origin of the bed.

PETROGRAPHY AND PETROLOGY OF CONGLOMERATE AND SANDSTONE

CONGLOMERATE

Conglomerate in the Gueydan ranges from slightly cemented to moderately cemented rock composed of moderately well-sorted frameworks of granules, pebbles, or cobbles with a sand or tuffaceous sand matrix. Clasts of volcanic rock, indurated tuft, and indurated bentonitic clay comprise almost all the gravel particles, although sand matrices may have several percent of constituents of other derivation.

Felsite pebble conglomerate (Soledad Member, type 1, Bailey, 1926, pp. 80–82)

This rock type is common in the middle part of the Gueydan in Duval and southern McMullen counties in Bailey's Soledad Member, where it occurs in lenses 2 to 10 feet thick and less than 100 feet long within sandstone beds. The only known pebble or cobble conglomerate beds in the Gueydan north of McMullen County occur in Karnes County. Here uncemented gravel lenses in sandstone comprise a section 20 feet or more thick where exposed in a gravel pit (Loc. K-8) and in a road-metal pit where conglomerate beds rest on clay of the underlying Whitsett Formation (Loc. K-10). Bailey (p. 80) reports conglomerate in Webb and Zapata counties but notes that it is difficult to tell whether the beds should be assigned to the Gueydan or younger formations. By far the coarsest and largest quantity of gravel is concentrated in northwestern Duval County. Here conglomerate and conglomeratic sandstone comprise 75 feet of section in the Soledad Hills escarpment. The average composition of pebble and cobble conglomerates in Duval County is estimated to be:

	Percent
Brown porphyritic felsite	40
Silicified clay and tuff	30
Varicolored porphyritic felsites	15
Vesicular or amygdaloidal lava fragments	10
Chert, limestone, and petrified wood	5

The chief difference between individual conglomerate beds is in the relative abundance of types and colors (brown, red, gray, green, yellow, purple, and black) of volcanic rock fragments. Gravel clasts are mainly rounded to well-rounded particles, particularly those coarser than 4 mm. The best indurated beds have a thin coating of white chalcedony or pale blue opal on the clasts. The sand matrix of the conglomerate is similar to the volcanic arenite described in a following section.

Boulder-size clasts are common in the coarser conglomerate, although nowhere do they predominate in the rock. The largest boulder recorded (Bailey, 1926, p. 80) is 2 × 1-1/3 × 1-1/4 feet. A feebly defined imbricate fabric exists in a few beds only; apparently the elliptical shapes of the pebbles were not conducive for well-developed preferred fabrics to form.

Bailey (p. 85) interpreted the conglomerate to be a fluvial deposit, an interpretation with which the writers concur. The lenticular shape of the conglomerate bodies suggests that they are ancient river gravel bars. The coarseness of many conglomerate beds indicates that the streams had high competency. The presence of horizontal laminae in sandstone beds associated with the conglomerates and of faint horizontal bedding within the conglomerate itself, indicates that at times deposition took place from currents in the upper flow-regime (Harms and Fahnestock, 1965). Normal, high-angle cross-beds typical of those produced by migrating bars with avalanche faces are present in the conglomerate, but low-angle cross-beds that appear to have formed as surfaces of accretion during the infilling of shallow channels are more common.

Composition of Igneous Pebbles

Pebbles of different rock types in Gueydan conglomerate were collected from numerous localities. The pebbles were sorted into groups of similar composition based on hand-specimen examination, then representative pebbles were selected for thin-section study. Intraclasts of silicified tuff or clay derived from previously deposited Gueydan sediment were not included in the study.

The composition of 23 rocks studied in thin section is: trachyte (12), trachyandesite (latites) (2), altered trachyte or trachyandesite (3), welded tuff (3), altered non-welded tuff (1), rhyolite porphyry (1), and 1 specimen too highly altered to classify. These figures are believed to be typical of the relative abundance, but not necessarily of the absolute abundance, of different rock types in the whole formation. The conglomerate beds have a wide range in the absolute abundance of different pebble types. Characteristics of the chief lithic types are summarized below. Detailed descriptions of individual pebbles are given in Appendix B, and photomicrographs appear as Plates 24–28.

Trachyte and trachyandesite.—Because of the alteration of the groundmass of these volcanic rocks of intermediate composition, the exact percentages of potash and plagioclase feldspar cannot be determined with certainty; hence, the assignment of rocks to the trachyte or trachyandesite clan is somewhat arbitrary. Rocks here classified as probably trachyandesite are similar texturally to the trachyte but contain more pyroxene in the groundmass. The trachyte as a group is characterized as amygdaloidal trachyte porphyry with 15 to 40 percent highly resorbed ("wormy") anorthoclase phenocrysts. Two rocks are porphyritic trachyte (less than 5 percent phenocrysts), and two are alkali trachyte that contain aegirine and a sodic amphibole. Approximately a third of the trachyte has a few unfilled vesicles. The largest igneous clasts in the formation are highly vesicular (40 percent) trachyte porphyry boulders up to 3 feet in diameter.

Anorthoclase phenocrysts are highly resorbed grains (Pl. 28A) up to 5 mm long and generally with closely spaced albite twin-lamellae. Several rocks have sufficient rhomb-shaped euhedra to be classified as rhomb porphyries. Clinopyroxene subhedra rimmed with hematite are the only common phenocrysts in addition to anothoclase, and they comprise only 1 to 2 percent of the rocks. Orthopyroxene (hypersthene) is present in one rock, and quartz microphenocrysts (2 percent) occur in one alkali trachyte. The phenocrysts in the alkali trachytes are alkali feldspars with moderate 2V's (30°–45°).

The trachyte with microcrystalline or phanerocrystalline groundmass has either trachytic or orthophyric textures. A few samples have a cryptocrystalline mesostasis, whereas in others the original texture has been obscured as a result of alteration of ferromagnesian minerals and growth of small grains of authigenic hematite. Primary groundmass minerals are alkali feldspar, oligoclase, and clinopyroxene. Iron ores and apatite are common accessory minerals.

Amygdules in the porphyry contain a variety of secondary minerals that have a complex paragenesis. In order of abundance the minerals that have been identified are chalcedony, calcite, quartz, zeolite (clinoptilolite?), hematite, opal, tridymite, albite, and celadonite (?).

Tuff.—The pyroclastic rocks are devitrified crystal-bearing (2 to 20 percent) vitric tuff with a trace of lithic fragments. The shards of three of the four samples studied have been flattened and compressed, a feature that typifies moderately compacted welded tuffs (Pl. 27A). The fourth sample is an opalized tuff in which the relic shards show no signs of deformation. All glass has devitrified to microcrystalline or cryptocrystalline products. Relic shards are distinguishable by either coarser crystals than the devitrified glass dust or by a rim of tiny hematite grains; the shards in one rock show superb axiolitic textures. Coarse clastic grains in the tuff include fragments of quartz, sanidine, clinopyroxene, and trachyte rock fragments.

Rhyolite porphyry.—The rhyolite porphyry (Pl. 28B) contains 10 percent K-feldspar phenocrysts, in part showing Carlsbad twins, in a blotchy textured matrix of indistinct microcrystalline feldspar grains and slightly larger quartz anhedra.

Pumice-pebble conglomerate (Fant Member, type 7, Bailey, 1926, p. 27; Gueydan, type 4)

Conglomerate in which all pebbles are pumice fragments is a rare rock type in the Gueydan. This type of conglomerate has been found only in Live Oak and McMullen counties in beds less than 6 inches thick. The rock is soft, massive-bedded conglomerate with rounded pink, white, bluish-gray, yellow, orange, and light green pebble-size pumice fragments encased in a tuff or shard-sand matrix. Thin sections show typical pumice textures; thin walls of glass formed around vesicles generally less than 0.10 mm long. Many fragments have elongate vesicles that produce a distinct flow structure to the clasts.

Bailey (pp. 72, 84) suggested that some pumice-pebble beds were stream-deposited but mentioned the possibility that others are accumulations of air-falls of pyroclastic debris. The lattter possibility is rejected here because the proposed volcanic sources for the Gueydan are believed to be several hundred miles distant and the pumice pebbles, as noted by Bailey, are of different types. The conglomerate beds are interpreted to be water-laid deposits. One conglomerate with a tubular-porous tuff matrix is interpreted to be a mudflow deposit because of the random orientation of shards and because the pebbles are not in mutual contact in the rock. It is likely that pumice fragments, because of their buoyancy, were concentrated at the top of the mudflow during their transport.

Tuff- and clay-granule and pebble conglomerate

Conglomerate composed predominantly of rounded elliptical clasts of indurated tuff and bentonite (Pl. 13) derived by the erosion of older Gueydan rocks is present from at least Duval to Karnes County. These beds are lenticular units less than 6 inches thick and in a few places contain pebbles larger than 2 inches. This fine-grained conglomerate is among the best-sorted rock in the formation. Beds generally are slightly cemented by opal or zeolite; a few beds have sparry calcite that fills all pores.

The difference in composition of these beds from the felsite conglomerate, with which they are interbedded in places, is a function of the availability of source material. The "intraclast-pebble" conglomerate reflects a lack of available volcanic-rock pebbles and this, in turn, suggests that the conglomerate was deposited by small tributary streams that did not reach far up-dip from the present site of deposition. In contrast, conglomerate with abundant volcanic pebbles is inferred to have been deposited by larger, major streams that extended far enough up-dip to erode material from outside the basin of deposition.

SANDSTONE

GENERAL

Sandstone forms a significant part of the Gueydan along its entire outcrop and exhibits significant mineralogic differences both along strike and, at least in Duval County, vertically through the formation. Sandstone interbedded with volcanic conglomerate in Duval and Karnes counties is, like the conglomerate, made up almost entirely of volcanic rock detritus and locally derived intraclasts from within the Gueydan. This volcanic arenite is mostly coarse to very coarse grained. In contrast, sandstone in the lower part of the Gueydan in and south of Duval County contains significant amounts of carbonate rock fragments and quartz that were derived from older sedimentary rocks. The sandstone north of Duval County is rich in quartz but contains only trace amounts of carbonate rock detritus. Sandstones in the lower part of the Gueydan and north of Karnes and south of Duval County are mostly fine- to medium-grained rocks.

Thomas (1960) studied sandstone from five locations within the study area and additional samples farther east. He also noted the major mineralogic differences along strike and found sandstone beds to become progressively quartz-rich to the east. Wendler (1934) studied sand samples from 8 localities east of the Guadalupe River, described the mineralogy of light- and heavy-mineral fractions, and presented histograms of grain-size analyses. McCracken (1967) studied samples from Gonzales, Lavaca, and Fayette counties with emphasis on sandstone petrology.

GEOMETRY AND STRUCTURES

Sandstone occurs in beds 1 inch to 2 feet thick that are lenticular in shape in those exposures which are sufficiently extensive that the lenses may be observed. The lenses attain widths of 50 feet but generally form composite units 5 to 20 feet thick that extend more than half a mile along strike.

Bedding types (Pls. 13B, 14A) in the sandstone are low- and high-angle cross-beds, horizontal laminae, and massive (structureless) bedding. Bedding generally is less distinct in conglomerate beds than in fine-grained, non-conglomerate strata. Additional sedimentary structures are rare; flute casts were found on the soles of only two beds (Duval County); parting lineation was found in 5 to 6 beds (Duval County); vertical, smooth-walled burrow fillings were found in several beds at one locality in Karnes County (Loc. K-10); well-formed current ripple-marks were found on only one bed (Duval County). Disturbed zones that may have been made by plant roots or burrowing animals were noted in 10 to 12 beds. Data on cross-bedding in the Gueydan were obtained from Duval, Karnes, and Fayette counties.

High-angle[8] and low-angle cross-bedding are about equally abundant. Included in the high-angle category, however, are many beds with angles of maximum inclination less than the angle of repose of sand (33°–35°). This is in part a result of the fact that the dip of a cross-stratum generally decreases toward the base of a cross-bed set. The upper part of such beds commonly has been eroded leaving only the gentler-dipping part of the bed preserved. Cross-bed dips range from 3° to 35° and average 15°.

Festoon cross-beds, the sets (or beds) of which have the shape of a festoon or filled trough, are far more common than the planar variety that are flat and tabular and are bounded by sub-parallel planes. Festoon cross-beds formed by the scouring and filling of small troughs that form in the front of lobate current ripples or dunes (Harms and Fahnestock, 1965) and also by the scouring of shallow U-shaped channels followed by later back-filling (McBride, personal observation). In both origins, the cross-strata form when grains slide down steep avalanche faces. In contrast, low-angle cross-strata form by the accretion of grains on gently sloping sand-point-bars or small bar forms without avalanching.[9] High-angle cross-beds in the Gueydan were formed by the migration of ripples or dunes with avalanche faces. Ripples ranged from a few inches to 2 feet high with wavelengths that were probably tens of feet long (dunes or megaripples).

In terms of fluvial mechanics, the ripple forms indicate conditions of flow assigned to the lower flow-regime, whereas the horizontally laminated sandstone indicates conditions of flow assigned to the upper flow-regime (Harms and Fahnestock, 1965; Simons et al., 1965).

All the sandstone studied by Bailey (1926), Thomas (1960), McCracken (1967), and the writers is interpreted to be of fluvial origin. Specifically, the sandstone was deposited in river channels in the form of ripples, bars, and scour-fillings, as indicated by the geometry and structure of the beds. Although the possibility exists that the shell-bearing sandstone in Starr County is marine, the abraded form of the fossils and their association with tuffaceous clay that is interpreted to be nonmarine, suggests that the mollusks, like the Cretaceous foraminifers, were reworked from older strata. The sandstone is not well enough exposed to display sedimentary features that might corroborate this interpretation, however. In an earlier study of one hand specimen from Trinity County, Goldman (1915) concluded that sand from the sample underwent wind transport and

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[8] Arbitrarily defined here as a cross-bed with an angle of inclination greater than 10°.

[9] Imbrie and Buchanan (1965) interpreted low-angle cross-beds in modern carbonate sands in the Bahamas to form by accretion of grains on the lee side of ripples or embankments during deposition from currents with a significant component of tangential fluid flow.

came to rest on a coastal or inland sand flat. Wendler (1934, p. 119) interpreted the Catahoula east of the Guadalupe River to be a near-shore deposit. If the oyster reef mentioned by MacNeil (1966, pp. 2353–2354) is in the Gueydan, brackish deposits are documented for at least one area.

Cross-bed dip directions of sandstone and conglomerate beds were recorded in

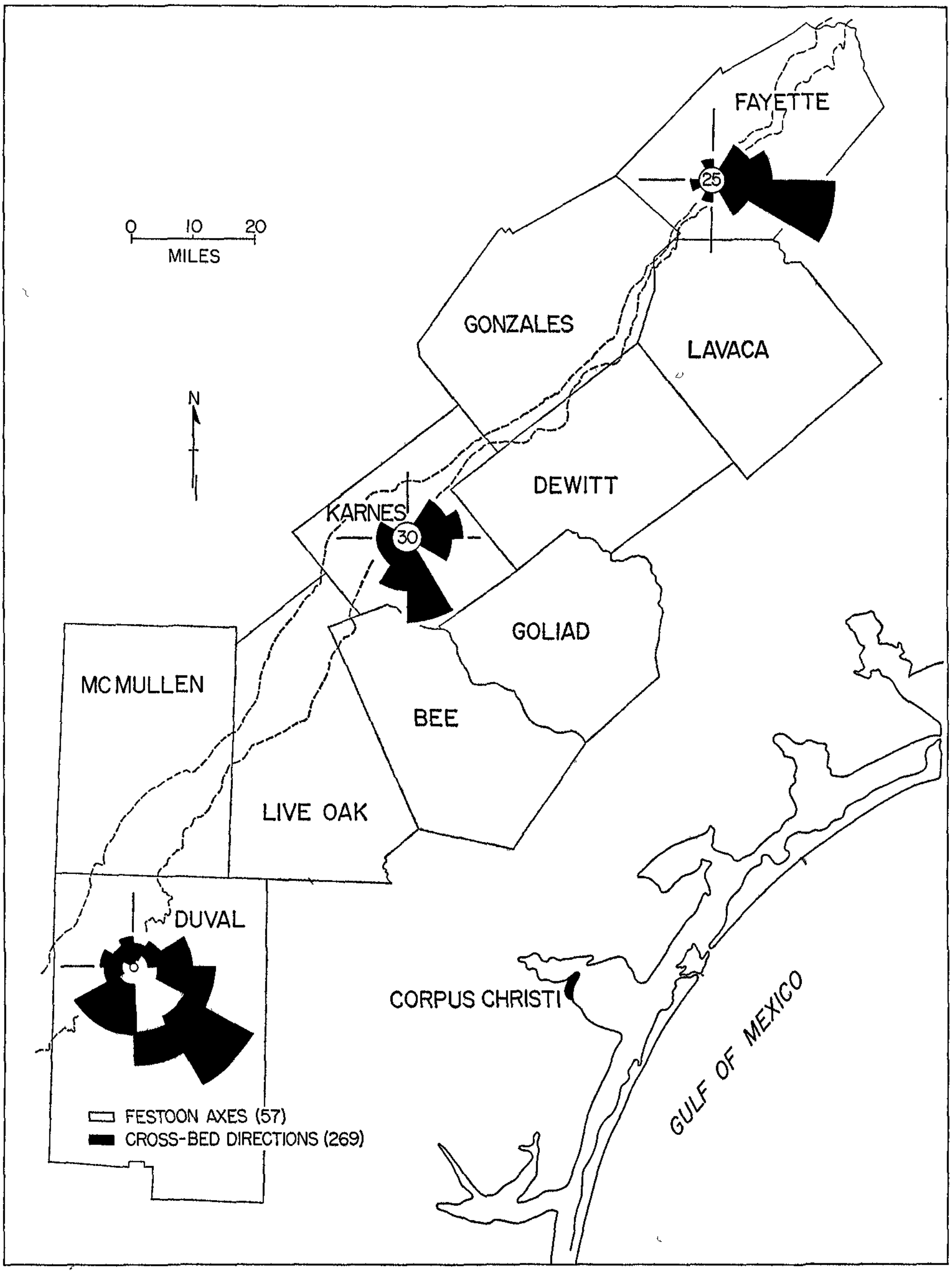

FIG. 3. Map showing cross-bed dip directions of the Gueydan Formation. Numerals indicate the number of readings represented in each rosette.

order to determine the paleocurrent pattern of stream transport. In fluvial deposits the average direction of dip is interpreted to define the ancient regional paleoslope, which in turn defines the regional paleostrike and trend of the shoreline.

Figure 3 shows rose diagrams for localities where cross-bed readings were obtained; the data include 269 cross-beds and 57 festoon axes from a wide area in Duval County, 30 cross-beds from two localities in Karnes County, and 25 cross-beds in Fayette County. Although the diagrams show considerable scatter, and have modes that span from 90° to 240° azimuth, the cross-beds and festoon axes dip predominantly toward the southeast. The writers infer from this that the paleoslope during Oligocene-Miocene(?) time was nearly the same but perhaps slightly more southerly than that of the present. Because of the variable dip directions around the edge of trough-shaped cross-bed sets, dip readings taken from such units commonly show more spread than for planar cross-beds. The standard deviation of all readings taken in Duval County, however, is 74.3°, a value typical of most fluvial sandstones.

ARCHITECTURE AND MINERALOGY

Gueydan sand and sandstone samples have a large range in average grain size. Mean sizes range from very fine to very coarse sand, although most samples are fine to medium sand. Conglomeratic sand and sandy conglomerate beds occur locally between Karnes and McMullen counties. Most sand and sandstone beds are moderately well sorted (estimated to range from 0.5 to 1.0 phi units). Although friable sands yield several percent of clay upon disaggregation, most clay is from disintegrated sand-sized clay clasts or clay that filtered into the sand framework by Recent or ancient soil? forming processes. Disaggregated samples sieved by McCracken (1967) are moderately well sorted and have an average sorting of 0.63 phi units.

Gueydan sandstone bodies have a wide range in types of framework grains, types and degrees of cementation, and matrix content. In order to quantify these variables, 100 counts were made of each of 27 thin sections to determine the percent of cement, clay, and pores in each rock; after this was done additional counts were made until 100 framework grains had been classified. To aid in identifying feldspars, K-feldspars were stained yellow by first etching slides free of their cover glasses in HF fumes for 10 to 60 seconds and then immersing them in a saturated solution of sodium cobaltinitrite. Plagioclase remains unstained by this technique. Results of the point counts are given in table 1 and are shown in figure 4. Photomicrographs are shown in Plates 14, 15, and 16.

In total rock volume, sandstone samples studied range from a trace to 39 percent cement (average 24 percent), from 0 to 5 percent clay matrix (average 2 percent), and 0 to 14 percent porosity (average 5 percent). The average porosity value determined in this study is lower than the average sandstone samples in outcrop, because moderately to well-indurated sandstone samples were purposely collected in favor of friable samples to facilitate the making of thin sections.

FRAMEWORK GRAINS

Quartz.—Gueydan sandstone generally is low in quartz compared with common varieties of sandstone; percentages range from 4 to 62. The average quartz content is 30 percent of the framework grains. Most quartz is the unstrained variety, relatively free from mineral or fluid inclusions, and commonly showing crystal faces; this type is characteristic of volcanic source rocks. It is estimated that more than 75 percent of the quartz of half the sandstone samples, and at least 66 percent of the quartz in the remainder, is this variety. Sections of quartz with pyramidal terminations are common, but doubly terminated crystals are rare. Negative crystal inclusions, common in much volcanic quartz, are rare in Gueydan quartz.

Most of the remaining quartz is the "common" variety, that showing slightly undulose extinction and possessing some

TABLE 1.—*Composition of Gueydan Sandstone Determined from Thin-Section Point Counts.*

	Framework Grains														
Sample No.	Quartz	Polyxline quartz	K-feldspar	Plagioclase	Tuffy clay	CRF[1]	Chert	VRF[2]	Silicic VRF[3]	Other grains	Calcite[4] pseudomorphs	Cement	Matrix	Pores	Comments
S-9	23	..	7	16	..	11	2	17	9	4	11	10	..	18	other = sandstone calcite cement
S-10	22	..	6	23	..	12	..	21	5	1	10	37	..	..	other = sandstone calcite cement
S-13	17	2	5	25	6	5	..	25	9	..	6	13	..	17	calcite cement
LGG-8	56	2	3	14	..	..	..	18	7	..	..	41	..	2	
LHH-7	44	3	8	17	2	7	2	9	1	..	9	34	..	..	caliche cement
LE-6	6	1	2	10	13	..	..	61	3	4	..	16	4	3	other = pyroxene
LA-3	19	2	5	19	6	12	.	25	7	..	6	22	5	1	
LD-8	4	1	9	8	27	1	1	42	4	2	1	25	1	6	
GW-2	11	3	10	24	8	.	..	36	2	6	..	24	3	1	other = pyroxene
LLL-1	14	3	7	20	3	13	1	20	2	4	13	33	3	..	
LG-8	18	3	3	11	6	20	1	27	2	2	7	26	2	1	other = sandstone
LP-8	10	..	6	6	57	..	..	15	6	..	..	14	4	7	
LI-3	20	..	8	31	6	11	..	16	1	..	7	22	2	4	
LO-7	24	1	1	29	16	1	..	18	3	..	7	27	4	1	
LAA-7	22	4	5	15	7	17	..	14	4	1	8	3	11	6	
AO	40	1	13	10	..	8	2	19	6	1	..	37	..	..	opal cement
LS-12	32	1	8	13	10	8	1	16	4	..	7	29	..	3	
LT-1	33	..	3	24	7	10	..	11	2	..	10	19	2	5	
K-10ss	51	1	17	11	..	..	..	17	3	..	22	1	9	..	zeolite cement
K-10x	48	4	17	5	11	..	..	10	5	..	..	18	2	14	zeolite and montmorillonite cement
K-10x1	20	..	2	1	1	1	4	53	10	8	..	33	..	..	granule conglomerate; mont. cement. other = petrified wood, sandstone
K-10B	50	1	9	14	6	..	..	13	6	1	36	..	..	..	fibrous opal cement
F-2H	32	2	17	28	2	..	..	18	1	..	..	..	2	14	
F-5	62	2	13	7	..	..	..	11	4	1	..	37	..	1	opal and zeolite cement
F-11	48	4	16	7	1	..	1	19	4	..	..	39	..	..	opal cement
F-4A	46	..	14	19	..	..	..	17	4	..	..	11	9	12	
Average	29.8	1.6	8.2	15.5	7.6	5.5	1.0	21.9	4.5	1.3	3.8	24.4	2.0	4.6	
M-10[5]	34	2	9	13	10	11	1	12	8	..	..	37	..	..	cement: 29% zeolite 8% chalcedony

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[1] CRF = carbonate rock fragments.

[2] VRF = volcanic rock fragments.

[3] Silicified volcanic rock fragments.

[4] Calcite pseudomorphs of feldspar.

[5] Problem boulder; not included in averages.

