University of Texas Bulletin

No. 2645: December 1, 1926

THE GUEYDAN, A NEW MIDDLE TERTIARY FORMATION FROM THE SOUTHWESTERN COASTAL PLAIN OF TEXAS

By

THOMAS L. BAILEY

Bureau of Economic Geology

J. A. Udden, Director E. H. Sellards, Associate Director

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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DR. EDWARD THEODORE DUMBLE

While this bulletin is in press announcement has been made of the death of Dr. Edward Theodore Dumble on January 25, 1927, at Nice, France. Dr. Dumble was the first to undertake a comprehensive subdivision of the Tertiary and Quaternary series of Texas; moreover, in recent years he and his associates of the Geological Department of the Southern Pacific Railroad have contributed a valuable paper on the geology of East Texas to the publications of the University of Texas. It is therefore fitting that in this publication which relates to a part of the area over which Dr. Dumble worked, that special acknowledgment should be made of his contributions to the geology of Texas.

Dr. Dumble was born at Madison, Indiana, March 28, 1852. At an early age he came with his parents to Houston, Texas, where he resided the greater part of his life. His college work was taken at Washington and Lee University, from which he received the degree of Bachelor of Science and later was honored with Doctor of Science. In his college work he majored in chemistry and geology. Although engaged in his early youth in business he did not lose his interest in science, but privately explored the geology of Texas. When the Geological Survey of Texas was established in 1888 he became State Geologist and served as Director of the Survey until 1894. Although no State funds were provided for this survey beyond February, 1894, Dr. Dumble's connection with the State in an official capacity continued until 1899. The publications issued by this survey under Dr. Dumble's direction stand as a fitting memorial to his ability as a scientist and director of scientific activities.

In recognition of his contributions to geology both as an official of the State of Texas and as a private citizen this bulletin of the University of Texas is dedicated to the memory of Dr. Edward Theodore Dumble.

THE GUEYDAN, A NEW MIDDLE TERTIARY FORMATION FROM THE SOUTHWESTERN COASTAL PLAIN OF TEXAS

BY THOMAS L. BAILEY[1]

INTRODUCTION

The announcement of the discovery of an important and extensive deposit of pyroclastic material in the southwestern Texas coastal plain and a brief discussion of its character and stratigraphic relations were given in a short article by the present writer[2] in March, 1924. This deposit was designated therein as the "Gueydan formation."

The object of the present paper is to describe the general lithology and petrography of the Gueydan formation, or Gueydan tuff; to discuss its stratigraphic relations to the adjacent formations and its partial or complete equivalence in age with the Oligocene rocks of eastern Texas; to discuss the probable mode of origin and source of the volcanic debris; and to outline the structural and physiographic features of that portion of the Texas coastal plain in which the Gueydan tuff outcrops.

The recognition of the Gueydan is of importance in this region, where many of the formations are lithologically similar, because it is quite unlike the adjacent formations in character. Certain members of the Gueydan tuff may be useful as key horizons in working out the detailed geologic structure of this district.

Discovery of the Gueydan formation.—In August, 1923, Mr. Henderson Coquat of Three Rivers, Texas, sent to Dr. J. A. Udden, Director of the Bureau of Economic Geology and Technology of the University of Texas, some

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[1]Manuscript submitted September, 1926, published March, 1927.

[2]Bailey, Thomas L., "Extensive Volcanic Activity in the Middle Tertiary of the South Texas Coastal Plains," Sci. (n. s.) LIX, No. 1526, pp. 299–300, 1924.

small fragments broken from large boulders of a dark vesicular lava. Thin sections and crushed portions of these fragments were examined under a petrographic microscope by the writer and were found to be trachyandesite or andesite. In a note accompanying the samples Mr. Coquat wrote that he had been able to trace boulders of this type across a large part of Live Oak and McMullen counties. With a view to ascertaining the mode of occurrence of this interesting igneous material and to obtain an idea of the extent of its outcrop, Dr. Udden asked the writer to make a short field study of it. Accordingly, in September, 1923, the writer spent four days in Live Oak and McMullen counties making a reconnaissance examination of the deposits containing the boulders and found them to consist largely of volcanic tuff beds. A summary of the results obtained at this time was published in *Science* as mentioned above.

The writer spent the summer of 1924 in making a detailed study of the Gueydan tuff and traced its outcrop for a distance of 240 miles. The present paper is based on the field work done at that time.

Acknowledgments.—The writer wishes to express his sincere appreciation to Mr. Henderson Coquat for conducting him to some of the best exposures of the igneous rock in Live Oak and McMullen counties. In fact Mr. Coquat had suspected the igneous origin of much of this material before the writer had seen it.

Location and delimitation of the area mapped.—The area discussed embraces a belt 240 miles long and from two to fourteen miles wide near the center of the southwestern half of the Gulf Coastal Plain of Texas, approximately paralleling the shore line at a distance of from 80 to 110 miles northwest and west of the Gulf of Mexico. This belt includes the surface outcrop of the above-mentioned Gueydan formation which was traced from a point near the town of Moulton, Lavaca County, midway between the Louisiana and Mexican boundaries of Texas, to a point twenty-two miles north of the lower Rio Grande at Rio Grande City, Starr

County, and seventy miles south-southeast of Laredo. The northwestern edge of the Gulf Coastal Plain is produced by the Balcones fault scarp at the edge of the Edwards Plateau. In the northern part of its length the belt is situated midway between the Balcones scarp and the Gulf coast. The southern part, however, is nearer to the coast than to the Balcones scarp because of the fact that the main Balcones fault zone changes its southwest trend north of San Antonio to a pronounced westward course south of San Antonio, while the Gueydan outcrop continues approximately parallel to the shore line. The discussion of the physiography is not restricted to the rather narrow belt outlined above, but includes also a general description of the physiography of much of the southwestern coastal plain of Texas. Several of the geological formations outcropping adjacent to the Gueydan are also discussed, although less intensively.

Previous work.—The published accounts of the geology and the geologic maps of that portion of the Texas coastal plain outlined above are strictly of a reconnaissance nature. The stratigraphic units have not been clearly defined nor fully described for the most part. This has led to considerable confusion, inasmuch as the same beds have been included in a certain formation by one writer and in an entirely different formation by another. Identical beds are not uncommonly placed in various formations at different localities along their strike, even by the same writer. This confusion has been due partly to a lack of extensive outcrops and partly to lateral variation in the lithology of some of these formations. It has also been caused by the fact that the writers did not give sufficient attention to the petrology of the district. A more thorough field study of the rocks would have prevented many wrong designations. For example, many beds of coherent white tuff have been identified as limestone, although they contain either no lime carbonate at all or very small traces of it. A careful examination of this particular rock with the hand lens would have revealed the presence of many pumice fragments and angular glass grains.

The first comprehensive attempt to subdivide the Tertiary and Quarternary rocks of the southwestern coastal plain of Texas into formations was made by Dumble[3] in a paper published in 1894. The type localities of the Frio, Oakville (Lapara), and Lagarto formations which were named and described in that paper by Dumble are found in Live Oak and McMullen counties near the center of the area here discussed, where the writer did his most detailed work. The Frio of Dumble includes both the Frio and Gueÿdan formations of the present writer. No pyroclastics are reported from the Frio, although he does mention beds of volcanic dust and ash in the Fayette, which underlies the Frio. His type localities of the Frio clay on the Frio and Nueces rivers are within the outcrop of the Gueydan tuff of the present writer.

In 1903, Dumble[4] published another paper in which he gave much additional information about the geology of southwestern Texas, including some detailed sections. Accompanying this report is a sketch map showing Dumble's interpretation of the distribution of the various Tertiary formations in the portion of southwestern Texas traversed. According to this map the Frio in Live Oak County would include most of the Gueydan as discussed in the present paper and a little of the Oakville, while the Frio proper of the present report is included for the most part in the Fayette by Dumble. In McMullen County, between Tilden and the southeast corner of the county, Dumble maps the Frio so that it includes the Frio proper and a small part of the lower Gueydan as described in this paper. His Frio thus includes a different set of beds in these two sections, as is proven by actually tracing the lower Gueydan tuff beds from one section to the other. The upper half of the Gueydan is included by Dumble in his Oakville and Lapara formations. The better consolidated white tuff beds of the lower

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[3]Dumble, E. T., "The Cenozoic Deposits of Texas," Jour. Geol., Vol. 2, No. 6, pp. 549–567, 1894.

[4]Dumble, E. T., "The Geology of Southwestern Texas," A. I. M. E. Trans., Vol. 33, pp. 913–987, 1903.

Gueydan have evidently been mistaken by Dumble for Reynosa limestone of Pleistocene age although they are interbedded with the strata which he calls Frio. Thus in the last paragraph on page 953 of his paper Dumble states:

> At the mouth of Comanche Creek, 15 feet of interbedded brown sands and sandy clays were found, but from that point to 0.5 mile south of the falls of the Atascosa everything seen belonged to the Reynosa and overlying beds.

On page 978 Dumble describes the following sections under the heading "Reynosa beds":

> At a hill half a mile north of the (Weedy or San Cristoval) creek we found the tuffaceous limestone, interbedded with yellow clays and sand, passing into lavendar clays at base. . . . (Section given).
>
> Following Weedy Creek to its junction with the Atascosa and that river to the "falls," three miles below, the Reynosa was seen to have an extensive development, forming precipitous banks from 20 to 30 feet high along the creek . . .

The writer has studied these sections and found excellent outcrops of the consolidated, non-calcareous white tuff, conglomeratic tuff and pumice-pebble conglomerates belonging to the lower part of the Gueydan formation.

In 1906 Deussen and Dole[5] published a paper which is devoted mainly to a discussion of the water supply of part of this region, accompanied by a brief account of the geology of McMullen and La Salle counties.

During a period of sixteen years following the preceding articles nothing of importance was published on the region. During this interim two commercial gas fields and one commercial oil field were discovered in the southern portion of the area, thus attracting the attention of geologists to that part of the district. Accordingly, in 1922, Sellards[6] pub-

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[5]Deussen, Alex., and Dole, R. B., "Ground Water in La Salle and McMullen Counties, Texas," U. S. Geol. Surv. W. S. Paper, 375g, pp. 141–177, 1916.

[6]Sellards, E. H., "Notes on the Oil and Gas Fields of Webb and Zapata Counties," Univ. Texas Bull. No. 2230, pp. 5–29, 1922.

lished a short bulletin on these oil and gas fields. The stratigraphy is briefly described. Sellards noted outcrops of light-colored volcanic ash containing plant impressions near Aguilares, and stated that they probably represent the Fayette formation.

During the next two years, 1923 and 1924, three papers accompanied by geologic maps appeared. Trowbridge[7] made a reconnaissance report on the geology of the coastal plain of Texas adjacent to the Rio Grande, in which he mentioned prominent beds of volcanic ash both in his Frio and Fayette (Eocene) formations. The writer does not agree with Trowbridge's location of the contact between the Frio and the Fayette, nor with his statement that the Oakville (Upper Miocene) and Lagarto (Lower Pliocene) formations do not outcrop in the vicinity of the Rio Grande. In 1923, Dr. J. L. Wortman of Brownsville, Texas, discovered[8] in the calcareous tuff or "ashy marl" deposits near Rio Grande City some determinable Upper Miocene fossils, including *Protohippus sejunctus* Cope, which prove that deposits of Upper Miocene age do outcrop. Moreover, massive beds of characteristic Oakville sandstone outcrop prominently six miles north-northwest of Rio Grande City. Trowbridge apparently included most of the Gueydan tuff in his Frio formation, but it is probable that some of his Fayette volcanic ash beds also belong in the Gueydan as here defined.

The greater part of Jones's paper[9] on the Webb and Zapata county oil fields is devoted to the structure of the region. He places considerable emphasis upon a widespread occurrence of "siliceous knobs, veins and bedded quartzites" as related to faulting and as evidence of it.

In the discussion of Jones's paper Dilworth Hager men-

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[7]Trowbridge, A. C., "A Geological Reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande," U. S. Geol. Surv. Prof. Paper 131D, pp. 97–98, 1923.

[8]Personal communication, November 14, 1923.

[9]Jones, R. A., "The Relation of the Reynosa Escarpment to the Oil and Gas Fields of Webb and Zapata Counties, Texas," Bull. Am. Assoc. Petr. Geol., Vol. VII, No. 5, pp. 532–545, 1923.

tioned the presence of volcanic ash beds in the area and suggested that the widespread occurrence of opal and other forms of silica was due to the leaching of silica from these beds. Alexander Deussen discussed the paper as follows:

> In answer to Mr. Hager's statement that the opal may be due to leaching of silica from volcanic ash beds, I wish to state that the volcanic ash beds continue clear across the state to the Sabine River. No opal occurs east of the Colorado River. It would seem that if volcanic ash were responsible for opal such knobs would occur wherever ash beds occur . . . [The writer would suggest in this connection that the more arid climate, causing a higher alkalinity of the ground water west of Colorado River, has made the ground water a more efficient solvent for the silica in the tuffs.]

Deussen also mentioned "rhyolite" boulders in the "Oakville sandstones" in Duval County and asked Jones what he considered to be their origin. Jones replied as follows:

> . . . I think the rhyolite boulders and blocks of vesicular basalt in the vicinity of the Government Well, northwestern Duval County, may have been transported from the west, for instance, Uvalde County.

By far the most complete geologic map and report on this area is by Deussen.[10] On page 91 he states:

> In the eastern part of the area under consideration, the Frio clay lies conformably beneath the Catahoula sandstone, but in the western part of the area it lies unconformably beneath the Oakville sandstone.

The present writer found that the Catahoula (Oligocene) does not lens out as stated by Deussen but passes by a gradual lithologic change to the southwestward into the Gueydan formation which continues to outcrop nearly to the Rio Grande. The Frio clay as mapped by Deussen includes the Gueydan (Oligocene) and the Frio (Eocene) of the present writer. Much of Deussen's "clay, sandy limestone

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[10]Deussen, Alex., "Geology of the Coastal Plain of Texas West of Brazos River," U. S. Geol. Surv. Prof. Paper 126 (1924).

and sandy clay" in the Live Oak and McMullen county sections is found by microscopic examination to be mainly tuff or argillaceous tuff. The light-colored platy bed shown above the clay or bentonite in his Plate XXVI is recognized by the present writer, who has studied this outcrop, as being a bed of trachyte or trachyandesite tuff.

A section of so-called Frio clay is described by Deussen on page 93 as follows:

> In the bed of Atascosa Creek at the crossing of the Oakville-Crowther road about eight miles northwest of Oakville, there is exposed 6 inches of green argillaceous sandy limestone, overlying 7 inches of green, calcareous, sandy clay.

The outcrops at this locality have been determined as tuff and argillaceous tuff by the present writer. Near this locality are found good outcrops of pumice-pebble conglomerate composed largely of rounded glassy pumice pebbles in a matrix of argillaceous tuff.

Deussen makes two short references to volcanic ash in his Frio formation. On page 92 he states: "Fragments of agatized wood, beds of volcanic ash and nodules and masses of white chalcedony may also be seen in places." Also on page 93: "Extensive beds of volcanic ash are found in the western part of Karnes County, about ten miles west-southwest of Karnes City."

In 1924 Dumble[11] published another paper which is based largely on field work by Paul L. Applin and Lyman D. Reed and on laboratory work by Mrs. Esther R. Applin and Miss Grace Newman. In this paper Dumble corrects several of references made in his earlier publications. The beds of white tuff which were formerly confused, at least in part, with the Reynosa are placed in the Frio and designated as "clays, sands, and sand-rock" in spite of the facts brought out by the following statement made on pages 434 and 435:

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[11]Dumble, E. T., "A Revision of the Texas Tertiary Section with Special Reference to the Oil Well Geology of the Coast Region," Bull. Am. Assoc. Petr. Geol., Vol. 8, No. 4, pp. 424–444, 1924.

> Under the microscope the differences of Frio materials from those of underlying beds are strongly marked. . . . The sand grains vary in fineness but are usually platy and angular fragments of volcanic ash. The quartz also appears in splintery needle-like fragments and in groups of hair-like filaments scattered through the sandy clays. [The so-called quartz is evidently glassy feldspar in part and in part filamentous volcanic glass or pumiceous fragments.]

In the same paper the Whitsett beds of Dumble include the Frio and the upper part of the Fayette formations of the present writer. The Frio as defined by Dumble is apparently identical with the Gueydan formation of the present writer. Dumble considers his Frio (the Gueydan) as Jackson (Eocene) in age, although he states that only one fossil, an undetermined leaf impression, was found in this formation. This seems inconclusive as will be indicated by later discussion.

Name.—Dumble's 1924 paper,[12] in which he redefined his Frio formation, appeared subsequent to the short paper in which the Gueydan formation was named and defined by the writer.[13] The formational name "Gueydan" has been introduced for the following reasons:

(1) The term "Frio clay" has been used for so many years that "Frio" immediately suggests to students of Texas stratigraphy a formation composed mainly of clay.

(2) The Frio is included in the Eocene by previous writers. Less confusion will result if the term "Frio" is retained for the lower portion of the old "Frio formation" as mapped by Deussen, which is composed principally of clays and is presumably of Eocene age.

(3) If the pyroclastics and associated rocks which are called in this paper the "Gueydan formation" are to be placed in one of the previously recognized stratigraphic divisions of the Texas coastal plain section, they should be placed in the Catahoula formation, their partial or

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[12]*Op. cit.*, pp. 424–444.

[13]Bailey, Thomas L., "Extensive Volcanic Activity in the Middle Tertiary of the South Texas Coastal Plain," Sci. (n. s.), LIX, No. 1526, pp. 229–300, 1924.

complete equivalent. However, the most characteristic lithologic type in the Catahoula is a quartzose sandstone, whereas the sandstone beds in the Gueydan are volcanic sandstones poor in quartz.

PHYSIOGRAPHY

GENERAL STATEMENT

The region under consideration in this paper is included in the Texas portion of the Gulf Coastal Plain physiographic and geographic province of the United States. Over one-third of the State of Texas belongs in this province. That third or fourth of the coastal plain which borders the Gulf of Mexico is an almost featureless, level plain sloping seaward at the gentle rate of two feet per mile. Farther inland the coastal plain slopes seaward at an average rate of from three to six feet per mile, and is so dissected by the action of streams that in many localities the land surface is quite uneven and hilly.

The general geologic structure of the coastal plain is homoclinal and the dip is toward the Gulf at a rate ranging from about 20 feet per mile for the youngest (Reynosa Pleistocene) formation, to 50 and even 120 feet per mile for the older formations (Miocene to Upper Eocene). The rocks underlying the part of the coastal plain which is discussed in this paper vary considerably in their resistance to erosion, both as to entire formations and as to members of the same formation. Rain and stream action has eroded the less resistant strata more deeply than the more resistant beds; the present land surface is consequently divided into a series of low, roughly parallel cuestas with steeper slopes or, in some places, even pronounced erosional scarps on their western or northwestern sides, and gentle, often nearly imperceptible, dip slopes toward the east and southeast. The scarps are of course produced by the outcropping edges of relatively resistant beds or a series of such beds. The flat dip-slope surface of a cuesta will be called a "cuesta-plain." Where there is rapid alternation of softer and harder beds the cuesta-plains are narrow and not very prominent. On the other hand, where the resistant beds are relatively thick or, if thin, very resistant to erosion, and where they are also separated from each other by a thick series of easily eroded beds, the individual cuesta-plains are much broader and the scarps are more prominent. The most pronounced erosional scarps are produced by thin but very resistant beds, such as siliceous-cemented sandstones, especially where such beds are underlain by a thick series of unconsolidated soft clays. The condition last stated has been responsible for the development of imposing mesas, such as Loma Alto, La Chusa, and San Caja, in southeastern McMullen and northwestern Duval counties. On these mesas is a comparatively thin cap of very hard, quartzite-like sandstones underlain by a thick series of unconsolidated, dust-like, tuffaceous clay deposits. These mesas are portions of the Oakville cuesta-plain which have been isolated from the main body of the cuesta by erosion. Erosion of the series of weak strata which separate the parallel cuesta ridges gives rise to flatter areas which may assume the form of valley-like depressions. For these the term "inter-cuesta-plain" is proposed.

The continuity of the cuestas is broken in many places by rather broad stream valleys which cut across them transversely so that the cuesta topography is not generally evident except in the more or less semi-arid southern fourth of the Texas coastal plain or where a series of very weak strata, such as soft clays, lie next to a series of resistant strata, such as well indurated sandstones or limestones. Thus the general topographic appearance of much of the district is that of a slightly uplifted and submaturely dissected plain or low plateau.

Nearly the whole of that part of the region southwest of San Antonio River in Karnes County is covered with a thick growth of various kinds of thorny bush or chaparral. This chaparral-covered district has a semi-arid, warm temperate climate and an average yearly rainfall of 25 inches or less. In the vicinity of the Rio Grande the annual rainfall is about 13 inches. North of the San Antonio the climate is more humid and portions of the district are sparsely to thickly wooded, but stretches of open prairie are very common in some belts. The rainfall in this more northerly part ranges from 25 to 35 inches a year.

RELIEF

The relief of the portion of the coastal plain with which we are concerned is nowhere great. The highest point is located in southeastern Webb County, one mile south-southeast of Mirando City, and according to the United States Army topographic surveys has an elevation of 1,004 feet above sea level. The lowest point is on the Nueces River three miles south of Three Rivers. The elevation of this point is 180 feet. The maximum relief for the whole area is thus 824 feet. The average relief of the entire district taken by topographic quadrangles (½ degree lat. and long.) is much less, only about 280 feet. The general difference in elevation between the tops of divides and the bottoms of adjacent larger stream valleys is from 200 to 400 feet for most of the district. Within a strip embracing both the outcrop of the Gueydan formation, as shown on the geologic map (Pl. I.) and two parallel belts, five miles wide, bordering the Gueydan outcrop on either side, some interesting differences in relief are noted. If the strip just defined be subdivided into segments intercepted by parallels of latitude 30 minutes apart, and the highest and lowest points in each segment be determined, the following data[14] are obtained:

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[14]These data are taken from the "Progressive Military Maps" based on topographic work by the "Corps of Engineers, U. S. Army, Southern Division." Some of the elevations are only approximate, but those near railroads and rivers are fairly accurate.

Latitudes	Highest Point	Lowest Point	Relief
Between 30 00 and 29 30	575 feet	325 feet	250 feet
Between 29 30 and 29 00	525 feet	190 feet	335 feet
Between 29 00 and 28 30	510 feet	220 feet	290 feet
Between 28 30 and 28 00	640 feet	180 feet	460 feet
Between 28 00 and 27 30	850 feet	350 feet	500 feet
Between 27 30 and 27 00	1004 feet	400 feet	604 feet
Between 27 00 and 26 30	700 feet	300 feet	400 feet
Between 26 30 and 26 00	370 feet	150 feet	220 feet

The most significant facts brought out by the above list are:

(1) There is a gradual decrease in elevation of 500 or 600 feet along the line of "highest points" both toward the northeast and toward the south from the point of maximum elevation. In other words, along the strike of the strata there is a distinct arching of the surface in northwestern Duval, eastern Webb, northeastern Zapata, and northwestern Jim Hogg counties, with the high point on the arch near Mirando City in Webb County.

(2) The greatest relief (604 ft.) to be found in any of the segments of the belt is in that segment in which the point of maximum elevation also occurs, in spite of the fact that no large streams are found in this locality at the present time. The lowest point in this segment is also higher than the lowest point in any other segment.

(3) The highest elevations in each segment are practically all situated to the southeast or east of the Gueydan outcrop, on the summits of inland-facing escarpments produced by the outcropping lower beds of the Oakville (Upper Miocene) sandstone and of the Reynosa (Lower Pleistocene) limestone. An exception is Tornillo Hill, located on the Karnes-Atascosa county line, eleven miles southwest of Falls City. This knoll of silicified sandstone is situated near the coastward margin of the outcrop of the Fayette (Upper Eocene) sandstone.

(4) The maximum elevations listed above are, in the southern half of the area, higher than any points situated twenty to fifty miles farther inland, up the general slope of

the coastal plain. This fact does not hold for much of the northern half of the district, which is situated northeast of Live Oak County.

These facts point to a geologically recent structural doming of the southern portion of the region with the center of uplift located near Mirando City. This arching was evidently so late that it is still reflected in the present topography, although the relatively small streams in this portion of the area have been rejuvenated sufficiently to produce the maximum relief near the center of this uplift. Deussen[15] has called this the Torrecillas arch and has discussed most of the evidence for it.

PHYSIOGRAPHIC DIVISIONS

Deussen[16] has divided this part of the coastal plain into belts which are, beginning with the one nearest the coast, as follows: (1) Reynosa Plain, (2) Oakville Plain, (3) Frio Plain, (4) Wellborn Plain. Each is given the name of the geologic formation on the outcrop of which it is situated, with the exception of the Wellborn Plain, which occupies the belt coincident with the Fayette outcrop. The writer agrees with these divisions except for the "Frio Plain." Deussen uses "Frio Plain" as the geographic division corresponding to the outcrop of his "Frio formation" or the Frio and Gueydan formations of the present writer. The writer would divide Deussen's "Frio Plain" into three physiographic belts south of the southwestern border of Karnes County. Beginning at the western or northwestern margin of this region the writer recognizes six physiographic divisions. These are briefly described below.

Fayette Hills Belt (Wellborn Plain).—This belt is from five to fifteen miles wide and is coincident with the outcrop of the Fayette formation. Its western margin is marked

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[15]Deussen, Alex., "Geology of the Coastal Plain of Texas West of Brazos River," U. S. Geol. Surv. Prof. Paper 126, pp. 6, 124 and 126, 1924.

[16]*Op. cit.*, pp. 8–10.

by a more or less prominent escarpment which is well developed near Smiley, Gonzales County, at Tilden and at Kings Hills, six miles southwest of Tilden, McMullen County, near Roma on the Rio Grande and at many other localities. This escarpment is not distinct in southern Webb and most of Zapata counties. Here the belt is a rolling plain interrupted along its length by a number of low cuesta ridges. The surface of the Fayette belt is rather maturely dissected by consequent streams transverse to the strike, but the major divides are broad and very gently convex upward, or nearly level in places. The steepest slopes in this, as in all the other belts in the region, occur close to the main streams. Because of the fact that the Fayette is composed of differentially resistant sandstone and clay or shale beds, a number of parallel large and small cuesta ridges are produced, which vary in number and prominence from place to place because of the lenticular character of the beds.

The soil of the Fayette Hills Belt is mainly a light buff or drab sandy loam, sand or loam, becoming finer textured in the southern part of the district where the rocks are more highly argillaceous. Some strips of dark gray clay-loam also occur. In many places, especially at the western margin, rocky sandstone slopes and cliffs are present.

In the semi-arid district south of Atascosa County the Fayette Hills are almost everywhere covered with a dense growth of thorny chaparral from five to fifteen feet in height, and of various genera. In many places prickly pear cactus abounds. Some of these shrubs have no leaves, but have chlorophyll-bearing thorns up to three inches in length. This thick covering of thorny brush makes geologic work difficult. In Atascosa and western Karnes counties the vegetation is mostly mesquite, but other kinds of thorny brush are present. Trees, such as cottonwood, elm, and live oak, occur along many of the larger streams. In Karnes County there is a fairly rapid transition from the brush characteristic of the more arid portion of the central coastal plain into comparatively open woods composed mainly of post oak. Along the river bottoms in the northern half of the district forests of large dicotyledonous trees of several kinds are found.

Frio Plain.—This division, as considered here, is a somewhat irregular, narrow belt which extends from the southwestern boundary of Karnes County to the Rio Grande and ranges in width from a mile or less in much of the northern part, to five miles or more in the southern part of McMullen County. It is coincident in extent with the outcrop of the Frio formation as shown on the geologic map (Pl. I). Although it is a rather narrow belt, it is nevertheless one of the most distinctive physiographic divisions of the area, because the Frio is more easily attacked by erosion than any other of the formations. This belt is a typical, nearly flat, rolling inter-cuesta-plain. In general its surface lies from 100 to 300 feet lower than that of the adjacent physiographic belts, giving the impression of a broad-bottomed valley. The Nueces River has taken advantage of the weakness of the Frio beds and has established its present course along the outcrop of these soft clays across McMullen County, a distance of more than thirty miles. In this portion of its course the Nueces becomes a subsequent stream. Even in portions of its extent not occupied by stream valleys the Frio Plain may exhibit a valley-like form. This feature can be noted on the Tilden-Three Rivers road from two to four miles east of the McMullen-Live Oak county line. Here is a low stretch containing, in the vicinity of the Frio River, pools of stagnant water, around which are found numbers of both dead and living mesquite trees. Since the trend of this low strip is almost transverse to the course of the Frio River, it can hardly be a second bottom of the Frio River. A much larger, although similar northward-trending topographic depression having a width of two miles or more, is located in northeastern Webb County ten or twelve miles northwest and north-northwest of Moglia and three miles west of the Gates ranch house. A few small wet-weather streams empty into the depression, and there is a small intermittent stream, Prieto Creek, flowing northward along its bottom and finally draining into the Nueces River. Notwithstanding the ease with which the

Frio formation is eroded, this depression is much too large a feature to have been produced by Prieto Creek. Moreover, the surface of the depression is covered by a thin veneer of gravel containing many pebbles as much as four inches in diameter which could not have been transported by Prieto Creek with its present volume and gradient. This depression is believed to have been a former channel of the Nueces River at a time when it probably emptied into Baffins Bay in Kleberg County. The other evidence in support of this conclusion will be discussed under "Drainage." In Zapata County this belt, like the Fayette Hills Belt, is not very distinct topographically on account of the more argillaceous, and therefore similar, character of the adjoining formations.

The soil of the Frio Plain is a dark gray or black, sticky clay which cracks along numerous small intersecting joints. Some of the low-lying portions are slightly saline and support a growth of salt-loving sedges. Patches of sandy loam soil occur in places. The vegetation is predominantly thorny chaparral including much mesquite. In Live Oak County and in parts of McMullen County open grassy prairies are found, though stretches of bad-lands are developed on a small scale.

Gueydan Hills Belt.—This physiographic division is produced by the outcrop of the lower and middle beds of the Gueydan formation, namely, the Fant and Soledad members of that formation. The approximate outcrops of these members are shown on the geologic map. This belt extends from western Karnes County to northern Zapata County and ranges from an average width of three miles in Live Oak and eastern McMullen counties to five or six miles in southern McMullen and northern Duval counties. South of Duval County it gradually narrows and is only about two miles wide at the south line of Webb County. The western margin of the belt is marked by a faint to pronounced escarpment which is produced by the outcropping edges of strata of consolidated white tuff considerably more resistant to erosion than the underlying Frio clays. The escarpment is very conspicuous for a distance of thirty-five miles in the neighborhood of the Nueces River in McMullen County, for here the river has carved out a fairly deep strike valley just northwest of the outcrop of the hard tuff beds. In places the scarp is marked by a row of picturesque, glaring white cliffs of tuff as much as fifty feet high. The best example of such cliffs is found at "Chalk Bluffs" on the Ray ranch, five and one-half miles south of Wentz in east-central McMullen County (Pl. III, Fig. 1). North of Duval County the white tuff scarps at the western margin of the Gueydan Hills Belt are the most prominent of all the cuesta scarps in this belt. But there are a number of other cuesta ridges showing westward-facing scarps developed east of the white tuff scarp, especially southwest of Live Oak County where the middle Gueydan consists of alternating beds of differential hardness. Most of the latter cuesta ridges are topographically less important than the nearly flat-topped ridges and narrow valleys produced by consequent or obsequent streams tributary to the Nueces and flowing at right angles to the strike of the cuesta ridges. The general impression one forms of this belt, especially when he looks from the eastern margin up the gentle slopes of the cuestas lying toward the west, is that of a low plateau. In southern Webb and northern Zapata counties the Gueydan Hills become very narrow and are almost completely wedged out by the Oakville and Reynosa escarpments. In most of Zapata County this physiographic division loses its identity and practically merges into a rolling plain formed by the outcrop of several formations, all of which are predominantly clays. This hilly belt is also only locally recognizable northeast of western Karnes County, because the lower Gueydan is composed of less indurated tuff and because there is no strip of Frio between it and the Fayette Hills Belt. Also, the whole Gueydan and the Catahoula into which it grades north of Karnes County have so narrow an outcrop in this part of the district that they do not have a marked effect upon the topography.

In northwestern Duval County are found a number of very striking, flat-topped hills which, if viewed from the west, resemble mesas. They occur near the eastern border and in the center of the Gueydan Hills Belt. The most impressive of these are the Soledad Hills on which the large new Soledad ranchhouse is located and which will serve as an illustration for a number of similar hills in this belt. The Soledad Hills are about two miles long by one-half mile broad and are elongated-elliptical in plan. Their long axis extends north-northwest, making an angle of approximately 60 degrees with the strike of the strata. On all sides except the east and southeast the hills rise steeply from 50 to 125 feet above the level of the surrounding rolling plains. The steepest slopes as well as the highest portions of these hills are located on the western side. This is due to the fact that they are produced by the outcrop of very resistant, thick, volcanic conglomerate beds which dip toward the southeast at the rate of approximately 100 feet to the mile. Because of the gentle dip of these conglomerates the surface of the hills appears nearly flat, except where small intermittent streams have made reëntrants into them. Some of these streams have in fact cut through part of the hard conglomerate and have partially dissected the mass of the hills, dividing the more elevated part into three mesa-like projections. The dip of the beds of which the hills are composed produces a cuesta slope on the eastern side so gradually that the surface of the hills practically merges into the lower plains area to the east and southeast. However, this cuesta slope has been somewhat trenched at its northern end by Soledad Creek, a stream flowing into the Nueces. Thus the hills have a mesa-like appearance on all sides except the southeast, furnishing the most distinctive land mark in Duval County. Similar but somewhat less prominent hills are fairly numerous in the western corner of Duval County, where this conglomerate or other beds of conglomerate are well developed. Small rounded hills are also produced by a more advanced stage in the erosion of such hills.

The soil produced by the weathering of the white tuff is a pale gray loam which is porous and light in weight. The beds of clay, which are commonly interbedded with volcanic tuff, give rise to a dark clay soil much like that of the Frio. The sandstones and conglomerate of the middle Gueydan produce gravelly or sandy loam soils. No stretches of deep sandy soil were observed in this belt.

The Gueydan Hills are in general thickly covered with thorny shrubs much like those which occur in the southern part of the Fayette Hills. On the higher hills near the Reynosa escarpment in southern Webb County small patches of greasewood, typical of the more arid regions of Texas, are found. Much mesquite is present, especially along the courses of intermittent streams where trees of it thirty feet high are found.

Gueydan Plain.—This strip of rolling to nearly flat plains country coincides, for the most part, with the outcrop of the upper Gueydan very friable, loess-like tuff and tuffaceous clay. Like the Frio Plain, this is an inter-cuesta-plain, but it is much broader than the Frio in most of the region. The Gueydan Plain is a distinct physiographic feature all the way from southern Gonzales County to Moglia in eastern Webb County. In the neighborhood of Moglia it narrows abruptly and ends at the foot of the Oakville and Reynosa escarpments, because the younger Oakville and Reynosa formations completely overlap the upper Gueydan. It ranges in width from less than a mile in Lavaca and Gonzales counties to five or six miles in most of Live Oak, McMullen, and Duval counties. Northeast of southeastern Atascosa County practically the entire outcrop of the Gueydan formation is included in the Gueydan Plain, on account of the fact that only a few thin beds of resistant rock occur, even in the lower Gueydan, in this portion of the district. A number of the tributary streams which flow across the Gueydan Plain have developed vertical-sided, flat-bottomed, inner valleys or channels very much like those developed by the streams flowing across loess plains. The tendency to form such valleys is evidently due to the well-developed vertical jointing in the tuffaceous clays of the upper Gueydan similar to that found in loess. Plate VIII, Figure 1, shows such a valley produced by White Creek in west-central Live Oak County.

The soil of the Gueydan Plain is a light gray to pale buff, rather porous loam or clay-loam. It supports through most of the area a chaparral growth similar to that found in the Gueydan Hills. In that portion northeast of Live Oak County the soil is generally black and rather fertile. Many open, prairie-like stretches occur, but some parts are covered with a scattered growth of small oak, mesquite, and other small to medium-sized trees. Along the major streams north of Duval County are fringes of timbered country.

Mesas.—Interrupting the monotony of the Gueydan Plain in southeastern McMullen and northwestern Duval counties are eight abrupt mesas or groups of mesas rising 100 to 160 feet above the adjacent plain. The largest of these, Loma Alto Mesa, is the highest point in McMullen County. San Caja is the most northerly of the mesas. The mesas owe their existence to the presence of a cap of siliceous-cemented, very hard Oakville sandstone and conglomeratic sandstone. This cap rock, although usually only from two to twenty feet thick, is so much more resistant to erosion than the underlying pulverulent tuff and clay that a surprisingly large amount of the latter has been removed, compared with the volume of the cap rock eroded during an equal period of time. The cap rock is nearly flat-lying, with the exception of San Caja where a definite tilt of 5 degrees or more toward the southwest is evident even in a photograph. The flat tops of most of these mesas have given rise to such fanciful names as "Devils Center Table," which is applied to the central mesa of the La Chusa group. A photograph of La Chusa is found in Plate IV of Deussen's paper. The slopes of all these mesas are practically covered with loose slabs of the cap rock left thus by removal of the soft underlying material. Overhanging cliffs are quite common at the base of the sandstone cap.

With the exception of Loma Alto, all of these mesas are situated on the eastern portion of the Gueydan Plain, as is to be expected since they are salients of the Oakville escarpment which have been separated by stream erosion from the main mass of the sandstone escarpment which forms the eastern boundary of the Gueydan Plain. In some places long, peninsula-like salients are in the process of being segmented into island-like mesas by headward erosion of streams into their sides. Loma Alto is situated fully two miles back of the main Oakville escarpment and owes its greater height to the fact that its cap rock is located higher up the regional dip of the basal Oakville.

Chalcedony Knobs.—In addition to the flat-topped mesas several much smaller conical or rounded knob-like hills are found in McMullen, Duval, and eastern Webb counties on the Gueydan Plain and in the western edge of the Oakville Hills Belt. Some of these knobs when seen from a distance are suggestive of small volcanic necks. They are only from 30 to 75 feet higher than the country immediately surrounding them, and 100 to 300 yards in diameter, but they furnish striking land-marks on account of their peculiar form and steep sides. These knobs look as though perched upon low circular eminences which have slopes that are slightly concave in profile. Such knobs owe their existence to the fact that they are composed of massive opal and chalcedony, or very hard quartzite-like sandstone which in places shows a good desert varnish. The principal knobs of this type are Tendita, Paint Hill, and the Seven Sisters, all of which are situated near the south line of McMullen County, from three to six miles east of Loma Alto Mesa, and Sernosa Hills, located about three miles southeast of the Soledad Hills (south end) in Duval county.

The Picachos Hills, in northern Duval County five miles southwest of Loma Alto, consist of three elliptical ridge-like elevations from forty to sixty feet high and a few much smaller and lower ridges trending North 42° East. The individual ridge-like hills do not form a continuous line but are arranged *en échelon,* with the general trend of the group likewise in a northeast direction. They owe their elevation to the resistance to erosion of steeply-dipping veins of chalcedony and opal.

Oakville Hills Belt.—Situated immediately southeast and east of the Gueydan Plain is a wide strip of rolling hilly country, of which the western portion has a general elevation of from 50 to 150 feet above that of the Gueydan Plain. The elevation of the Oakville Hills Belt gradually decreases toward the southeast or east following the regional slope of the coastal plain. Probably the boldest escarpment in the region north of Duval County is that which separates the Oakville Belt from the Gueydan Plain. This is known as the Oakville escarpment, because it is capped by the Oakville sandstone. The sandstone has a much greater resistance to erosion than the underlying Gueydan tuff. The prominent mesas, such as Loma Alto, are portions of this scarp which have been disconnected from the main body by erosion. The Oakville Hills Belt is coextensive with the outcrop of the Oakville formation, northeast of McMullen County, and has an average width of seven miles. In this county it narrows rapidly and its breadth averages only two or three miles in McMullen and Duval counties. In eastern Webb County the overlying Reynosa limestone so nearly completely overlaps the Oakville that the escarpment formed by the western edge of the Reynosa merges into the Oakville scarp. The Oakville Belt is thus practically absent as a separate physiographic unit in Webb and in most of Zapata and Jim Hogg counties, but emerges from beneath the Reynosa again in northwestern Starr County. In southern and central Starr County it attains a breadth of from three to five miles. The most dissected part of the Oakville Hills Belt is near its western margin, while the surface near the eastern margin is gently undulating.

The soil of this belt is usually a deep mantle of light buff to light gray, medium-grained sand. It supports a thick growth of thorny brush like that found on most of the other physiographic divisions in this part of the district. In Live Oak and Karnes counties many patches of post oak, live oak, and other hardwoods alternate with the brush. In eastern Karnes and the countries farther northeast the belt is generally a treeless, hilly prairie.

Reynosa Cuesta Plain.—The Reynosa Plain is one of the largest physiographic divisions of the coastal plain of Texas, attaining a width of forty miles in the vicinity of Hebbronville, Jim Hogg County, and extending from Guadalupe River to the Rio Grande. The numerous large outliers of Reynosa limestone capping many of the higher hills between its present western border and the Balcones escarpment suggest that this plain was formerly much more extensive than it is at present. The time of its greatest extent was not later than the Pleistocene Epoch, for the Reynosa limestone is of lower Pleistocene age. Since forming it has been warped considerably as shown by a discordance in the elevation of its surface of over 500 feet between a point on its western edge near Mirando City, Webb County, and a similarly situated point near Green, in southern Karnes County. Deussen,[17] in discussing this warping of the Torrecillas Plain, the higher of the two principal terraces into which he divides the Reynosa Plain, calls the upwarped part of this plain the "Torrecillas Uplift," as has been previously mentioned.

The western border of the Reynosa Plain comes into the area under discussion only in that part which is situated south of Duval County, but the writer has crossed the entire width of the plain at several places. Its western margin is marked by a very abrupt erosional scarp. Streams have cut reëntrants into the scarp at numerous localities, but in other places, notably in eastern Webb County, the scarp forms a nearly continuous line of cliffs from 20 to more than 100 feet high. Some of the salients from this scarp have been disconnected from the main Renoysa Plain, forming mesas similar to those capped by Oakville in McMullen County. These Reynosa-capped mesas are practically all situated less than one-fourth mile from the main Reynosa scarp and are generally much smaller and rarely so prominent as those capped by the Oakville.

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[17]Deussen, Alex., U. S. Geol. Surv. Prof. Paper 126, pp. 5, 6, 124 and 126, 1924.

On account of its cuesta character the surface of the Reynosa Plain is progressively more dissected toward the west, being quite rugged close to the escarpment parts of it. The broad, flat-topped interfluves and narrow, steep-sided valleys indicate that the youthful stage in the cycle of erosion has not been passed. There is thus a greater area of nearly flat surface than of distinctly uneven surface in this belt, so that the term "plain" is thought to be the most appropriate designation for this physiographic division.

In portions of the Reynosa Plain the soil is thin and the country is rocky with many irregular patches of white limestone and limy conglomerate outcropping. Other parts are well covered with a thick mantle of red clay or red sandy loam soil and locally by deep yellowish sand or coarse gravel. South of the Nueces, the more dissected westerly part of this belt is usually covered with a close growth of chaparral and cactus, forming in many places impenetrable thickets. The rest of the plain is an open grassy prairie country with occasional clumps of mesquite dotting its surface here and there.

DRAINAGE

The principal river systems, beginning at the northeast, are Guadalupe, San Antonio, Nueces, and Rio Grande. Only Nueces River receives important tributaries in this region. With the exception of the well-known Rio Grande, all of these streams head in the Edwards Plateau from 190 to 250 miles from the coast. Except for the Nueces and its confluent, the Frio, these rivers flow across the district in a definite southeasterly direction and are normal consequent streams. These rivers and some of the larger creeks have developed silt-covered flood plains from one-quarter mile to more than two miles wide. In addition to the flood plain and the high Uvalde terrace, which represents the inland extension of the surface of the Reynosa Plain mentioned above, one to three silt or gravel-covered terraces are usually present on one side or the other of the important streams. These concordant terraces represent successive stages in the uplift of the coastal plain. Since Deussen[18] has treated these terraces very thoroughly, they are merely mentioned by the present writer.

Probable capture or diversion of the Nueces River.—The courses of the Nueces and its confluent, the Frio, have certain distinctive features which have never been fully explained. Northwest of southeastern La Salle County the Nueces flows southeastward, practically paralleling the courses of the other major streams of the coastal plain. From southeastern La Salle County to Oakville, Live Oak County, a distance of fifty-six miles, measured in a straight line, the river flows northeast, almost at right angles to its upper course. Near Oakville it joins the combined Atascosa and Frio, makes a sharp, right-angled turn to the southeast and continues in this direction to the Gulf of Mexico at Corpus Christi Bay. A few miles farther north the Frio practically repeats the course of the Nueces except that the bends are not quite so pronounced, and it is evident that the same agencies caused the change in the course of both rivers. Deussen[19] explains the abnormal courses of these rivers as follows:

> The map shows that no streams cross the Torrecillas uplift in its highest part. The upper course of Nueces River heads directly for it, but instead of crossing the uplift the stream has apparently been deflected by it more than 50 miles to the northeast. Frio River shows a similar though not so pronounced deflection before it joins the Nueces near Oakville. The minor drainage lines on the uplift also seem to have been affected by the uplift, for they radiate from it in all directions. This arrangement suggests that the uplift not only diverted Nueces and Frio rivers but established a new system of consequent streams upon its slopes.

Deussen uses the peculiar bends in the Nueces and Frio rivers in support of the efficacy of his Torrecillas uplift but gives no definite evidence that these rivers were actually diverted from former channels, nor does he by any means

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[18]*Op. cit.*, pp. 13, 14, 15 and 114–119.
[19]*Op. cit.*, p. 126.

rule out the alternative that the changes in the courses of these rivers were caused by stream piracy.

The writer would submit the following data in support of the existence of a former channel for the Nueces:

(1) In northeastern Webb County, southeast of the upper large bend in the Nueces is found the very wide, valley-like depression described on page 23 which may be traced for ten miles or more in a north-south direction. The floor of the depression is nearly covered with loose chert gravel of the same type as that found on the gravel terraces of the Nueces in McMullen County, and is apparently incapable of being distributed over such a wide belt by the small intermittent stream, Prieto Creek, which now occupies the center of this depression. The gravel does not furnish such satisfactory evidence as do the size and form of this depression, for the gravel may be residual from a former capping of Reynosa, which commonly carries abundant chert pebbles.

(2) The Reynosa escarpment makes a very pronounced eastward bend two miles north of Moglia, near the east line of Webb County, and there is a very large southeastward-extending reëntrant in this scarp in western Duval County, six miles northeast of Moglia at Parilla Creek. This reëntrant is suggestive of a water-gap produced by a large stream. If the upper course of the Nueces were projected it would pass through this gap and to the Gulf via Baffins Bay.