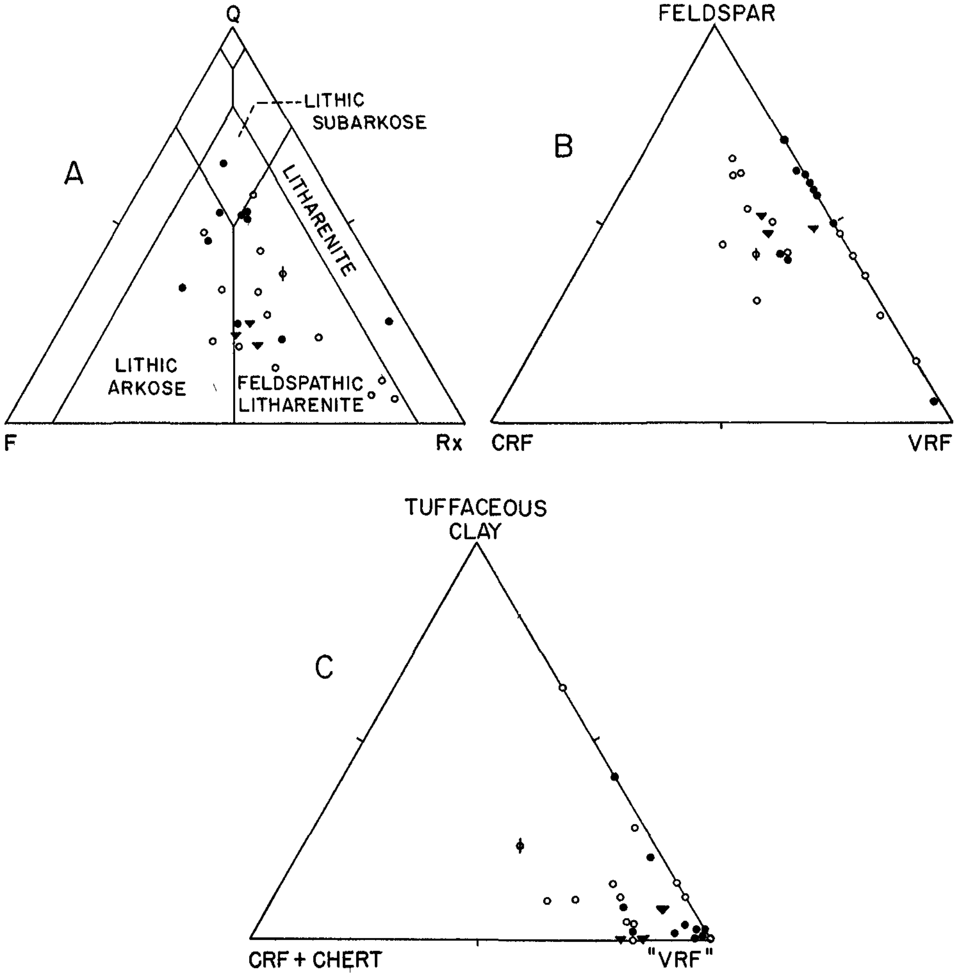

FIG. 4. Composition of Gueydan sandstone. Open circles = samples from Duval and McMullen counties; solid circles = samples from Live Oak, Karnes, and Fayette counties; triangles = samples from Starr County; circle with vertical line = quartzite sample from McMullen County.

A. Plot using McBride's (1963) classification scheme. Q pole = quartz and chert; F pole = feldspar and pseudomorphs of feldspar; Rx pole = rock fragments.

B. Feldspar pole = feldspar and pseudomorphs of feldspar; CRF pole = carbonate rocks; VRF pole = volcanic rock fragments and silicic volcanic rocks.

C. "VRF" pole = all grains of volcanic derivation exclusive of clays; CRF and chert pole = carbonate rock fragments and chert.

fluid and mineral inclusions. Highly undulose or polycrystalline grains are rare; in many slides no such grains are present. Polycrystalline grains, particularly those with highly undulose crystal units, are thought to be most abundantly derived from metamorphic source rocks; hence, they were tabulated separately from other quartz types. The average content of polycrystalline quartz is only 2 percent, and few of these grains are highly strained. The suggestion of a lack of a significant contribution from metamorphic source rocks is confirmed by the neat absence of other metamorphic rock fragments.

Quartz grains are mainly subangular, but a few angular and subrounded grains are present in most slides. Well-rounded grains are rare. Angular, sliver-like grains of volcanic quartz are conspicuous in a few slides.

K-feldspar.—Sanidine, identified by an index of refraction less than that of Canada balsam and low 2V, is the only K-feldspar in many sandstone bodies and is far more abundant than orthoclase or microcline. Feldspar grains are chiefly untwinned (80 percent), although Carlsbad (15 percent) and polysynthetic grid-twins (5 percent) also are present. The latter twinning is typical of complex soda-rich alkali feldspars; optic figures were obtained on a few grains to verify the presence of anorthoclase.

Grains range from euhedral and nonrounded (rare), to slightly rounded and subhedral (common), to well-rounded (rare). The degree of roundness is not a reliable indication of the amount of abrasion, however, because many feldspar phenocrysts in pebbles of volcanic rock in Gueydan conglomerate have poorly developed crystal faces and round, resorbed edges.

In well-cemented rocks the K-feldspar is still fresh, whereas in calcite-cemented rocks, up to half the K-feldspar grains have been replaced completely by calcite. These pseudomorphs, which are easy to recognize because they are clear single-crystal grains of calcite having cement in optical continuity with the grain, were tabulated separately in the point counts and were included with the K-feldspar grains in all plots of sandstone compositions. Incipient vacuolization is shown by feldspar in poorly cemented rocks.

Plagioclase.—Plagioclase ranges in abundance from 1 to 31 percent and averages 16 percent. Approximately 45 percent of the grains are untwinned, 45 percent have albite twins, and 10 percent have polysynthetic grid twins. Only 1 percent of the grains are zoned. Oligoclase, andesine, anorthoclase, and a trace of perthite are the only species positively identified. Grains are similar in habit and roundness to K-feldspar. Although many grains are fresh, the plagioclase shows greater average alteration than K-feldspar. The spectrum of altered grains shows that the process of alteration generally proceeded stepwise: first, moderate vacuolization; second, moderate sericitization; and finally, more intense alterations by both processes.

Volcanic rock fragments.—Sand-sized grains of VRF's are composed chiefly (80 percent) of small plagioclase laths in a dark fine-grained groundmass. Grains that are only a mosaic of K-feldspar and plagioclase or quartz are minor (20 percent), and grains of only dark fine-grained groundmass are rare. Granule-size and larger clasts commonly contain phenocrysts of feldspar. Highly resorbed (wormy) plagioclase is conspicuous in some granule-size VRF's. The grains are mainly fragments of volcanic rocks with felsic to intermediate compositions, although dark grains of basalt are also present. VRF's are prominent grains in all Gueydan sandstone (Pl. 14B); they range in abundance from 10 to 61 percent and average 22 percent.

Clay clasts.—Rounded montmorillonite claystone or bentonite clasts (Pl. 16A) range from silt-free to approximately 50 percent silt-size feldspar and quartz, locally with a trace of shards. Most grains have a random orientation of clay particles but a few are foliated. Clay clasts are chiefly yellow brown to dark brown. These grains are intraclasts of lithologic units that are interbedded with sandstone beds. Clay clasts are absent or present in trace amount in 7 of the 27 sandstone samples but comprise 57 percent of one sample. They average 8 percent of framework grains.

Carbonate rock fragments.—Fragments of limestone are locally abundant in the Gueydan. They comprise more than 10 percent in 8 samples and average 5.5 percent of framework grains. They are chiefly micrite (85 percent), about 10 percent of which contain foraminiferal tests (Pl. 15B). Oyster- and echinoid-bearing clasts are present in trace amounts. Grains of calcite spar and microspar are the other grains present. The limestone types are typical of many Cretaceous formations now exposed to the west of the Gueydan outcrop.

Fossils.—In addition to the reworked Cretaceous fossils mentioned above, trace amounts of petrified wood and phosphatic bone fragments showing Haversian canals are present in several slides (Pl. 15A). It is uncertain whether these are reworked or indigenous fossils.

Chert and silicified volcanic rock fragments.—Grains composed chiefly of microquartz (grains less than 20μ in diameter and including fibrous chalcedony and non-fibrous microcrystalline types; Folk, 1965, p. 80) are common constituents. Some are grains of chert that have formed by the replacement of carbonate rocks and are derived from carbonate rocks, whereas the majority are silicified and devitrified glassy volcanic rocks. Evidence for the latter origins is that pseudomorphs of feldspar laths or remnants of feldspar grains are present, and the mosaic of microquartz is more non-uniform in grain size and coarser (10–20μ) than typical chert from carbonate rocks. On the basis of such textural characteristics, grains were assigned to chert and silicified VRF categories during point counting. Chert ranges in abundance from trace amounts to 4 percent and averages 1 percent, whereas silicified VRF's range from 1 to 10 percent and average 4.5 percent.

Heavy minerals.—Heavy minerals were identified and counted from 9 sandstone samples from Duval County, and cursory examination was given to separations from Fayette, Karnes, and Starr counties. Grains from friable sandstone were settled using tetrabromoethane (sp. gr. = 2.96) and mounted in Canada balsam.

Heavy minerals in the samples ranged from 3 to 11 percent by weight of all grains. Opaque iron oxides (limonite, hematite, magnetite) comprise an estimated 66 to 90 percent of the heavy fraction. Percentages of non-opaque minerals were made for 9 samples by identifying 100 grains encountered along line traverses (table 2). Medium- to coarse-grained sandstone samples rich in VRF's yield a suite dominated by augite, titanaugite, and hornblende. Fine- to medium-grained sandstone samples containing fewer VRF's are rich in zircon, sphene, garnet, and apatite. In the samples from Fayette, Karnes, and Starr counties, zircon and apatite comprise more than 85 percent (estimated) of the non-opaque fraction. Many samples have phosphate bone fragments. Barite is an authigenic mineral present in several samples.

As expected, the heavy mineral suite in the samples examined is dominated by grains of igneous, and particularly volcanic, derivation. Moreover, most zircon and much apatite occur as nonrounded euhedral grains that have undergone little abrasion. The presence of rounded apatite and tourmaline, however, suggests some contributions from older sedimentary rocks. McCracken (1967) found small amounts of staurolite and kyanite in his

TABLE 2.—*Mineral types (in percent) of non-opaque heavy mineral grains in Gueydan sandstone, Duval County, Texas.*

	(Lithic Sandstones)			(Fine-grained Lens in Volcanic Sandstone)		(Volcanic Sandstones)			
Sample Number	**LII-2**	**LI-8**	**LJJ-7**	**LB-7**	**LY-2**	**LA-9b**	**LE-8**	**LU-8**	**LM-3**
Zircon	41	48	22	60	67	2	23	3	7
Apatite	4	14	32	4	5	2	6	1	tr
Garnet	19	14	9	6	7	1	tr	1	tr
Sphene	10	11	6	14	4	2	6	4	1
Epidote	7	2	1	5	7	tr	2	2	..
Augite	1	..	..	..	1	34	18	58	40
Titanaugite	..	..	..	..	..	29	5	29	41
Hornblende	..	..	5	2	2	21	29	1	6
Basaltic hornblende	2	2	4	7	1	7	8	tr	4
Biotite	3	2	3	2	3	2	3	2	1
Barite	6	4	15	.	..	tr	tr	tr	..
Tourmaline	2	1	1	..	..	..	..	..	..
Rutile	tr	1	2	tr	tr	..	..	..	tr

samples farther north. He documented evidence for some contribution from metamorphic terrain but could not determine whether the metamorphic minerals were first cycle or polycyclic in origin.

Other studies of heavy minerals from the Gueydan have been made by Goldman (1915) and Wendler (1932, 1934).

CEMENT AND DIAGENESIS

Important post-depositional changes are grain condensation caused by compaction during burial, and cementation. Most Gueydan sandstone beds are cemented by zeolite (clinoptilolite) in combination with either calcite or opal and chalcedony. Sandstone with both calcite and opal and uncemented sandstone are rare. Feebly cemented, friable sandstone is locally abundant, however. Grain condensation, shown by smashed soft-rock fragments and an increase in closeness of packing, is greatest in calcite-cemented and uncemented sandstone. The opal-cemented sandstone has the freshest VRF's and feldspars; hence, the alteration of these grains is chiefly a diagenetic process.

The most common sequence of cement is:

(1) thin (0.02 mm) coating of lath-shaped zeolite crystals that in very few examples exceed 0.01 mm in thickness;

(2) opal rim, commonly clear and isotropic, but some fibrous with low birefringence;

(3) chalcedony filling of remaining pores; and

(4) calcite following chalcedony or opal (rare), or after zeolite. Most opal-cemented rocks are tightly cemented and have no porosity. Except in two samples with microspar cement (probably caliche), the calcite occurs as spar.

A few sandstone beds are loosely bound by thin rims of montmorillonite, whose platelets are preferentially oriented tangentially to grain surfaces. Such clay skins, or argilans (Brewer, 1964, p. 212), formed by the deposition of clay carried by descending ground water.

Sandstone beds from several localities in Duval County are cemented by a radioactive mineral which was not isolated or identified.

Viewed on the flat stage in thin section, framework grains surrounded by opal have uneven, embayed boundaries and appear to be partly replaced by opal. Such uneven boundaries, however, most probably are illusions produced by viewing thin edges of cement where they lap onto framework grains. Calcite has locally replaced entire K-feldspar grains and parts of some VRF's.

STRATIGRAPHIC DIFFERENCES IN COMPOSITION

The regional difference in grain size and mineral composition of Gueydan sandstone has been mentioned. The variability in composition is shown in figure 5, where data from 21 samples have been averaged in 7 areas between the Rio Grande and Colorado River. Northward from the Rio Grande, sandstone increases in quartz and feldspar but decreases in plagioclase, silicified VRF's, and chert. VRF's and tuffaceous clay clasts increase to Duval County, then decrease farther north. Carbonate rock fragments are present only in trace amounts north of Live Oak County. Porosity and amount of cement show no trend.

Vertical stratigraphic differences have been observed only in Duval County, where sampling density is greatest. Sandstone in the middle part of the formation (Soledad Member of Bailey) is considerably richer in VRF's than sandstone lower or higher in the section. Sandstone below the Soledad is richest in carbonate rock fragments and tuffaceous clay.

CLASSIFICATION AND PROVENANCE

Compared with most sandstone, that of the Gueydan is poor in quartz but unusually rich in feldspar and rock fragments, particularly VRF's. Hence, it is not practical to apply commonly used sandstone names. Most are best described as **volcanic lithic arkose or feldspathic volcanic** arenite, depending on whether feld-

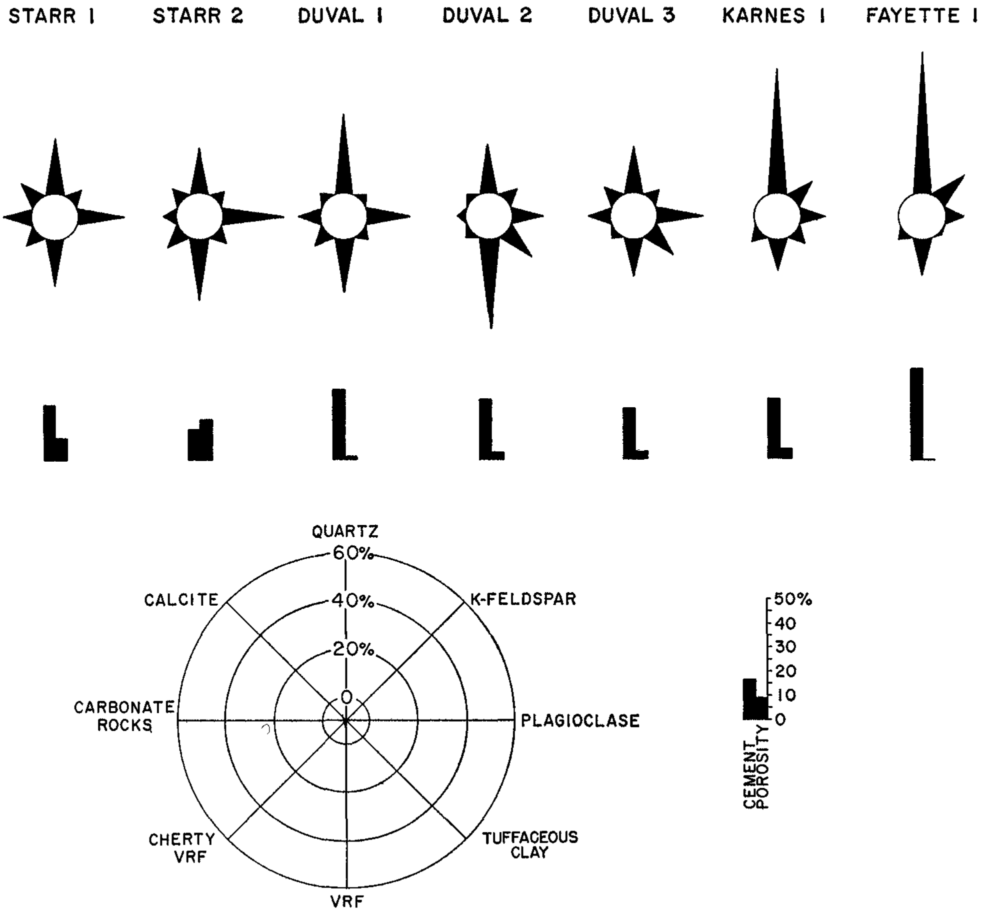

FIG. 5. Diagram showing variability of Gueydan sandstone along strike. Star diagrams summarize data from south (Starr 1) to north (Fayette 1) and are based on the following number of samples: Starr 1, 2; Starr 2, 1; Duval 1, 3; Duval 2, 3; Duval 3, 7; Karnes 1, 3; and Fayette 1, 2.

spar or VRF's predominate. The average composition of major constituents of the samples studied is 32 percent quartz plus chert, 38 percent rock fragments, and 30 percent feldspar (table 1).

Variations in several chief components of the sandstone are shown in figure 3.

It is clear that most detritus in the sandstone is derived from volcanic or hypabyssal intrusive rocks, inasmuch as the feldspar and volcanic rock fragments are diagnostic of such sources. Even most of the quartz in some rocks is of volcanic origin, as attested by the β-quartz habit and non-undulose extinction of such grains. Grains contributed by older sedimentary rocks include carbonate rock fragments, reworked fossils, chert, and minor amounts of quartz. The presence of foraminifers among this group suggests that the sedimentary components were derived from Cretaceous rocks exposed in what is now the Edwards Plateau. Tuffaceous clay grains certainly were derived from within the Gueydan. The near absence of rock and mineral grains of metamorphic derivation shows that the basement rocks in the Llano uplift were not contributing detritus to the parent streams at the time of Gueydan deposition.

SOURCE OF IGNEOUS DETRITUS

The location of the source area(s) of the pyroclastic detritus, flow rocks, and perhaps shallow intrusive rocks present as detritus in the Gueydan has been inferred by several previous investigators. Jones (1923, p. 545), in reply to a question following presentation of a paper, stated his opinion that "the rhyolite boulders and blocks of vesicular basalt (sic) in the vicinity of Government well, northwestern Duval County, may possibly have been transported from the west, for instance the area of igneous plugs in Uvalde County." Bailey (1926, pp. 156–164) presented a detailed list of evidence that could support either a localor a distant source and concluded that the evidence strongly favored but did not prove a local source. He (p. 164) favored the hypothesis that ". . . the old volcano or volcanoes were located near the Gueydan belt but are now covered by post-Gueydan sediments." One center of volcanic activity was believed located in southwestern McMullen or western Duval County.

Plummer (1933, pp. 720–721), Sayre (1937, p. 40), and Thomas (1960, p. 17) supported Bailey's interpretation that the volcanoes were close to the present outcrop. Plummer noted that the ash may have come from the Davis Mountains and other volcanic centers in Trans-Pecos Texas, in contrast to a local source of the coarser clastics. Hagner (1939, p. 70) placed the source of the ash southwest of bentonite outcrops examined by him in Karnes County. MacNeil (1966, p. 2363) believed Catahoula detritus came from centers of volcanic activity in the Rocky Mountains and that coarse sediment was transported by streams but ash was transported by wind. McCracken (1967) favored a west Texas or New Mexico source for sand-sized detritus.

The writers conclude that both the pyroclastic detritus and coarser volcanic-hypabyssal rock detritus were most likely derived from west Texas or northern Mexico, although the evidence is not conclusive. The pyroclastic material may have come from volcanoes located farther west than the area from which the flow material was derived.

EVIDENCE FAVORING A DISTANT WESTERN SOURCE

(1) A large terrane of Tertiary hypabyssal rocks, flow rocks, and pyroclastic debris is exposed in the Davis Mountains, in and west of Big Bend National Park, and in a poorly known adjacent area in northern Mexico. Many rocks in these areas are alkali-rich and silicic to intermediate in composition. Aegirine-bearing trachyte and trachyandesite pebbles in the Gueydan are strikingly similar in composition and some textural features (vesicular texture, rhomb-shaped highly resorbed feldspar phenocrysts) to lavas and intrusive rocks in Big Bend National Park (Maxwell and Dietrich, 1965). Although rocks with the style of devitrification shown by welded tuff pebbles in the Gueydan have not been described in the western localities, welded tuffs are present in the Park and are common west of the Park and in the Davis Mountains (DeFord, 1958; Snyder, 1962; Anderson, 1965).

(2) Paleocurrent data in Gueydan strata show that the streams flowed down a paleoslope toward the southeast; hence, detritus was derived from a region on the west.

(3) The closest known source of pyroclastic material of mid-Tertiary age also is in the west Texas—northern Mexico region.

(4) High-altitude winds currently blow from the west. Isobaric contour maps of the southwestern part of the United States and adjacent Mexico were prepared by Lindemann from records published by the United States Department of Commerce, Weather Bureau (1957). Maps were drawn that are based on pressure readings of 700, 500, 200, and 100 millibars, which correspond approximately to altitudes of

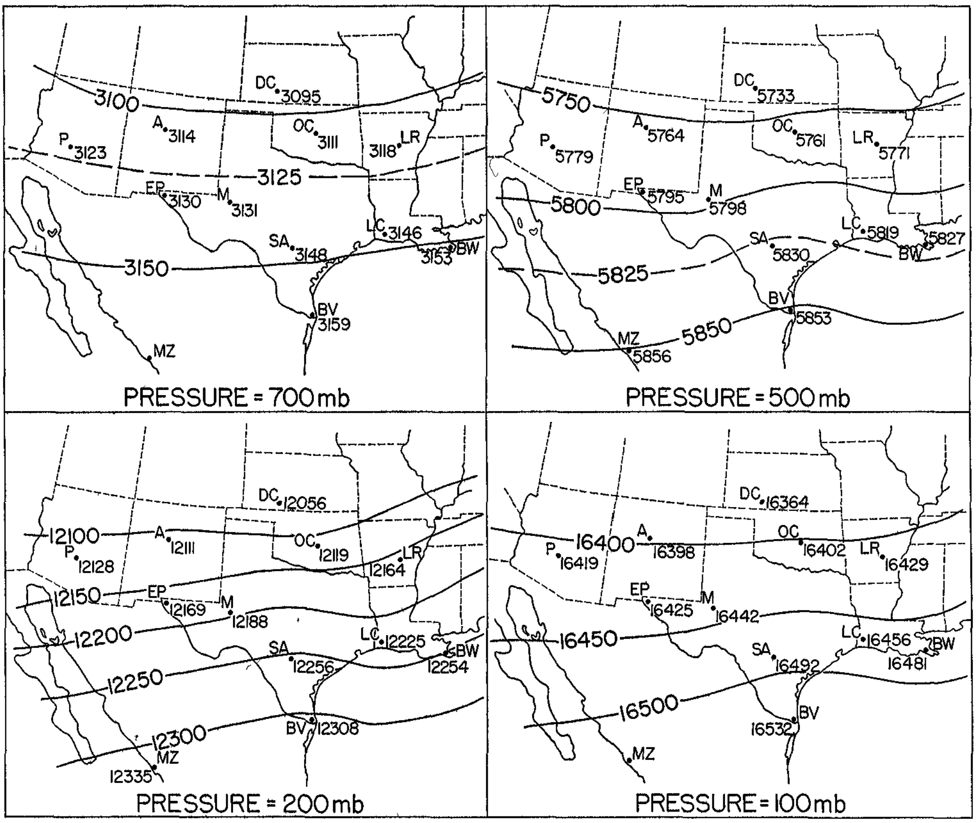

FIG. 6. Isobaric contour maps of the southwestern part of the United States and northern Mexico. Winds move parallel with the contour lines, which show elevations above sea level at which pressure readings (700, 500, 200, and 100 millibars) are the same. Elevations are given in geopotential meters (1 geopotential meter = 0.98 meters). City abbreviations: DC= Dodge City; P = Phoenix; A = Albuquerque; OC = Oklahoma City; LR = Little Rock; EP = El Paso; M = Midland; SA = San Antonio; BV = Brownsville; LC = Lake Charles; BW = Burrwood; MZ = Mazatlan. Data from U.S. Department of Commerce, Weather Bureau (1957).

10,000, 17,500, 36,000, and 50,000 feet above sea level. Data for a 10-year period were averaged and contoured on an interval of 50 geopotential meters (fig. 6). The maps show that the winds come from W. to S. 70° W. at the various altitudes. In a study of high-velocity winds over Texas, Cunningham (1957) showed that at 35,000 feet, 78.6 percent of the winds had a velocity less than 100 knots, 21.4 percent had velocities over 100 knots, and 0.5 percent had velocities exceeding 200 knots.

The velocity and direction of upper-atmosphere winds are controlled chiefly by temperature, rotation of the earth, and position of the poles. Paleomagnetic data suggest that the position of the poles has not changed greatly since the beginning of the Tertiary (Runcorn, 1962) ; hence, the present wind system is probably similar to that during deposition of the Gueydan strata. Thus, pyroclastic debris that reached upper-level winds would have drifted eastward. The widespread distribution of ash and tuff in Gueydan and correlative strata in east Texas and Louisiana and Mississippi indicates that the volcanic eruptions which supplied the ash were of gigantic scale. Even if eastward drifting of ash is accepted as likely, it is not possible at present to locate the volcanic sources. Not only can ash travel great distances by wind, but also there are no obvious petrographic peculiarities to establish the petrologic province from which it came. MacNeil (1966, p. 2363) favors a Rocky Mountain source, whereas the writers favor the west Texas-northern Mexico source because it is closer and more in line with easterly wind drift.

EVIDENCE FAVORING A PROXIMAL SOURCE

Evidence in support of a proximal source of both coarse and fine detritus has been marshalled by Bailey (1926). The main points are presented below followed by the writers' comments.

(1) Some tuff beds may have been deposited as mudflows which Bailey inferred to originate on the flanks of volcanoes. However, mudflows can originate at any place where rapid runoff might saturate unconsolidated ash and are not restricted to slopes of volcanoes.

(2) Tridymite in Gueydan tuff was cited as a hot gas-phase mineral that supported nearby volcanism. Re-examination of Bailey's thin sections showed that the mineral in the tuffs is clinoptilolite,[10] an authigenic zeolite that can form from cold alkaline water.

(3) Bailey found 50 or more andesite boulders between 1 to 2 feet in diameter that apparently weathered out of tuffaceous clay in McMullen County. Bailey contended the boulders were too large and angular to have been transported more than 100 miles by streams and noted that some boulders resemble volcanic blocks that are found on cinder cones. Sayre (1937, p. 40) reported the largest boulder seen by him was about 3 feet long. Freeman measured boulders 40, 36, and 25 inches in diameter in the field.

The large size (Pl. 17) of several boulders and their present weight are the strongest evidence to discredit the distant source proposed herein. The distance from the Gueydan outcrop in Duval County to Big Bend National Park is 300 miles.

However, large boulders are truly rare in the formation; most gravel-size material is less than 4 inches in diameter, and few particles exceed 6 inches in diameter. Most boulders longer than 12 inches seen by the writers are subrounded to well-rounded vesicular to amygdaloidal lava. Vesicles are now filled with secondary opal, chalcedony, and calcite that now contribute perhaps 30 percent of the weight of the boulders. An important point is that the largest boulders do not occur in conglomerate (stream deposits) but occur as residual debris weathered from tuffaceous clay. The dispersed fabric of the boulders in clay suggests the beds are mudflow deposits. Certainly mudflows are capable of transporting boulders the size and weight of those found in the Gueydan, and especially if vesicles were unfilled at the time of transport. However, mudflows were probably not the chief agent of transport of the large clasts. The interpretation favored here is that gravel-size clasts were transported chiefly as bedload by streams, and that mudflow transport was rare and for short distances only. Other means of transporting large clasts are known, such as rafting by trees or ice, but it is impossible to evaluate these possibilities for the Gueydan.

(4) Bailey noted that the scarcity of pebbles and boulders other than lava in the conglomerate beds in Duval County is difficult to explain, unless the parent volcanic blocks were close by when the conglomerate formed. The pebble types certainly show that igneous material was available almost to the exclusion of other rocks (except locally derived tuff and clay), but the writers interpret this to mean that, during the time of Gueydan deposition, nonigneous bedrock was mantled by pyroclastic material across thousands of square miles, and lava flows were exposed across a more extensive area of west Texas than at present. Some Cretaceous limestone was exposed as shown by detritus in Gueydan sandstone, but no gravel-size clasts of limestone have been found.

(5) Twenty feet of light green rock that Bailey (1926, p. 154) described as serpentine was penetrated at a depth of 230

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[10] A. D. Weeks et al. (1958) earlier suggested that the tridymite reported by Bailey might be heulandite, a zeolite isomorphous with clinoptilolite.

feet by the Hawley well located 2 miles southeast of old Fant City in central Live Oak County. Bailey interpreted the serpentine to be an intrusive body and additional evidence of igneous activity in the vicinity. The writers have not been able to locate the cuttings from this well and cannot evaluate the significance of the unusual rock from data on hand. The presence of serpentine is difficult to explain in a region of silicic igneous rock detritus.

Another possible clue to volcanism that Bailey mentioned is a glazed tuff with a slaggy appearance that he found a quarter of a mile north of the Hawley well mentioned above. He suggested that the rock was fused by hot volcanic vapors or by the burning of escaping natural gas. The writers did not see this rock type during their study and therefore cannot evaluate its significance.

(6) Accretionary lapilli with graded texture (Pl. 10A) found by McBride are most commonly formed as mud pellets in ash falls within a few miles of volcanic vents. However, because they can form in loose ash by other processes, they cannot be considered conclusive evidence of a nearby source. Although unaltered lapilli have been found in only one bed, pisolites that may be altered lapilli suggest they may once have been more abundant.

EVIDENCE AGAINST A PROXIMAL SOURCE

As noted by Bailey (1926, p. 158), failure to find volcanic necks or parts of cones in the vicinity of the Gueydan is damaging to the hypothesis of a local source. He concluded that other evidence was adequate to indicate that the source vents were down-dip from the present Gueydan outcrop and buried by younger strata, or perhaps up-dip and buried by Quaternary terrace deposits. Although these possibilities exist, no gravity or seismic anomalies down-dip from the outcrop that suggest such buried vents have been reported. Gravity and magnetic anomalies are known up-dip from the Gueydan outcrop, but they are over buried plugs of Mesozoic age (Moody, 1949). Inasmuch as the paleocurrent data show the Gueydan streams flowed southeast, it is unlikely that a vent down-dip (on the east) from the outcrop could have provided lava to the streams flowing southeastward. Lava and welded tuff are more resistant to erosion than most strata in the Gueydan and adjacent formations, yet no such outcrops are known to occur in Texas closer than Big Bend National Park.

OTHER POSSIBLE SOURCE AREAS

Jones's (1923) suggestion that igneous plugs in Uvalde County were the source vents of Gueydan strata was discredited by Bailey (1926, pp. 158–159), who noted that the rock there and in small exposures in Kinney and Travis counties is totally different from rocks in the Gueydan and are of Cretaceous age. The shallow intrusive rocks in the Uvalde region have been studied by Whitman Cross (*in* Vaughan, 1900), Lonsdale (1927), and Spencer (1966). Spencer reported that half the igneous bodies are melilite-olivine nephelinite, a third are olivine nephelinite, and the remainder are analcite phonolite, olivine basalt, and nepheline basanite. The largest volcanic neck in Travis County consists of basalt and limburgite (Hill, 1890). Sand-size rock fragments of basalt occur in small amounts in Gueydan sandstone, but grains or pebbles of the other subsilicic rock types are not present in the formation.

Moody (1949) mentioned the presence of trachyte porphyry in Louisiana and tinguite in Mississippi that were penetrated by deep wells, but the locations are not suitable as source areas for the Gueydan.

Igneous rocks of Tertiary and possibly Mesozoic age crop out extensively in northeastern Mexico. Little is known about the age and rock types of this area, but an alkali-rich igneous rock province apparently extends south of west Texas for several hundred miles along the Sierra de Tamaulipecas in Coahuila and Nuevo Leon, Mexico (McKnight, 1963). McKnight studied one of the closest Tertiary igneous outcrops to the Gueydan equivalent in Mexico (220 miles south-southwest of Duval County) in the Sierra de Picachos, Nuevo Leon. The area has shallow intrusive rocks that include syenite, gabbro, andesite, and basalt in addition to contact-metamorphic rocks. These rocks are also not a likely source of Gueydan detritus because particles of the plutonic and contact-metamorphic rocks are not present in the Gueydan.

CLAY DIKES

Dikes of pastel-colored, generally pink, bentonitic clay that cut through rocks of the Gueydan are conspicuous features (Pl. 19) at numerous localities. They apparently are most abundant in Duval County, but excellent examples are known from Starr, McMullen, and Karnes counties. Dikes have sharp contacts with host rocks, which include conglomerate, sandstone, and tuffaceous clay. The dikes are nearly vertical but have slightly sinuous courses. They have a uniform width that ranges from approximately 1/16 inch to 33 inches but averages 2 to 3 inches. Dikes extend the limit of individual outcrops; the greatest vertical distance seen is 20 feet (Starr County), and the greatest lateral distance is 150 feet (Duval County).

The dikes are compact, moderately indurated and range from nearly pure bentonite to gritty clay with as much as 30 percent shards, quartz, and feldspar of silt size. Most dikes have a distinct banding (Pl. 20) that trends parallel with their walls. Thin sections show the bands differ in degree of brown color (iron oxide?) and in clay particle size and degree of parallel orientation. The latter feature is shown by different degrees of mass extinction beneath crossed polarizers; the clay particles are moderately to well oriented.

Silicification of dike material and adjacent wall-rock has occurred in places. Veins of pure opal or chalcedony occur in a few dikes as post-intrusion fracture fillings.

In Duval County dikes are most abundant in the vicinity of faults, where they locally occur as dike swarms. Figure 7 shows rose diagrams for the orientations of 177 dikes (including a few sandstone dikes) and 52 fractures from Duval County and 19 dikes from one outcrop in Starr County (Loc. S-1). The strong NE-SW trend of dikes is identical with the major fracture trend and indicates that the dike trend is structurally controlled.

The internal structure of the dikes shows that they were injected and are not open-fissure fillings. It is uncertain whether the dikes were injected from above or below, although one dike in Karnes County (Loc. K-8) extends upward from a clay that appears to be its source bed. Dikes now range from approximately 60 percent to nearly pure montmorillonite, but the possibility exists that they were intruded as ash that was later argillized. This is unlikely because the montmorillonite particles are preferentially oriented parallel with the dike walls. This texture would not be likely to develop if the dikes were glass shards that were argillized after injection.

Although clastic dikes are present in many formations, most are formed by the injection of porous clastic material into less permeable strata (*i.e.,* sand into mud or clay). Gueydan dikes are unusual in that clay, impermeable now at least, intrudes more permeable strata. Another peculiarity is that dikes in Karnes County cut through beds of uncemented sand and gravel (Loc. K-8) and nevertheless have sharp contacts with the host strata.

The writers believe that the clay dikes in the Gueydan formed along early fractures when slurries of newly formed bentonite were unable to de-water slowly. With compaction, fluid pressures built up until released during injection of the dikes.

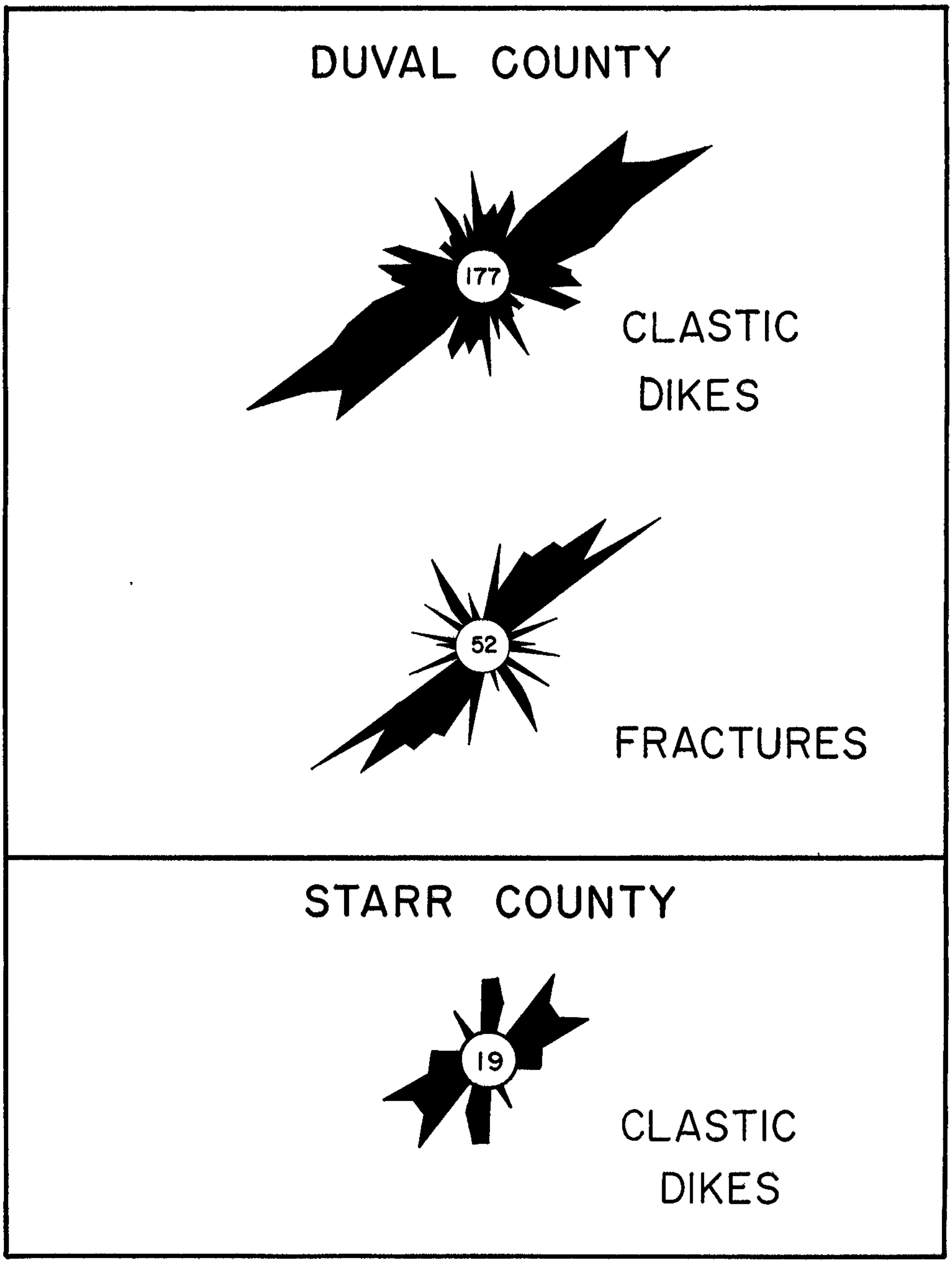

FIG. 7. Rosettes showing orientation of clastic dikes and fractures in the Gueydan. Numerals refer to the number of readings in each rosette. Starr County data are from Rio Grande City.

SILICEOUS VEINS AND KNOBS

More than 50 scattered hills of circular or elliptical shape form prominent landmarks in southern McMullen and northern Duval counties. These hills or knobs (Pl. 21A) have relief ranging from 20 to 100 feet and areas up to several acres. They are underlain by rocks rich in chalcedony and opal that resist erosion better than softer host rocks. The siliceous material occurs as chalcedony-cemented sandstone, silicified tuffaceous clay, and as bands and veins of light bluish-gray to white opal and chalcedony. The rocks in some knobs are blotchy because of differences in grain size (coarse mega-quartz to cryptocrystalline chalcedony) and color. Locally rocks are extremely vuggy. Stratification in beds of chalcedony-cemented sandstone is visible locally but absent in most exposures. Geologic relations of the siliceous rocks with the host rocks are difficult to unravel because talus boulders and blocks litter the base of the hills. Some knobs are supported only by irregular boulders and blocks of quartzite that are strongly but unevenly polished. Although most knobs crop out in the upper part of the Gueydan, several occur in the overlying Oakville and Goliad(?) Formations,

Bailey (1926, pp. 149–154) described a connected series of siliceous hills in Duval County (Los Picachos Hills) as a vein complex formed by silicification of tilted Gueydan strata adjacent to a reverse fault. He emphasized that most other hills in the vicinity are rounded knobs underlain by silicified flat-lying strata in which quartzitic beds and boulders predominate. He regarded the rounded knobs as residuals of locally silicified parts of formerly more extensive Oakville sandstone beds.

Sayre (1937, p. 74) later mapped another hill (Cedro Hill) underlain by veins in Duval County and identified two porcelainlike beds of halloysite and in which the writers also found kaolinite.

Price (1933, p. 519) suggested that the silica knobs may have formed by successive replacement of aragonite by calcite and calcite by chalcedony, although silica may have been the first to precipitate.

The hills underlain by veins and described by Bailey and Sayre are situated on major faults that cut the Gueydan and, in places, younger strata. The linear distribution of many other knobs is along known or suspected faults. Hence, the structural control of the siliceous veins and knobs is apparent. Bailey's suggested mode of origin for Los Picachos Hills, by water circulating along fault planes and depositing opal and chalcedony and locally replacing wall rock, also seems to be applicable to several of the knobs. However, the quartzite beds and boulders present in many knobs pose a problem.

Thin sections (Pl. 22) show that the quartzite beds and boulders are composed almost entirely of quartz and chert sand grains and are generally without feldspar; a few have trace amounts of silicified clay clasts and silicified VRF's. Chert ranges from an estimated 5 to 20 percent of the grains and is highest in sandstone with chalcedony cement. Most chert grains are a mosaic of chalcedony of uneven particle size that are typical of silicified VRF's rather than replaced carbonate rocks. Ghost textures of VRF's can be seen in a few grains. The quartzite has either a chalcedony cement which fills all pores or rims of incomplete quartz overgrowths which leave a porosity of 3 to 8 percent. Many have a mottled texture (Pl. 22A) caused either by different types of cement or disturbed distributions of sand grains. In general, the quartz-cemented sandstone is better sorted and has many rounded to well-rounded grains. A few grains have abraded quartz overgrowths. The chalcedony-cemented quartzite is poorer sorted, generally has well-oriented grains that define bedding, and contains more silicified clay clasts.

Possible modes of origin of the quartzite suggested by Bailey (1926, pp. 151–154) are as silicified sand lenses in the Gueydan or Oakville, silicified sandstone dikes or blocks of Oakville sandstone dragged down by faulting, and residuals of silicified parts of formerly more extensive Oakville sandstone beds. As noted by Bailey, the quartzite resembles Oakville sandstone in texture and composition more than Gueydan sandstone. However, none of the sandstone of either the Oakville or Goliad(?) studied by the writers is identical in composition to any of the quartzite samples. The former contain moderate to large amounts of feldspar and VRF's; the quartzite contains no feldspar and only a trace of VRF's. The quartzite has undergone replacement of some framework grains by chalcedony; "chert" pseudomorphs of feldspar and VRF's are present in many beds. Even allowing for such diagenetic changes, the textures do not compare well with Gueydan, Oakville, or Goliad(?) samples studied by the writers. The possibility exists that sandstone beds higher stratigraphically within the Oakville or Goliad(?) differ from those lower in the section, but additional data are needed.

An additional hypothesis not considered by Bailey is that the sandstone was silicified after injection from below rather than from above. One of the writers (Freeman, 1966) believed the sandstone boulders were derived from formations several thousand feet below and driven upward by high-pressure gas escaping along faults, and that much tuff in the Gueydan may have been similarly brought to the surface. Evidence to support this view currently is being assembled for publication and hence will not be presented here.

CALCITE VEINS

Veins of calcite occur along several fracture zones in Duval and McMullen counties. A few are associated with siliceous knobs located in the upper part of the Gueydan, but they have been found across the outcrop belt in these counties. The veins range in width from less than 1 inch to more than 10 feet and locally form vein-rich zones 30 feet wide. Lengths range from several feet to more than 2 miles.

The calcite is light brown, fibrous, and banded like onyx (Pl. 21B). The bands are straight or scalloped and commonly end abruptly against adjacent bands. Many give off a petroliferous odor when freshly broken.

Bailey (1926, p. 148) suggested that the calcite is recrystallized aragonite that was precipitated from solutions migrating along faults.

DIAGENESIS

Post-depositional changes in mineralogy and texture of Gueydan strata have been important in producing the present varied suite of rock types present. Many changes are caused by the highly reactive character of the abundant glass present in the original deposits. The following summarizes the more significant changes, many of which have been mentioned earlier in this report.

DEVITRIFICATION-ALTERATION

Original glass finer than coarse silt-size has largely altered, devitrified, or been argillized to montmorillonite. Non-argillic alteration products optically are a cryptocrystalline mosaic of feebly birefringent particles in which only poorly crystallized cristobalite and zeolite have been found in a few samples. The alteration products have clearly formed from original glass particles, but whether this was truly devitrification (formation of crystallites from a glass phase) or a solution reaction is uncertain. X-ray patterns of powdered fresh sand-size shards yield no peaks and most do not even have a hump typical of glass. Under high magnification, many shards show straight to curved hairlines visible by Becke lines. These lines probably are initial devitrification phenomena.

The time of devitrification is unknown.

ARGILLATION

Much glass altered to montmorillonite and amorphous clay. Although it is not certain whether the montmorillonite formed directly from glass or from devitrification products, the former is more likely. **Ca^{++} and Na^{+} montmorillonite and mixed-layer Ca^{++}-Na^{+} montmorillonite** (Roberson, 1964; Thomas, 1960) were produced. Trace amounts of illite and kaolinite in Gueydan bentonite reported by Roberson may be detrital.

Probably much argillation took place prior to burial in soils during the time of Gueydan deposition. The presence of clasts of bentonite and tuffaceous clay in sandstone shows that montmorillonite was present during the time of Gueydan deposition. The zonation described by Thomas of **Ca^{++}** montmorillonite in the lower (Fant Member) part of the Gueydan and mixed-layer Ca^{++}-Na^{+} montmorillonite in the upper part (Soledad and Chusa Members) may indicate weathering under different climatic conditions.

The random distribution of clay minerals that fill pores in some friable bedded tuff (Pl. 18B) in contrast to well-oriented particles of clay skins, suggests that some montmorillonite precipitated directly from solution.

ZEOLITIZATION

Clinoptilolite is the only zeolite species recognized in Gueydan strata, although hairlike needles of another zeolite(?) occur in amygdules in several lava boulders. Clinoptilolite occurs as cavity linings and fillings in tuffs (Pl. 16B), as tiny crystals of devitrification products, and rarely as a direct replacement of tuff frameworks. Only one bed has been found that has been altered chiefly to zeolite (Pl. 18A). It occurs also as coatings on sand grains either alone or in combination with silica to form a widespread cement in Gueydan sandstone. Here it generally preceded other cements.

The occurrences of Clinoptilolite show that, in part, it precipitated from pore-filling solution. In comparison with other **origins of clinoptilolite, the solution likely** was ground water of alkaline composition formed by reaction with constituents leached from fine-grained glass (Hay, **1963). A. D. Weeks and Eargle (1963)** showed that subsurface formation water from the Gueydan and adjacent formations is alkaline in the Karnes County uranium area (22 Gueydan samples ranged from pH of 7.3 to 8.5 and average 7.7) and attributed zeolite in Jackson (late Eocene) strata to have formed from constituents leached from glass and other unstable silicates of volcanic origin.

SILICIFICATION

Silification is most noticeable in the opal-cemented and chalcedony-cemented sandstone and silica knobs and veins, but opal occurs also as pods, nodules, and lenses of opalized bentonite. The silicic constituents are generally the youngest diagenetic products with the exception of clay skins and calcite. The silica likely was dissolved from glass by ground water, a feat requiring high alkalinity (Krauskopf, 1959). The silica in the knobs and veins can be dated as post-faulting.

Millot et al. (1963, pp. 408–409) suggested that the concentration of ions in solutions precipitating silica controls whether quartz, chalcedony, or opal is produced; quartz precipitates in purest waters and opal in least pure waters. A. D. Weeks and Eargle (1963) noted that silica-cemented parts of sandstone beds of the Gueydan Formation and Jackson Group in Karnes and Atascosa counties rarely extend more than 10 feet below the surface, that is, the silicification is a surface feature. They attributed the silicification to weathering and soil-forming processes that operated during a hotter, drier climate, perhaps during middle Pleistocene.

CALICHIFICATION AND SOIL PHENOMENA

Surficial porous strata of the Gueydan are more or less calichified throughout the area studied. Calichification is most pronounced in and south of Karnes County. The caliche ranges in occurrence from common sparse grains disseminated throughout tuff, clay, and sandstone to rare concretionlike nodular masses dug up by bulldozers in McMullen County that are as compact and hard as limestone. The calcite occurs chiefly as a mosaic of anhedral grains less than 30μ in diameter.

A. D. Weeks and Eargle (1963, p. 27) noted that caliche in Karnes County (Pl. 23A) is being dissolved by Recent weathering and suggested that it, as well as silica induration, formed during a dry, hot climate during the middle Pleistocene. They suggested that much of the calcium in the caliche may have been derived from volcanic minerals and glass in the tuff. The range of conditions under which caliche forms is unknown. Thick hard caliche crusts form in the dry tropics and sub-tropics in soil subject to alternate wetting and drying (Vageler, 1933, pp. 72–73; Charles, 1948). However, calcite concretions and stringers occur even in wet tropical soils if there is a pronounced dry season (Mohr and van Baren, 1954).