(3) The elevation of the Nueces River in the southeastern corner of La Salle County where it makes the bend to the northeast is only 320 feet. That of the Rio Grande at Laredo, which is the point on the latter river nearest the bend in the Nueces, is about 420 feet. Also the elevation of the highest points on the present surface is 500 feet greater in eastern Webb County than in Karnes County east of the Nueces, indicating a general lowering of the land surface toward the northeast so that the river located farther to the east has the advantage.

(4) Southwest of Karnes County the Reynosa and Oakville escarpments are distinctly higher than at any points in the territory situated twenty to fifty miles farther inland,

although this is not true for Karnes County and the country northeast along this belt. These escarpments thus constitute a barrier which is difficult for rivers to cut across.

(5) Most of the large streams in the Texas coastal plain empty into irregular shallow bays which have apparently been produced by a recent slight depression of the coast or by scour of these rivers accompanying a recent uplift. Such a bay is Baffins which does not now receive any large stream.

If the Torrecillas uplift is responsible for the change in the course of the Nueces, a reasonable assumption, the change necessarily occurred after the deposition of the Reynosa, which is involved in the arching. Therefore this change must have taken place in Pleistocene or Recent time, as the lower Reynosa is Pleistocene in age. Since this is recent enough for portions of the former channels of the river to be preserved, the valley-like depression mentioned above could be an old channel of the Nueces.

This change in course may have been produced (1) by river piracy, (2) by diversion, or (3) by a combination of the two. Deussen, in the preceding quotation, states that the Nueces and Frio were "deflected." This is interpreted to mean that these rivers left their channels of their own accord, because they were unable to cut down as fast as the uplift proceeded, although he gives no evidence for the exclusion of piracy. Deussen states further that "the vertical movement at these places (Torrecillas and Ojuelos) was probably not less than 200 feet." An uplift of this magnitude is quite insufficient to divert the Nueces and Frio rivers at their present degree of intrenchment, unless it were exceedingly rapid or were associated with a depressive movement in the region of the present subsequent portions of these rivers. That the whole district has been recently uplifted to some extent is shown by the accordant terraces found along these rivers at present.

From the evidence at hand the writer is unable to rule out the hypothesis that the rivers were actually diverted. It seems just as logical, if not more so, for the major portions of these streams to have been captured by the headward erosion of subsequent tributaries of the present Atascosa along a belt of weak strata occupied by the present Frio Plain. The surface of the main divides in the district has already been shown to have a definite northeastward plunge. The Atascosa would thus have been in a favorable position to effect such a capture.

The remaining alternative is that such a subsequent tributary to the Atascosa did exist before these rivers changed their courses but did not actually tap the rivers. Instead, the rivers at flood time may have suddenly found a more favorable channel to the northeast than that across the Torrecillas arch and, coming to the subsequent valleys formed by tributaries to the Atascosa, followed these valleys to their junction with the Atascosa. Even the hypothesis just stated would not hold unless the rivers were very low grade streams and much less intrenched than at present.

Unfortunately, no conclusive evidence as to which of the three hypotheses is correct can be gained by a study of the comparative width of the Nueces Valley both above and below the point where it makes the northwestwardly swing. This inability to reach a definite conclusion is due to the fact that throughout most of the subsequent stretch the valley is situated in the very soft and easily removed Frio clay. In western McMullen County where the river cuts obliquely across the harder lower Gueydan tuff beds several steep bluffs are present; the inner valley is somewhat narrower than the portion just above the subsequent stretch. There are rapids in the river here, but all these features may be simply due to the greater resistance to erosion of the tuffs, which would prevent the river from widening its new valley so quickly here as it would higher up the course.

STRATIGRAPHY

The geologic formations exposed in the coastal plain of Texas consist principally of marine and fresh water sandstones, clay, limestones, conglomerates, and mixtures of these types ranging in age from lower Cretaceous (Comanchean) to Recent. Beds of pyroclastics—tuffs, volcanic conglomerates, bentonites, and tuffaceous sands and clays—are present both in the Cretaceous and the Tertiary. Near the Balcones fault zone, at the northwestern margin of the coastal plain, ten or more volcanic necks and small dikes, sills and laccoliths are found. Most of the intrusives in the coastal plain are situated in Uvalde County from sixty to seventy-five miles west of San Antonio.

Duessen[20] has given a table of the formations of the southwestern coastal plain showing their general lithology and thickness; the writer will merely list the formations in order, for the reader's convenience. This list is in agreement with Deussen's division except that the "Frio clay" of Deussen is separated into two formations, the Frio (corresponding to the lower part of the Frio clay of Deussen) and the Gueydan tuff. The Lapara sand is included in the Lagarto. The sequence and general lithology of the Tertiary formations of the southwestern coastal plain of Texas are as follows:

15. Alluvium and wind-blown sand		Recent
14. Beaumont clay. Disconformity? 13. Lissie gravel. Disconformity? 12. Reynosa limy conglomerate and limestone Unconformity.		Upper to Lower Pleistocene (Fluviatile)
11. Lagarto clay, sandstone and sand. Unconformity? 10. Oakville sandstone. Unconformity.		Lower Pliocene-Upper Miocene (Fluviatile)
9. Gueydan tuff, volcanic conglomerate, sandstone and bentonitic clay. (Equivalent, at least in part, to Catahoula sandstone.)		Oligocene or (and) Lower Miocene ? (Continental pyroclastic and fluviatile)
8. Frio clay. 7. Fayette sandstone, clay and shale.	Jackson Group	Upper Eocene (Marine,palustrine and fluviatile)

[20]*Op. cit.*, pp. 20–23.

6. Yegua clay. 5. Cook Mountain sandstone. 4. Mt. Selman clay and sandstone. Unconformity.	Claiborne Group (Marine and some fluviatile)	Middle Eocene (Marine and continental)
3. Carrizo sand and sandstone. Disconformity. 2. Indio sandstone, shale and lignite. Unconformity.	Wilcox Group (Mainly fluviatile)	
1. Midway clay.		Lower Eocene (Marine)
Unconformity. Upper Cretaceous clay.		

Of the above formations only the Fayette, Frio, Gueydan, Oakville, and Reynosa outcrop in the portion of the coastal plain with which this paper deals. These formations have a regional dip to the southeast ranging from 80 to 120 feet per mile in the oldest or lowest and about 20 feet per mile in the youngest or highest. The truncation of their dipping strata by erosion causes the formations to outcrop in belts which roughly parallel the present shore line of the Gulf of Mexico. The Gueydan is the formation with which this paper is particularly concerned and the formations associated with the Gueydan will be described mainly with the purpose of bringing out their lithologic dissimilarity to the Gueydan and their stratigraphic relations to it.

OTHER FORMATIONS OUTCROPPING IN THE VICINITY OF THE GUEYDAN

Underlying Formations (Jackson Group)

FAYETTE FORMATION

Distribution and stratigraphic relations.—The Fayette outcrops in a belt which averages 4 miles in breadth in Gonzales County, gradually increases in width to 7 miles in Karnes and Atascosa counties and to 8 or 10 miles or more in parts of McMullen and northeastern Webb counties. In southern Webb County it narrows rather abruptly to 5 miles or less near Aguilares, widens to 10 miles or more in northern Zapata County and narrows again to 7 or 8 miles near the Rio Grande in western Starr County. Southwest of the Atascosa-Karnes county line the Fayette outcrop is separated from that of the Gueydan by a rather narrow strip of Frio clay but northeast of that line no Frio clay can be recognized; here the Gueydan is found to rest directly on the Fayette. The contact between the two latter is apparently conformable or slightly disconformable. The term "Fayette" is used by the writer with the same significance as Deussen uses it in Professional Paper 126.

Lithologic character.—There is considerable difference between the prevailing lithologic character of the Fayette in northeastern Karnes County and in Gonzales County and its character in the portion of the area farther southwest discussed in this paper. In the more northerly district much of the Fayette consists of very light grayish-cream to white, non-calcareous, platy-bedded, sandy to silty tuffaceous shales or very fine-grained shaly sandstones, which very commonly carry leaf impressions. This rock is generally more or less cemented with opal although some of the more friable samples of it break down readily into a doughy mass. Under the microscope the argillaceous substance which constitutes most of the shale is found to have a mean index of refraction of about 1.51, an index far too low for kaolin. It is identified as montmorillonite, the principal mineral of bentonite, which is commonly formed by the alteration of volcanic glass. The light weight of this rock suggests a tuff although only a few angular, much altered grains which suggest volcanic glass are noted. No fresh glass grains, which are abundant in the Gueydan, were seen in four typical fresh samples taken from as many localities in Atascosa, Karnes, and Gonzales counties. When a mechanical separation of the samples is made, grains coarser than 1/16 millimeter in diameter are found to comprise less than 1 per cent to 10 per cent of the entire sample. Most of these grains are between ⅛ and 1/16 millimeter, and very few grains coarser than ¼ millimeter are present. The sorting is considerably better than rocks of somewhat similar appearance found in the Gueydan formation. A large number of sub-rounded grains of various minerals including numerous chert grains are noted, indicating that the material of which the tuffaceous shale is composed has been reworked or mixed with non-volcanic material, probably by water, and therefore probably is not a true volcanic tuff or dust. The mineral composition of fine sand grains found in this rock with their estimated percentages, taken from a typical sample collected on Dewee's ranch, seven miles southwest of Falls City, is as follows:

Plagioclase (mostly oligoclase and andesine)—32%; opaline crusts (from cement)—20%; orthoclase and sanidine—10%; quartz— 25%; chert—10%; chalcedony—2%; augite—trace; hypersthene—trace; brown hornblend—rare; green hornblend—rare; magnetite—trace; tourmaline (brown and blue varieties)—rare; apatite—trace; altered volcanic glass(?)—trace; chlorite—trace; limonite—trace. Most of the grains of heavy minerals are rounded. Casts of small *Corbula*-like pelecypods ⅜ inch in length are occasionally found in the dark-colored beds of this shale.

Similar light-colored tuffaceous shales and, also, extremely friable, flaky and thinly laminated, light buff to grayish-pink, tuffaceous shales carrying a great abundance of leaf impressions are found in several horizons in the Fayette farther southwest, in western Karnes and in Atascosa, McMullen and other counties. These beds also contain a number of worn grains and are evidently reworked volcanic dust deposits. Beds of "volcanic ash" have been reported from the Fayette by several writers as mentioned previously, but such beds are generally thin and do not comprise much of the formation. In the wells west of Calliham a bed of surprisingly hard, white, kaolin-like bentonite is encountered near 600 feet and practically at the base of the Fayette. This bed is very hard to drill through on account of the swelling of this substance.

In the upper part of the Fayette (or possibly lower Gueydan with a Catahoula facies) in Gonzales County are found prominent beds of light gray or brownish-gray, medium-grained, indurated, quartzose sandstone, the weathered surfaces of which show abundant small criss-cross, vein-like ridges approximately an inch in width. On breaking this rock the vein-like masses are found to extend through the rock and to be composed of harder sandstone of a nearly pure white color, while the areas between them are more friable and more or less stained with iron oxide. The vein-like masses are evidently due to the leaching and cementing action of silica-bearing solutions migrating along the joint cracks in the sandstone. Since the rest of the rock does not possess so much cement it is less resistant to weathering and erosion. The white color is due in part to the sinter-like opaline cement.

Some horizons of fine-grained, light buff, argillaceous sandstone and cavernous silty to sandy clay or shale carry a fair abundance of marine pelecypods and gastropods of Eocene age. The cavernous spaces in this sandstone are due to the solution of numerous fossils. Such a bed outcrops four miles southwest of Sample, Gonzales County. These fossils together with the numerous plant remains from the tuffaceous beds have fairly well established the Jackson age of the Fayette.[21]

In La Salle, McMullen, Atascosa, and western Karnes counties the Fayette is developed in its more typical facies and consists largely of sandstones. The most common lithologic type, as especially well illustrated in numerous well sections in Live Oak and McMullen counties, is a light gray, friable, massive to platy-bedded, or laminated, non-calcareous to slightly calcareous, fine-grained, silty, arkosic, sandstone. Cross-bedding is very common, though it is not always present. On weathering most of the sandstone becomes light buff in color. In the majority of the sandstone beds fossils are rare but several horizons carry an abundance

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[21]Deussen, Alex., U. S. Geol. Surv. Prof. Paper 126, pp. 82–84, 1924.

of generally poorly preserved, chalky-looking pelecypod shells, including a large number of *Tellina eburniopsis?* Conrad. Lignitic streaks or partings and thin beds of olive-green clay are also common in many of the sandstones.

The microscopic analysis of a core sample of light gray, friable, imperfectly laminated, slightly calcareous, very fine-grained silty sandstone from a depth of 648 feet in the Black Panther Oil Company's Nicols No. 1 well (located in northern Live Oak County just west of the Atascosa River, five miles north of Three Rivers) will illustrate the physical and mineralogical character of much of the Fayette sandstone. The description is as follows:

Sorting.—Above ½ mm. (only pyrite concretions)—1%; ½–¼ mm.—3%; ¼–⅛ mm.—30%; ⅛–1/16 mm.—36%; silt and clay—30%; Grains are mostly subangular.

Composition of washed material (coarser than 1/16 mm.)—Plagioclase (mostly andesine and labradorite)—35%; orthoclase and sanidine —4%; quartz—10%; chert—25%; gray or greenish-gray andesite(?) grains (some show hyalopilitic texture)—10%; calcite (from cement) —1%; foraminifera (*Globigerina* sp. and *Textularia globulosa*)—5%; zircon—trace; barite—trace; magnetite—trace; muscovite and leached biotite—trace; silicified wood fragments—trace. The foraminifera listed above are probably secondarily derived from the Cretaceous clays.

The extraordinarily high percentage of plagioclase and the presence of small worn grains of andesite or a similar extrusive igneous rock are the noteworthy features made evident by the above descriptions and are a clew to the probable origin of the sandstone. This is not a local characteristic of the Fayette but has been found to be true of outcrop and well samples of this formation from Starr, Webb, McMullen, Karnes, and Gonzales counties as well.

Massive beds of extremely hard, light gray to grayish-buff, medium-grained arkosic sandstone occur at many localities in the Fayette, especially in the upper portion. This rock breaks with a conchoidal fracture like quartzite, through some of the quartz, feldspar, and chert grains, because the chalcedonic and opaline cement is almost as resistant to fracture as the sand grains. This hard sandstone is responsible for the existence of more or less commanding hills, such as Tornillo Hill on the Karnes-Atascosa county line.

Massive to imperfectly laminated clay strata of an olive-green to buff color, some very slightly calcareous and often gypsiferous clays and some clays of a purplish-red color are more extensively developed than the sandstone strata, in the Fayette outcrops south of Webb County and are not uncommon as far north as western Karnes County. In many places south of Atascosa County such beds carry great numbers of large oysters, *Ostrea georgiana* Conrad. These are especially abundant near the Rio Grande, a number of the outcrops of Fayette being literally covered with fragments of these shells.

Many thin beds or streaks of lignite and lenses of unfossiliferous, apparently concretionary limestone, are encountered in this formation, while silicified wood fragments and even complete logs are present in many places.

Veins in the Fayette.—Near Calliham in eastern McMullen County the Fayette greenish clays contain lenticular, horizontal veins of creamy-white, silky, fibrous aragonite, partly recrystallized into calcite, which attain, in places, a thickness of ten feet or more for a single vein. These veins usually follow the bedding planes in the clay and the aragonite fibers are perpendicular to the vein walls. A hill one-half mile west of Calliham is capped by a ten or fifteen-foot vein of this aragonite. This hill is crossed by the Calliham-Tilden road where the upper part of the horizontal vein is well exposed in a road cut. The aragonite is so abundant at this locality that many tons of it have been hauled away to fill mud-holes in the roads of this vicinity. This is probably the only case on record of nearly pure vein aragonite being used for road metal. Several other veins of the same kind outcrop lower down this hill and on nearby hills.

The veins occur near the crest of the faulted anticline on which the Calliham oil field is situated. Since the wall-rock clay is very soft and plastic, and since thin, lenticular, horizontal inclusions of the unaltered clay are isolated in the midst of the non-argillaceous vein material, it is evident that no gaping fissures existed. Therefore, this seems to be a case where the force of crystallization of the aragonite, probably facilitated by the attendant relief of pressure in the crest of the anticline, has been sufficient to push up gradually the overlying clays so that the veins have been able to attain their present thickness.

Origin.—The presence of abundant leaves of land plants and lignitic streaks in some strata of the Fayette and numerous marine fossils in other beds indicate low-lying coastal plain or near-shore conditions of deposition with frequent oscillations in the level of the land surface. The formation is thus, in part, continental (probably fluviatile and palustrine) and part marine. That the Fayette sediments were subjected to current action is inferred from the cross-bedded character of some of the sandstones. The source of at least part of the detritus was probably in the interior of the coastal plain as shown by the presence of small, redeposited foraminifera derived from the Cretaceous formations farther inland. The predominance of feldspar, the occurrence of grains of altered volcanic rock and the beds of tuffaceous shale and altered volcanic dust show that volcanic eruptions were in progress immediately preceding, and during Fayette time. The source of this volcanic material was possibly the same as that from which the succeeding Gueydan tuff was derived but the tuffaceous material of the Fayette is very fine-textured and may have come from a distant source such as the Rocky Mountain Tertiary volcanoes. Some of the plagioclase may have been derived from plutonic dioritic or granodioritic rocks. If so, the source of this part of the feldspar was probably several hundred miles distant, because the nearest area of plutonic rocks now exposed (the Central Mineral Region) is composed very largely of true granites and gneisses containing abundant microcline but only a little plagioclase. Practically no microcline is noted in the Fayette. It is apparent that a large amount of volcanic material has entered into the composition of the Fayette sandstones on account of the great quantity of glassy plagioclase feldspar and worn fragments of more or less altered andesite. It might be conceived that large deposits of volcanic debris were extant in Fayette time a short distance to the northwest of its present outcrop, but the Yegua formation which underlies the Fayette in apparent conformity contains little volcanic tuff or ash, while in the formations outcropping still farther inland volcanic debris is even less common. In order to explain the large amount of plagioclase feldspar in the sandstones which comprise most of the Fayette formation, an enormous volume of igneous, possibly volcanic, debris must have been removed. It is impossible to tell, without a petrographic study of the older sedimentary formations outcropping farther inland just how much of this feldspar might have been derived from older sediments outcropping in the coastal plain of Texas. The chert, tourmaline, probably much of the quartz, the secondary foraminifera, and some of the other components of the Fayette show that the volcanic debris was mixed with a large amount of non-volcanic detritus, probably derived from the erosion of Cretaceous and Lower Eocene sedimentary rocks which were outcropping in the Texas coastal plain to the west and north.

FRIO FORMATION

Distribution.—As was mentioned before, the name "Frio formation" is used here with a different significance from its usage by any previous writer, so far as known. The Frio formation here designates those predominantly argillaceous strata which lie conformably or disconformably beneath the light-colored or white tuffs of the Gueydan formation and conformably on the Fayette formation, which consists largely of sandstones in most of the area under discussion. The writer has followed the outcrop of the Frio along a belt paralleling the Fayette outcrop from a point in extreme southeastern Atascosa County near the Karnes county line, to the Rio Grande. In Atascosa and Live Oak counties the belt is quite variable in width because it is partly or almost completely overlapped by the Gueydan formation. Its width in these two counties and in eastern

McMullen County ranges from less than a mile to four miles, as shown on the geologic map. The Frio-Fayette contact south of central McMullen County is only approximately located on the map. This lower contact is very difficult to follow accurately on account of the dearth of outcrops. However, the Gueydan-Frio contact, or upper contact, is believed to be fairly accurate, because the relatively hard beds of the basal Gueydan are apt to outcrop and are therefore more easily traced, except in Zapata County where few outcrops of any kind are seen, save along the Oakville-Reynosa escarpment. The Frio formation fails to outcrop northeast of Atascosa County although it is quite typical in appearance up to the point of its disappearance. Northeast of this point the Gueydan rests on the Fayette so that it is quite unlikely that the Frio beds pass into lithologically dissimilar beds along their strike. Their disappearance is possibly due in part to the thinning of the Frio toward the northeast but they are more probably overlapped by the Gueydan, because some unfossiliferous, pink and green clays, lithologically similar to the Frio, were encountered in the Lavaca County Oil Company's Laas No. 1 well in eastern Lavaca County between 2,070 and 2,392 feet and in wells in Karnes County. The log of the Laas well is found in a publication by the present writer.[22]

Lithologic character.—The Frio consists almost entirely of very soft and plastic, gypsiferous, creamy-green to light grayish-green and purplish-pink clays or variegated pink and green clays. The clay is generally unstratified and breaks up into minute angular fragments along the closely spaced joint cracks so that good outcrops are very difficult to find. It is quite uniform in character throughout the region of its outcrop. Many beds contain numerous creamy-white, calcareous concretions and a few beds carry cream-colored opaline and chalcedonic concretions up to six inches in diameter. One of the best exposures of the upper Frio beds is found in a cut along the San Antonio, Uvalde &

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[22]Bailey, T. L., "The Geology and Natural Resources of Colorado County," Univ. Texas Bull. No. 2333, pp. 150–153, 1923.

Gulf Railway, one mile northwest of Fant City, Live Oak County. This section is of considerable interest because it illustrates the general lithology of the Frio and the apparently conformable character of the Gueydan-Frio contact, and also shows a marked, reversed dip of the strata due to either a small anticlinal fold or a fault with the northwest side downthrown.

SECTION IN CUT ON S.A.U. AND G. RY. 1 MILE NORTHWEST OF FANT CITY

Gueydan (Fant member):

2. Grayish-white, very friable, rather massive-bedded tuff or bentonitic volcanic sand (exposed only at northwest end of cut on account of reversed dip) .... 12′

Frio:

1. Creamy-gray to greenish, plastic, gypsiferous clay containing thin lenticular streaks of sandy material. The gypsum occurs in clusters or in irregular streaks of acute-edged, platy crystals from 1/16 to 1/4 inch long distributed rather abundantly through the clay. The surface of the clay is nearly covered with these selenite crystals. Approximate thickness exposed at southeast end of cut .... 15′

Strike N 30° E; Dip 10° NW (Taken on No. 2).

A complete section of the Frio in Live Oak County was obtained in H. Coquat and Associates' Hicks No. 1 well and is given on pages 94–100.

The contact between the greenish-gray Frio clay and the brownish-gray, medium-grained Fayette sandstone is exposed at the bridge on the Three Rivers-Whitsett road one mile south of Whitsett. The basal beds of Frio exposed here consist of creamy-green very soft and plastic, bentonitic clay which contains a great abundance of flattish gypsum crystals. These crystals are generally in irregular seams but may be scattered through the rock. The clay is noncalcareous and weathers to a tawny color.

PETROGRAPHIC DESCRIPTION OF FRIO CLAY, 1 MILE SOUTH OF WHITSETT, LIVE OAK COUNTY

Sorting.—About 15% of washed material (coarser than 1/16 mm.) is present in the sample and fully 90% of this washed material is secondary gypsum crystals or fragments of them. The sand grains that occur are subangular to angular, and are between ¼ and 1/16 mm. in diameter.

Composition of Washed Material.—Gypsum—90%; plagioclase (mostly oligoclase, but occasional albite, andesine and labradorite grains)—3%; orthoclase and sanidine—1%; quartz—5%; chert 1%; volcanic glass (often pitted as if by corrosion)—trace; microcline—rare; barite—trace; magnetite—trace; green hornblend (well rounded)—trace; calcite—trace; titanite (rounded)—rare; foramifera (fragments of *Globigerina,* probably derived from Cretaceous rocks)—trace.

A sample of Frio clay from four miles west of Rio Grande City was found to have a composition almost identical to that of the above sample except that the sample from near Rio Grande City contains a number of composite concretions of limonite, goethite, and gypsum. *Ostrea georgiana,* an Eocene oyster, was also found here.