A major theme of this report is that Gueydan tuff and clay have been altered by soil-forming processes that operated during deposition of Gueydan strata. However, soil textures and probably some caliche at the top of the Gueydan developed after deposition of the Gueydan and before deposition of the overlying Oakville(?) conglomerate. Much caliche in the Gueydan certainly is younger, perhaps middle Pleistocene as suggested by A. D. Weeks and Eargle (1963). However, pebbles of caliche occur as clasts in Goliad conglomerates in Duval County and, in addition, indicate a pre-Pleistocene stage of caliche development. Information available at present is inadequate to determine in detail the conditions of caliche formation during or subsequent to Gueydan deposition.

OTHER MINERALS

Barite, pyrite, and unidentified uranium minerals occur also as diagenetic products.

SUMMARY AND GEOLOGIC HISTORY

The Gueydan Formation is chiefly tuffaceous clay with lesser amounts of volcanic sandstone, tuff, bentonite, volcanic conglomerate, and some ash. The rocks are derived almost entirely from volcanic and hypabyssal intrusive rocks or alteration products of such rocks. Regional relations indicate that the lowermost Gueydan beds were deposited on an erosion surface of low relief that truncated late Eocene and Oligocene(?) strata.

The formation was deposited probably during the Oligocene and perhaps early Miocene times during a period of major volcanism in the Big Bend region of west Texas and adjacent northern Mexico. Pyroclastic material from volcanoes drifted eastward and blanketed a large part of Texas and neighboring states and northeastern Mexico. Following rainfalls, much loose ash was eroded easily and transported as mudflows that flowed down the paleoslope toward the southeast. Some pyroclastic debris reached the area of present outcrop of the Gueydan solely by wind transport following eruptions of gigantic scale, but much was reworked by streams or mudflows.

From the beginning of Gueydan deposition, rivers flowing gulfward deposited channel sands containing debris derived chiefly from outcropping volcanic rocks and to a lesser extent from Cretaceous limestone exposed in what is now the Edwards Plateau. Later, a major stream (perhaps the ancestral Rio Grande) transported gravel-size clasts of trachyte, trachyandesite, welded tuff, and rhyolite at least as far east as Duval County. These rocks are similar to rocks now exposed in Big Bend National Park and farther west.

Soils developed on the ashy strata and much glass was altered to montmorillonite to produce tuffaceous clay and bentonite. Streams eroded these altered sediments and transported grains gulfward. Small streams deposited sand composed largely of reworked Gueydan strata. Roots of plants that grew in the soil locally penetrated tuff and clay to produce a tubular-porous texture. In places, soil pisolites and other lumpy glaebules formed and were locally reworked by streams or mudflows. Layers and lenses of opalized and calichified ash and clay formed within the soil.

During the latter part of Gueydan sedimentation, the accumulation of ashy strata kept pace with soil formation and thick deposits of pink and light gray tuffaceous clay were formed. The manner of deposition of the ash is uncertain, but air-fall, fluvial, and mudflow deposits are probably represented.

In many places, bentonite, tuffaceous bentonite, and locally sandstone were injected along early formed fractures to form clay and sandstone dikes.

After Gueydan deposition, the present outcrop area underwent erosion for an unknown length of time. A soil profile that developed on the erosion surface locally is preserved beneath the cover of stream-deposited sands and gravel of the Oakville (Miocene) and perhaps Goliad(?) (Pliocene) Formations.

A stratigraphic zonation present within the formation is probably the result either of a difference in climate during deposition and soil formation or of changes in Gueydan strata that were controlled by depth of burial or by different ground waters at different depths. The zoned elements are zeolite, Ca^{++} montmorillonite, and tuff which are dominant in the lower part of the formation and tuffaceous clay, mixed-layer Ca^{++} and Na^{+} montmorillonite, and scarcity of zeolite which characterize the upper part of the formation.

Following deposition and shallow burial, considerable glass underwent solution and hydrolysis to produce alkaline ground water. The water could not circulate well in the bentonitic strata and hence moved only short distances before authigenic clinoptilolite was precipitated in pores in tuff and sandstone. Later, silica was precipitated as opal and chalcedony. Siliceous water moved along faults that cut Gueydan and younger strata and locally replaced wall rock and precipitated veins of opal and chalcedony. Differential erosion has left these silicified zones as prominent knobs in Duval and McMullen counties.

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APPENDIX A

MEASURED SECTIONS

Sections were measured using a pocket steel rule, Jacobs staff, and Brunton compass. Only diagnostic properties of individual beds are included in the following descriptions.

Detailed descriptions of individual rock types, such as tubular-porous tuff, bentonite, etc., are given in the text.

Measured Section 1

Locality.—Live Oak County; 10 miles north of Three Rivers on U. S. Highway 281. The section begins 200 feet north of the highway and 100 yards north of San Cristoval Creek and was measured toward the conical hill exposed in the road cut. Units 1–6 are east of the road, the remainder west of it (Loc. L-10). The section is in the lower third of the formation. Measured by E. F. McBride on July 18, 1963.

		Thickness in feet
Gueydan Formation—		
(H)	Tubular-porous tuff. Structureless grayish-white beds with crudely defined bedding planes 3 to 14 inches apart. Many beds have distinct vertical joints, many of which developed along desiccation cracks. Desiccation polygons common on weathered bedding planes. Well indurated	11
(G)	Intercalated tuffaceous clay (70%), ash (20%), and bentonite (10%). Lenticular beds rest on channeled surfaces with up to 3 feet of relief. Several ash beds are well laminated. One bed of tuffaceous clay has apopheses of ash (derived from the overlying bed) introduced as load pockets. Nodules of silicified clay up to 3 inches are present in several clay beds. Bright green pisolites and accretionary lapilli occur in a discontinuous ash bed 4 feet from the base of the unit (Pl. 1A)	9
(F)	Gray-white clay. Poorly exposed	8
(E)	Green bentonite. Clay is tough and has sub-conchoidal fracture	0.3
(D)	Bentonite. Mottled red and green clay has sub-conchoidal fracture. Laminae are absent but crude bedding planes are spaced 1 to 3 inches apart	6.5
(C)	Clayey tuff. Soft, gray, crudely bedded unit. Upper few inches is silicified tuff with root tubules	4.5
(B)	Red clay grading upward to green tuff. The clay is soft, compact, breaks with conchoidal fracture, and is slightly tuffaceous. Tuff is clayey and unbedded	1
(A)	Interbedded pale-red clay and cream-colored tuff. Poorly exposed in badland topography; weathered surface of outcrop has uneven popcornlike texture	9
	Total	49.3

Measured Section 2

Locality.—Live Oak County; Lang Creek, 7 miles west of Three Rivers on county road south of State Highway 63. Section starts in the floor of creek 50 yards north of county road; measured up the hillslope southwest of the creek. The section is approximately within the lower third of the formation. Measured by E. F. McBride on July 18, 1963.

		Thickness in feet
Gueydan Formation—		
(H)	Tuff. White to light-gray tuff in beds 1 to 12 inches thick; internally structureless. Beds are moderately porous, rough, and harsh owing to shard content. Several lenses of pumice-pebble conglomerate 6 inches thick; pebbles of pastel-colored pumice up to 1½ inches long. Unit rests abruptly on unit G	18

(G)	Interbedded pink bentonite and white tuffaceous bentonite in layers approximately 6 inches thick	3
(F)	Interbedded pink to red bentonite and tuffaceous bentonite. Bedding not visible owing to poor exposure of the unit. Bentonite breaks with sub-conchoidal fracture; tuffaceous bentonite is compact	16
(E)	Calichified bentonite. Hard, compact unit that increases in hardness upward. Breaks with conchoidal fracture. Structureless but several bedding planes are visible. Silicified plant roots found in a thin section of this bed	0.5
(D)	Tuff. Like unit (B) except well laminated and is 30 percent clay	2
(C)	Bentonite. White, soft, structureless clay with approximately 20 percent silt shards. Basal 6 inches has scattered red siliceous nodules up to 3 inches long	4.5
(B)	Tuff. Gray-white to cream, friable fine tuff with crude bedding planes 6 to 18 inches apart. Faint laminations and cross-beds 3 inches thick are visible in places. Moderately sorted shards, tuff clasts, and siliciclastic grains with clay skin matrix	6
(A)	Tuff. Lumpy and pisolitic gray-white tuff that in places has desiccation polygons 6 to 12 inches across that are exposed along bedding planes in floor of creek. Tubules and pores form 10 percent of rock. Moderately indurated. Exposed only in creek bed	12
	Total	62

Measured Section 3

Locality.—Live Oak County; hillslope 1.1 miles southwest of Knew triangulation station; 0.7 mile south of intersection of U. S. Highway 281 and State Highway 39, then west 5.8 miles on an unnamed county road, then north 0.5 mile to hilltop on west side of ranch road. Measured by P. S. Freeman in 1962.

		Thickness in feet
Gueydan Formation—		
(E)	Fine- to medium-grained sandstone. Light green indurated bed filling a channel	0.5
(D)	Tuffaceous clay. Yellowish-green, non-stratified plastic clay	5
(C)	Medium-grained sandstone. Dark-gray, indurated unit with poorly defined cross-beds. Contains well-rounded tuffaceous sandstone clasts up to 1 foot in diameter	10
(B)	Porous tuff. Clayey, harsh, indurated unit devoid of bedding. More clayey and hackly, fractured at base	35
(A)	Very fine vitric tuff. Non-vuggy, white to gray friable unit	3
	Total	53.5

Measured Section 4

Locality.—McMullen County; hilltop 7 miles west of San Cajo triangulation station; 2.1 miles north of Ranch Road 1962, south side of creek. Measured by P. S. Freeman in 1962.

		Thickness in feet
Gueydan Formation—		
(F)	Green bentonitic clay; breaks with conchoidal fracture	0.5
(E)	Friable porous tuff. Gray to white, very fine-grained bed	2
(D)	Mudstone; tough, non-stratified, white	4
(C)	Porous tuff. Indurated gray to white, very fine-grained bed. Desiccation cracks (2 inches apart) in middle of bed	3
(B)	Clay. Gray plastic, slightly tuffaceous bed containing secondary barite crystals and an incomplete turtle skeleton	4
(A)	Tuffaceous clay. Yellowish-brown unbedded unit	3
	Total	16.5

Measured Section 5

Locality.—McMullen County; hillside on north side of creek, 0.4 mile north-northwest of Measured Section 4. Measured by P. S. Freeman in 1962.

	Thickness in feet
Gueydan Formation—	
(H) Fine- to medium-grained sandstone	0.5
(G) Bentonite. Green clay that breaks with conchoidal fracture	2
(F) Very fine porous tuff. Friable, gray unbedded unit	2
(E) Tuffaceous clay; gray to white and slightly plastic	4
(D) Very fine, porous tuff. Gray indurated tuff devoid of bedding	3
(C) Porous, vuggy, sandy tuff containing greenish-white pumice pebbles and pieces of petrified wood. Devoid of bedding	36
(B) Porous pisolitic tuff; white to gray, structureless unit that rests on a surface that dips 4° southeast	4
(A) Same as unit (B)	4
Total	55.5

Measured Section 6

Locality.—Duval County; section measured in a ditch along road that leads to the Mobil Oil Company's power house from the main Piedre Lumbre oil-field road; 7.2 miles north of Freer (N. 27°59′30″ and W. 98°27′). Section is in the middle third of the formation. Measured by W. L. Lindemann in 1962.

	Thickness in feet
Gueydan Formation—	
(F) Tuffaceous clay. Light green, slightly indurated unit with lenticular beds ¼ inch thick. Stained locally by limonite on joint surfaces	9
(E) Fine- to medium-grained sandstone. Slightly friable rusty brown unit with indistinct bedding. Abundant clay clasts	5
(D) Tuffaceous clay. Light green, compact, similar to unit (A)	2
(C) Conglomeratic fine- to medium-grained sandstone. Chiefly structureless beds differing from neighbors slightly in grain size. A few contorted beds produced by slumping. Green (fresh) to orange-red (weathered) beds range from slightly friable to indurated. The unit includes a few thin conglomerate lenses with large clasts (up to 1 foot in diameter) of clay and stringers of green clay similar to units (A) and (D)	38
(B) Sandy clay-pebble conglomerate. Light-green, slightly friable to well-indurated structureless unit that is locally stained by limonite	5.5
(A) Sandy tuffaceous clay. Soft and friable, crudely bedded, and broken by closely spaced joints. Caliche and limonite present along joints and bedding planes	8
Total	67.5

Measured Section 7

Locality.—Duval County; section measured 300 yards east of U. S. Highway 59, 2.4 miles northeast of intersection of State Highway 44 east of Freer; on west-facing escarpment. Section measured by E. F. McBride July 1963.

	Thickness in feet
Goliad(?) Formation (basal part only)—	
(A) Pebbly fine-grained sandstone. Structureless, moderately to poorly sorted unit that is light gray to chalk white. Well indurated; cemented chiefly by calcite but opal-cemented lenses up to 18 inches long occur locally. Well-rounded pebbles are chiefly chert, quartz, volcanic rock fragments, and silicified clay	6

Disconformity with 6 inches of relief.		
Oakville(?) Formation (complete section)—		
(A)	Clay-pebble to cobble conglomerate. Bed is structureless, friable to indurated (where cemented by calcite), and pink owing to the abundance of pink silicified clay and tuff clasts. About 8 percent of the pebbles are volcanic rocks. Lenticular beds up to 6 inches thick make up the unit	4
Disconformity with 6 inches of relief.		
Gueydan Formation (partial section)—		
(D)	Pink tuffaceous clay. Moderately well indurated. Forms a prominent vertical face on the hill. The unit is severely calichified and altered by other soil-forming processes. Well-formed vertically oriented tubes or fingers of clay up to 1 inch wide and separated by ½–1 inch are abundant at the top of the unit (*see* p. 13 for a detailed description of this feature). Bedding planes are only locally present. A lens of rounded tuff pebbles 2 feet thick passes laterally and gradationally into structureless tuff	8
(C)	Pink crumbly slightly tuffaceous clay. No bedding visible. Forms a bench	9
(B)	Covered	5
(A)	Pink tuffaceous clay. Poorly exposed; strongly calichified. Randomly oriented veinlets of caliche cut the unit. No bedding visible. Soil pisolites and clasts of clay (up to 4 mm in diameter) with uneven boundaries are sparsely scattered in the unit	25
	Total Gueydan section	47
	Total measured section	57

Measured Section 8

Locality.—Duval County; road cut 1 mile west on unpaved road that intersects with State Highway 44, 3 miles north of Freer, in Government Wells oil field. The section is in the middle third of the formation. Section measured by W. L. Lindemann in 1962.

		Thickness in feet
Gueydan Formation—		
(D)	Medium- to coarse-grained sandstone. Mostly structureless, but poorly defined cross-beds up to 1 foot thick are visible in places. Yellow-green to greenish-gray beds are friable to weakly cemented by calcite but moderately calichified at the top. Abundant clay and tuff clasts	13.5
(C)	Sandy tuffaceous clay. Light green (fresh) to brown (weathered) lens-shaped unit. Compact and indurated	1.5
(B)	Medium- to coarse-grained sandstone. Poorly sorted, friable to slightly indurated, yellow green to red. Lenticular beds discernible by differences in grain size; sparse cross-beds dip to the southeast. Cement is opal. Coarsest clasts are clay particles	11
(A)	Sandy tuffaceous clay with thin lenticular interbeds of bentonite and rusty red conglomeratic sandstone (at base). Clay beds are light green, compact, and broken by closely spaced joints. Coarse clasts in the sandstone include volcanic rock fragments and silicified clay	7.5
	Total	33.5

Measured Section 9

Locality.—Duval County; section measured up the west-facing scarp 2.1 miles south of U. S. Highway 59 along the paved road on Duval County ranch. Section is in the middle part of the formation. Measured by W. L. Lindemann in summer of 1962.

	Thickness in feet
Gueydan Formation—	
(C) Interbedded sandstones and conglomerate. Beds range from 3 to 18 inches thick and show massive, laminated, and cross-bedded structures. Grain sizes range from conglomeratic medium- to very coarse-grained sandstone and sandy granules to pebble conglomerate. Beds are poorly to moderately sorted, gray to brownish gray, and friable to moderately indurated with opal cement. Gravel clasts are volcanic rock fragments and silicified clay clasts. Clasts form an intact framework. Poorly cemented beds have up to 15 percent porosity	45
(B) Covered	5
(A) Clay. Poorly exposed, soft, gritty, pink unit with no bedding detectable. Contains several east-trending compact, pink clay dikes 2 to 4 inches wide. Caliche veinlets occur along curved fractures	37
Total	87

APPENDIX B

DESCRIPTION OF IGNEOUS ROCKS FROM THE GUEYDAN FORMATION FROM THIN-SECTION STUDY[11]

1. Devitrified crystal-bearing vitric welded tuff. Sample LX-1 (Pl. 24A). Texture: relic vitroclastic; devitrified. Grain size of crystals: 0.05 to 3.0 mm. Crystal fragments (15%) and a few trachyte rock fragments are scattered in a groundmass of devitrified glass. Faint relic flattened shards stand out as relatively clear grains in a background clouded by hematite specks. Glass has devitrified to a microcrystalline mosaic in which iron-oxide specks and tiny authigenic laths of either feldspar or zeolite are discernible. In a few areas shards have been replaced by the unknown mineral with axiolitic texture.

Crystal fragments are untwinned sanidine (12%), bipyramidal quartz (paramorphs after beta-quartz) (3%), and trace amounts of hematite pseudomorphs of femags. Feldspar and quartz grains are severely fractured.

2. Slightly amygdular trachyte or trachyandesite porphyry (rhomb porphyry). Sample LX-4 (Pl. 24B). Texture: porphyritic; holocrystalline; weakly aligned phenocrysts. Grain size: phenocrysts, up to 5.0 mm; groundmass, microcrystalline. Phenocrysts: anorthoclase (25%), hematite pseudomorphs of pyroxene (5%), augite (1%), iron oxides (tr), apatite (tr.); amygdules (3%), groundmass; alkali and calcic feldspars (50%), iron oxide and altered femags (16%). Anorthoclase occurs as severely resorbed rhomb-shaped crystals showing closely spaced twin lamellae; outer rims along all resorbed pockets and exterior surfaces are more sodic than interiors. Hematite pseudomorphs of pyroxene occur also as inclusions in oligoclase. Augite grains are round and have oxidized rims of opaque iron oxides.

The groundmass is a dark-brown mixture of microfelsite and hematite (after femags) in which only a few relic femags and feldspar microlites are visible.

Amygdules are filled with an intergrowth of fibrous microquartz, calcite, hematite, chalcedony, and albite, the latter commonly with radial fabric.

3. Altered lithic-vitric tuff. Sample LC-8 (Pl. 25A). Texture: relic vitroclastic. Grain size of clasts: 0.04 to 3.0 mm. Lithic grains (15%), crystal fragments (5%), altered glass (80%). Pumice (replaced by tiny spherules of opal and chalcedony) and minor trachyte comprise the lithic fragments; quartz, feldspar, and clinopyroxene comprise the broken crystal fragments.

Relic shards are outlined by a brownish-yellow platy mineral in a background of devitrified glass dust that now shows only very feeble birefringence of cryptocrystalline grains. The shards do not appear to have been flattened or elongated and show no signs of welding.

4. Alkali trachyte. Sample LXX-7 (Pl. 25B). Texture: phaneritic, trachytic. Grain size: maximum, 2.0 mm; average 0.7 mm. Alkali feldspar (80%), aegirine (10%), amphiboles (5%), quartz (2%). The rock has exceptional alignment of slender feldspar laths, most of which are cloudy from vacuolization and alteration products. Aegirine occurs as microphenocrysts and finer intergranular grains that have formed by the alteration of a sodic amphibole and lesser common hornblende. Aegirine and amphibole partly enclose feldspar laths. Small grains of femags have been saussuritized. Quartz occurs as anhedral microphenocrysts associated with aegirine. Several veinlets of chalcedony transect the rock.

5. Porphyritic alkali trachyte. Sample LX-8 (Pl. 26A). Texture: glomeroporphyritic, trachytic. Grain size: phenocrysts, 0.3 to 2.0 mm; groundmass, 0.01 to 0.1 mm. Alkali feldspar phenocrysts (2V = 30°–40°) (5%), amphibole (tr); groundmass, alkali feldspar (80%), aegirine and sodic amphibole (13%), iron oxides (2%).

Highly fractured phenocrysts are clustered among a matrix with a well-developed trachytic texture. Aegirine and the amphibole are small (0.05 mm) grains intergranular to the feldspar laths and show moderate clouding because of alteration products.

6. Vesicular, amygdaloidal trachyte porphyry. Sample 70 (Pl. 26B). Texture: vesicular, amygdaloidal, porphyritic, holocrystalline. Grain size: phenocrysts, 0.2 to 4.5 mm; groundmass, cryptocrystalline to 0.02 mm. Phenocrysts (40%, excluding vesicular and amygdular part of rock): anorthoclase (38%), hematite pseudomorphs of pyroxene (70%), iron oxides (30%). Sub-rhomb-shaped anorthoclase grains are severely resorbed internally, have soda-rich rims, and closely spaced twin lamellae. The groundmass is nearly opaque because of the abundance of iron oxides formed as alteration products of primary femags.

Vesicles (40% of rock) are lined with secondary minerals and approximately 30 percent are completely filled. Secondary minerals include spherulitic tridymite, fibrous opal, flamboyant chalcedony, quartz, calcite, zeolite, and an unidentified brown fibrous mineral with negative relief.

7. Amygdaloidal trachyte rhomb porphyry.

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[11] Mineral percentages given are estimates.

Sample LXX-8 (Pl. 28A). Texture: amygdaloidal; porphyritic; holocrystalline. Grain size: phenocrysts, 0.05 to 5.5 mm; groundmass, cryptocrystalline to 0.02 mm. Phenocrysts: anorthoclase (36%), augite (1%), hematite pseudomorphs of pyroxene (2%), apatite (1%); groundmass: feldspar microlites (30%), red hematite specks and limonitic alteration products of femags (30%); trace amounts of iron oxides and apatite.

Anorthoclase shows well-developed sieve-texture because of severe internal resorbtion; grains generally have closely spaced twin lamellae, sodic rims, and many are fractured. The abundance of rhomb-shaped phenocrysts permits this rock to be called a rhomb porphyry.

The groundmass is bright red in reflected light and nearly opaque in transmitted light because of the abundance of small hematite grains.

Amygdules (20% of rock) are filled chiefly with fibrous microquartz and small amounts of hematite, spherulites of tridymite, and a mineral with low birefringence and high index (apatite?). Many amygdules have a concentric zigzag pattern produced where inward-projecting quartz crystals have been coated with hematite and later filled with a younger generation of quartz. Such elliptical amygdules with concentric zigzag patterns resemble painted Easter eggs.

8. Vesicular and amygdaloidal trachyte porphyry. Sample LXX-2. Texture: vesicular, amygdaloidal, porphyritic, holocrystalline. Grain size: phenocrysts, 0.05 to 5.0 mm; groundmass, cryptocrystalline to 0.02 mm. Phenocrysts: anorthoclase and oligoclase (39%), pale-green clinopyroxene (1%); groundmass: microcrystalline felsite (40%), needles of femags (10%), iron-oxide dust (10%).

Anorthoclase and oligoclase are strongly sieved because of internal resorbtion; less than half the original volume remains in some crystals. In addition, grains show closely spaced twin lamellae and soda-rich rims. Pale-green clinopyroxene (augite?) in places is replaced by a yellow fibrous mineral (serpentine) and calcite. The groundmass ranges from greenish brown to brown with an increase in iron-oxide alteration products.

About 60 percent of the vesicles (30% of the rock) are filled, chiefly with calcite, but some have a pale-brown vermicular phyllosilicate and a colorless mineral that probably is a zeolite.

9. Altered amygdaloidal porphyry(?). Sample LX-9 (Pl. 27B). Texture: amygdaloidal, porphyritic, cryptocrystalline to glassy. Grain size: phenocrysts, 0.06 to 5.0 mm; groundmass, cryptocrystalline. Phenocrysts: anorthoclase and oligoclase-andesine (39%), clinopyroxene (1%), orthopyroxene altered to hematite (tr); groundmass (60%): trace amounts of apatite and iron ores.

Feldspar phenocrysts are sieve-textured owing to internal resorbtion; many are rhomb-shaped. Clinopyroxene grains have cores of pigeonite (2V = 5°, colorless, biaxial positive).

The deep reddish-brown groundmass appears to be an altered glass; it now shows an undulatory mosaic with feeble birefringence.

The rock is unusual in the amount and fabric of its amygdules (50% of rock). The amygdules range from tiny spherical spots (5μ) to long, tear-shaped to highly flattened bodies 4 mm long. The axes of the flattened vesicles are well aligned and bend around phenocrysts. Small vesicles are filled with fibrous opal, whereas large ones also have chalcedony and calcite with axiolitic texture.

10. Welded vitric tuff. Sample K-10-Pl (Pl. 27A). Texture: vitroclastic, welded, layered, axiolitic. Grain size: rock and crystal fragments, 0.07 to 2.5 mm; glass, cryptocrystalline to 0.5 mm. Glass shards (60%), glass dust (38%), quartz (1%), sanidine (1%), hypersthene (tr), aegirine-augite (tr), trachyte fragments (tr), iron ores (tr).

All glass has devitrified. Shards are outlined by hematite dust and dark devitrification products but have clear centers composed of feebly birefringent microfelsite that generally is axiolitic. The divitrified dust is a dark-brown mixture of hematite and feebly birefringent microcrystalline minerals.

The rock is well layered because of flattened shards and collapsed vesicles. Shards have been bent around projecting edges of crystals and attest to plasticity at the time of accumulation.

Most crystal fragments have rounded outlines, sanidine is badly fractured, and clinopyroxene grains have oxidized borders. One crystal of bipyramidal quartz (paramorph after B-quartz) is present.

11. Rhyolite porphyry. Sample K-10-P3 (Pl. 28B). Texture: porphyritic, holocrystalline. Grain size: phenocrysts, 0.2 to 3.0 mm; groundmass, cryptocrystalline to 0.2 mm. Phenocrysts: K-feldspar (12%); groundmass: microfelsite (60%), quartz anhedra (18%), limonitized femags (10%), accessory iron ores (tr).

K-feldspar phenocrysts are slightly resorbed; half show Carlsbad twinning; several have partly exsolved to microperthite.

The ground mass is blotchy because of uneven distribution of altered femag needles; light (66%) and dark (34%) areas are poor and rich, respectively, in alteration products.

Plates 1–28

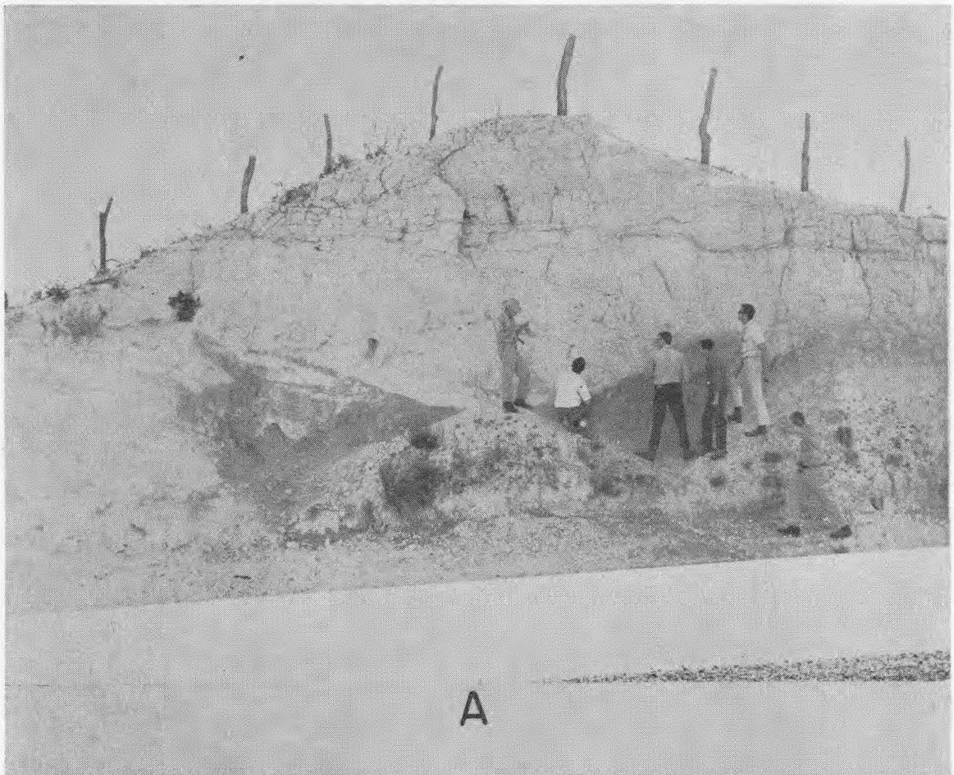
Plate 1

Outcrops of tuff, ash, and bentonite

A. Roadcut in conical hill capped by tubular-porous tuff. Pure ash beds (the dark wet units) are overlain by clayey tuff. The uneven contact on the ash beds is a channeled surface. Locality L-10.

B. Badland topography and "popcorn" surface developed on bentonite and bentonitic clays. Locality L-10.

Lithology and Petrology, Gueydan Formation **Plate 1**



A

B

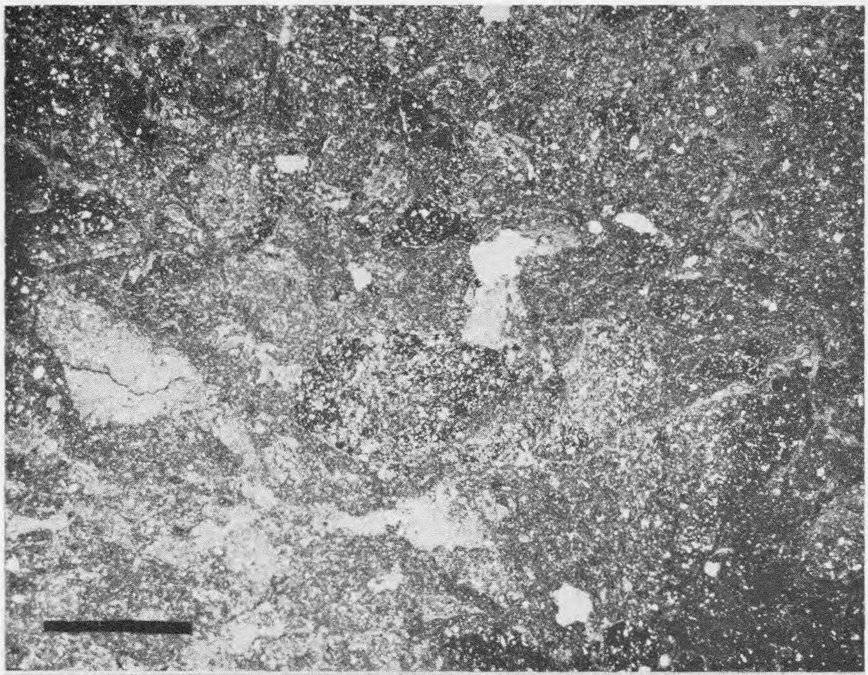
Plate 2

Photomicrographs of tuffaceous clay

A. Tuffaceous clay showing unstratified, mottled texture. Lumps or clasts (?) with different textures are visible within the matrix. Ordinary light. Scale is 4 mm long. Sample DH-8E, core from Choke Canyon dam site, Live Oak County.

B. Pink tuffaceous clay. Large shards are glass, but small shards and matrix are argillized and devitrified. Scale is 0.5 mm long. Ordinary light. Sample and Locality S-5.

Lithology and Petrology, Gueydan Formation **Plate 2**



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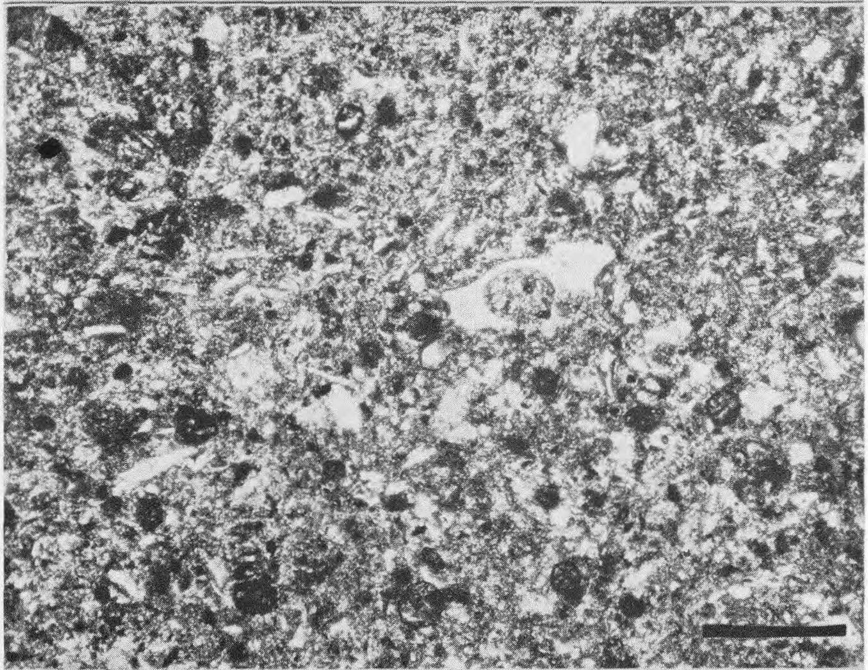


B

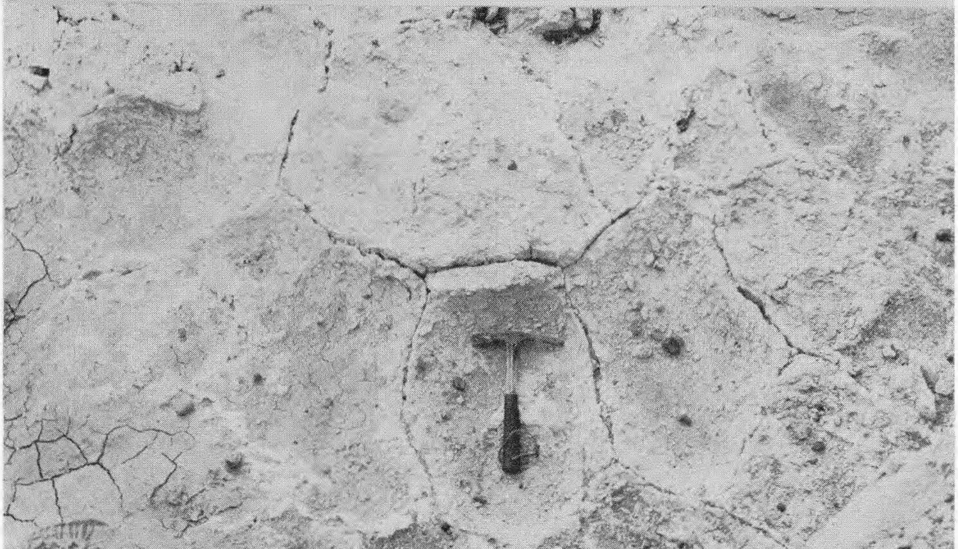
Plate 3

Lumpy pisolitic tuff

A. Vertical face of lumpy pisolitic tuff bed. Face is perpendicular to bedding. Point of mattock for scale. Locality L-2.

B. Desiccation cracks and polygons on upper bedding surface of lumpy pisolitic tuff bed. Locality L-2.

A



B

Plate 4

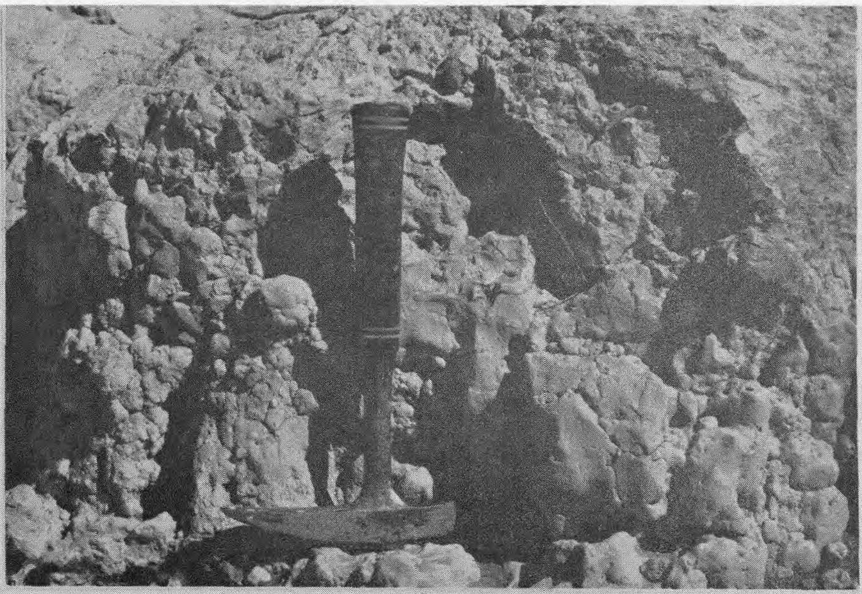
Lumpy pisolitic tuff

A. Vertical face of tuff bed showing lumpy texture. Locality L-2.

B. Photomicrograph of tuff with a wide range in size of pisolites. White areas are tubules and pinpoint pores. Scale is 3 mm long. Ordinary light. Sample CYC, locality, McMullen County.

C. Photomicrograph of tuff with banded pisolites and a few tubules. The dark color of the pisolites is imparted by iron and manganese oxides. Shards are devitrified. Scale same as B. Ordinary light. Sample 23, locality, McMullen County.

Lithology and Petrology, Gueydan Formation **Plate 4**



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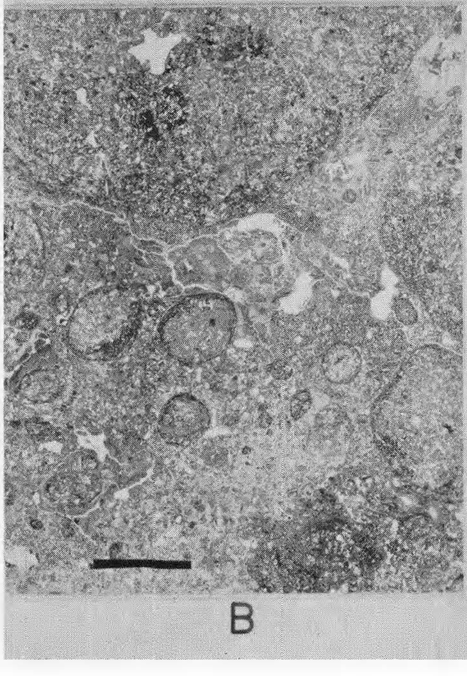


B

C

Plate 5

Photomicrographs of tuff

A. Tuff intermediate in texture between lumpy-pisolitic type and tubular-porous type. Small dark pisolites are clasts. Section is perpendicular to bedding; note absence of shard orientation or stratification. Scale is 1.3 mm long. Ordinary light. Sample LA-3A, Locality L-2.

B. Lumpy-pisolitic tuff with a small dark pisolite. Voids are areas where tuff has apparently been removed during weathering. Glass shards below cross-hair are encased in montmorillonite, elsewhere the matrix is devitrification products. Scale is 0.5 mm. Ordinary light. Sample LA-6, Locality L-2.

C. Pisolitic tuff viewed between crossed polarizers. Pisolite (dark) is composed of feebly birefringent devitrification products. Matrix has long montmorillonite fibers that rim crystal fragments. A clay-lined tubule is at lower right. Scale same as B. Sample CYC, locality, McMullen County.

Lithology and Petrology, Gueydan Formation **Plate 5**

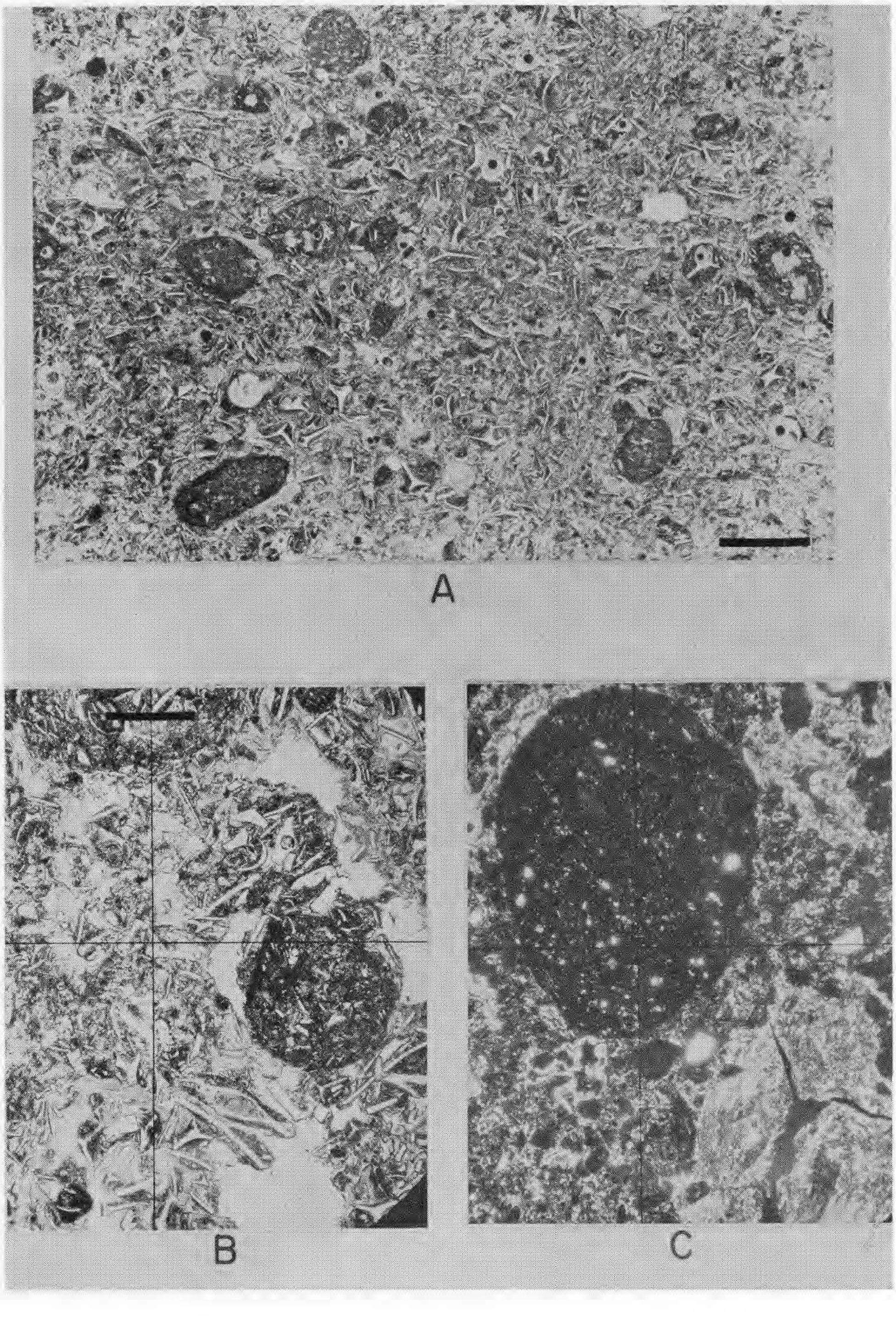


Plate 6

Outcrop and X-radiograph of tubular-porous tuff

A. Thin bed of tubular-porous tuff showing well-formed vertical joints (desiccation cracks?) overlying tuffaceous clay. Tuff fills a small channel in the clay. Locality, ¼ mile north of Frio River, 2 miles NW of Three Rivers, Live Oak County.

B. X-radiograph of tuff showing pattern of tubules. Core is 2¼ inches wide. Locality, Three Rivers, Live Oak County.

Lithology and Petrology, Gueydan Formation **Plate 6**

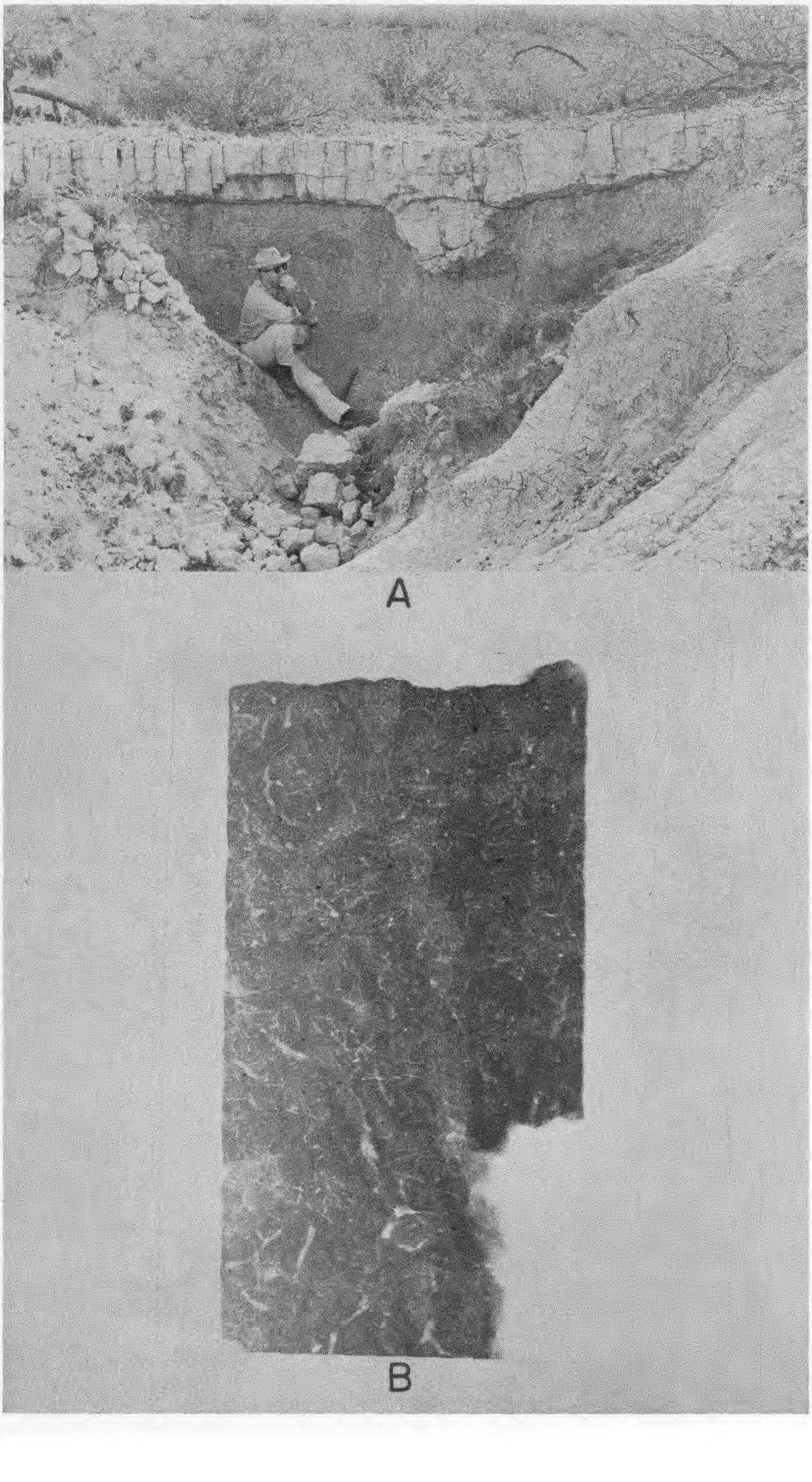


Plate 7

Photomicrographs of tubular-porous tuff

A. Devitrified tuff viewed between crossed polarizers. A montmorillonite-lined tubule is in the center of the field; circular patch in upper left is a clay clast or argillic alteration spot. Crystal fragments are white in a matrix of feebly birefringent devitrification products. Scale is 0.5 mm long. Sample LO-25A, Locality L-10.

B. Vitric tuff. Glass shards in a matrix of devitrification products. Montmorillonite fibers are parallel with shard boundaries and outline them. Scale is same as A. Ordinary light. Sample 5, locality, McMullen County.