A similar analysis was made of a purplish-pink and light grayish-green, mottled, gypsiferous, marly clay, containing some bentonite and numerous microcrystalline calcareous concretions, collected from a small gully near the northwest corner of Live Oak County, six miles southeast of Crowther.

PETROGRAPHIC DESCRIPTION OF FRIO CLAY FROM NORTHWESTERN CORNER OF LIVE OAK COUNTY, 6 MILES SOUTHEAST OF CROWTHER

Sorting.—Washed material comprises only about ½% of the sample. About 90% of this washed material consists of secondary calcite and gypsum. Even when the gypsum and calcite are excluded the sorting of the washed material is poor, the sand grains ranging from 1 mm. (rare) to 1/16 mm. with the maximum separate between ¼ and ⅛ mm.

Composition of Washed Material.—Calcareous concretions (up to 2 mm. in diameter)—55%; transparent granular calcite—6%; gypsum crystals—30%; plagioclase—2%; sanidine—trace; quartz—trace; chert—1%; volcanic glass (partly altered)—trace; opal—1%; green hornblend—1%; hypersthene—2%; epidote—1%; barite—trace; zircon—trace; titanite—trace; magnetite—trace; pyrite—trace;

limonite—trace. No fossils are noted in this sample, but *Textularia globulosa* and *Globigerina* sp., which are probably derived from the Cretaceous marls, are quite numerous in an associated bed of creamy-green calcareous clay.

Beds of flaggy, cross-bedded, mottled brownish-pink and grayish-green, friable, argillaceous, fine-grained sandstone are locally present near the top of the Frio. The most prominent outcrop of this rock is found in the southwestern corner of McMullen County, two miles northwest of Walker ranch. These sandstones are associated with clays carrying opaline concretions. Thin beds of concretionary limestone are of very local occurrence in the Frio.

The only indigenous, aquatic fossils seen in the Frio clay by the author were a few specimens of *Ostrea georgiana* Conrad found in the vicinity of the Rio Grande. These oysters are much more abundant in the Fayette formation. Portions of silicified trees are found in the Frio also.

Correlation and stratigraphic relations.—The Frio clay was named for the Frio River by Dumble[23] in 1894 and the type locality then described occurs in the upper Gueydan formation of the present writer. However, in a later paper,[24] he maps the Frio in Live Oak County in such a way that it includes most of the Gueydan and practically none of the Frio (as recognized in the present paper), while in McMullen County it includes the Frio and also most of the lower Gueydan but excludes the beds of his type locality in Live Oak County. The same beds found at this type locality are placed in the Oakville and Lapara in southeastern McMullen County, and a number of the exposures of Gueydan capped by Oakville on mesas, such as Loma Alto and La Chusa, are found in his report on page 969 under the heading "Lapara Sections." The Frio, as defined in this latter paper, is thus not a stratigraphic unit. In a recent paper,

[23]Dumble, E. T., "The Cenozoic Deposits of Texas," Jour. Geol. Vol. 2, No. 6, pp. 549-567, 1894.

[24]Dumble, E. T., "The Geology of Southwestern Texas," Trans. A.I.M.E., Vol. 33, pp. 913–987, 1903.

Dumble[25] defines his Frio so that it is practically coincident with the writer's Gueydan, but believes it to be of Jackson, Eocene (not Oligocene or younger) age. His reason for placing these beds in the Eocene is given in the following quotation taken from page 435.

> No fossils except a leaf impression were found in the beds here assigned to the Frio.
>
> The Jackson age of the Frio is indicated by the fact that we have traced *what we consider to be its continuation*[25a] southward to the Conchos River in Mexico where it forms a good part of the Pomeranes Mountains, and on the eastward—facing slopes of these mountains we find this Frio overlain by beds of fossiliferous sands and clays belonging to the lower Oligocene.

The Gueydan beds (Dumble's Frio) were not found to outcrop on the Texas bank of the Rio Grande. Since Dumble does not describe the Mexican beds, it is impossible to know to which strata he referred in the expression "continuation southward" of his Frio. Opposed to the Eocene age of the Gueydan are the following facts:

(1) The same strata were traced by the writer from Dumble's type locality of his Frio in Live Oak County to southern Gonzales and northern Lavaca counties where they overlie beds of typical Catahoula (Oligocene) sandstone and underlie typical Oakville (Upper Miocene) sandstone. The relations in these counties are quite clear. Since the distance is much shorter from Dumble's type locality to Gonzales County than the Conchos River in Mexico, there is less chance of error in mapping. With the exception of a few offsets due to dip faults there is no marked discontinuity in the outcrop of these strata between the type locality and Gonzales County such as exists for twenty miles north of the Rio Grande and for an unknown distance south of that river.

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[25]Dumble, E. T., "A Revision of the Texas Tertiary Section with Special Reference to the Oil-Well Geology of the Coast Region," Bull. Am. Assoc. Petr. Geol. Vol. 8, No. 4, pp. 424–444, 1924.

[25a]Italicized by the present writer.

(2) The marked variation in width of the Frio clay belt, as defined by the writer, and its disappearance northeast of Atascosa County, probably because it is overlapped by the Gueydan, strongly suggests an unconformity or disconformity between the Gueydan and the Frio although their contact in most of the places where it is exposed appears to be conformable or nearly so.

As has been previously mentioned on pages 6–7, Trowbridge[26] has included beds ranging in age from Upper Eocene to Lower Pliocene in his "Frio Formation" and placed this "formation" in the Eocene. The author has found it quite possible to subdivide the Frio of Trowbridge into the Frio, Oakville, and Lagarto formations along the north side of the Rio Grande.

Deussen's Frio embraces both the Gueydan tuff and the Frio clay. In regard to the age of this "formation" Deussen[27] makes the following statement on page 91:

> The sparse fauna of the Frio clay makes its correlation difficult. The lower beds in southwest Texas carry *Ostrea georgiana* Conrad, which may indicate a deposit of either late Eocene or early Oligocene age. The upper beds may be in part of early Oligocene age, but until further evidence is available the formation is classified as of late Eocene (Jackson) age.
>
> In eastern Texas beds of clay that are in general of similar lithologic composition overlie the Catahoula sandstone. These clays were originally described by Kennedy under the name Fleming beds and were by him subsequently erroneously correlated with the Frio clay. Later Matson found a Miocene fauna in the upper part of the Fleming clay of eastern Texas and western Louisiana, indicating that this part of the formation at least is of Miocene age and corresponds in time with the Oakville sandstone of southwestern Texas.
>
> Work done by Matson in 1912 along Sabine River showed that the beds heretofore called Fleming represent probably two stratigraphic units instead of one. The upper unit belongs to the Miocene, the lower unit is probably of the Oligocene.

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[26]Trowbridge, A. C., "A Geologic Reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande," U. S. Geol. Surv. Prof. Paper 131D, pp. 97–98, 1923.

[27]Deussen, Alex., "The Geology of the Coastal Plain of Texas West of Brazos River," U. S. Geol. Surv. Prof. Paper 126, pp. 91–95, 1924.

> The Catahoula sandstone of eastern Texas disappears west of Colorado River. Its time equivalent in southwestern Texas may be the upper part of the Frio clay.

As shown by these statements, Deussen recognized the possibility that part of this Frio might be Oligocene. The writer's division of Deussen's Frio still leaves in the Frio the lower beds, which occasionally carry *Ostrea georgiana,* and which are more probably of Eocene age, but places the major portion of the former Frio in the Gueydan (Oligocene). The writer feels amply justified in separating Deussen's Frio formation into two stratigraphic units, because (1) the Gueydan consists mainly of tuff; and is lithologically and genetically quite different from the Frio clay; (2) the Gueydan appears to overlap the Frio, thus suggesting at least a slightly unconformable or disconformable relationship; (3) at least a portion of the Frio appears to be lagoonal while there is no evidence that any portion of the Gueydan is lagoonal; (4) the physiographic expression of the Frio outcrop is quite different from that of the lower half of the Gueydan; (5) the term "Frio clay" has been used extensively in geologic literature to designate deposits which were considered by the writers using the term to be of Eocene age, therefore the term should be usd only for those predominantly argillaceous beds which are more probably of Eocene age. The lithologic distinction alone is of sufficient significance to warrant the usage of separate formational names, even though the formations should later be proven to be entirely Upper Eocene or entirely Oligocene in age.

Thickness.—The thickness of the Frio formation in western Live Oak County is determined as 137 feet in the Hicks No. 1 well located near Simmons. The formation is probably 250 feet thick near the Rio Grande.

Origin.—The lower beds of the Frio are possibly of lagoonal origin, as shown by the presence of occasional oysters, and apparently represent a continuation of the Fayette cycle of deposition. The argillaceous character of the bulk of the Frio suggests quieter conditions than those under which the Fayette sandstone was formed, possibly occasioned by the formation of an off-shore bar like the present Padre Island. The general paucity or absence of marine fossils, and the presence of silicified wood might indicate continental conditions, such as exist on the seaward border of low-lying coastal plains, or enclosed lagoonal conditions. The lack of stratification and the poor sorting of the coarser particles in these clays are also more commonly noted in fresh-water clay than in marine clay deposits. The presence of bentonite and volcanic glass fragments in the Frio shows that volcanic activity was in progress during or before the deposition of this formation, but that these volcanic materials have been mixed with abundant foreign material is evident from the presence of well-rounded grains of chert, quartz, epidote, and worn Cretaceous foraminifera. The abundance of gypsum crystals and the almost complete absence of carbonaceous material are suggestive of aridity or at least seasonal aridity. Berry[28] mentions a probable local aridity at intervals during Jackson time in the western Gulf region; he believes from the plant evidence that the climate was subtropical. He also states that most of these plants are of the coast-inhabiting types.

OVERLYING FORMATIONS

Upper Miocene—Lower Pliocene Series

OAKVILLE FORMATION

Distribution and stratigraphic relations.—The Oakville formation of probable Upper Miocene age overlies the Gueydan unconformably. The stratigraphic break between the two formations is probably a large one as indicated by the following facts: (1) A quite irregular erosion surface at the contact of the two formations is well exhibited on the eastern side of San Caja Mesa in eastern McMullen County and at other localities. (2) The surface of the Gueydan is

[28]Berry, E. W., "The Middle and Upper Eocene Floras of Southeastern North America," U. S. Geol. Surv. Paper 92, pp. 129–133, 1924.

stained dark gray to black by carbonaceous material for a depth of from a few inches to several feet below the base of the Oakville at practically every place where the contact has been observed. This phenomenon is very evident at San Caja, under some of the overhanging ledges of Oakville conglomeratic sandstone. The dark material at this contact is very similar in appearance to the present soils of the upper Gueydan and is believed to be a fossil soil. (3) Pebbles of the light pink argillaceous tuff from the upper Gueydan are noted in abundance in the basal beds of the Oakville conglomerate on Loma Alto Mesa and at several similar situations. (4) The average dip of the middle and lower Gueydan is about 80 to 100 feet per mile southeast, while that of the Oakville is only 40 to 50 feet per mile southeast. The upper Gueydan may have a lesser dip than the middle and lower beds of the formation, but dips can rarely be obtained in these upper beds on account of their massive character.

Northeast of McMullen County the Oakville formation outcrops in a belt from four to twelve miles wide. Here the upper contact is largely taken from Deussen's map in Professional Paper 126 of the U. S. Geological Survey. South of McMullen County it becomes conspicuously narrower and in southeastern Webb, most of eastern Zapata and western Jim Hogg counties it forms a belt from a few feet to one-quarter mile wide along the front of the Reynosa escarpment. In certain places in this escarpment it appears to be entirely missing but at least a few feet are generally present between the middle Gueydan interbedded conglomerates and tuffaceous clays and the overlying Reynosa limestone and limy conglomerate.

It is the writer's opinion that the Reynosa erosion scarp partly owes its prominence in Webb and Zapata counties to the presence of a layer of very resistant, silicified Oakville sandstone and conglomerate which outcrops beneath the less resistant limy beds of the Reynosa. The stratigraphic relations in this portion of the escarpment are rather confusing owing to the fact that three conglomerates of as many geologic ages are present. The writer's interpretation of the section is illustrated in the accompanying sketch, Figure 1. The relations on this scarp are somewhat obscured by

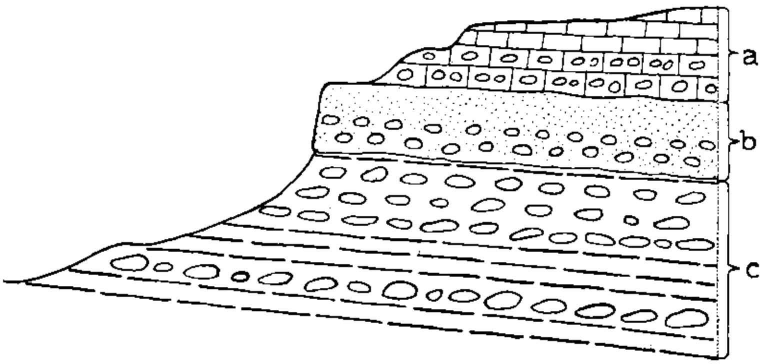

FIGURE 1.—Idealized Sketch Section of Reynosa Escarpment, ½ mile N. 20° E. of Mirando City, Webb County. *a*, Reynosa; *b*, Oakville; *c*, Gueydan.

loose blocks from the overlying beds. The author does not feel perfectly sure that the lower conglomerate is the same one which occurs in the middle Gueydan, but it contains numerous pebbles of volcanic rocks and the pink silicified argillaceous tuff (?) matrix is like that of the Gueydan conglomerate and unlike that seen in any conglomerate of unquestioned Oakville age. In addition to this evidence, beds of argillaceous tuff or porous bentonitic clay appear to be interbedded with the lower conglomerate beds.

In Starr County, at a point six miles north of Rio Grande City, the Oakville belt again widens to three miles or more.

Lithologic character.—The Oakville is predominantly a formation of sandstones, though interstratified clay beds are quite common and a basal conglomerate or conglomeratic sandstone is generally present. The Oakville sandstone is typically a massive-bedded to intricately cross-bedded, rather friable, light buff to light gray, medium-grained, calcareous sandstone which practically always carries small rounded pellets or pebbles of buff, brown, or greenish clay. Small worn fragments of pelecypod shells are also characteristic of this sandstone. Where the sandstone has been silicified, no shell fragments are noted. Normally the Oakville sandstone is cemented by transparent crystalline calcite. The presence of clay pebbles, which rarely occur in the Fayette except at the top of the formation, the coarser texture, the dominance of quartz over feldspar and the less argillaceous character of the sandstone are features which generally serve to distinguish the Oakville sandstone from that of the Fayette. Also the Fayette formation frequently carries beds of marine fossils that are indigenous to the formation, while the fossils indigenous to the Oakville are teeth and bones of land vertebrates, especially of Upper Miocene horses. However, small fragments and, occasionally, entire worn shells of *Gryphea, Exogyra,* and other marine invertebrates which have been washed into these Miocene beds from older sedimentary formations are of common occurrence. The presence of water-worn Cretaceous shells in the Oakville sandstone has been noted by Dumble.[29]

A sample of lower Oakville sandstone was collected from the summit of a hill one and one-half miles southwest of Kittie on the Simmons-Kittie road in central Live Oak County. This is a friable, imperfectly cross-bedded to massive, light buffish-gray, medium-grained, calcareous sandstone which contains a few rounded pellets of brownish-yellow clay up to 1 centimeter in diameter and numerous shell fragments visible to the naked eye. A petrographic description of this rock is given below as an example of the lithology of the Oakville sandstone.

PETROGRAPHIC DESCRIPTION OF LOWER OAKVILLE SANDSTONE FROM 1½ MILES SOUTHWEST OF KITTIE IN LIVE OAK COUNTY

Sorting.—2–1 mm.—trace; 1–½ mm.—3%; ½–¼ mm.—48%; ¼–⅛ mm.—33%; ⅛–1/16 mm.—4% clay and silt (mostly from clay pebbles)—12%. The grains are largely subangular.

Composition of Washed Material.—Quartz (includes a few short double-ended pyramidal crystals)—40%; orthoclase (mostly pinkish in color)—6%; plagioclase (mainly oligoclase and andesine)—7%; microcline—trace (frequent); chert (honey-yellow, pink, gray and black in color)—20%; calcite (from cement)—25%; water-worn pelecypod

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[29]Dumble, E. T., "The Cenozoic Deposits of Texas," Jour. Geol., Vol. 2, p. 557, 1894.

and gastropod shell fragments—2%; biotite—trace; magnetite—trace; limonite—trace (common); zircon—trace; silicified wood—trace; barite—trace; chalcedony—trace; foraminifera (probably reworked) —trace. One phosphatic or altered glauconitic cast, ⅔ mm. long, of a foraminifer resembling *Bigenerina* is noted and this may be an indigenous fossil.

The analysis of a slightly conglomeratic, partly silicified sandstone believed to be Oakville, which is exposed on the upper part of the Reynosa escarpment one-half mile northeast of Mirando City, Webb County, was made for the purpose of comparing it with undoubted Oakville sandstone. This analysis is strikingly similar in composition to the analysis of Oakville sandstone given above.

PETROGRAPHIC DESCRIPTION OF A SANDSTONE (PROBABLY OAKVILLE) FROM THE REYNOSA ESCARPMENT, ½ MILE NORTHEAST OF MIRANDO CITY, WEBB COUNTY

Sorting.—4–2 mm.—2%; 2–1 mm.—3%; 1–½ mm.—13%; ½–¼ mm.—51%; ¼–⅛ mm.—14%; ⅛–1/16 mm.—2%; clay and silt (mostly from clay pebbles—15%. The great majority of the sand grains are subangular but about 8% of them are beautifully rounded and show small angular, nearly equant pits which probably indicate that the good rounding of these latter grains is due to wind erosion.

Composition.—Quartz—45%; orthoclase—3%; plagioclase (mainly oligoclase and andesine—12%; chert (mostly dark gray to black, but some yellow or pink in color)—20%; calcite (from cement)—15%; chalcedony and opal (from cement)—5%; biotite—trace; magnetite—trace; zircon—trace; water-worn fragments of pelecypods and gastropods—trace; small foraminifera (probably all reworked)—trace.

The composition of this sample is not only similar to that of many of the unquestioned Oakville samples, but is also quite dissimilar to that of the samples of the Fayette and Gueydan sandstones. This is offered as good evidence in support of the writer's contention that Oakville sandstone does outcrop south of Duval County and in contradiction of Trowbridge's opinion[30] that this sandstone does not outcrop here.

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[30]Trowbridge, A. C., "A Geologic Reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande," U. S. Geol. Surv. Prof. Paper 131D, p. 98, 1923.

At many localities in McMullen, Duval, Webb, and Zapata counties the basal beds of the Oakville are exceedingly hard, due to replacement of the normal calcite cement with chalcedony and opal. This siliceous-cemented sandstone has been called quartzite by several authors, but an examination with a hand lens is sufficient to show that it is not a metamorphic rock. Every gradation between the very hard siliceous sandstone and the friable calcareous sandstone can be seen. All the mesas in McMullen and Duval counties are capped with this sandstone. The appearance of the sandstone capping San Caja Mesa is shown by Plate II, Figure 1.

Beds of hard and siliceous to friable and argillaceous conglomerate or conglomeratic sandstone are commonly present at or near the base of the Oakville formation. The pebbles in this conglomerate are of dark-colored chert, white vein quartz, silicified wood; pinkish and greenish tuff, and tuffaceous clay from the underlying Gueydan occur locally. These pebbles are generally rounded.

Thin lenses to ten-foot beds of massive, soft, marly clay containing abundant white calcareous concretions are not uncommon in the Oakville. This clay is generally buff or mottled buff and greenish-gray in color but the clay may also be pink or greenish.

In the vicinity of Rio Grande City there is a belt of very soft and powdery, slightly calcareous to strongly calcareous, pinkish-white andesitic or trachyandesitic volcanic dust or tuff. This tuff is composed mainly of fresh platy, volcanic glass ($n=1.503$) fragments which are mostly below ¼ mm. in length, and a number of angular fragments of andesine crystals in a bentonite matrix. These beds are excellently exposed beneath the Reynosa limy conglomerate cap rock on the north side of La Cruz Mesa, three miles east of Rio Grande City. This belt of soft, fine-grained tuffs is over three miles wide but good exposures are not common. In the Alcorn Oil Company's Santo Domingo well drilled about five miles southeast of La Cruz Hill this tuff bed was struck at 300 feet and it extended to a depth of 517 feet with only a 20-foot clay bed at 370 feet breaking its continuity. This gives a thickness of approximately 200 ft. for the pyroclastic material. The typical sandstone beds of the Oakville were penetrated at approximately 640 feet and continued, with numerous clay breaks, to a depth of about 800 feet. The tuff beds are overlain by the Lagarto clays of probable Lower Pliocene age. Thus the tuff appears to belong at the top of the Oakville formation. A petrographic study of this tuff shows that it is quite similar in mineral composition to the tuff of the upper Gueydan, although the latter is situated unconformably below the Oakville sandstone in the stratigraphic column. In the upper Oakville tuff beds Dr. Wortman found some teeth and bones of *Protohippus sejunctus* Cope, thus establishing the Upper Miocene or Lower Pliocene age of the beds. It is very probable that the tuff beds near Rio Grande City belong to a more recent period of volcanic eruption and are probably from a Mexican source, because only a few thin beds of bentonite have been observed in the Oakville north of Starr County, nor are any thick beds of pyroclastics known in the Oakville from wells north of Starr County. The other, less likely, alternative is that the unconformity at the base of the Oakville in McMullen County and farther northeast does not represent an important time interval and that part of the upper Gueydan tuff is of Upper Miocene age as well as the Oakville. If the second hypothesis be the correct one, the Oakville sandstone in Starr County was deposited earlier than the Oakville sandstone farther north and east.

Origin.—The origin of the Miocene-Pliocene deposits of which the Oakville is a part has been previously discussed by the writer,[31] and the study of the Oakville in the present area does not add many new data to the former studies. The Oakville was probably deposited by rivers along the seaward margin of a coastal plain having fairly low relief, for a study of the unconformity at the base of the formation indicates that the surface on which the sediment was deposited was very slightly undulatory. The materials of

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[31]Bailey, T. L., "The Geology and Natural Resources of Colorado County," Univ. Tex. Bull. 2333, pp. 95–96, 1923.

which the Oakville is composed evidently came from the north and west. This is indicated by the presence of water-worn Cretaceous fossils in the formation together with the fact that the nearest present outcrop of Cretaceous rocks bearing these fossils is north and west of the Oakville exposures. The rather fresh pink orthoclase and microcline in these beds suggest a granitic source, as does some of the quartz which contains apatite prisms. The nearest granitic areas known are those in the Central Mineral Region of Texas, in Llano and surrounding counties, also north of this area. Some granitic areas in Mexico may be equally near to the extreme southern portion of the region. The plagioclase in this sandstone is probably largely from the pyroclastic beds of the Gueydan and Fayette formations. The occasional large foraminifera found in the Oakville may have been introduced from the Gulf by tidal waves or storm waves. The sand grains and pebbles of chert are evidently derived from the cherty concretions and lenses which are so abundant in some of the Cretaceous limestones.

The rivers that brought down this material were either quite large or had a steeper gradient than most of the present silt-depositing rivers because the Oakville consists mostly of cross-bedded and lenticular, medium to coarse sands.

PLEISTOCENE SERIES

REYNOSA FORMATION

Age and distribution.—Trowbridge,[32] Deussen,[33] and other writers have placed the Reynosa in the "Pliocene(?)" and have stated that no fossils have been found in the formation. in 1923, Dr. J. L. Wortman[34] discovered the upper and lower jaws and teeth of *Equus* cf. *fraternus* only two feet above the base of the Reynosa formation at La Cruz Hill, three miles

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[32]Trowbridge, A. C., U. S. Geol. Surv. Prof. Paper, 131D, p. 98, 1923.