Lithology and Petrology, Gueydan Formation **Plate 7**

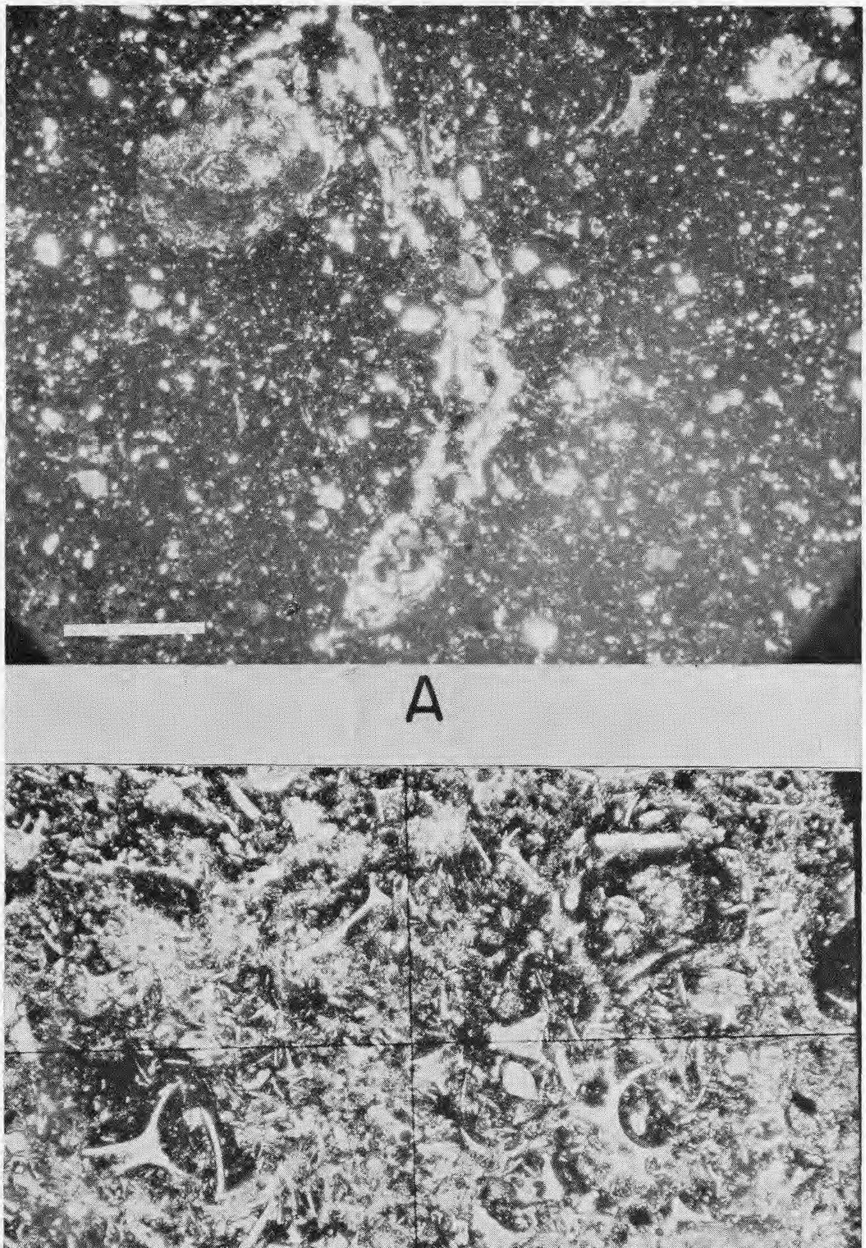


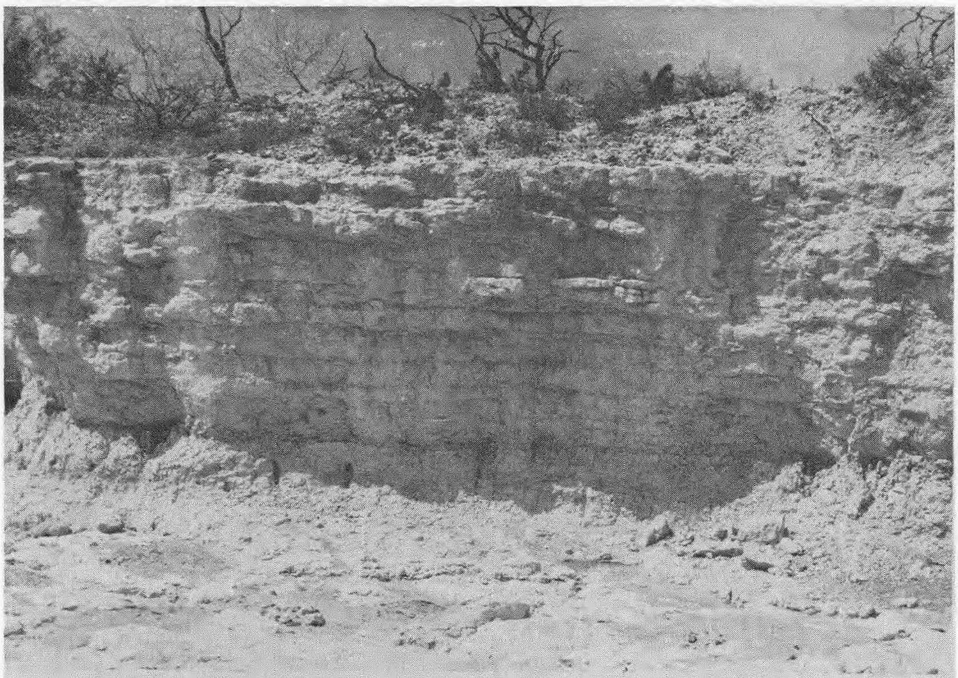
Plate 8

Friable bedded tuff

A. Exposure in bank of Lang Creek. Bedded tuff rests on lumpy-pisolitic tuff. Locality L-2.

B. Exposure showing crude bedding and distinct vertical jointing in friable bedded tuff. Locality L-2.

Lithology and Petrology, Gueydan Formation **Plate 8**



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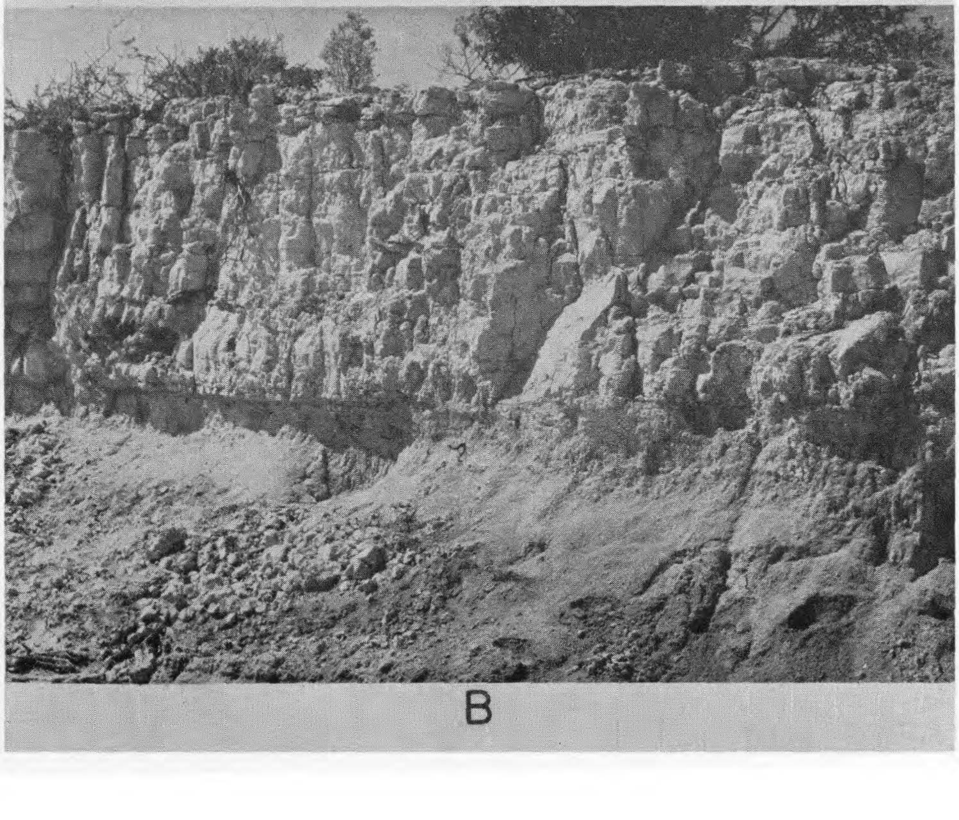


B

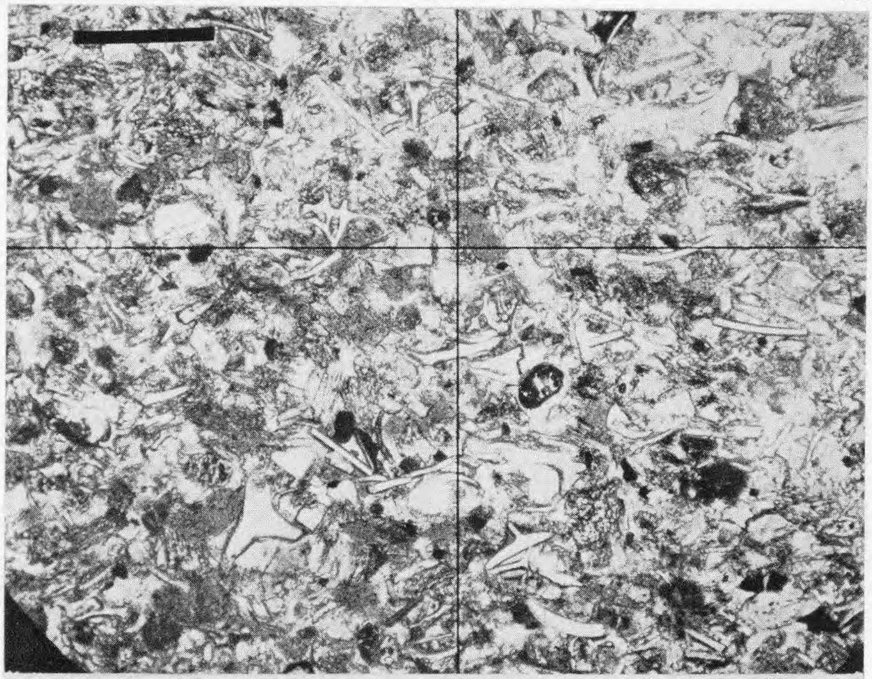
Plate 9

Photomicrographs of tuff

A. Friable bedded tuff. Bedding is parallel with the horizontal cross-hair. Clear grains are glass shards; dark gray grains are clay or bentonite clasts. Scale is 0.5 mm long. Ordinary light. Sample LA-5, Locality L-2.

B. Friable bedded tuff. Shards have a weak alignment parallel with bedding (long dimension of photograph). Scale same as A. Ordinary light. Sample LA-2A, Locality L-2.

Lithology and Petrology, Gueydan Formation **Plate 9**



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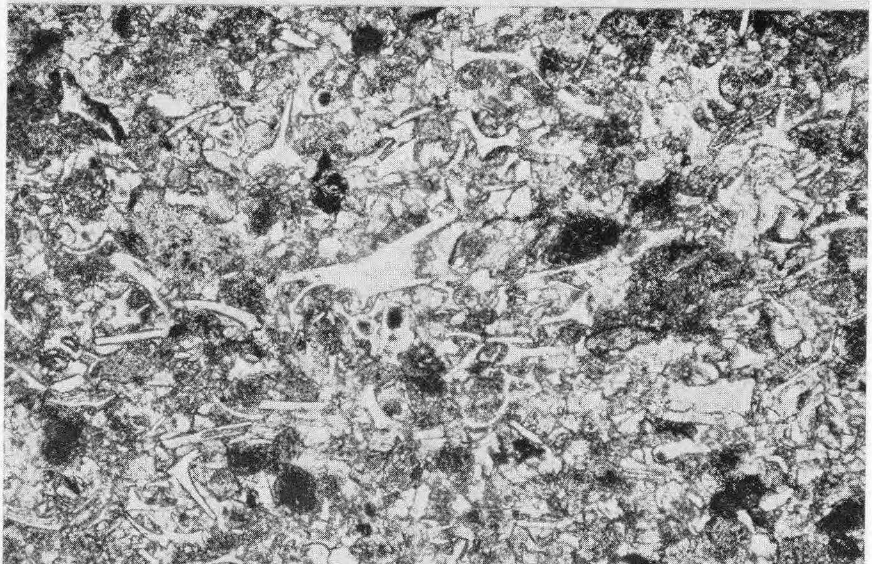


B

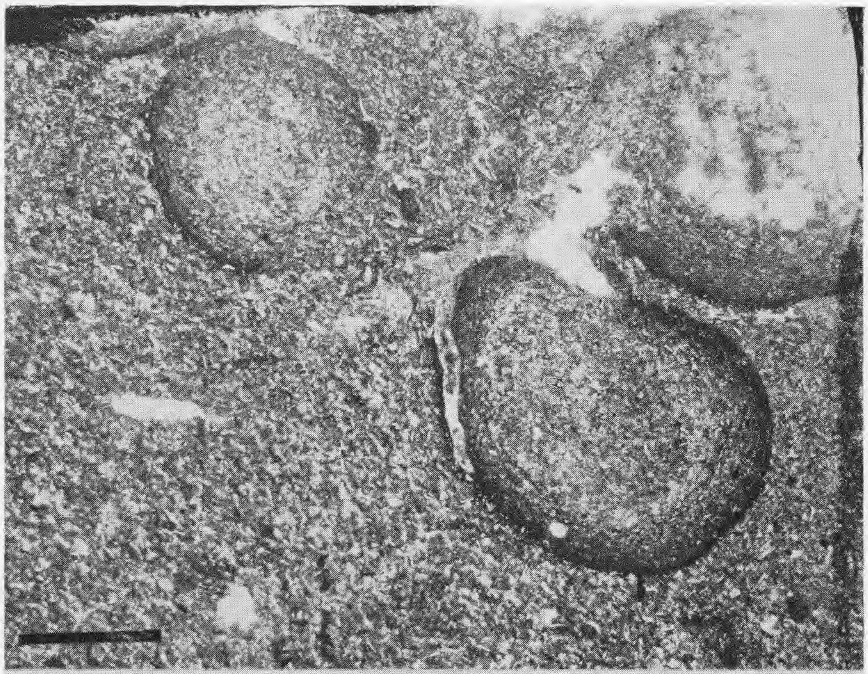
Plate 10

Photomicrographs of ash

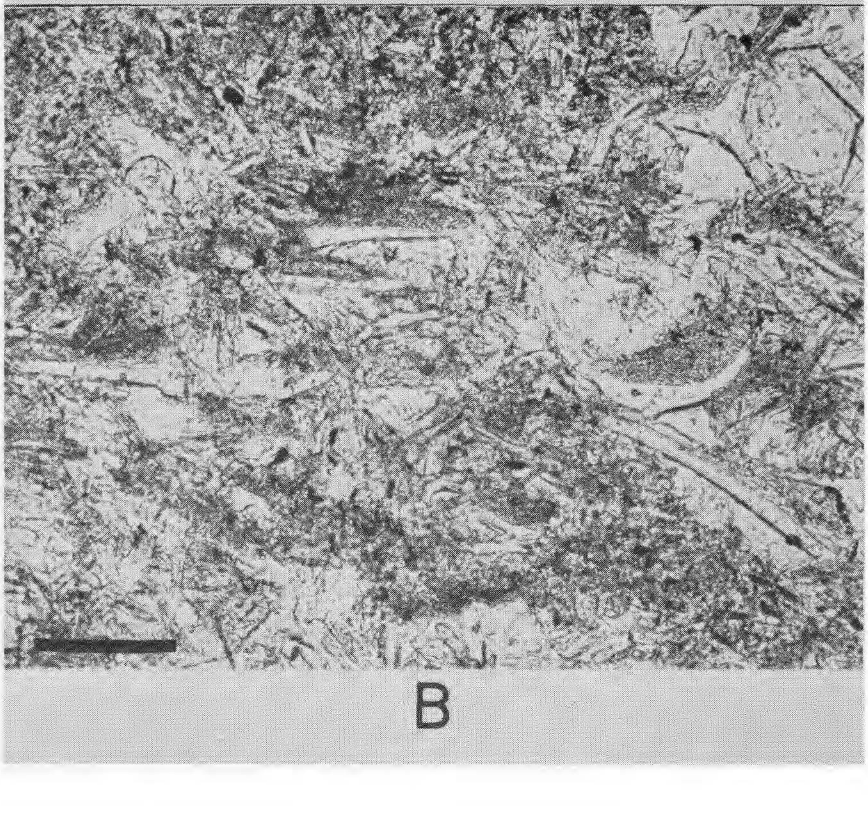
A. Accretionary lapilli in air-fall ash. Lapilli grade from coarse in center to fine dust at periphery. Scale is 2.00 mm long. Ordinary light. Sample LO-21A, Locality L-10.

B. Geopetal fabric in air-fall ash. Glass dust (dark areas) rests in piles on top of horizontally aligned shards. Scale is 0.14 mm long. Same sample as A.

Lithology and Petrology, Gueydan Formation **Plate 10**



A



B

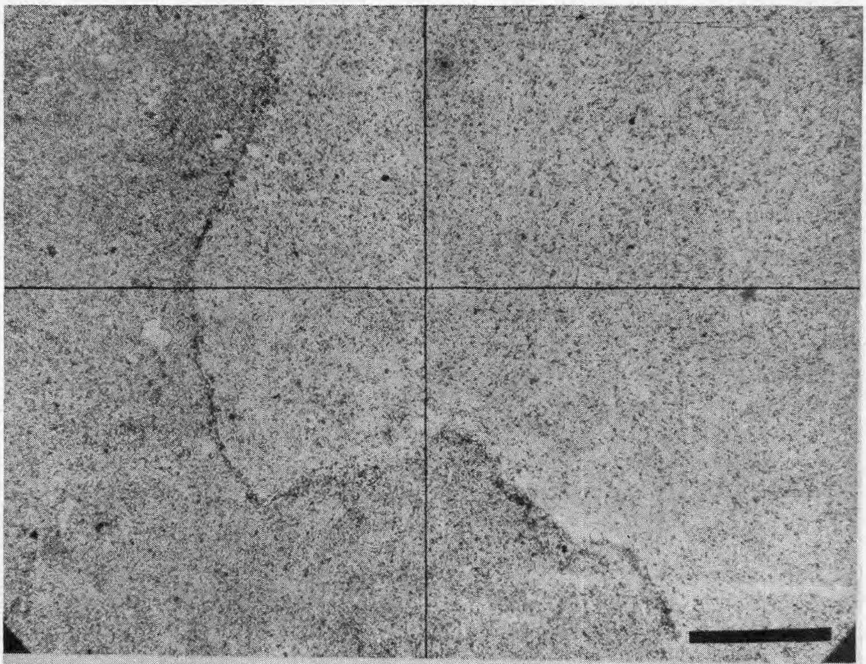
Plate 11

Photomicrographs of bentonite

A. Bentonite viewed in ordinary light perpendicular to bedding. Darker area to left of irregular line is stained by iron oxide. Scale is 0.5 mm long. Sample LO-33, Locality L-2.

B. Same as A, but polarizers crossed. Montmorillonite in the area to right is a mosaic of cryptocrystalline grains; to the left the montmorillonite occurs in larger grains with a "brush-heap" texture.

Lithology and Petrology, Gueydan Formation **Plate 11**



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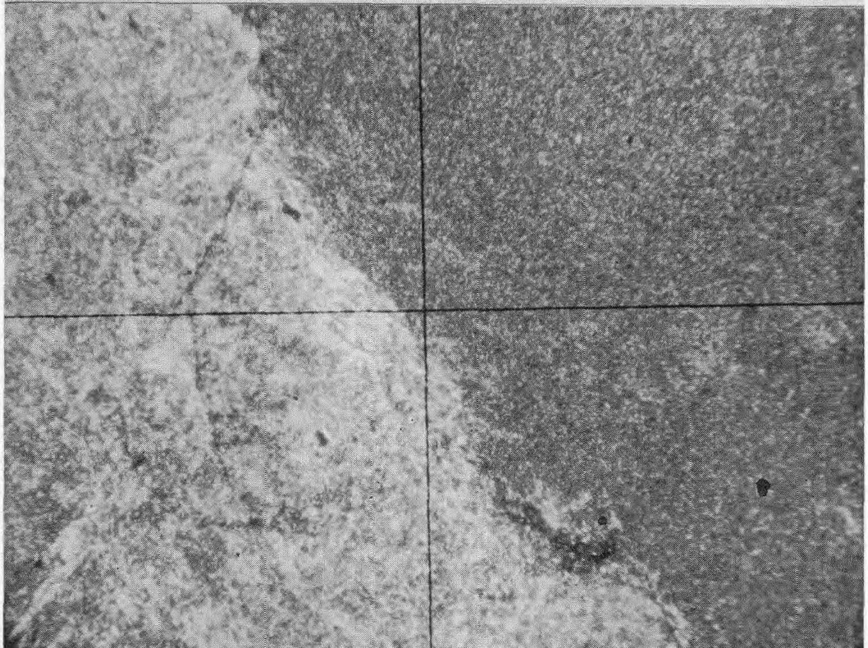


B

Plate 12

Photomicrographs of opalized clay and calichified clay

A. Opalized clay. Sample is approximately 60 percent opal, 40 percent montmorillonite, and a few quartz crystal fragments. Scale is 0.5 mm long. Ordinary light. Sample 200 (Bailey's collection), locality unknown.

B. Calichified tuff with silicified plant root. Root is opal; dark grains are microcrystalline calcite; light grains are sparry calcite. Scale is 0.14 mm long. Ordinary light. Sample LA-12, Locality L-2.

Lithology and Petrology, Gueydan Formation **Plate 12**

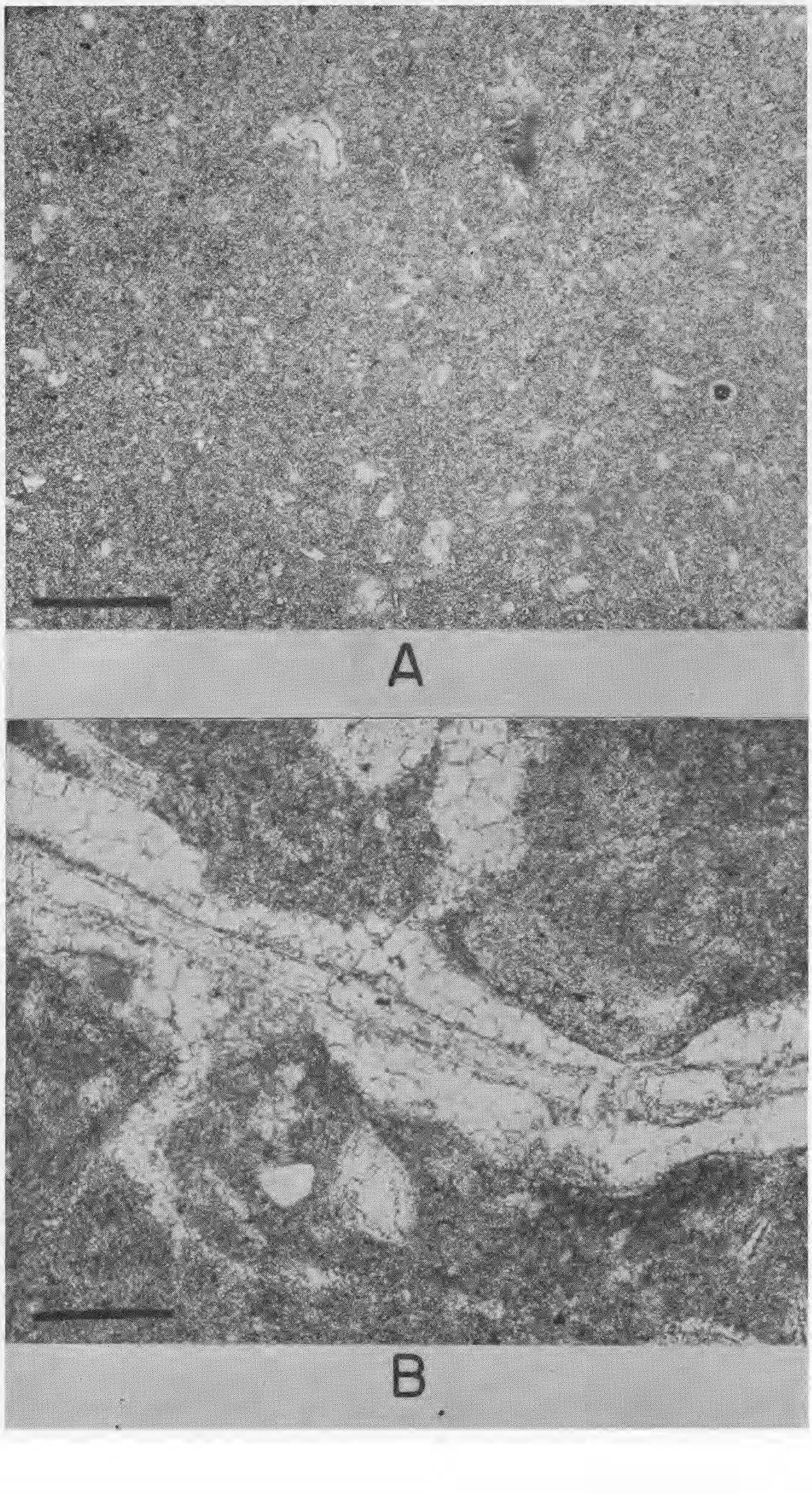


Plate 13

Outcrops of conglomerate and conglomeratic sandstone

A. Pebble conglomerate. Clasts are chiefly silicified and zeolitized tuff and bentonite pebbles and lesser volcanic rock fragments. Pencil for scale. Locality K-8.