[33]Deussen, Alex., U. S. Geol. Surv. Prof. Paper 126, p. 102, 1924.

[34]Personal communications, Nov. 14, 1923.

east of Rio Grande City in Starr County. This establishes the age of the Reynosa as Pleistocene, probably Lower Pleistocene. In the portion of the southwestern Texas coastal plain northeast of Live Oak County the Lagarto formation, of probable Lower Pliocene age, lies between the Oakville and Reynosa beds; southwest of Live Oak County the Lagarto and most of the Oakville have been overlapped by the Reynosa beds. It is not only in the latter part of the region that the Reynosa appears in the area under discussion except for small patches which cap many of the higher hills throughout most of the Texas coastal plain.

Lithologic character.—The Reynosa consists of white to pinkish, porous caliche limestones, sandy and pebbly caliche limestones and conglomerates with an abundant matrix of white caliche. Considerable argillaceous material is also present in many of the Reynosa beds. The deposits are generally cross-bedded on a large scale and most of the beds are lenticular. The limy conglomerate is the principal lithologic type. The pebbles and cobbles in this conglomerate are mostly of black, gray, and yellowish brown chert with a small admixture of sandstone, shale, limestone, and other sedimentary rocks, but various types of volcanic rock, mostly andesites and trachyandesites, are also represented. Pebbles of chalcedony, agate, and vein quartz of various other colors are fairly common. Granitic pebbles are rare in the Reynosa of this area. The size of the pebbles ranges from 1 mm. in diameter to 30 cm. or possibly more, and the shape is usually rounded or subrounded, although among the smaller sizes many pebbles are subangular.

The limestones in the Reynosa are practically always impure, owing to the presence of sand, clay, or scattered pebbles. They are often porous and tufa-like in appearance. In places the limestone is composed of rounded, pebble-like masses of a slightly denser texture than the matrix; manganese dendrites are often present on the surface of such pebbles. Some of these pebble-like masses are imperfectly concentrically banded and therefore of concretionary origin, possibly having been formed in situ. Others appear to be water-worn pebbles, probably produced by contemporaneous erosion. Many nearly horizontal outcrops of the Reynosa show an imperfect banding parallel to the surface, thus suggesting that the limestone was deposited by precipitation from solution in successive layers.

Origin.—It would require a great deal more work than the writer has done before a satisfactory solution of the problem of the origin of the Reynosa could be offered. A microscopic study of thin sections of these rocks would probably throw some light on the subject, but thin sections are very difficult to make because of the friable character of the rocks. The gravel, sand, and limy clay beds have evidently been laid down by streams, and that these probably overloaded streams meandered back and forth across almost the entire coastal plain of Texas is indicated by the wide distribution of cappings of this formation on most of the higher hills. It seems likely from the evidence which has been discussed in the above description of the Reynosa limestone that at least a part of it is caliche which was precipitated on the surface due to the upward capillary migration of calcareous waters and their evaporation at the surface.

[35]Trowbridge has discussed some of the theories for the origin of the Reynosa, but states at the beginning of his discussion:

> 'To attempt at this time a complete explanation of the conditions under which this complex formation was deposited and cemented would be premature.'

Trowbridge subsequently states that Deussen has suggested that some of the limestone may have been deposited by ground water while the main mass of the formation was being laid down by streams.

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[35]Trowbridge, A. C., U. S. Geol. Surv. Prof. Paper 131D, p. 100, 1923.

THE GUEYDAN FORMATION

The Gueydan formation, which is composed largely of pyroclastic material, was named by tbe writer[36] from the Gueydan ranch and survey in southeastern McMullen County, where the upper part of the formation is well exposed. The locaton of the Gueydan ranch is shown on the accompanying geologic map, Plate I. The formation outcrops most prominently and is most typically developed in northern Live Oak, southeastern McMullen, and northwestern Duval counties because the pyroclastic material becomes interstratified with a larger amount of fluviatile material to the northeast and to the south of these counties. The longitudinal extent of the outcrop of the Gueydan formation can best be observed by referring to the map. The width of the outcrop ranges from three miles in southern Gonzales County to approximately fifteen miles in northwestern Duval County.

Dip and thickness.—Northeast of the west line of Duval County the regional dip of the Gueydan is southeast, but south and west of that line the dip is east. Dips can be measured with a fair degree of accuracy only on the more consolidated white tuffs in the lower part of the formation and on some of the sandstone beds in the middle part. The angles of dip commonly range from ½° to 2°. An average of more reliable dips in Live Oak and McMullen counties is about 0° 48′ or 73 feet to the mile. Dips up to 6° are not uncommon, especially in the neighborhood of local folds and faults, and nearly vertical dips are sometimes noted in the beds next to fault planes, where the strata have been dragged up or down by the movement along the faults. In general the beds in the Gueydan formation lie so nearly horizontal that the direction of their dip can rarely be determined with certainty except on fairly large outcrops.

The thickness of the Gueydan cannot be directly determined from the width of its outcrop because the unstratified

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[36]Bailey, Thomas L., "Extensive Volcanic Activity in the Middle Tertiary of the South Texas Coastal Plain," Sci. (n.s.) Vol. LIX, No. 1526, p. 299, 1924.

character of the beds in the upper third, or possibly half, of the formation precludes the determination of the dip in this part. It is probable that the dip of this upper portion is not greatly different from that of the lower beds because the Oakville which overlies the Gueydan unconformably, or at least disconformably, has an average regional dip of about ½° or 46 feet per mile southeast and east; the underlying upper Gueydan beds can hardly have a smaller angle of dip than this. In a few localities some of the uppermost beds of the Gueydan are faintly stratified and appear to have a slightly lower angle of dip than the lower beds. Another uncertainty regarding the thickness of the Gueydan arises from the fact that the strata may either thin or thicken down the dip, depending upon whether the volcanic source of the material was situated northwest or southeast of the present outcrop. Estimates of thickness[37] are as follows:

Estimated average thickness in Gonzales County	190 ft.
Estimated average thickness in Karnes County	350 ft.
Estimated average thickness in Live Oak County	600 ft.
Estimated average thickness in McMullen County	650 ft.
Estimated average thickness in Duval County	850 ft.

The section in Karnes and Live Oak counties is known to be faulted, therefore well records have been used in making the estimates in these counties. Elsewhere the estimates are based on width of outcrop.

Well records furnish the most satisfactory method for determining the thickness of these nearly horizontal strata but an examination of the samples from the wells is necessary because tuffs are generally logged as clays or sandy clays. The writer has studied a nearly complete set of samples from H. Coquat and Associates' Hicks No. 1 well in Live Oak County and from the Alcorn Oil Company's Santo Domingo well in Starr County. He has examined

[37]A dip of 60 feet per mile, a probable approximation, has been assigned to the upper massive beds of the formation, and the necessary assumption is made that the formation has not thinned or thickened appreciably at the Oakville-Gueydan contact.

with a hand lens a number of samples from the Iowa-Texas Syndicate's Peters No. 1 well in Duval County; and has made microscopic examinations of occasional samples from several wells in Live Oak County which pass through a portion of the Gueydan formation.

The Hicks well is located about one-half mile northwest of the center of the Gueydan outcrop and penetrates a part of the middle beds and all of the lower beds of the formation. In this well 330 feet of Gueydan are present. In Kepley, Anglin, and Carl's Wesch No. 1 well, which begins in the Oakville one mile east of the Oakville-Gueydan fault contact in Live Oak County, 169 feet of Oakville are apparently present. Below the Oakville, between 169 and 450 feet, the strata all belong to the upper Gueydan. The writer was unable to obtain any samples from below 450 feet in this well. However, there is apparently a gap in the Gueydan section between the beds at 450 feet in the Wesch well and the beds which outcrop at the Hicks well. The magnitude of this gap is indeterminate. If the sections of Gueydan in these two wells be added together we obtain a thickness of 611 feet. If the beds of the lower Gueydan have not diminished in thickness within the fifteen miles (measured at an angle of 25 degrees to the strike of the strata) which separates the two wells, the total thickness of the Gueydan is not less than 611 feet in Live Oak County. Thus, the writer's allowance of 600 feet for the Gueydan section in Live Oak County can hardly be too great. It is quite probable that as much as 700 feet of Gueydan are present in this county.

The Peters well in southwestern Duval County, nine miles northeast of Moglia, Webb County, starts near the base of the Oakville. Samples from 28 feet and 208 feet were seen by the writer, and they are evidently Gueydan tuff. The driller reports similar tuff beds down to 900 or 1,000 feet. The samples from 1,000 to 1,300 feet were also examined and appear to be Frio clay. Between 1,300 and 1,950 feet a yellowish-gray sandstone, apparently Fayette, is the principal rock type. From this well record, it appears that the Gueydan in southern Duval County is between 870 and 970 feet thick. The greater thickness in the Peters well agrees with the greater width of outcrop in Duval County in indicating an exceptional thickness for the Gueydan in this region.

In the Santo Domingo well in southeastern Starr County samples of very well preserved, consolidated, light-colored tuffs resembling those of the lower Gueydan were encountered at depths of 1,253–1,255 and 1,444–1,480 feet. The beds between 852 and 1,253 feet are bentonitic clays containing fragments of volcanic glass and they probably belong to the Gueydan formation, although they are much more argillaceous than the typical Gueydan. If this interpretation be correct 628 feet of Gueydan are present beneath the overlapping Oakville, Lagarto, and Reynosa beds in Starr County.

Lithologic character.—The Gueydan is separable on the basis of lithologic character into three members which are, beginning with the lowest, as follows:

(1) The Fant tuff (characterized by mud flows).
(2) The Soledad volcanic conglomerate, sandstone and tuff.
(3) The Chusa argillaceous tuff and tuffaceous clay.

The Fant member is named from the town of Fant City, in northern Live Oak County, near which are found numerous good exposures of the indurated white tuff. The Soledad member is named from the Soledad Hills, in western Duval County, which are composed of the conglomerate of lava pebbles typical of this member. The name of the Chusa member is taken from La Chusa Mesa, in southeastern McMullen County because good outcrops of the pulverulent, pisolitic tuffaceous clay which characterizes this member are exposed on the slopes of La Chusa beneath the Oakville capping. The approximate contacts between each of these members are indicated on the geologic map by broken lines. In the part of the Gueydan outcrop south of McMullen County the Soledad member (middle Gueydan) is very prominently developed and certain of its strata probably replace along their strike some of the beds of a different lithologic character in the Fant and Chusa members. All three members are recognizable throughout the area under discussion except in Gonzales and northwestern Lavaca counties, where the lower and middle Gueydan tuffs are interbedded with a number of siliceous sandstone beds having a Catahoula facies, and in Webb, Zapata, and northern Starr counties where the upper member is completely overlapped by younger formations.

FANT MEMBER (Lower Gueydan)

The lower Gueydan or Fant tuff differs from the remainder of the formation in the following features: (1) Most of the tuff beds in the Fant member are white in color; (2) many beds of considerably indurated and columnar jointed or sun-cracked tuff of mud flow origin occur; (3) small tridymite plates are found in the vesicular cavities in some of the indurated tuffs.

General lithology.—(1) The most characteristic rock type in the lower Gueydan is a fairly well indurated, massive-bedded, somewhat vesicular, white or creamy-white, fine-textured but generally lumpy trachyte or trachyandesite tuff. Some of these tuff beds commonly have a light bluish-gray or greenish-gray color when wet but other beds remain creamy-white. A large chunk of creamy-white tuff was brought up from a depth of eighty-five feet in Coquat's Hicks No. 1 well in Live Oak County. This proves that the white color is not due to weathering as Dumble[38] believes. The individual beds of this tuff are generally from eight inches to two feet thick. The beds thin and thicken from place to place so that it is evident that the bedding planes are not plane surfaces but are gently undulatory. No trace of stratification can be noted within a separate bed of this type. The upper surfaces of these tuff beds are prominently fissured by more or less gaping, vertical, polygonal joint

[38]Dumble, E. T., "A Revision of the Texas Tertiary Section, etc." Am. Assoc. Petr. Geol., Vol. 8, p. 434, 1924.

cracks resembling the columnar jointing of many basaltic lava flows. Some of the joint blocks exhibit upwarped edges and are quite suggestive of non-marine sun-cracks.[39] The joints have evidently been produced by contraction upon dehydration. Tuff exposures exhibiting this columnar jointing or sun-cracking are clearly pictured in Plate IV, Figure 2. At "Chalk Bluffs" on the Ray ranch in western McMullen County, six miles south of Wentz, are found a number of large slabs of hard white tuff which have fallen from a massive tuff bed higher up the bluff. The upper surface of these slabs has a very distinct ropy structure, like that exhibited by some types of pahoehoe lava. The mineral and glass grains in this tuff are mostly oriented with their long axes parallel, thus demonstrating that the peculiar ropy appearance is due to flow structure. A photograph of this ropy tuff is found in Plate VI, Figure 2. The flow structure, the wavy bedding, the marked vesicular character, the presence of subrounded lumps of the same type of tuff as the matrix, the prominent columnar jointings, the lack of stratification within an individual bed, and the sun-cracking together indicate that these indurated tuff beds were deposited as mud flows from one or more volcanic vents. The outcropping edges of these tuff beds are rough and irregular with numerous rounded to angular pits, giving a scoriaceous appearance to the rock. This gnarly aspect of the outcrops can even be distinguished in the photographs and is illustrated by Plate IV, Figure 2; Plate V, Figure 2; Plate VI, Figure 1. A closer examination of this tuff reveals the presence of a few to numerous angular to well-rounded, bluish-gray, silky pumice fragments (lapilli), as well as abundant sharp, platy to filamentous glass grains and angular fragments of glassy feldspar. The tuff has a fine pisolitic to coarse lumpy appearance except where it has been silicified. This feature is produced by the presence of more or less rounded masses of tuff which range in diameter from 1/8 mm. or less to several inches. The larger masses have many small

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[39]Kindle, E. M., "Some Factors Affecting the Development of Mud Cracks," Jour. Geol., Vol. 25, pp. 135-144, 1917.

irregularities on their surfaces and frequently give only a suggestion of a rounded or elliptical form. They are separated from each other by ramifying dendritic masses and films of a yellowish or pale greenish substance which consists of a mixture of bentonitic and opaline material. Some of the tuff beds are composed almost entirely of such roundish lumps, which give to the rock a conglomeratic appearance. In a few localities veins of light bluish barite occur in the joints or cracks between the lumps instead of the opal and bentonite. The large lumps are composed of the same kind of tuff as the matrix in which they are included and they possibly represent fragments of a dehydrated and somewhat solidified crust which was formed on the upper surface of the mud flow and later engulfed; these fragments were subsequently comminuted and partly rounded by rolling over and over in the more liquid volcanic mud below. Also, the spheroidal masses may have been formed near the ends of mud flows by a process similar to that which produces a mass of irregular blocks of the solidified crust in the ends of lava flows. In other words, the more liquid mud may have pushed forward, incorporated fragments of the partially solidified mud at the front of the flow, and rounded them by rubbing them against one another as the mud flow proceeded. It is impossible to ascertain which of these plausible explanations is the true one, and it is probable that several processes have contributed to the formation of the larger lumps. These larger lumps are commonly composed of a number of smaller lumps. Lacroix[40] has described and photographed tuffs composed of such pisolite-like bodies of various sizes up to nearly 1 cm. in diameter. He states that they have been formed by the cohesive action of rain drops. Many of the smaller pisolite-like bodies in the Fant member of the Gueydan tuff have probably originated in this manner. Some of the smaller lumps are pumice pebbles, rounded, no doubt, by the attritional action of finer particles and other pumice fragments

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[40]Lacroix, A., "La Montagne Pelée et ses Eruptions," Paris, Masson et Cie, p. 420 and fig. 181, 1904.

while the mud flow was in motion. A few of these rounded pumice lapilli may have had an original rounded form. Lacroix[41] states that the pumice lapilli from Mont Pelée, both from vertical projections and inclined fiery clouds, are ordinarily rounded on account of their slight hardness and their fragility due to their porous structure. It is, therefore, more probable that the Gueydan pumice lapilli were rounded after their expulsion from the volcano. Many of the very small rounded bodies are hollow and are evidently glass bubbles. These smallest spherules are abundant in tuff beds where only a few of the larger tuff lumps occur.

The vesicular cavities, which are common in this tuff, are very irregular to rounded or flat ellipsoidal in shape and may be lined or completely filled with soft waxy, cream-colored to light gray, or pink bentonite. Crusts of transparent, botryoidal hyalite opal or mixtures of bentonite and opal are present in other cavities. In a few of the tuff beds in Live Oak, McMullen, Webb, and Starr counties some of the cavities are lined with tiny glittering plates of tridymite or with a mixture of botryoidal hyalite and tridymite. These minerals are discernible with a hand lens, but the crystal form of the tridymite cannot be distinguished without a microscope. The tubular cavities probably represent channels along which steam and other vapors—originally included in the mud flow—escaped. In certain beds these tubular cavities, now filled with opal and bentonite, are quite prominent and resemble small smooth-surfaced rootlets crossing each other at various angles. Some dendrites of manganese and limonitic concretions are seen in this tuff. No fossils have been found in the mud-flow tuff beds.

(2) A number of beds of light gray to white or grayish-pink, very dense textured, chert-like silicified tuff or "porcellanite" are present at many localities in the Fant member, especially near its base. Although this rock has a hardness of 5 or 6, and breaks with a conchoidal fracture like that of chert, it is cut by closely spaced, irregular, conchoidal joint cracks which cause it to break down readily

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[41]*Op cit.*, p. 371.

into such small angular fragments that it is difficult to obtain a large hand specimen of the rock. Some of this rock occurs in platy beds like those of chert, while other samples are difficult to distinguish megascopically and without chemical and hardness tests from a dense-textured limestone. All gradations between this rock and slightly silicified, typical, vesicular tuff are present. Some of the best exposures of this silicified tuff are found near Wentz in McMullen County and on the Chapote ranch, six miles northwest of Loma Alto, in McMullen County and at several localities near Simmons in western Live Oak County. The beds are commonly most completely silicified in their lower portion. Adjacent beds above and below these may be only slightly silicified. Harker[42] states that silicification is very common in the acid tuffs.

(3) Friable, regularly bedded, white to light gray or yellowish-green, medium-grained tuffs, which on first glance resemble sandstones, are commonly interstratified with the mud-flow tuffs. These tuffs are entirely different in appearance from the mud-flow tuffs. They have evidently reached their place of deposition by settling through the air. The air-deposited tuffs are so friable that they may easily be crushed by a slight pressure of the fingers into a powder of angular grains, many of which are platy. The individual grains are predominantly of volcanic glass and may be identified with a hand lens. In many samples over half the grains are of fine to coarse sand grade; therefore, this type of tuff will be classified as sand-tuff. The remainder of each sample is fine material, largely bentonite, which causes a sample of the rock to break down quickly into a doughy mass when placed in water. An individual bed of this sand-tuff attains a thickness of ten feet in the bluff on the northwest side of the Nueces River, three-quarters mile northwest of Simmons. The tuff in this bed tends to break roughly parallel to the bedding but the rock seems to be homogeneous from top to bottom and is the product either of a single explosive volcanic outburst or of several outbursts in

[42]Harker, Alfred, "Petrology for Students," 5th Ed., p. 259, 1919.

such rapid succession that material of the same type fell continuously to a depth of ten feet or more. This type of sand-tuff probably comprises one-fourth of the Fant member in western Live Oak and eastern McMullen counties.

(4) Many beds of soft, creamy-gray to grayish-green argillaceous (bentonitic) tuff are intercalated between beds of tuff of other types. These are probably formed in part by the nearly complete alteration by hydration of original fine-textured tuff or volcanic dust beds into clay-like bentonite and in part by the reworking of some of the other types of tuff by streams. The reworked tuffaceous clays can sometimes be distinguished from the bentonitic tuffs by current-bedding, poorer sorting and the presence of chert grains in the former, although the two types are very similar in appearance.

Lying loose on the outcrops of certain beds of pinkish or white, argillaceous Fant tuff in the southwestern corner of McMullen County, are found a great number of water-worn, reddish-brown to dark gray boulders and pebbles of non-porous to vesicular and amygdaloidal, porphyritic trachyandesite or acid andesite. These boulders commonly range from 3 cm. to 30 cm. in diameter and resemble many of the boulders which occur so abundantly in the middle Gueydan (Soledad) conglomerate. A photograph of a group of these boulders is shown in Plate VII, Figure 1. The boulders appear to have weathered out of the tuff beds in this region and, in fact, many are coated or have their vesicles filled with the tuff.

(5) Several thick beds of purplish-pink and grayish-green mottled, non-calcareous to marly, unlaminated, bentonitic clay are found in the lower Gueydan; these are rarely exposed except where capped by resistant tuff which protects them from rapid disintegration into soil. From well records it appears that about one-third of the Fant member is composed of this type of clay. The clay carries many elliptical, pinkish to whitish, dense-textured to granular calcareous and siliceous concretions up to 10 cm. in diameter. Dark splotches and dendrites of manganese oxide are common along fracture surfaces throughout these concretions.

Similar manganese dendrites are also present in the joint cracks of the surrounding clay. These clays are evidently fluviatile—having been derived from the erosion of older Gueydan tuff beds and of Frio clay and older formations. These clays are very similar in appearance to those of the Frio except that the former contain very little gypsum, which is quite abundant in the Frio.

(6) Beds of creamy-gray to light pinkish-brown, fine to medium-grained, argillaceous, arkosic, and generally tuffaceous sandstone of fluviatile origin are also present in the Fant tuff. This sandstone is characteristically cemented with opal but a mixture of opal and calcite cement is quite common. The creamy-gray sandstone is thick in parts of Duval, Webb, and Zapata counties. It is evidently derived in part from the erosion of tuff beds.

(7) Coarse to fine conglomerates composed largely of bluish-gray, rounded to subrounded pumice pebbles or lapilli are locally present in the Fant tuff. The matrix of these pebbles is a medium-grained sandy tuff, tuffaceous sand or bentonitic clay. Such conglomerates are rather uncommon in the Fant member, being much more characteristic of the Soledad, or middle member. The best exposure of pumice-conglomerate (which may belong to the basal Fant beds since it appears to be on the upthrow side of a fault here) is located on the Armstrong place, one-quarter mile west of the Atascosa River in the northeast corner of the Thomas Henry survey in northern Live Oak County. Lacroix[43] has described beds composed almost entirely of pumice lapilli in his section of the pyroclastic material covering Pompeii. The Gueydan pumice pebble or lapillus beds may have been formed by a process of gravitative sorting similar to that described by Lacroix in Vesuvian eruptions, but it is quite as probable that running water concentrated this coarse material.

A conglomerate composed of large water-worn boulders or pebbles of white mud-flow tuff and a few chert pebbles

[43]Lacroix, A., "La Montagne Pelée après ses Eruptions," Paris, Masson et Cie, p. 120, 1908.

is exposed at the "Falls" of the Atascosa River. It rests upon a slightly irregular, eroded surface of a yellow, gypsiferous clay which is probably Frio. The beds in this region commonly show dips of 10 to 20 degrees northwest, apparently having been dragged into this attitude by faulting. If the clay underlying the conglomerate at the "Falls" of the Atascosa is really Frio, then a slight unconformity exists between the Gueydan and the Frio in this vicinity.

Lithologic variations along the strike of the Fant member.—In Zapata County the tuff beds of the Fant member are thinner and the member as a whole becomes more argillaceous in character than at its type locality in Live Oak County. The clays in the Gueydan south of McMullen County commonly carry some gypsum and are therefore difficult to distinguish from the Frio clays. The white tuff beds which outcrop prominently from six to twenty miles north and somewhat west of Mirando City in Webb County are mapped as part of the Fant member of the Gueydan, although they may represent a different horizon of tuffs and belong in the Fayette formation. These tuffs have evidently been placed in the Fayette by Trowbridge, as shown by his map.[44] The uncertainty in regard to the exact position of the white tuff beds, which are traceable through eastern Webb and most of Zapata counties, is due to the fact that the white tuff beds in the lower Gueydan of northwestern Duval County appear to be rather thin and are interbedded with gray, buff, and brownish conglomeratic sandstones and bentonitic clays, whereas, in Webb County, similar white tuff beds are again thick and outcrop prominently. The tuff beds in Webb County are non-vesicular, platy-bedded and generally more silicified than farther northeast, thus differing from the typical Gueydan. On the other hand there are some beds of grayish-white, friable sand-tuff of the same character and composition as the Fant sand-tuff in Live Oak County. Interbedded with these tuffs in Webb County are beds of light gray, somewhat silicified,

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[44]Trowbridge, A. C., U. S. Geol. Surv. Prof. Paper 131D, Plate XXVII, 1923

tuffaceous sandstone, containing a large number of biotite flakes and rounded to angular grains of reddish-brown or dark gray, hyalopilitic andesite or trachyandesite. Underlying the series of tuffs and tuffaceous sandstones are greenish-gray and pink and green mottled, gypsiferous clays containing a few lenses of friable sandstone. Similar clays outcrop over a strip three to five miles wide lying west of the base of the tuff, and are believed by the writer to belong in the Frio formation instead of the Fayette. These clays and some of the bentonitic clay beds in the tuff series contain logs of silicified wood up to ten inches in diameter. The logs show distinct angular rings and contain a number of large pores which resemble resin ducts. It is probable that they are logs of gymnospermous trees, but they have not been identified. Similar logs are abundant in the Catahoula formation in eastern Texas. For the several reasons given above, these white tuffs and associated rocks are mapped with the Gueydan formation.

Outcrops of lumpy, vesicular, white, tridymite-bearing, mud-flow tuff of appearance and petrographic character identical to those of the mud-flow tuff of Live Oak and McMullen counties are found in the hills west of the Mirando City oil field, one mile southwest of Mirando City, underlying the middle Gueydan conglomerate and tuff. Similar tuff is also found six miles north of El Sauz, Starr County, twenty feet west of the Hebbronville-Rio Grande City road. Here it is surrounded by Reynosa limestone. These two outcrops indicate that the Fant trachyte tuff extends south as far as northern Starr County, even though the stratigraphically lower, platy-bedded tuffs of Webb and Zapata counties should later be proven to belong in the Fayette formation.

Northeast of Atascosa County no mud-flow tuffs are noted in the Fant member which here consists of slightly consolidated sand-tuff and finer bentonitic tuffs, as well as tuffaceous clays and sandstones. In Gonzales County and eastward, many beds of coarse-grained, friable to extremely well-indurated, quartzose sandstone, of a character typical of that of the Catahoula sandstone in East Texas appear in the Fant and Soledad members. These beds are dissimilar to any rocks found elsewhere in the Gueydan. Thus, the Gueydan grades eastward along its strike into the Catahoula (Oligocene) sandstone.

Sections.—The following sections will illustrate the character of the Fant tuff at its outcrop.

SECTION ON CHARLIE YORK CREEK, 4 MILES WEST OF THREE RIVERS, BETWEEN THREE RIVERS-TILDEN ROAD AND FRIO RIVER, LIVE OAK COUNTY

	Ft.	In.
9. Alternating harder and softer, massive-bedded and wavy-bedded, creamy to yellowish-white, somewhat lumpy, mud-flow tuff and argillaceous tuff	10–12	
8. Indurated, creamy-white, vesicular tuff with a distinct lumpy texture. The tuff lumps are spheroidal in form and range from ⅛ inch to 1 inch in diameter	1½–2	
7. A somewhat indurated bed of vesicular, bentonitic, mud-flow tuff which is light yellowish-green when dry and blue-gray with a soapy appearance when wet	2	4
6. A massive, projecting ledge of greenish-gray, fairly hard, vesicular tuff containing numerous interwoven, cylindrical, root-like bodies, composed of a mixture of opal and bentonite, in the joint cracks	11	6
5. Rather soft, coherent, olive-green to blue-gray, soapy, bentonitic tuff much like No. 7	1	
4. Covered	2	
3. Hard, white, dense-textured, vesicular, mud-flow tuff	1	4
2. Like No. 8		7
1. Hard, whitish, vesicular tuff with vesicles stained brown with bentonite carrying limonite		6
(Base of No. 1 is 1 foot above Frio River at medium high stage and is covered by mud.)		
Total thickness	32	

The greenish-gray or bluish-gray tuff beds described in this section are of rare occurrence in the Fant member.

HILL-SIDE SECTION WEST OF SIMMONS-WENTZ ROAD, 2½ MILES NORTHWEST OF SIMMONS, LIVE OAK COUNTY

	Ft.	In.
Reynosa:		
14. Reynosa conglomerate cemented with abundant caliche, containing many chert pebbles and some pebbles of trachyte or rhyolite and andesite		4
Gueydan (Soledad member):		
13. Light grayish-pink, friable sandstone containing volcanic glass grains	3	
12. Light gray and pinkish mottled, coarse-textured, porous tuff, containing an abundance of bluish-gray, rounded pumice pebbles most of which are between ⅛ inch and ½ inch in diameter. A number of rounded pebbles and cobbles of red or brownish-gray, extremely vesicular or honeycombed, andesite up to 9 inches in diameter are occasionally found included in this tuff	30	
Fant member:		
11. Very porous, gritty, rather friable, white trachyte or trachyandesite tuff containing small, bluish pumice pebbles or lapilli. This tuff is very light in weight. It becomes finer grained and more argillaceous toward the base	3	6
10. Creamy-gray, closely jointed, bentonitic clay or altered tuff. On fresh surfaces many small, pisolite-like bodies (probably altered glass bubbles) are noted	2	4
9. Light gray to white, conglomerate-like, mud-flow tuff which weathers white and shows many vesicular cavities. The conglomeratic appearance is due to a large number of tuff lumps and some weathered pumice pebbles or lapilli which are enclosed in the finer textured, slightly darker matrix	2	4
8. Like No. 10	6	10
7. Massive, rather tough, plastic, much jointed clay of a variegated light pink and light green color. Becomes predominantly green and somewhat sandy 1 foot above the base of this bed. The clay is stained black with manganese oxide along many of the joint planes. Imbedded in the clay are numerous, rounded or elliptical concretions composed of a mixture of opal, chalcedony and argillaceous matter. The concretions are whitish, yellowish-gray, pink and light green in color or are mottled with these colors like the surrounding clay. Many smaller, dense-textured, whitish, calcareous concretions and streaks of calcite are also noted	11	4

		Ft.	In.
6.	Soft and friable, laminated, greenish-white, argillaceous sand-tuff composed mainly of slivers and plates of volcanic glass	1	4
5.	Light purplish-pink and grayish-green mottled, stiff joint clay showing imperfect lamination. This grades into No. 6 at the top		8
4.	Light grayish-green, soft and friable, massive-bedded somewhat argillaceous sand-tuff		10
3.	Unstratified, soft, much jointed and easily eroded, light creamy-green, sandy tuffaceous clay (evidently fluviatile). Many spicular fragments of volcanic glass can be seen in this material. Near the surface the bed is cut by stringers of caliche	5	11
	Local disconformity (surface of disconformity has the form of a stream channel, as shown in Plate 4, Fig. 1).		
2.	Massive to platy-bedded, grayish-white to light green, sand-tuff composed almost entirely of megascopic volcanic glass fragments. The lower 18 inches is quite friable. Above this is a calcite-cemented, somewhat indurated layer which forms projecting ledges in the bank of Lang Creek, where layer is exposed. A few seams of more argillaceous, finer grained tuff are also present. This bed contains rounded to irregular, sandy, calcareous concretions up to 3 inches in diameter	5	9
1.	White, somewhat indurated tuff containing many roundish, yellow to rusty spots or irregular splotches due to spheroidal, earthy, limonite concretions which form the centers of such spots. The concretions are about ¼ inch in diameter. In the bed of Lang Creek, where No. 1 is best exposed, it shows prominent polygonal jointing or mud-cracks. Base not exposed. Thickness exposed	5+	
	Total thickness of section	80	

Strike of No. 2 is N. 70° E.

Average of dips taken on No. 2 is 0° 51′ or 80 feet per mile, south.

SECTION OF NORTH HILL OF "CHALK BLUFFS" ON RAY RANCH, 6 MILES SOUTH OF WENTZ, McMULLEN COUNTY. (See Plate III, Fig. 1.)

		Ft.	In.
Quaternary:			
9.	Caliche-cemented chert gravel	0–2	

Gueydan (Fant member):	Ft.	In.
8. Dense-textured, much jointed, hard, grayish-white, porcelain-like, silicified tuff	1	
7. Rather soft and easily weathered, grayish-white, argillaceous tuff on bentonitic clay, grading into creamy-gray silicified tuff at the top	11	
6. Bedded (1-foot beds), so lumpy as to appear conglomeratic, fairly hard, vesicular, creamy-gray to white tuff with many irregular mottlings and streaks of a light brownish-pink color	4	
5. Glaring white, lumpy, vesicular, massive-bedded, indurated trachyte (?) tuff showing sun-cracks and columnar jointing. The upper surface of this bed in places shows a peculiar, distinctly ropy, flow structure which evidently represents the old surface of a single mud flow. Such ropy surfaces are apparently local and are usually seen only in detached blocks which happened to break along the surface of the old mud flow. This bed projects prominently from the upper portion of the bluff	6	
4. Rather soft and plastic, argillaceous, unstratified, creamy-white to light gray, lumpy tuff containing many glass fragments	4	6
3. Glaring white, lumpy, vesicular, massive-bedded, fairly hard, mud-flow tuff. Contains yellowish streaks of bentonite and opaline material along joints. This white tuff bed is much thicker on the south hill of "Chalk Bluffs" than here. This difference in thickness may have been caused by the presence of an old stream valley on the site of the south hill, which may have been one of the channels of the mud flows	6	8
Minor Disconformity (?)		
2. Soft, soapy, creamy-white, argillaceous tuff containing many volcanic glass fragments and a few pumice lapilli. Opaline streaks are common. The upper 6 feet contains purplish-pink streaks and splotches. Many spheroidal lumps having smoothed surfaces are present in this tuff	15	2
Frio (?):		
1. Purplish-red, mottled and streaked with greenish-gray, unstratified, joint clay containing in certain layers numerous rounded, cream-colored to pinkish, siliceous concretions, 2 to 6 inches in diameter. Streaks of opaline material are pres-		

	Ft.	In.
ent. The lower 2 feet is almost completely impregnated with opal, and is closely jointed. Base not exposed (covered with terrace gravel and silt from Nueces River)	6+	
Total Thickness	56	4

Strike of beds N. 40° E; dip 2° S.E.

SECTION ON BLUFF LOCATED IN SECTION 853, WEBB COUNTY, 18 MILES NORTH OF MIRANDO CITY

	Ft.	In.
Gueydan (?) (Fant member):		
6. Lamellar, somewhat sandy, fine-textured, non-vesicular, white trachyte (?) tuff. This rock has a slaty appearance produced by a set of low-angle joint fractures which cut the bedding planes at slight angles. Vertical rectangular jointing is also well developed	3	
5. Creamy to greenish-gray, very gypsiferous, soft, plastic, bentonitic clay	2	6
4. White or creamy-white, platy-bedded, friable, somewhat vesicular tuff	1	6
Frio(?):		
3. Massive, closely jointed, greenish-gray, gypsiferous, somewhat sandy clay containing a few horizontal streaks with a pinkish color. No. 3 becomes predominantly pink near the base	6	
2. Very irregularly bedded and lenticular, somewhat plicated, light gray, friable, medium-grained sandstone which is darker gray on exposed surfaces. This bed shows a few minor crumplings. It is cut by many thin, selenite veins, especially along bedding-planes. Some satin-spar is present in vertical lines	2	3
1. Rather massive, pinkish-gray, soft, argillaceous sandstone or sandy clay which resembles beds seen in the upper Frio in southwestern McMullen County. This sandstone becomes sun-cracked on exposure like clay. Contains many seams of selenite along bedding and vertical point planes. Base not exposed. Thickness	3	6+
Total Thickness	19	

Strike doubtful, but apparently nearly E. and W. Dip approximately ½° or less N.

This section may possibly be in the Fayette.

SOLEDAD MEMBER (Middle Gueydan)

The Soledad member of the Gueydan tuff is characterized by beds of volcanic conglomerate, the pebbles of which consist partly or entirely of trachyandesite, andesite, trachyte, and similar effusive rocks, bluish-gray pumice and pink to light green tuff; by brown, pink and conspicuous, yellowish-green, volcanic sandstone composed of volcanic debris similar to that of the conglomerate; and by beds of pink and light green, powdery, argillaceous tuff, bentonite and tuffaceous clay. Silicified tuff lenses are small but fairly common. This member is thickest and most typically developed at Soledad Hills and Government Wells in western and northwestern Duval County. It appears to thin out gradually along the strike both northeast and south of these localities. However, the member is traceable to the northeast as far as central Karnes County and to the south as far as northeastern Zapata County, perhaps farther.

(1) The most unique and distinctive rock in the Soledad member is that found at the Soledad Hills and numerous other localities in Duval, Webb, and Zapata counties. (See Plate VII, Figure 2.) As seen at Soledad Hills, the type locality, it is a fine conglomerate to a very coarse cobble or boulder conglomerate of a dark brownish-gray color which grades into conglomeratic sandstone in numerous horizons. The rock is cemented with a great abundance of milky-white to bluish, or translucent opal and chalcedony. The light-colored cement contrasts sharply with the dark pebbles, giving the rock a very striking appearance. Some of the opal is of the fire-opal variety, showing a faint to distinct play of colors. The chalcedony is finely banded. In many places nearly half of the cementing material consists of pinkish to buff, chert-like, silicified tuff or silicified tuffaceous clay. The pebbles which are unmistakably water-worn, range in size from 1 mm. up to large boulders. One of these boulders measures 2 feet by 1⅓ feet by 1¼ feet. The larger pebbles, cobbles, and boulders are usually concen-

trated in certain strata or lenses. Other strata or lenses consist of fine conglomerates, grits, or even coarse sandstones. The common range in the diameter of the pebbles is between 3 cm. and 20 cm. The majority of grains and pebbles above 2 mm. are well rounded to subrounded. Most of these are elliptical in outline and a number are quite flat with rounded edges; their parallel orientation causes the rock to appear well stratified. Practically all of the boulders, cobbles, and larger pebbles in the conglomerate are composed of porphyritic to aphanitic volcanic rocks representing several petrologic types, including trachyandesite, trachyte, andesite, and a few other types. The commonest colors are reddish-brown, chocolate-brown, and dark gray, but green, red, light gray, purple, and occasionally white pebbles are found. Most of these pebbles and boulders are dense, but some are amygdaloidal or vesicular. The large boulder mentioned above has a spongy-looking texture, and is no heavier than many boulders half its size. The smaller pebbles and sand grains also consist of the same kinds of effusive rocks, but many small pebbles of pink or light green, fine-textured tuff or silicified tuff occur. Less than 10% of the rock consists of small, rounded pebbles or coarse sand grains of light brown or yellowish chert and vein quartz. Interbedded with the conglomerate beds are a number of lenses or beds of pink argillaceous tuff and silicified tuff. This conglomerate is fully 75 feet thick at its type locality. West of Government Wells in northwestern Duval County it is represented by several thick conglomerate beds separated by beds of tuff, clay, and sandstone. At localities a few miles northeast and a few miles south of the Soledad Hills the volcanic rock pebbles are mixed with a considerable number of large chert, quartz, and silicified tuff pebbles; and at Parilla Hills in extreme western Duval County, five miles northeast of Moglia, Webb County, the volcanic pebbles comprise only 10% or less of the conglomerate, with only occasional large boulders of volcanic rock. Much opal and chalcedony cement is present here but probably half of the matrix and cement of the conglomerate consists of pinkish or light green silicified clay like that which is also common in the Soledad Hills conglomerate and at Government Wells. In Webb and Zapata counties the Soledad conglomerate carries only 5% or less to 20% of volcanic rock pebbles and boulders but some pebbles of this type seem to occur throughout the conglomerate. In these counties the Oakville sandstone and conglomerate generally rests directly on top of the Soledad conglomerate, causing difficulty in determining at what point the Soledad ends and the Oakville begins along the face of the Reynosa or Bordas escarpment. It is also impossible to know without borings to what extent this Soledad conglomerate is overlapped by the Oakville and Reynosa. Conglomerate of this type has not been seen north of the Duval-McMullen county line, but some of it probably extends into McMullen County before lensing out.

(2) Below the Soledad conglomerate is a persistent horizon of a peculiar green volcanic sandstone. At some localities similar beds occur also above the conglomerate or interstratified with it. Green sandstone of this type has been seen as far northeast as northern Live Oak County where a small outcrop of the sandstone appears on the Naves ranch, three and three-quarter miles southeast of Fant City along the main Three Rivers-Pleasanton road. Other good exposures are found six and one-half miles north of Loma Alto Mesa and two and one-quarter miles northwest of Loma Alto schoolhouse in McMullen County. Several beds of this sandstone are seen in the road at Government Wells, Duval County, and one mile west of that settlement. The rock is a fairly intense to light yellowish-green, friable, generally somewhat laminated and cross-bedded, medium-grained, gritty, argillaceous sandstone. The green color is produced by a greenish, argillaceous, possibly chlorite-bearing matrix and coating on the sand grains. In this sandstone a few to a considerable number of rounded grains are found, which indicate that the grains have been subjected to erosion. Many grains in the sandstone are composed of fine-grained andesite, trachyandesite, and other

volcanic rocks; the remainder is composed of feldspar, chert, and volcanic glass. The rock in Live Oak County consists very largely of sharp-edged volcanic glass fragments. It is possible that this green sandstone may be used as a key horizon because it is rather thin and has a distinctive appearance.

(3) Massive to cross-laminated beds of brownish-gray, grayish-cream, or brownish-pink, tuffaceous sandstones constitute one of the most prominent rock types in the Soledad member. These sandstones are friable to well indurated in character and range from coarse to fine-grained in texture. They occur at several horizons in the middle Gueydan, forming a series of cuesta ridges in McMullen County between the Ray ranch and San Caja Mesa. Most of this rock is medium-grained in texture, and the usual brownish color is due in part to the large number of red, yellow, brown, gray, and black grains of volcanic rock, such as trachyandesite, and grains of chert, and in part to the brownish-pink or light pink argillaceous material which occupies some or all of the spaces between sand grains. This argillaceous material seems to be tuffaceous and is in places silicified like that material which forms part of the matrix or cement for the Soledad conglomerate. Both the brownish (3) and the green (2) sandstones of the Soledad member are evidently derived from the same general source as the Soledad conglomerate, because the volcanic rock grains and the matrix of the sandstones are of the same types as the pebbles and the matrix of the conglomerate. Angular to somewhat worn volcanic glass grains and small pumice pebbles occur abundantly in some localities in this brownish sandstone. Many of the grains in the coarser textured sandstones are well worn and rounded by stream action and even in the finer grained type most of the grains are subangular instead of angular. In some beds a number of rounded, brownish-pink, often silicified, argillaceous tuff or clay pebbles are noted. In addition to the argillaceous material, which may act as a cement, a large or small amount of granular calcite cement is found. Some specimens contain opaline cement also. In Karnes County, three miles

south of Falls City, a horizontal outcrop of this argillaceous sandstone shows well developed, vertical cracks which appear to be sun-cracks. They are filled with stringers of soft white caliche, although the sandstone itself contains very little calcareous cement. This is the most northerly outcrop of the Soledad sandstone that was found.

(4) An exceedingly interesting and unusual rock contained in the middle Gueydan is a light brownish-pink, greenish or whitish pumice-conglomerate. The pumice pebbles, of a subrounded to well rounded shape, are cemented by a scanty matrix of rather friable, somewhat argillaceous, porous, vitric tuff of a pinkish or light greenish color. On account of the remarkable rarity of any extraneous, non-volcanic material in this rock and from the marked vesicular character of the matrix it is possible that it is of purely eruptive origin and that the pumice fragments are lapilli which became rounded by grinding against one another during transportation through the air or in a mud flow, or in a volcanic rock slide. However, the pumice pebbles show a most striking variety of colors—bluish-gray, greenish-gray, cream-colored, yellowish-green, and dark gray or nearly black—which suggests that the pumice came from more than one volcanic vent or from several eruptions from the same vent, and may have later been concentrated by running water. Conglomerates of this type outcrop six and one-half miles south of Wentz, eastern McMullen County; four miles southwest of Simmons; and also on the south bank of Weedy Creek, two miles east of Fant City, Live Oak County. Other beds containing pumice pebbles have an argillaceous or sandy matrix and are quite evidently stream-deposited.

(5) Associated with the pumice-conglomerate beds are friable, brownish-pink tuffs with a vesicular structure. These beds are practically never white in color and are usually much more friable than the somewhat similar beds in the Fant member. They also contain less glass and more bentonitic material than the Fant beds and commonly carry small angular grains of brownish trachyandesite or andesite. Many brownish-pink, extremely friable or pulverulent beds

of very fine-grained argillaceous or bentonitic tuff and tuffaceous clay are intercalated with the tuff beds.

Volcanic Boulders.—The tuffaceous clay beds and the purer tuff beds in the Soledad member carry a few rounded, apparently water-worn boulders of red-brown to dark gray, very vesicular andesite or trachyandesite. These are found in many parts of Live Oak, McMullen, and Duval counties. They range from 1″ to 1′ in diameter. Most of the boulders are very spongy and light in weight. The largest boulders found anywhere in the area are exposed in a gray loam soil on a chaparral-covered plain on Section 480, J. E. Murphy survey, two miles northeast of Loma Alto Mesa, where fifty or more of the boulders were seen. Several of them are subangular to angular in form, as much as two feet in diameter, and each weighs several hundred pounds. A few do not seem to have been worn at all. They consist of dark gray to nearly black, vesicular, acid andesite or trachyandesite carrying many partly resorbed platy phenocrysts of plagioclase up to three centimeters, or one inch, in length. The outcrop of the boulders forms a fairly definite line, probably because the lens or bed in the Soledad member which carries them has been tilted and then truncated by erosion. The only rock that outcrops near these boulders is a pink, friable, argillaceous tuff belonging to the upper part of the Soledad member or to the lower part of the Chusa member of the Gueydan formation. In addition to the volcanic boulders a few angular to rounded cobbles and pebbles of hard siliceous sandstone resembling that of the Fayette are locally found in the tuff beds just mentioned. It is difficult to conceive of a method by which such a great number of large boulders could have been concentrated here unless an old volcanic vent is located within a few miles of this locality.

(6) Beds of whitish or pinkish clay are interbedded with the previously described rocks. These clays, as well as the sandstones and most of the conglomerates, are evidently of fluviatile origin.

(7) Underlying the pumice conglomerate on the bank of Weedy Creek, two miles east of Fant City, is a dense-

textured, rather soft, somewhat conglomeratic, unfossiliferous limestone. A number of sun-cracks are seen in this limestone. They are filled with a tuff which contains pumice pebbles. That this is a fresh-water limestone seems probable from these relationships. A fairly coarsely crystalline limestone containing euhedral rhombs of siderite was penetrated in the Hawley well located one mile south of the Weedy Creek outcrop and two miles southeast of Fant City. Below this conglomeratic limestone, twenty feet of serpentine was encountered.

Sections.—The following are given as the most representative sections of the Soledad member exposed.