B. Faintly laminated conglomeratic sandstone. Pebbles are chiefly tuffaceous clay clasts. Locality, Duval County.

Lithology and Petrology, Gueydan Formation **Plate 13**

A

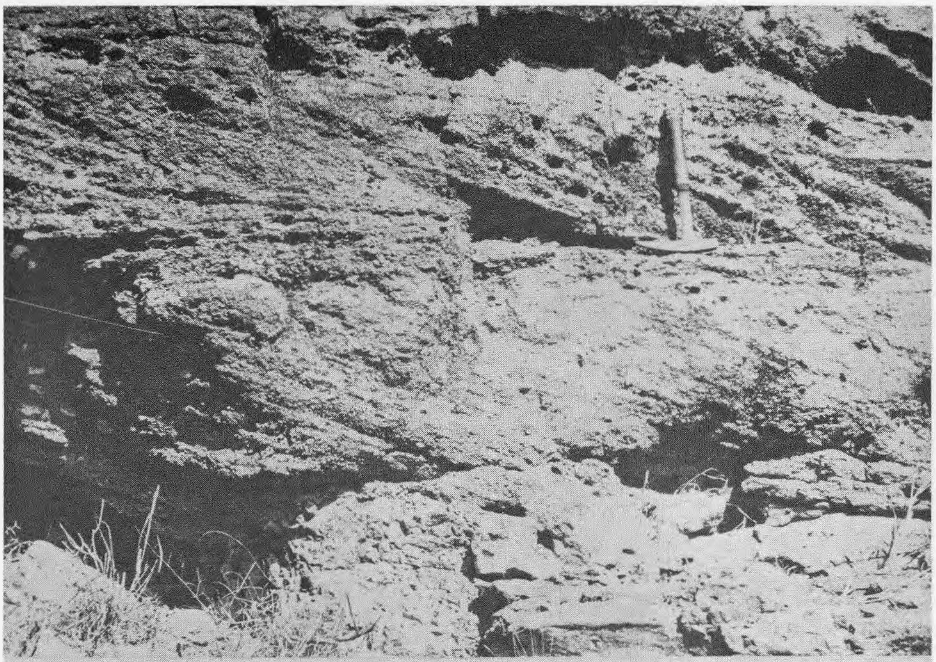
B

Plate 14

Outcrop and photomicrograph of sandstone

A. Cross-bedded fluvial sandstone. Locality LD-8.

B. Photomicrograph of volcanic arenite. Grains are chiefly volcanic rock fragments and tuffaceous clay. Cement is zeolite and uraniferous mineral. Scale is 1.0 mm long. Ordinary light. Sample and Locality GW-2.


A

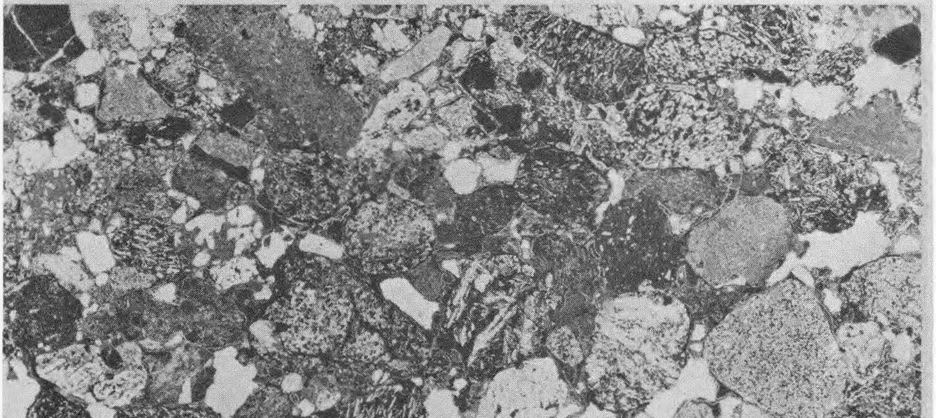

B

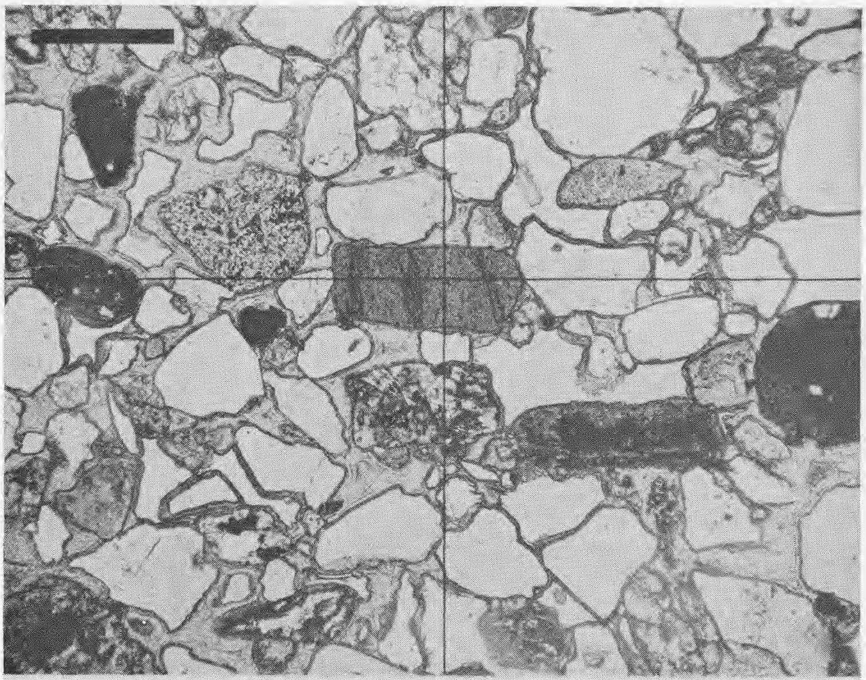
Plate 15

Photomicrographs of sandstone

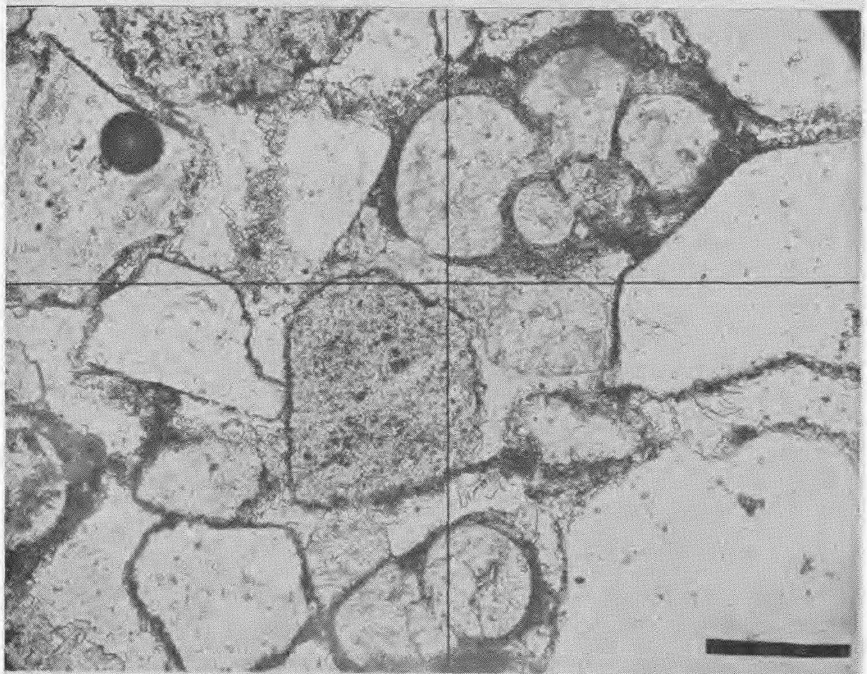
A. Volcanic arkose. Clear grains are quartz and feldspar; dark grains are volcanic rock fragments. Cross-hair rests on phosphatic bone fragment. Cement is opal. Scale is 0.5 mm. Ordinary light. Sample and Locality K-10.

B. Sandstone bearing reworked Cretaceous foraminifers. Cross-hair rests on detrital carbonate grain. Grain to lower left of cross-hair is a volcanic rock fragment. Cement is zeolite (tiny laths) and calcite. Scale is 0.14 mm long. Ordinary light. Sample MS, locality, Duval County.

Lithology and Petrology, Gueydan Formation **Plate 15**



A



B

Plate 16

Photomicrographs of sandstone and zeolitic tuff

A. Volcanic arenite. Cross-hair rests on tuffaceous clay clast; clear grains are plagioclase and sanidine. Cement is zeolite and opal. Scale is 0.5 mm long. Ordinary light. Sample and locality LD-8.

B. Tubular-porous tuff with tubule lined by mosaic of zeolite grains (clear laths). Matrix is a mixture of zeolitized shards and devitrified finer constituents. Ordinary light. Scale same as A. Bailey's sample 202. Locality unknown.

Lithology and Petrology, Gueydan Formation **Plate 16**

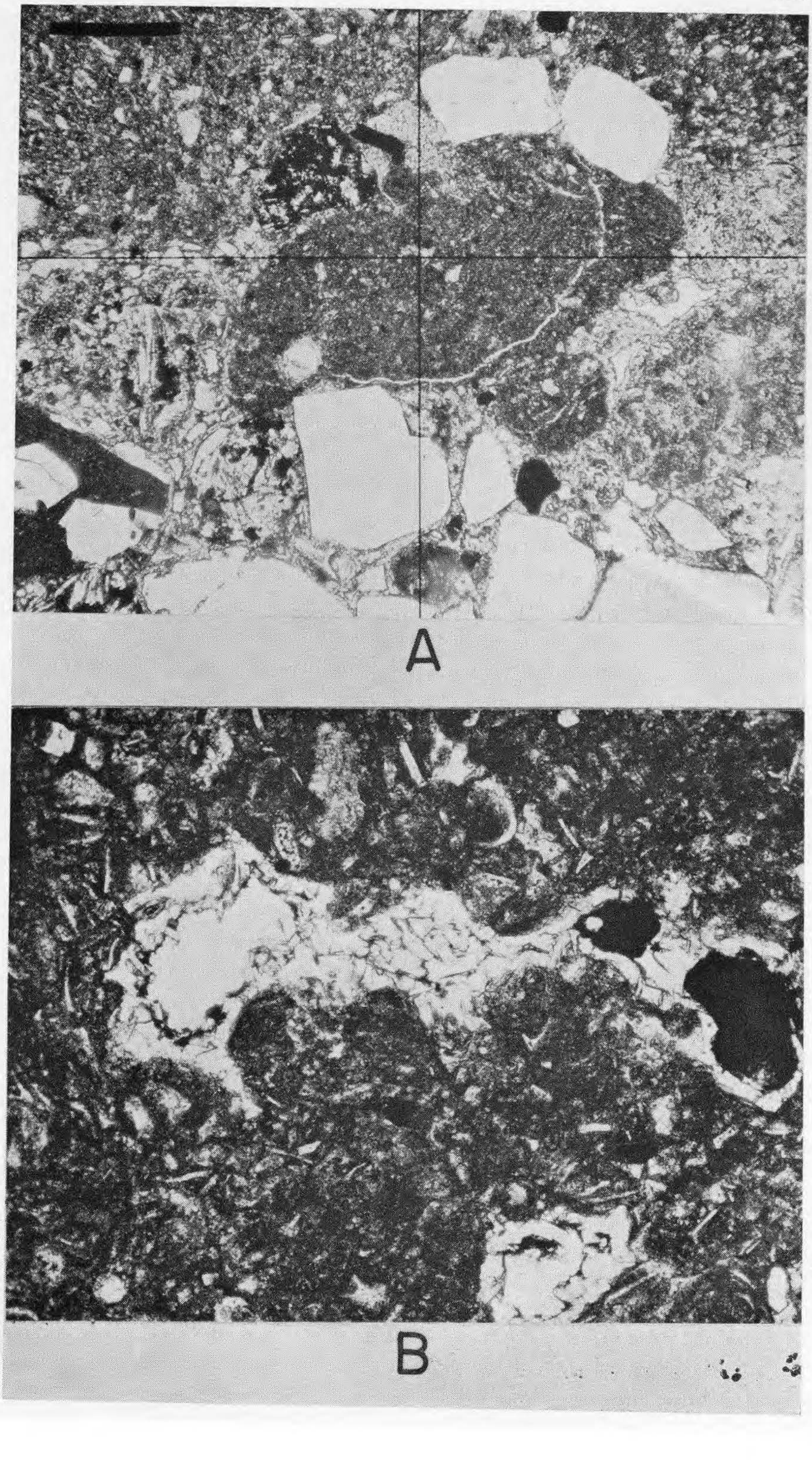
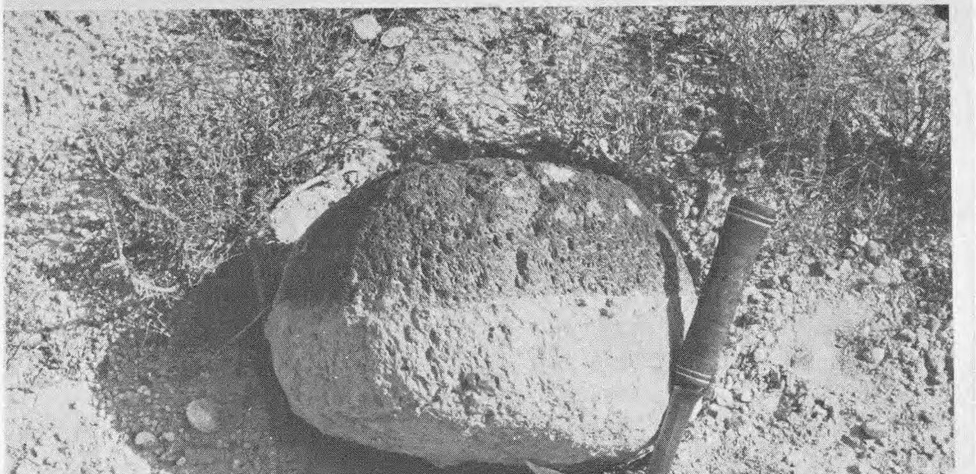


Plate 17

Boulders of vesicular lava weathered from tuffaceous clay and tuff in McMullen County.

Lithology and Petrology, Gueydan Formation **Plate 17**

A



B

Plate 18

Photomicrographs of altered tuffs

A. Tuff altered largely to zeolite. Shard outlines barely visible. Scale is 0.14 mm long. Ordinary light. Bailey's sample 205. Locality unknown.

B. Tuff with unaltered shards encased in montmorillonite that formed either by argillation of matrix or precipitation from solution. Scale is 0.5 mm long. Ordinary light. Bailey's sample 207. Locality unknown.

Lithology and Petrology, Gueydan Formation **Plate 18**

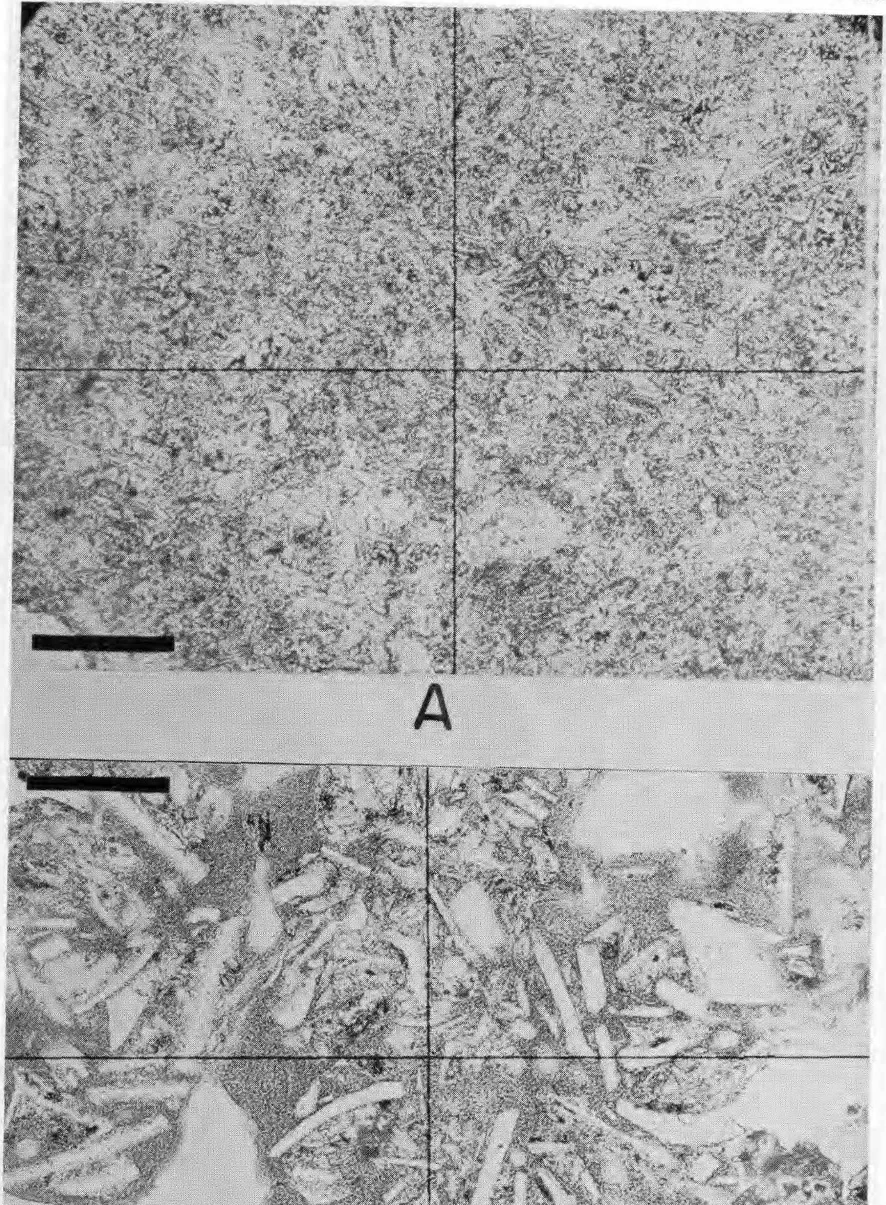


Plate 19

Clay dikes in clay and sandstone

A. Clay dike cutting crudely bedded pink tuffaceous clay. Locality S-1.

B. Clay dike cutting poorly cemented sandstone. Locality, Duval County.

Lithology and Petrology, Gueydan Formation **Plate 19**

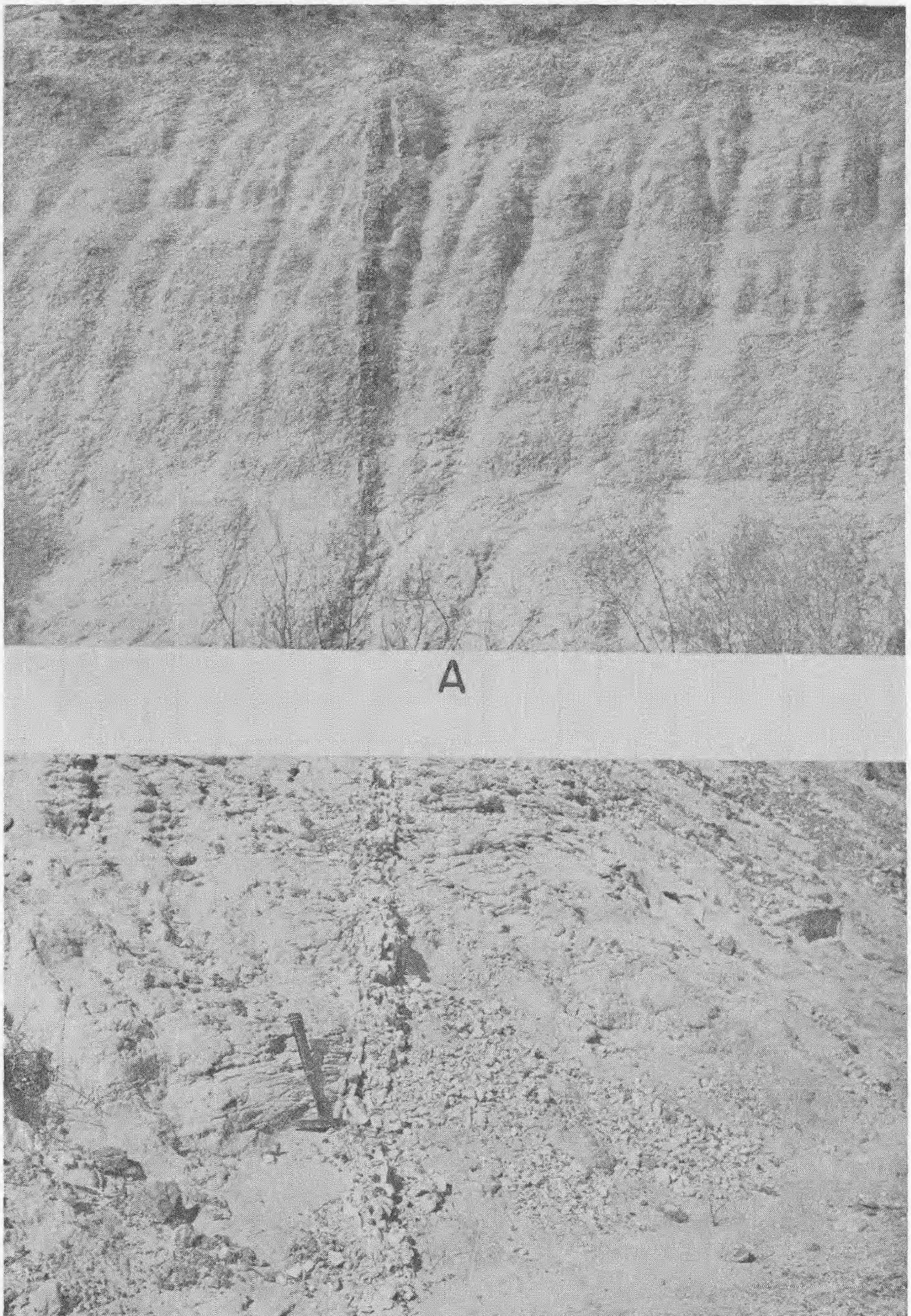


Plate 20

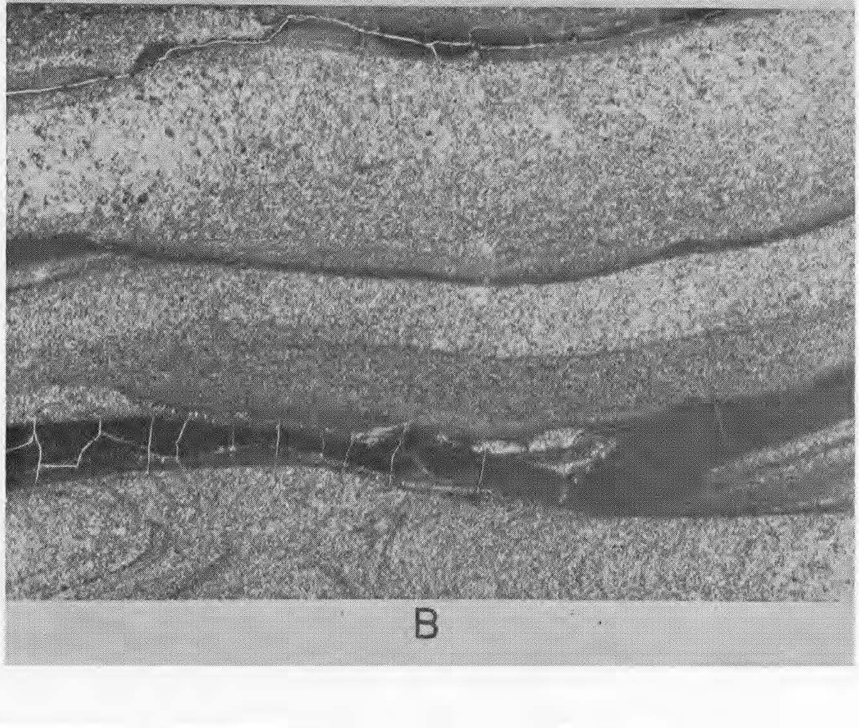
Clay dikes

A. Close-up of clay dike showing banding. Locality, Duval County.

B. Photomicrographs of clay dike showing banding. Dark bands are montmorillonite. Contorted bands are visible in lower part of photograph. White lines are shrinkage cracks. Ordinary light. Sample and Locality S-1.

Lithology and Petrology, Gueydan Formation **Plate 20**

A



B

Plate 21

Silica knob and calcite vein

A. Silica knob weathered in relief from softer tuffaceous clay. Locality, Paint Hill, McMullen County.

B. Sawed surface of banded calcite vein. Locality, Duval County.

Lithology and Petrology, Gueydan Formation **Plate 21**

A

B

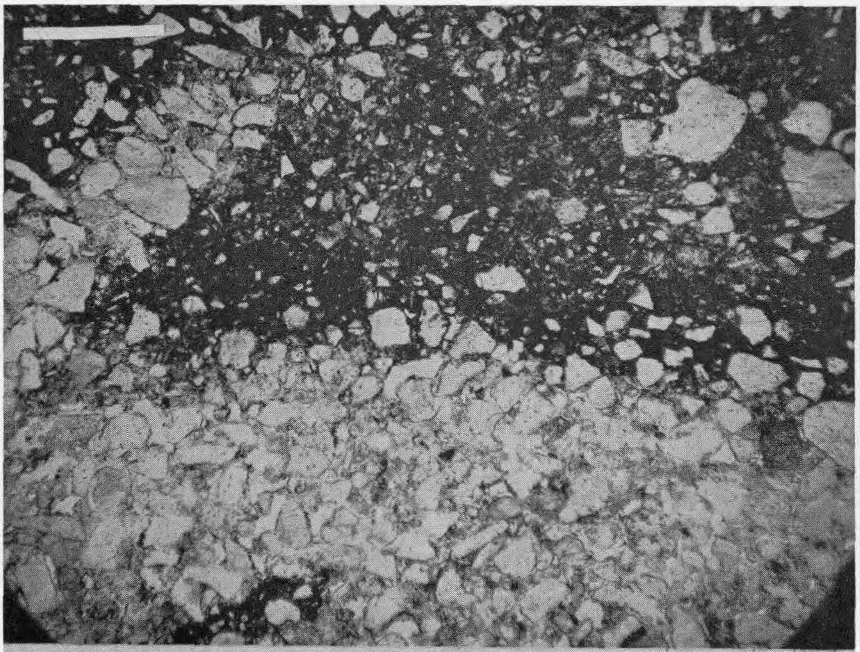
Plate 22

Photomicrographs of rocks from silica knobs

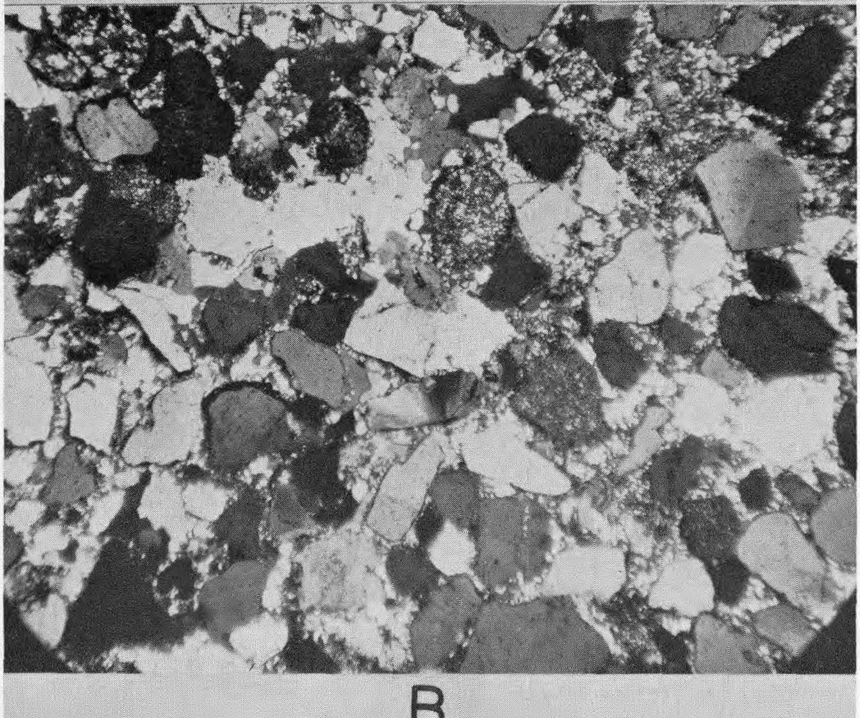
A. Sandstone with mottled texture. Light layers of well-sorted sand interfringe with dark (manganese oxide?) poorly sorted layers. Cement is quartz and chalcedony. Scale is 0.5 mm long. Ordinary light. Sample MKO, locality, McMullen County.

B. Sandstone rich in grains of quartz and chalcedony. Cement is quartz and chalcedony. Scale same as A. Crossed polarizers. Sample ATP, McMullen County.

Lithology and Petrology, Gueydan Formation **Plate 22**



A



B

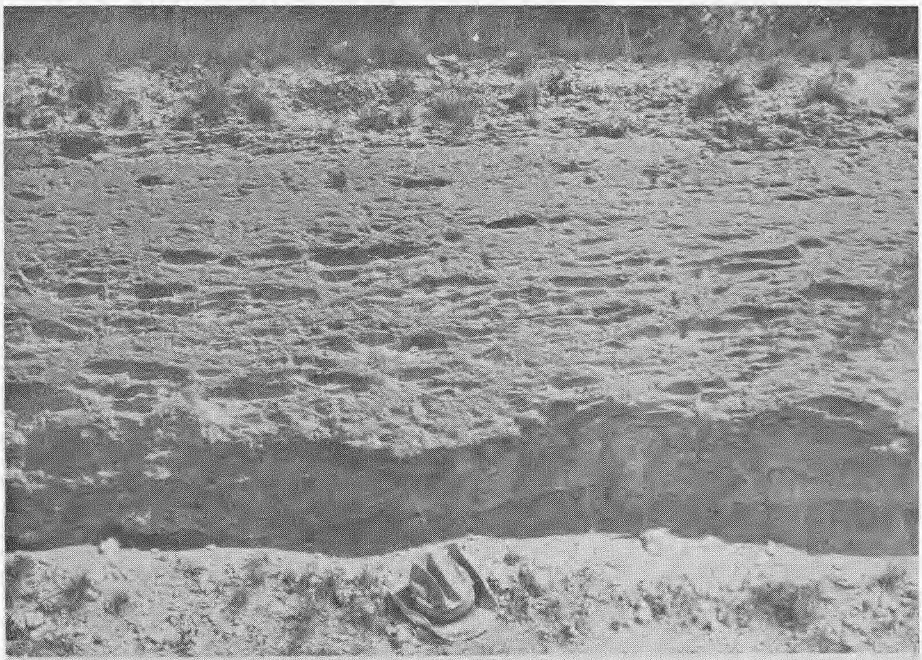
Plate 23

Calichified tuff and clay

A. Bladed face of calichified tuff exposure. Locality, Karnes County.

B. Tubular or pipe-like structures in calichified tuffaceous clay. White patches are caliche, dark areas are tuffaceous clay. Locality, Loma Novia, Duval County.

Lithology and Petrology, Gueydan Formation **Plate 23**



A

B

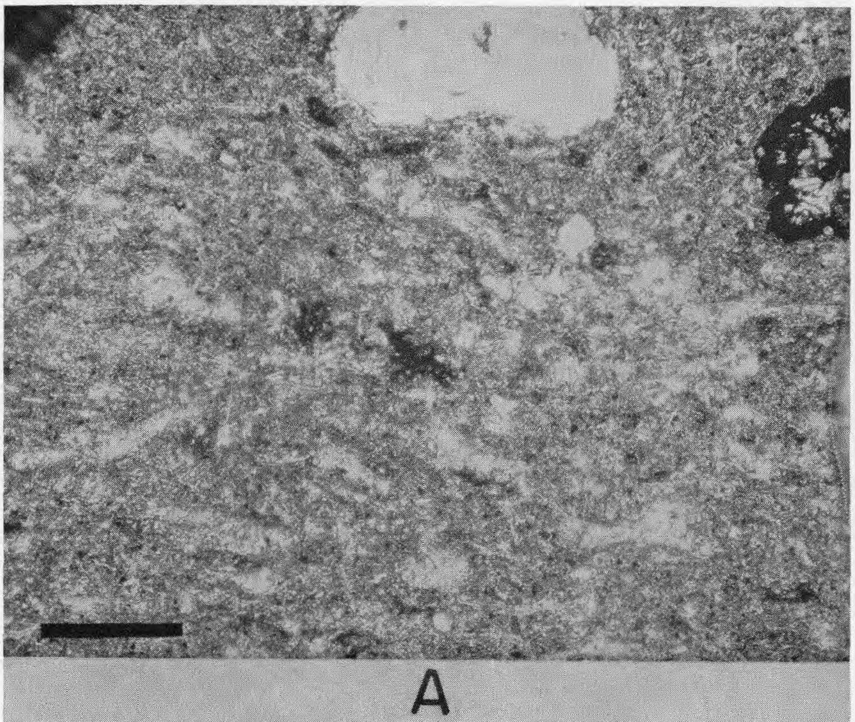
Plate 24

Photomicrographs of igneous rocks

A. Devitrified crystal-bearing vitric tuff. Relic shards are elongate clear patches. Scale is 0.5 mm long. Ordinary light. Sample LX-1.

B. Amygdular trachyandesite porphyry. Resorbed oligoclase (upper left) and iddingsite after olivine (lower left) phenocrysts are prominent. Scale same as A. Ordinary light. Sample LX-4.

Lithology and Petrology, Gueydan Formation **Plate 24**



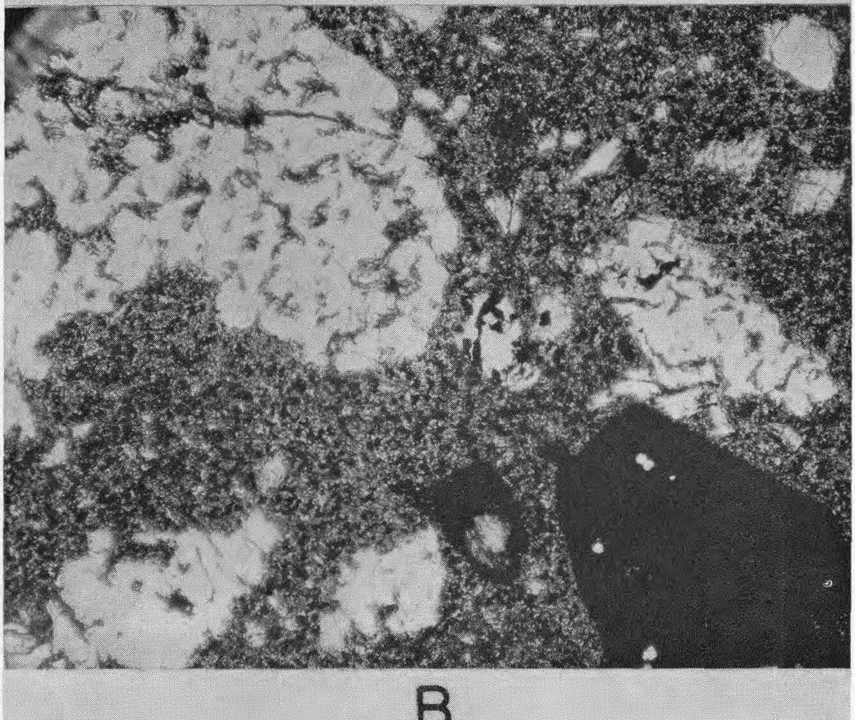


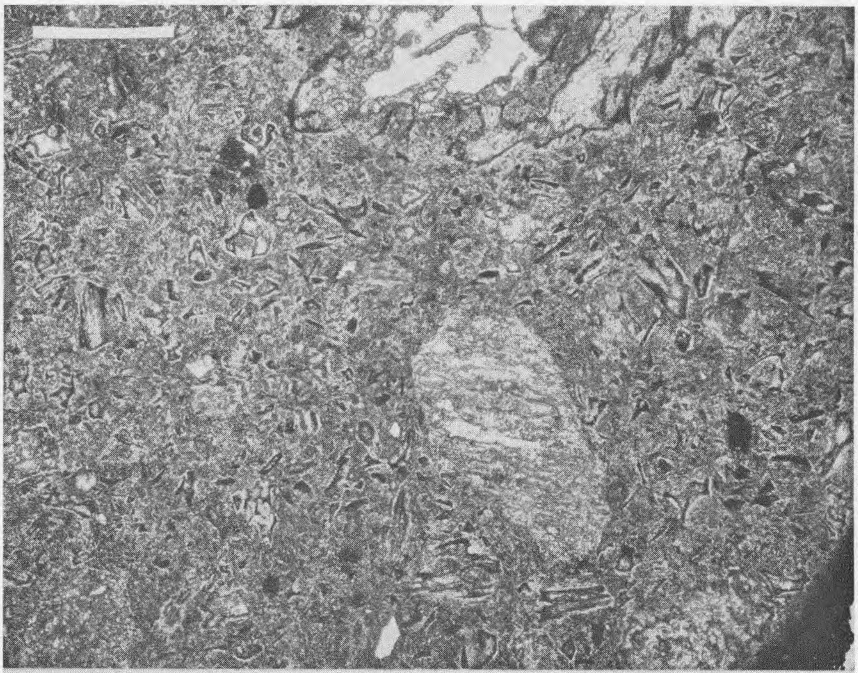
Plate 25

Photomicrographs of igneous rocks

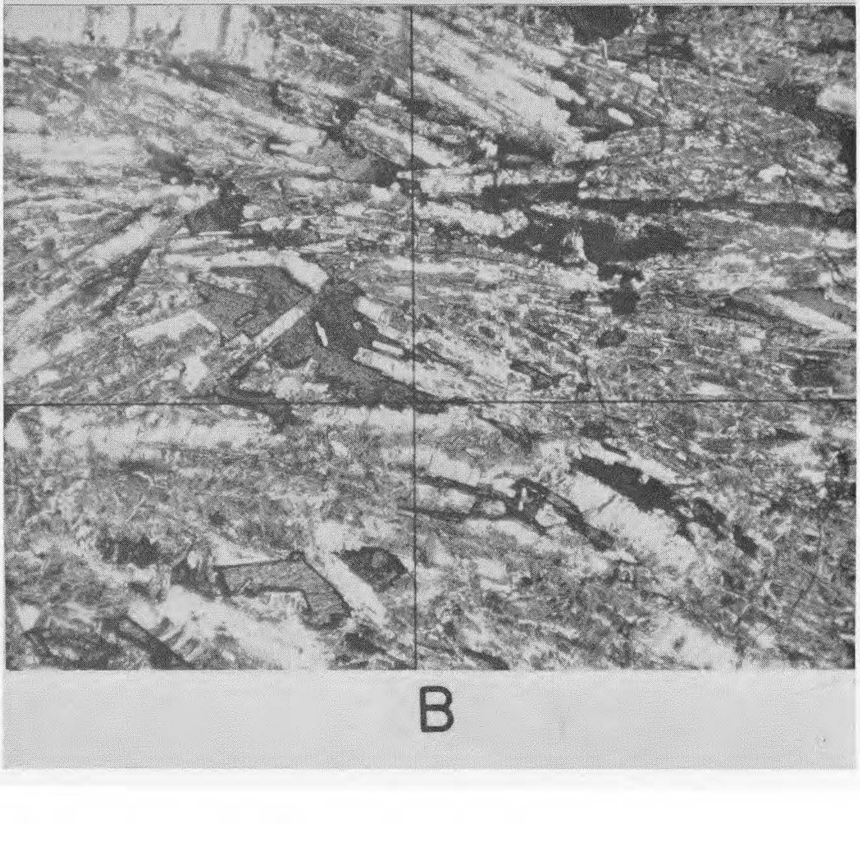
A. Altered lithic-vitric tuff. Shards now composed of cryptocrystalline devitrification products. Scale is 0.5 mm long. Ordinary light. Sample LC-8.

B. Alkali trachyte. Well-aligned cloudy feldspar laths predominate. Cross-hair rests on aegirine. Scale same as A. Ordinary light. Sample LXX-7.

Lithology and Petrology, Gueydan Formation **Plate 25**



A



B

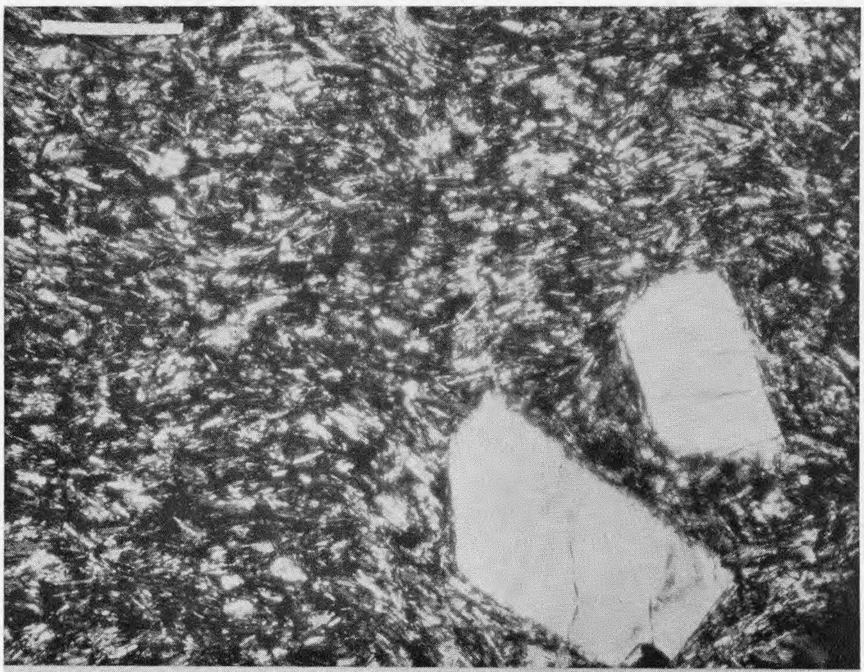
Plate 26

Photomicrographs of igneous rocks

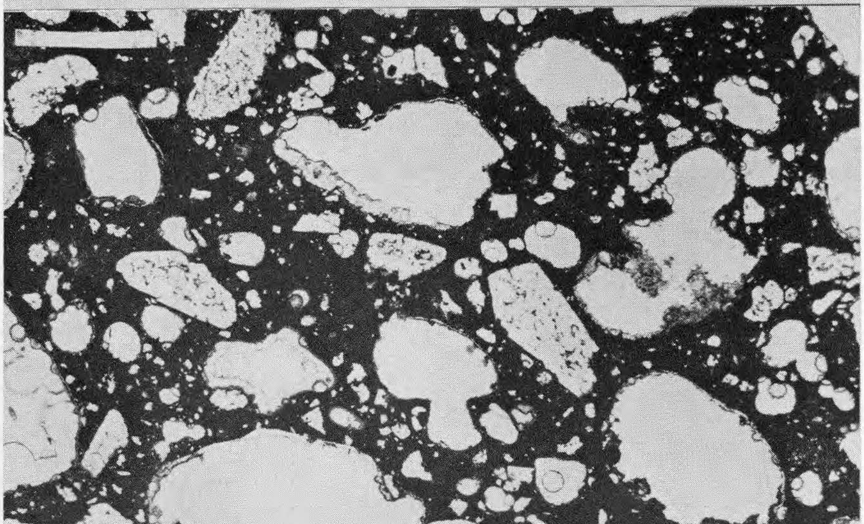
A. Porphyritic alkali trachyte. Alkali feldspar phenocrysts in groundmass of alkali feldspar, aegirine, and iron oxides. Scale is 0.5 mm long. Ordinary light. Sample LX-8.

B. Vesicular, amygdaloidal trachyte porphyry. Phenocrysts are oligoclase. Vesicles are lined in places by secondary minerals. Scale is 2.0 mm long. Ordinary light. Sample 70.

Lithology and Petrology, Gueydan Formation **Plate 26**



A



B

Plate 27

Photomicrographs of igneous rock and welded tuff

A. Welded vitric tuff. Compacted and flattened shards are outlined by hematite dust. Large grains are quartz. Scale is 0.5 mm long. Ordinary light. Sample K-10-II, Locality K-10.

B. Altered amygdaloidal porphyry. Vesicles are strongly compacted. The groundmass (altered glass?) is deeply stained by iron oxide. Scale same as A. Ordinary light. Sample LX-9, locality, Duval County.

Lithology and Petrology, Gueydan Formation **Plate 27**

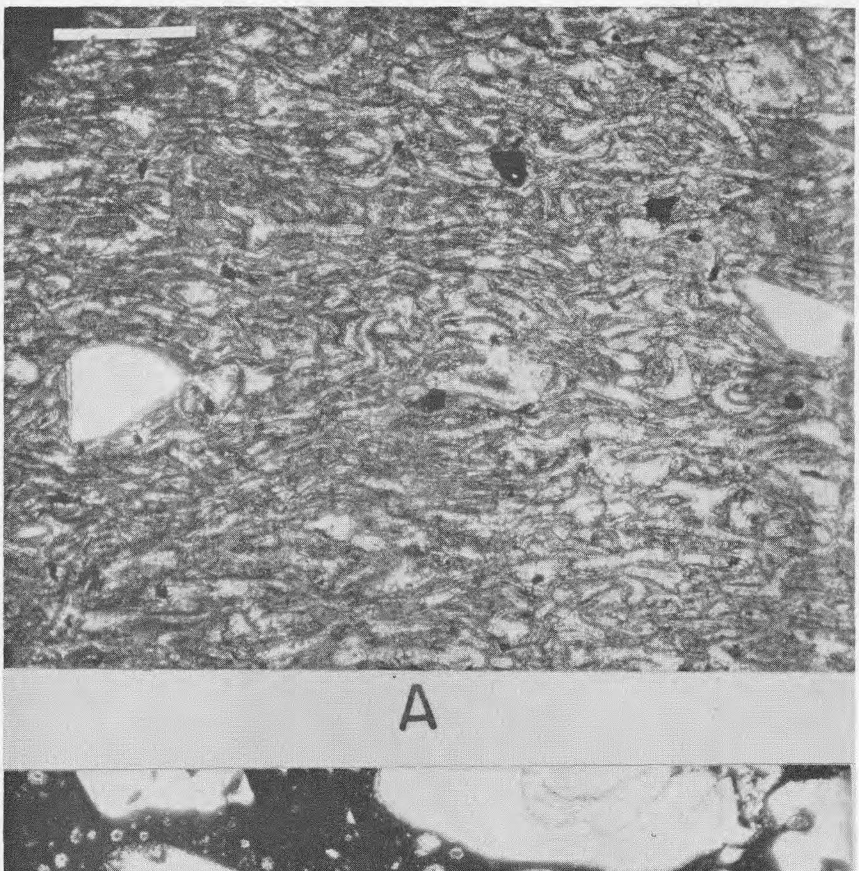
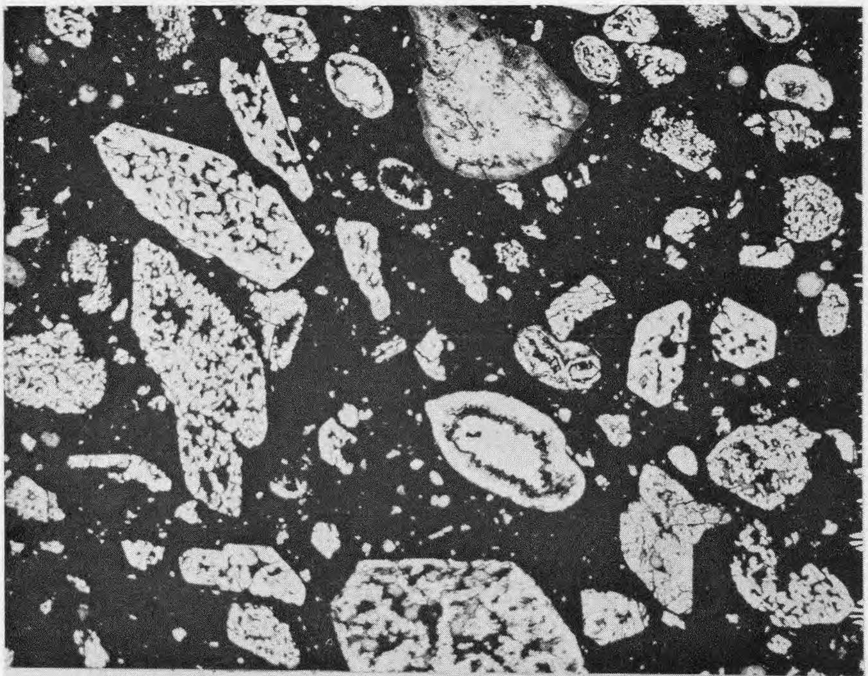


Plate 28

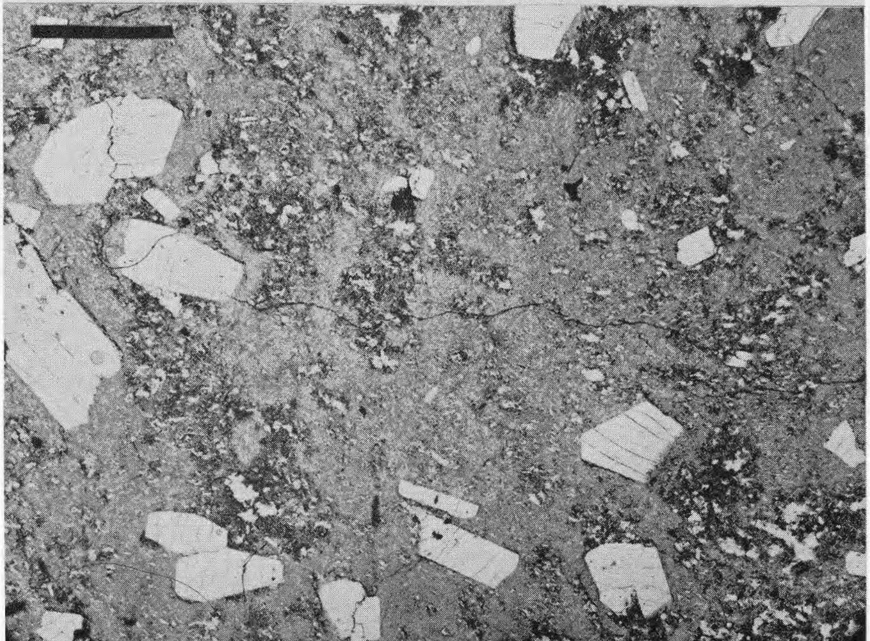
Photomicrographs of igneous rocks

A. Amygdaloidal trachyandesite (rhomb) porphyry. Strongly resorbed oligoclase phenocrysts. Vesicles marked by inward-projecting quartz crystal faces. Scale same as B. Ordinary light. Sample LXX-8.

B. Rhyolite porphyry. Sanidine phenocrysts in groundmass of feldspar and quartz. Scale is 2 mm long. Ordinary light. Sample K-10-P3, locality, Karnes County.



A



B

Index