SECTION 2 MILES NORTH OF GOVERNMENT WELLS, DUVAL CO., IN BLUFFS ON BOTH SIDES OF COTULLA ROAD

	Feet
Gueydan (Soledad member):	
4. Coarse-grained, grayish-brown sandstone or grit and conglomerate with vertical and lateral gradations from sandstone to conglomerate. These rocks are fairly hard, and thin to massive-bedded. The pebbles consist mainly of buff, gray, or light brown chert but many pebbles of brown, red and purplish trachyandesite (?) and pink argillaceous tuff and clay are also present. The pebbles are generally rounded and range in size from coarse sand to boulders 1 foot in diameter. The largest boulders consist of vesicular volcanic rocks	20
3. Brownish-pink, dense-textured, sandy, much jointed silicified tuff or tuffaceous clay containing numerous irregular lenses, streaks, and pockets of coarse sandstone or fine conglomerate. This grades into No. 4. Thickness	1
2. A yellowish-green, very friable, arkosic, pebbly grit or coarse conglomeratic sandstone. Many of the sand grains and pebbles in this sandstone consist of volcanic rocks, apparently andesite and trachyandesite. The cement is a mixture of greenish argillaceous material and calcite. The base of this bed has a 5° inclination to the south	12

Feet

Disconformity

Fant member (?):

1. Profusely jointed, more or less silicified, dense-textured, white tuff grading upward into a soapy, cream-colored bentonite which breaks into spheroidal joint fragments and irregular to tetrahedral pieces. Some glass grains containing bubbles can be seen in the upper portion with the naked eye 15

   Total Thickness 47

   Dip uncertain, beds approximately horizontal.

SECTION AT SOUTH END OF SOLEDAD HILLS, NORTHWEST DUVAL COUNTY

Gueydan (Soledad member):

2. Well-indurated to friable, brownish-gray, massive-bedded conglomerate consisting almost entirely of pebbles, cobbles and boulders of porphyritic volcanic rocks of several types (mostly trachyandesite) and some of tuffaceous clay. The cement is white chalcedony, opal and silicified tuffaceous (?) clay. Some lenses and angular, boulder-like masses of pink silicified tuffaceous clay up to 2 feet in thickness are present in places....50

Disconformity (?):

1. Soft, powdery, finely pisolitic, pink altered tuff or bentonitic clay containing streaks and lenses of conglomerate like No. 2. Base not exposed. Thickness exposed 25

   Total Thickness 75

   Approximate strike N. 24°E; Dip ½°—1° S. E.

SECTION ¼ MILE EAST OF THE McMULLEN COUNTY LINE, 4 MILES SOUTHWEST OF SIMMONS, LIVE OAK COUNTY

Soledad member:

9. Brownish-pink, friable, porous, andesite (?) tuff composed mainly of volcanic glass fragments and containing a few rounded boulders (possibly in part volcanic bombs) of red-brown vesicular andesite? 4

		Ft.	In.
8.	Hard to friable, thin-bedded, light brownish-pink, feldspathic sandstone containing many angular volcanic glass fragments and subangular grains of andesite? Grades into No. 9 at top	20	
7.	Covered	14	
Fant member:			
6.	White, friable and powdery, fine-grained, argillaceous tuff or dust-tuff		5
5.	Hard, green and pink mottled, closely jointed, silicified clay or shale		5
4.	Fine-grained, friable, sand-tuff of light gray color	1	
3.	Like No. 6		4
2.	Hard, olive-green, silicified clay shale		6
1.	Like No. 6		6
	Total Thickness	41	2

SECTION ON WEEDY CREEK, LIVE OAK COUNTY, 2 MILES ABOVE FANT CITY BRIDGE

		Ft.
Soledad member:		
3.	Conglomerate composed almost entirely of pumice pebbles in an argillaceous tuff matrix of a pink color. In the lower part are boulders and pebbles of soft white limestone	2
2.	An irregularly bedded lens of sun-cracked, rather soft, white limestone. The sun-cracks are filled with tuff carrying pumice pebbles. This lens grade upward into limestone-tuff conglomerate	1
Fant member:		
1.	Somewhat indurated, lumpy, vesicular, mud-flow tuff to water's edge in Weedy Creek	6
	Total Thickness	9

The rocks here are considerably crumpled. In one place a small northeast striking fault with a displacement of 7 feet is seen. The northwest is downthrown.

Dips on these beds variable, 2°—5° S.W., S. and S.E.

SECTION ON BRANCH OF ROCK CREEK, 1/8 MILE NORTH OF NOPAL-NIXON ROAD, 8 MILES SOUTH OF SMILEY, GONZALES COUNTY

		Feet
Gueydan (Soledad member(?) with Catahoula facies):		
6.	Fairly friable, porous, wavy-bedded, medium-grained, argillaceous, tuffaceous(?) sandstone which is cemented with white, waxy opal. Rock shows many red splotches of ferruginous material formed from the weathering of tiny, trigonal or hexagonal plates of vitreous, orange-yellow jarosite which commonly occurs in some of the vesicle-like cavities in the rock. The beds of this rock are commonly 6 to 8 inches thick. They resemble tuff beds in the gnarly appearance of their outcrop. Thickness of No. 6	10
Fant Member:		
5.	Unstratified, creamy-white, rather lumpy, argillaceous tuff	12
4.	Very much cross-bedded and laminated, very friable, fine-grained, white, tuffaceous sandstone, composed largely of volcanic glass	7
3.	Lamellar, white, tuffaceous shale containing lenses of pure white, powdery, bentonitic tuff 8 inches thick. Thickness of No. 3	4
2.	Like No. 4	6
1.	Lamellar, creamy-white, fairly hard, shaly, vitric tuff, interstratified with a few 1-foot beds of grayish white, friable sand-tuff. Base not exposed. Thickness exposed	10
	Total Thickness	49

Beds which appear to be identical to No. 6 in physical character and mineralogical composition have been observed ½ mile east-northeast of Rockland, Tyler County, about 100 miles northeast of Houston in East Texas, in strata of practically unquestionable Catahoula age. These beds can also be traced from the locality of this section into northwestern Lavaca County, near Moulton, where they are mapped with the Catahoula by Deussen.[45]

CHUSA MEMBER (Upper Gueydan)

The Chusa member consists of non-indurated, very tuffaceous clays and argillaceous tuffs which are generally unstratified. In a few localities they contain small, angular to rounded pumice lapilli or pebbles. This member is thus

[45]Deussen, Alex., U. S. Geol. Surv., Prof. Paper 126, Plate VIII, 1924.

composed of the same kind of material which is commonly interbedded with the Soledad sandstone and conglomerate strata, and grades downward into the latter member. The Chusa contains some thick, fine-grained, vitric tuff or volcanic dust beds, but it seems to be essentially composed of the finer debris from underlying tuff beds which has been mingled with variable amounts of extraneous, non-volcanic material by stream action. Most of it is, therefore, not tuff but should be more appropriately termed bentonitic or tuffaceous clay. This member, as noted previously, is completely overlapped by younger formations south of Duval County, but northeast of McMullen County it appears to be the thickest portion of the Gueydan. The thickness has not been determined because a complete section of this member is nowhere exposed in one vertical outcrop, and because the beds are practically unstratified, which prevents recognition of definite horizons by which to correlate outcrops. Some borings beginning above the top of the Chusa member have passed through it and other members of the Gueydan into the underlying Fayette and Cook Mountain formations, but the writer has been unable to secure enough samples from these wells to establish the thickness of the Chusa member. The member persists as a more or less distinct stratigraphic horizon beyond the northeastern limit of the region studied, where beds of almost identical appearance are seen to overlie the Catahoula sandstone in eastern Gonzales County and a few miles northwest of Moulton in northwestern Lavaca County. Similar strata are also exposed in the upper Catahoula and basal Fleming clays near Rockland, Tyler County, in eastern Texas. All the lithologic types in the Chusa member grade into one another and are of rather similar appearance, except for color. The color evidently depends upon whether the iron content is in a ferric or a ferrous state. In the more humid part of the district, that part northeast of Live Oak County, the color is light green or grayish-green and the iron is evidently in a ferrous state, while in the more arid region southwest of that county the color is largely pink or brownish-pink from the presence of ferric iron. In Live Oak County part of these strata are pink and part are green. Contacts between the strata of unlike color are here gradational and irregular. A detailed study of this variation in color may throw some light on the origin of red beds.

The principal lithologic type of the Chusa member is an unstratified, non-calcareous to marly, very poorly consolidated, pisolitic or lumpy, bentonitic clay or friable bentonite which commonly outcrops in vertical faces like loess. (See Plate VIII, Figure 1.) The clay practically everywhere shows a prominent pisolitic or pseudo-pisolitic structure. In many varieties the spheroidal pisolites are quite small, from ¼ mm. to 1 cm. in diameter, the smaller sizes being predominant. The matrix between the pisolite-like bodies in the non-calcareous varieties is apparently the same material as that which forms the pisolites. In the calcareous varieties the matrix is locally much more calcareous and therefore more resistant to weathering than the pisolites. Consequently the pisolites weather out, leaving the surface of the outcrop with a honey-combed appearance. Such honey-combed rocks are exposed one-quarter mile north of Three Rivers, Live Oak County. These clays are cut in many places by vertical and variously inclined stringers, one-eighth inch to four inches thick, of argillaceous chalky material in which subangular sand grains are often included. Spheroidal or lobate concretions of similar material from one-quarter inch or less to six inches in diameter are also usually present and commonly occur in horizontal lines. Some of these concretions are well indurated. Around many of the concretions are found systems of radiating fractures similar to those which may be observed around serpentinized olivine in a thin section of partly weathered olivine gabbro. These fracture lines have evidently been produced by the pressure exerted by the growing concretion on the surrounding clay, for the reason that no similar sets of fractures were seen except around these concretions or around cavities from which concretions had evidently been removed by solution or weathering. In some exposures it is evident that practically all the calcium carbonate in the rock has been concentrated in the calcareous concretions because the pisolitic clay does not effervesce in hydrochloric acid. Good exposures of the finely pisolitic pink bentonites and bentonitic clays are found in the high, wall-like banks of White Creek, in western Live Oak County, two to four miles south and southwest of Simmons; at the type locality of the Gueydan formation (Gueydan ranch in eastern McMullen County); on the slopes of La Chusa, San Caja, Rosalier, Loma Alto, and the other prominent Oakville-capped mesas in southeastern McMullen County. The rock on White Creek is apparently a nearly pure bentonite—when placed in water, it absorbs the water with a singing sound and crumbles down almost immediately into a doughy mass which contains very few gritty particles. Many of the coarser particles in this rock consist of volcanic glass. Exposures of the coarsely pisolitic or lumpy, generally calcareous, light green to nearly white bentonitic clays are found in several localities around Three Rivers, including the type locality of Dumble's Frio on the Frio River just west of Three Rivers; four and one-half miles southeast of Gillett, Karnes County, on Ecleto road; three miles northwest of Nopal, Gonzales County, on Smiley road; and two miles northwest of Cheapside, on Gonzales road. The green, marly, bentonitic clay in many places contains only a few volcanic glass grains and will not "slake" very readily in water on account of the calcareous cementing material.

A few thick beds of faintly stratified, friable, greenish-white, more or less lumpy and porous, fine-grained, vitric tuff or altered volcanic dust are exposed on the north bank of the Nueces River in Live Oak County, about three miles above its junction with the Frio River. In parts of this extensive outcrop are a few thin, cross-laminated, sandy lenses. These contain a number of small, bluish-gray pumice pebbles, in addition to abundant worn quartz, chert, and feldspar grains, evidently of fluviatile origin. These sand lenses apparently represent minor interruptions in the deposition of the volcanic ash from the atmosphere.

Locally the uppermost beds of the Chusa member are stratified and have a lamellar bedding. These beds contain only a few glass fragments. They are light green in color or green splotched with pink, very friable, and are interbedded with sandy clays in places. The only exposures of this type of somewhat bentonitic, marly clays seen by the writer are located at Los Picachos Hills, in north-central Duval County, and along a salty tributary of Sulphur Creek near the Live Oak County Demonstration Farm, eight miles east-southeast of Fant City. The beds at Los Picachos are cut by a northeast striking fault producing a drag-dip of 10 to 40 degrees or more to the southeast. The beds adjacent to this fault are closely fenestrated with minute, fibrous, calcite veinlets.

Sections.—On account of the unstratified character and the homogeneity of most of the Chusa member, considerable thickness of this member must be placed in a single bed.

SECTION AT NORTHEAST END OF LOMA ALTO MESA

		Feet
Oakville:		
4.	Brownish-gray coarse sandstone and conglomeratic sandstone, well silicified, containing numerous pink tuff or tuffaceous clay pebbles and a large number of water-worn fragments of silicified wood	1–3
Gueydan (Chusa member):		
3.	Pink, pulverulent, tuffaceous clay containing streaks and crusts of friable, whitish caliche along joints	65
2.	Covered	20
1.	Like No. 3	5
	Exposed thickness of Chusa member	90

The base of No. 1 is not exposed; the section is covered below this bed. The strata are practically horizontal, or possibly dip ¼ degree northeast at the south end of the mesa. From other exposures of rock like No. 3 and exposures of rock similar to this (except as to color, a light green) in the vicinity of Loma Alto Mesa, the Chusa member is known to be over 160 feet thick, with the base not exposed.

SECTION ON NORTH BANK OF NUECES RIVER, 3 MILES ABOVE MOUTH OF FRIO RIVER, LIVE OAK COUNTY

Chusa member:	Feet
2. Greenish-white, soft, argillaceous tuff, often with a lumpy texture; this forms a vertical to overhanging cliff	18
1. Whitish, somewhat sandy, friable tuff containing cross-bedded sand laminae, of evident fluviatile origin, and occasional pumice pebbles	12
Total thickness exposed	30

SECTION ON WEST BANK OF WHITE CREEK, 1 MILE ABOVE THE MOUTH, LIVE OAK COUNTY

	Feet
2. Dark gray, clay soil	1–3
1. Fine-grained, soapy feeling, exceedingly friable, creamy-pink, occasionally splotched with greenish-white, bentonitic clay having a fine, pisolitic texture. This outcrops in vertical cliffs resembling loess cliffs. Contains abundant oval to botryoidal, dense-textured, friable to well consolidated, argillaceous, calcareous concretions up to 8 inches in diameter. These concretions appear to be relatively more abundant along certain horizontal lines than elsewhere. Streaks of white caliche are common along joint cracks. Thickness	35

Sections of Gueydan and Catahoula in wells.—The most complete, available sections of the Gueydan and Catahoula formations are furnished by two wells. A fairly complete set of samples from these wells were studied under the binocular and the petrographic microscopes. Therefore the records here given are believed to be reliable. The well Wilson No. 1 drilled in the Catahoula formation of East Texas is included here for comparison with the Gueydan, of the Hicks No. 1, its probable age equivalent.

DESCRIPTION OF SAMPLES FROM H. COQUAT AND ASSOCIATES, HICKS NO. 1 WELL LOCATED 1 MILE WEST OF SIMMONS, LIVE OAK COUNTY

	Feet	
	From	To
Gueydan (Lower Soledad and probably part of Fant member):		
1. No samples received. Reported as pink tuff, tuffaceous clay and some sandstone		75

	Feet From	To
Fant member:		
2. Consolidated, creamy-white, somewhat silicified, lumpy, non-calcareous, trachyte(?) tuff. Consists of over 80% glass. Most of the remainder is opal (from the cement), leverrierite and sanidine. A few grains of biotite and quartz are noted	75	94
3. Light pinkish-brown, fairly hard, opal cemented, argillaceous, tuffaceous sandstone containing many rounded sand grains. Some spheroidal patches of crystalline calcite up to 5 mm. in diameter are noted. Most of the sand grains are between ½ and ⅛ mm.; there is about 30% of clay. A number of black biotite flakes and numerous subrounded, yellow, orange, red, brown, and dark gray, andesite grains having a chert-like appearance can be identified with a hand lens. These give the rock a speckled appearance. The grains in the abundant washed material range from 1/16 mm.—2 mm. in diameter. Practically all those over ½ mm. are colorless calcite from the cement. The sizing of the remainder is approximately as follows: ⅛—¼ mm.—35%; ¼—⅛ mm.—50%; ⅛—1/16 mm.—15%. The mineral composition is estimated: (1) Plagioclase (mostly andesine and oligoclase, sometimes with brown glass inclusion)—40%; (2) brown and reddish andesite(?) grains (showing andesine microlites and magnetite crystals in a glassy matrix)—15%; (3) chert (mostly yellow, orange and gray)—20%; (4) sanidine—2%; (5) quartz —5%; (6) calcite—10%; (7) volcanic glass grains—5%; (8) ilmenite—trace; (9) magnetite 1%; (10) augite—trace; (11) biotite—1%; (12) chalcedony—trace; (13) apatite—trace; (14) chlorite—trace; (15) opal—1%. No fossils noted	94	102
(Note: This is evidently a fluviatile deposit representing the erosion and redeposition of considerable andesitic(?) tuffaceous material mixed with much non-volcanic chert, quartz, etc. The clay present is apparently montmorillonite, a decomposition product of vitric tuff.)		
4. Light magenta grading into cream-colored, non-calcareous, massive, somewhat silty clay which breaks with a subconchoidal fracture when dry.		

		Feet From	To
	It breaks down fairly readily in water but not so rapidly as bentonite. Washed material comprises about 1% of sample. The grains in the washed material range from 4 mm. (manganiferous concretions) and 1 mm. (rounded quartz grains) to 1/16 mm. Most grains are between ¼ and 1/16 mm. They vary from well-rounded to sharply angular but the majority are subangular. The mineral composition is estimated as follows: (1) Quartz—20%; plagioclase (mostly andesine but ranging from oligoclase to labradorite)—25%; (3) sanidine—5%; (4) manganiferous concretions—20%; (5) chert and chalcedony (mostly cream-colored, gray and yellow)—25%; (6) magnetite—1%; (7) zircon (a few crystals 2 mm. by ¼ mm.)—trace; (8) epidote—trace; (9) rutile—trace; (10) apatite—trace; (1)) biotite—trace; (12) andesite grains (reddish)—1%; (13) microcline—trace; (14) opal (crusts and grains)—1%; (15) altered volcanic glass—trace; (16) orthoclase (partly altered)—20%	102	118
5.	Tawny-white to grayish-white, very friable, calcareous, vitric tuff	118	120
6.	Somewhat sandy, slightly calcareous, mottled brownish-pink and greenish-gray bentonitic clay or tuffaceous clay in which are imbedded a number of cuttings of coherent, dark green, altered andesite(?) tuff. On exposure to air for several months the green tuff has assumed a yellow-brown color and contains much limonite. Washed material from this mixed tuff and clay sample comprises about 2% of total sample. It appears to be poorly sorted on account of the abundance of limonite grains and calcareous and manganiferous concretions. A fair number of rather large, apple-green, impure chloritic grains are present. The largest grain is a calcareous concretion 1 cm. in diameter. Practically all the size separates between 2 and ½ mm. are composite grains or concretions. Most of the true sand grains are between ¼ and 1/16 mm., although grains up to ½ mm. are common. The grains are subangular and angular. The washed material is composed of plagioclase (mostly andesine and labradorite), sanidine, gray, yellow, and orange chert, limonite		

No.	Description	Feet From	To
	grains, calcareous and manganiferous concretions, quartz, yellow-green chloritic grains, chalcedony, much volcanic glass, andesite(?) grains, opal, apatite and magnetite. Most of the glass is clear and fresh; contains bubbles and cylindrical cavities	120	124
7.	No sample. Reported dark brown volcanic sandstone	124	140
8.	White trachyte or trachyandesite tuff, much like that from 85 feet, interbedded with bluish-gray bentonitic tuff and tuffaceous clay	140	200
9.	No samples. Reported as alternating beds of greenish tuff and red and green bentonitic clay containing pyrite	200	290
10.	Light magenta-red, massive, rather hard and somewhat silicified, non-calcareous, silty clay which breaks with conchoidal fracture. Washed material about 1% of sample. This consists of subangular to subrounded and some angular grains of andesine and oligoclase feldspar, quartz, sanidine, pyrite crystals, opaline crusts and a few calcite grains. No glass or fossils present	290	300
11.	A variegated light buff, pink and greenish, imperfectly finely laminated, marly, bentonitic clay. The washed material comprises less than 1% of the sample. Greenish, dense-textured, argillaceous, calcareous concretions make up most of the washed material. The remainder consists of oligoclase, sanidine, hematite and limonite concretions, magnetite, opal, quartz and a few grains of volcanic glass and zircon	300	315
12.	Light grayish-green, tuffaceous clay which contains much crystalline calcite. The calcite crystals are between 1–⅛ mm. but many granular or drusy masses of calcite crystals reach a diameter of 2–4 mm. Calcite comprises over 95% of the washed material and about 25% of the total sample. A small amount of dolomite is also present. The other minerals in the washed material include plagioclase (mostly oligoclase), orthoclase, quartz (rare), clear volcanic glass, barite, chlorite, opal, pyrite, green hornblende, tridymite(?), augite, pyrite and magnetite. Plagioclase is much more abundant than any mineral besides calcite. Glass is quite frequent. The tridymite(?) is associated with botryoidal opal	315	330

		Feet From	Feet To
Frio:			
13.	Light, creamy-green, pyritiferous, non-calcareous, massive clay containing a few thin lamellae of fine, silty sand. Washed material consists of plagioclase feldspars (largely andesine and labradorite), sanidine, quartz, pyrite, opal, magnetite and a little chlorite and apatite	330	380
14.	A hard, massive, light creamy-green, nearly non-calcareous clay which breaks with conchoidal fracture. The clay is somewhat silicified. Nearly all the clay particles have a much lower index of refraction than kaolin. The washed material consists principally of opaline crusts and concretions, numerous tiny pyrite crystals (pyritohedrons), partly rounded quartz grains and angular to subangular feldspar grains. Only a trace of washed material is present, the clay being remarkably free from grit	380	396
15.	A magneta-red, splotched with a small amount of light grayish-green, massive, sticky, marly clay. Washed material comprises a small fraction of 1% of the sample. It is composed of the following minerals arranged in order of abundance: Feldspar (sanidine, orthoclase, andesine, labradorite, some albite and oligoclase), quartz, pyrite, calcite, hematite, opal, chert and a few grains of glass. A calcite cast of a Textularia (probably derived from older sediments) is noted	396	414
16.	No samples	414	451
17.	Hard, dense-textured, white, fresh-water, argillaceous limestone. No fossils are present		451
18.	Light creamy-green, strongly calcareous, bentonitic, argillaceous silt or fine sandy clay. Washed material comprises about 3% of total. It consists largely of angular feldspar grains (of which the majority are andesine and labradorite) and granular calcite fragments. Albite, orthoclase, chlorite, quartz, opal, biotite and pyrite are present. Secondary (Cretaceous) foraminifera of the genera Globigerina and Textularia are fairly common. A large number of calcareous concretions are present	451	453
19.	Like the preceding except that less sand and silt are present	453	460

	Feet From	To
20. A light creamy-green, strongly gypsiferous, noncalcareous, irregularly jointed and slickensided bentonitic clay. The gypsum appears in the washed material as irregular crusts. Similar crusts and rounded concretions of opal are abundant also. No sand grains are coarser than ½ mm. and over 90% of the washed material is between ¼ and 1/16 mm. Gypsum comprises about 30% of it. The sand grains consist of plagioclase (mainly oligoclase to andesine), chert, quartz, volcanic glass (rare), sanidine and a few chloritic grains. Plagioclase is more abundant than quartz	460	467
Fayette:		
21. Light grayish to yellowish-green, calcareous, medium-grained, argillaceous sandstone. About 75% of the abundant washed material is between ¼ and ⅛ mm.; about 15% is between ⅛ and 1/16 mm. The remaining coarser material is pyrite crystals and calcareous concretions. Most of the sand grains are subangular but rounded grains are not rare. The washed material is composed mainly of quartz, chert and plagioclase (oligoclase to labradorite, often zoned). Some grains of gypsum, hornblend, hypersthene, fibrous aragonite, volcanic glass, magnetite, pyrite, chlorite, epidote, calcite, biotite and zircon are noted. A number of fragments of greenish volcanic rock are also present. Foraminifera or calcite casts of them are quite common, forming probably 2% of the washed material. These are round-chambered Textularia and two species of Globigerina. They are probably derived from the Cretaceous	467	474
22. Very similar to the preceding sample. The present sample contains more pyrite and more greenish, partly altered lava fragments, some of which show feldspar laths and apatite prisms. Foraminifera of the same species as in the preceding sample are present in about the same abundance. Hornblend and hypersthene are very rare	474	498
23. White, argillaceous, probably concretionary limestone	498	500

		Feet From	To
24.	Light yellowish-green, sandy clay containing many granular calcareous concretions and much pyrite. Washed material consists of plagioclase, quartz, chert, pyrite, calcite, gypsum, sanidine, zircon and rare grains of microcline and barite. Poorly preserved Globigerina and Textularia are noted	500	540
25.	No samples	540	560
26.	A light gray, well-indurated, calcareous cemented, fine-grained sandstone. About 20% of the rock consists of calcite cement. Many dark gray chert and bluish-green altered volcanic rock grains are noted with a hand lens. The other minerals in the sand are plagioclase (mostly oligoclase and andesine), quartz, chert, hypersthene, zircon, pyrite and magnetite. No potash feldspar noted. Fresh glassy plagioclase comprises over half the sand grains. A few casts of Globigerina and Textularia are imbedded in the cement	560	561
27.	Medium-grained, white, argillaceous, fresh-water or concretionary limestone containing no fossils		562
28.	A peculiar whitish, slightly sandy, argillaceous and opaline rock, probably an altered and silicified impure tuff. It consists mainly of nearly colloidal leverrierite particles and irregular opaline masses. A number of grains of angular to subangular sanidine and oligoclase feldspar, volcanic rock and quartz the size of silt and fine sand are present throughout the rock	570	580
29.	A laminated, somewhat sandy, marly clay containing numerous streaks and laminae of lignite and carbonaceous clay. The washed material consists of abundant lignite, plagioclase, chert and quartz grains and less common pyrite, orthoclase, calcite, zircon, and apatite grains. Globigerina and Textularia are common. A good showing of gas was encountered here	590	600
30.	Light gray, very argillaceous, calcareous, medium-grained sand or friable sandstone containing many grains above ¼ mm. in diameter. This rock contains about 20% of dark gray or black chert grains	600	602

The Hicks well section indicates that (1) the Fant member, and presumably the Gueydan as a whole, thickens toward the Gulf of Mexico, as do most of the other formations of the Gulf Coastal Plain. This follows from the fact that the Fant member in the Hicks well is thicker than its calculated thickness from the width of its outcrop and its dip directly northwest of the well; (2) there seems to be a much smaller proportion of true tuff and more tuffaceous clay and sandstone of evident fluviatile origin than is found in the Fant member at its outcrop; there is a clearly defined alternation of pyroclastic and fluviatile deposits.

The alternation of volcanic and fluviatile deposits is also brought out by the study of the Catahoula section afforded by the Wilson well in Tyler County. This suggests that the Catahoula and Gueydan were being deposited during the same epoch of explosive volcanic activity, although the Catahoula was evidently deposited much farther from the centers of activity.

DESCRIPTION OF SAMPLES FROM THE TEXAS AND SOUTHERN PETROLEUM COMPANY'S WILSON NO. 1 WELL, LOCATED ON CHERRY SURVEY, ABOUT 4 MILES NORTHWEST OF ROCKLAND, TEXAS

	Feet	
	From	To
Catahoula:		
Cuttings of light yellow and greenish-gray, non-calcareous, rather pure bentonite. The washed material consists mainly of cream-colored, often angular, grains of argillaceous material which seems to be altered volcanic glass, at least in part. A number of angular to slightly worn quartz, feldspar, gypsum, muscovite and chert grains and numerous small pyrite, and marcasite concretions are noted. No fossils present	44	47
Cuttings of powdery, non-calcareous, cream-colored, volcanic tuff. A small amount of washed material consisting of partly altered volcanic glass, gypsum and a few grains of quartz, chert, mica and feldspar noted	47	51

	Feet From	To
Fine cuttings of light greenish-yellow, non-calcareous bentonite and tuff. Probably half of the washed material consists of unaltered volcanic glass grains up to 1 mm. in diameter. Many show bubbles and elongated tubular cavities. The other minerals noted are quartz, chert, feldspar, pyrite and marcasite	51	63
Cuttings of unconsolidated, light creamy-gray, fine-grained, argillaceous tuff which has the consistency of fine friable sandstone. Considerable leverrierite is present. The washed material is abundant and consists largely of unaltered volcanic glass or pumice fragments. Many grains of partly altered volcanic glass are also present. Most of the glass grains are ½ to ⅛ mm. in diameter	63	74
Fresh, pale-gray, medium-grained, loose, volcanic sand. About 60% of the sample consists of volcanic glass grains. The remainder consists of quartz, chert, pyrite and feldspar grains. These grains are mainly sharply angular but a few are even subrounded. This sample probably represents a volcanic ash deposit which has been sorted and reworked by water	74	84
Like the preceding except finer grained	84	97
A light yellowish-green bentonite or largely altered volcanic ash like 51–63 feet. About 30% of the washed material consists of brassy tin-white marcasite concretions, many of which are spherical	97	100
Cuttings of greenish-gray and a little purplish-gray bentonite mixed with lignite fragments and coarse to fine, more or less rounded sand	100	110
Cuttings of greenish-gray bentonitic clay and much loose, light gray, quartz sand. Much lignite is present. This sand consists mainly of quartz although glassy feldspar and chert are common. Nearly all of the chert is black. Possibly 10% of the grains are subrounded or well rounded. Most of the grains are subangular. No volcanic glass noted; 80% of the washed material is between 1 and ¼ mm., with ½–¼ mm. the largest separate. Some of the quartz has a bluish cast like that in the so-called "rice sands"	110	114
A coarse-grained, loose, "rice" sand. Over half of the grains are between 1 and ½ mm. The largest grains are 2 mm. in diameter. A number of the grains are elongated, and a large percentage, probably 25%, are polished. The bluish translucent cast which causes		

	Feet From	Feet To
the quartz grains to resemble rice is apparently due to a very thin coating of opal. Quartz is by far the most abundant mineral but chert and feldspar are common, and a number of lignite fragments are present. The majority of the grains are subrounded to subangular. Only 5% or less are well rounded	114	117
Cuttings of light creamy-green, non-calcareous, bentonitic clay mixed with a number of lignite fragments. The washed material consists mainly of lignite, altered volcanic glass, quartz, feldspar and chert grains	117	121
Loose sand and a few fragments of cream-colored bentonite like sample from 110–114 feet. Many "rice sand" grains present	121	122
Cream-colored, non-calcareous bentonite	122	126
Mixed cuttings of bentonite, lignite and coarse sand	127	143
Bentonite and much loose, medium-grained sand. Much of the sand is rounded and polished	143	150
Coarse and medium, loose light gray sand	160	164
Fine cuttings of cream-colored bentonite, loose sand and lignite	164	166
Loose, bluish-white, coarse to medium, "rice sand" and a few cuttings of bentonite	166	181
Cuttings of cream-colored bentonite, dark purplish-gray shaly clay and much "rice sand"	181	183
Coarse to medium, rather poorly sorted, loose sand	183	185
Cuttings of creamy bentonite and some lignite and dark shaly clay	189	205
Like the preceding sample except that more lignite is present	205	211
Sample consists of several large flat fragments of lignite	211	212
Cuttings of creamy bentonite, considerable lignite and purplish-gray, non-calcareous, hard, shaly, clay. Some coarse and medium sand also present	219	222
Cuttings of soft, black lignite	222	225
Cuttings of creamy bentonite, purplish-gray shale and lignite	225	233
Cuttings of lignite and cream-colored bentonite. The washed material consists mostly of lignite, but considerable poorly sorted medium and fine sand is present. A number of slivers of gypsum noted	233	238

	Feet From	To
Bit sample of cream-colored, light purplish and light greenish, non-calcareous bentonitic clay and some light gray sandstone. Many fragments of opal-cemented sandstone noted in the washed material. A few round marcasite concretions noted. Most of the washed material besides the sandstone fragments is composed of subangular to rounded quartz, feldspar and chert grains and angular grains of altered volcanic glass	240	246
Large fragments of a good grade of lignite	246	250
Cuttings of creamy bentonite, purplish shale, lignite, siliceous sandstone and loose sand	250	262
Like preceding sample	262	264
Cuttings of cream-colored bentonitic clay, lignite and purplish-gray shaly clay	264	283
Yellowish-gray, coarse to fine, silty, loose sand	283	285
Fine cuttings of cream-colored, non-calcareous bentonitic clay and lignite	285	315
Whitish or light gray, medium and fine loose sand	315	317
Cuttings of cream-colored bentonitic clay and some lignite	317	379
Like the preceding except more lignite and numerous sandstone fragments are found in the washed material	379	385
Cream-colored to light greenish-gray, non-calcareous, sandy, bentonitic clay	385	387
Like sample from 379–385 feet	387	435
Like sample from 285–315 feet	435	454
Fairly large fragments of brownish, soft lignite and a little light-colored clay	454	456
Creamy to pale gray, bentonitic clay, much loose, coarse and medium sand and some lignite	456	462
Loose, medium-grained, light gray, non-calcareous sand and a few lumps of friable sandstone	462	471
Cuttings of cream-colored, bentonitic clay, dark purplish-gray, shaly clay and light gray or whitish, opal-cemented sandstone. The sandstone has rather angular grains	471	474
Coarse-grained quartz sand and some sandy clay. Pyrite and lignite noted	474	478
Mixed cuttings consisting mainly of lignite. Some coarse sand and light gray sandy clay are also present. A small amount of gypsum and sulphur is also noted	478	480

	Feet From	Feet To
Light greenish-gray somewhat bentonitic clay and some sand. Pyrite and chert are noted	480	483
Light gray, fine to coarse sand. Some of the fragments have been partly fused by the core barrel. A little pyrite and chert are present	482	484
Light greenish-gray, bentonitic clay and fine sand. Some lignite, chert and pyrite noted	484	485
Fine-grained, white sandstone containing some lignite and gypsum	485	487
Light greenish-gray, sandy clay containing a large amount of fine sand. Lignite and orange-colored quartz are noted	487	492
Mixed cuttings consisting mainly of lignite. Some sand and sandy clay is present. Some fragments of the lignite are coated with sulphur	492	498
Jackson (Eocene).		

The samples from 44–498 feet consist mainly of interbedded, light-colored, bentonitic clays, light gray, loose sands and sandstones, and lignitic material. In the portion of the section above 100 feet several beds of very slightly altered volcanic tuff and reworked tuff containing much fresh volcanic glass occur. Associated with the lignite seams, probably below each, are thin beds of dark purplish, rather hard, shaly clay or shale.

PETROLOGY OF THE GUEYDAN ROCKS

Method of study.—The writer has made a petrographic study of over 100 samples of various types of Gueydan rocks in an effort to ascertain the conditions of deposition of these rocks and the source of the material of which they are composed. These rocks, with the exception of a few of the mud-flow tuffs and silicified tuffs in the Fant member, the chalcedony and opal-cemented Soledad conglomerates and sandstones, and the boulders and pebbles of volcanic rocks which are included in many of the Gueydan beds, are too friable to be made into thin sections. However, thirty thin sections of the better indurated tuffs were studied; photomicrographs of a few typical tuff sections are shown in Plate IX, Figures 1 and 2, and Plate X, Figure 1. The poorly consolidated rocks were separated into their constituent particles by washing the samples in water, the clay and silt being removed by decanting the fine silt and clay particles which remain suspended in the water for more than a few seconds. After the clay and silt were removed the washed material (consisting of particles generally coarser than 1/16 mm.) was dried and sieved. Portions of each of the three sieve separates ranging from ½–¼ mm., ¼–⅛ mm., ⅛–1/16 mm., respectively, were immersed in oils of known indices of refraction and studied under a petrographic microscope. These three separates correspond to medium, fine, and very fine sand according to Udden's classification.[46] The coarser separates were studied with a hand lens or a binocular microscope. A number of unwashed samples were also examined with a binocular microscope in order to ascertain their textural features. The mechanical composition of about twenty typical samples was obtained by (1) weighing the dry sample before washing, (2) later, weighing each of the sieve separates of the dried washed material, to ascertain the percentage of the total sample in each separate, (3) subtracting the weight of the total washed material from that of the unwashed sample to obtain the approximate percentage of clay and silt. In the remaining eighty samples studied the percentages of different sized sand grains in the washed material were estimated by comparing the volume of each separate with that of the others. The percentage of clay and silt was estimated similarly by comparing the volume of the total washed material with the volume of the sample before washing. This method of estimation is not exact but the results are close enough for comparison with the typical samples the mechanical composition of which was determined more accurately by weight. The mineral composition was estimated by comparing the number of grains of a given mineral with the total number of grains within a typical portion of a slide

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[46]Udden, J. A., "The Mechanical Composition of Clastic Sediments," Bull. G.S.A., Vol. XXV, pp. 655–744, 1914.

covered by the microscopic field. The percentages thus estimated are only approximations but give a much clearer idea of the composition of a certain rock than a mere listing of minerals, possibly accompanied by a few qualifying adjectives like "abundant" and "frequent."

CLASSIFICATION OF PYROCLASTIC ROCKS

Before discussing the petrography of the fragmental volcanic rocks of the Gueydan it is advisable to define the terms which will be applied to these pyroclastic rocks. Pirsson[47] has classified fragmental volcanic rocks on the basis of size; his definitions are substantially as follows:

1.[48] *Volcanic bombs*—fragments the size of an apple and above.
   - *Volcanic breccia*—a rock composed of these large fragments not exhibiting signs of water erosional wear.
   - *Volcanic conglomerate*—a water laid conglomerate consisting of coarse volcanic material showing wear.
   - *Agglomerate*—a rock consisting of a tumultuous assemblage of blocks of various sizes found in old volcanic conduits (after A. Geikie).
2. *Lapilli*—fragments the size of nuts.
   - The rocks composed of fragments of this size are also called *volcanic breccia* if not water worn, and *volcanic conglomerate* if water worn.
3. *Volcanic ashes*—fragments the size of shot or small peas.
   - The rocks composed of fragments of this size are called *volcanic breccia* if composed of coarse ashes, and *tuff* if composed of fine ashes.
4. *Volcanic dust*—finest material.
   - *Tuff*—the rock consisting of volcanic dust and fine ash.

Geike[49] restricts the terms, volcanic bombs, to round, elliptical or discoidal pieces of lava from a few inches up to one or more feet in diameter which are generally finer grained or slaggy on the outside. The larger masses of hardened lava up to several feet or yards in diameter which do not exhibit the form and other characteristics of bombs

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[47]Pirsson, L. V., "The Microscopic Character of Volcanic Tuffs," Am. Jour. Sci. (4), XL, pp. 191–211, 1915.

[48]NOTE.—The division points between 1, 2, 3 and 4 are the half-way points.

[49]Geikie, A., "Text-book of Geology," 4th Ed., p. 172, 1903.

are called volcanic blocks. Geikie defines lapilli as ejected fragments of lava of various shapes varying in size from a pea to a walnut. He calls all the fragments smaller than lapilli volcanic sand or volcanic ash. His definitions of fragmental volcanic rocks are essentially the same as those of Pirsson.

These writers agree in using size as the basis for classification of pyroclastic rocks but the above definitions are not satisfactory, because nuts, apples, peas, and shot vary considerably in size. More definite size limits together with a statement of the proportions of various sized particles in a given pyroclastic rock are needed before any uniformity in the usage of these terms can be attained. Thus the same rock may be called volcanic breccia or agglomerate by one writer and volcanic ash or tuff by another. It is the tendency of many geologists to call any pyroclastic rock or epiclastic rock containing much volcanic material, "volcanic ash," regardless of what its texture may be.

For the sake of clarity in the discussion of pyroclastic rocks and similar rocks which have been formed by the erosion and redeposition of pyroclasts the writer proposes the classification given below. This system is adapted from Udden's classification of clastic sediments. On account of the very poor sorting in most pyroclastic rocks only a few of Udden's subdivisions[50] are used. Wentworth's system[51] of class terms for clastic sediments has also been introduced with considerable modification and simplification into the scheme proposed for pyroclastics. The writer prefers to use 50% as the class division point for pyroclastics, instead of the 80% division point used by Wentworth for sediments, because clastic volcanic rocks are rarely as well sorted or graded as many sediments are.

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[50]Udden, J.A., "The Mechanical Composition of Clastic Sediments," Bull. G.S.A., Vol. XXV, pp. 655–744, 1914.

[51]Wentworth, C. K., "A Scale of Grade and Class Terms for Clastic Sediments," Jour. Geol., Vol. 30, No. 5, pp. 377–392, 1922.

TABLE I

CLASSIFICATION OF FRAGMENTAL VOLCANIC ROCKS

Diameter and percentage of component fragments.		Pyroclastic Rocks (Show no effects of erosion)	Epiclastic Volcanic Rocks (Composed wholly or in part of volcanic fragmental material which has been transported and redeposited by water.)
Above 256 mm.	50%	Very coarse volcanic breccia	Volcanic boulder rock
256–32 mm.	50%	Coarse volcanic breccia	Coarse volcanic conglomerate
32– 4 mm.	50%	Medium volcanic breccia	Medium volcanic conglomerate
4– 1 mm.	50%	Fine volcanic breccia	Fine volcanic conglomerate
1–½ mm.	50%	Coarse sand-tuff (Volcanic ash when unconsolidated)	Coarse tuffaceous sandstone (Tuffaceous sand when unconsolidated)
½–¼ mm.	50%	Medium sand-tuff	Medium tuffaceous sandstone
¼–⅛ mm.	50%	Fine sand-tuff	Fine tuffaceous sandstone
⅛–1/16 mm.	50%	Very fine sand-tuff	Very fine tuffaceous sandstone
Below 1/16 mm.	50%	Dust-tuff or mud-tuff (Volcanic dust when unconsolidated)	Tuffaceous shale (Tuffaceous clay when unconsolidated)

The division of the above table headed "Epiclastic Volcanic Rocks" is equivalent to the "non-contemporaneous tuffs" of Green.[52] The rocks of this division commonly contain water-worn volcanic fragments as well as some non-volcanic rock fragments.

Pirsson has aptly divided tuffs into (1) Vitric tuffs, com-

[52]Green, J. F. N., "The Vulcanicity of the Lake District," Proc. Geol. Assoc., Vol. 30, pp. 153–182, 1919.

posed largely of glass fragments; (2) Crystal tuffs, composed mostly of crystals or fragments of crystals which were formed in the magma before eruption; (3) Lithic tuffs, composed principally of igneous rock fragments either of lava from magma in the crater or of rocks surrounding the crater. All the true tuffs in the Gueydan are of the vitric type.

Johnston-Lavis[53] separates fragmental volcanic ejectamenta into:

1. Essential—gaseous and solid portions of the magma.
2. Accessory—portions of the cone which crumble and are reejected.
3. Accidental—portions of non-volcanic rocks or of volcanic rocks of earlier geological date which underlie the volcano.

It is generally impossible to distinguish between 1 and 2 in a tuff. The tuff of the Gueydan evidently belongs to the first two classes but some parts probably contain fragments belonging to Class 3 because a few fragments of chert and sandstone are noted in the tuff.

CHEMICAL COMPOSITION

With the hope that chemical analyses of the freshest samples of the Gueydan tuffs obtainable might throw some light on the petrologic classification of these rocks, six fresh samples representing the principal types of tuff found in the Gueydan formation were submitted for analysis. The analyses were made under the direction of Dr. E. P. Schoch, Director of the Industrial Chemistry Experiment Station of the University of Texas and are as follows:

[53]Johnston-Lavis, H. J., "On the Fragmental Ejectamenta of Volcanoes," Proc. Geol. Assoc., Vol. 9, pp. 421–432, 1886.

Sample No.	1	2	3	4	5	6
SiO_2	55.89%	57.05%	67.13%	46.15%	58.90%	59.38%
Al_2O_3 Fe_2O_3	16.44	21.40	11.91	12.02	18.23	16.75
MgO	1.35	1.09	1.42	0.78	1.48	0.43
CaO	0.16	1.64	3.11	15.10	2.51	1.47
Na_2O	1.03	2.11	2.36	2.87	3.03	2.29
K_2O	0.36	0.38	0.28	0.43	1.20	0.56
SO_3	2.93	2.35	1.53	2.38	4.03	3.20
Ignition loss	14.43	12.70	11.55	14.75	10.34	13.07
Total	92.59	98.72	99.29	94.48	99.72	107.15

Note:

No. 1.—Typical vesicular Fant tuff, 2½ mi. N.W. of Simmons, Live Oak Co.

No. 2.—Light grayish-green, vesicular tuff of the most basic variety seen in the Fant member, 4 mi. west of Three Rivers, Live Oak Co.

No. 3.—Dense-textured, somewhat silicified, micaceous white tuff probably belonging to the Fant member but possibly Fayette, 6 mi. N.N.W. of Mirando City, Webb Co. High silica percentage is due to presence of secondary silica.

No. 4.—Massive-bedded, friable, calcite-cemented sand-tuff, resembling sandstone, from Fant member 2½ mi. N.W. of Simmons, Live Oak Co. High percentage of CaO is due to calcareous cement.

No. 5—Grayish-pink, gritty tuff of Soledad member, 4 mi. S.W. of Simmons near McMullen-Live Oak county line.

No. 6.—Light pink, friable, finely pisolitic bentonite or tuffaceous clay from the Chusa member, White Creek 2½ mi. S.E. of Simmons.

The SO_3 in these rocks probably is from barite and gypsum, although very small amounts of these minerals were found when they were analyzed microscopically. Barite veins were noted in a number of these tuffs but the percentage of CaO, with which the BaO was evidently included, is not as high as would be expected from the amount of SO_3 present. Possibly some of the SO_3 is present in soluble iron, aluminum or sodium sulphates which would not be detected in the microscopic analyses of water-washed samples. The principal features brought out by these analyses are the high percentages of combined water, probably mainly in the clay mineral, montmorillonite, to which the glass in the tuffs chiefly alters, and the low percentage of the alkalis, soda, and potash. The much greater proportion of soda than of potash is also an interesting fact and strongly suggests that these are not normal, potash-rich rhyolite or trachyte tuffs and is in keeping with the fact that most of the feldspar grains in these rocks are found to consist of albite-oliogoclase.

The large ignition loss in these rocks is evidently H_2O except in No. 4, which contained much CO_2. This high percentage of water causes a corresponding lowering of the percentages of the elements originally present, thus obscuring the true chemical affinities of the rocks. In fact, the analyses as they stand do not correspond to recorded analyses of any fresh igneous rocks, although they are not unlike the analyses of certain weathered igneous rocks. If the analyses are recalculated on the basis of only 2% water, a generous allowance for most fresh volcanic rocks, some figures are obtained which may give a better idea of the composition of these tuffs when first erupted. The recalculated analyses may be close enough to the analyses of fresh volcanic rocks which appear in literature to give a clue as to which rock family these tuffs belong. No. 4 is also recalculated on a calcite-free basis, as nearly as is possible from the analysis. The recalculated analyses are:

Sample No.	1	2	3	4	5	6
SiO_2	69.99%	64.97%	74.90%	68.42%	64.58%	69.03%
$Al_2O_3Fe_2O_3$	20.65	24.39	13.28	17.87	19.98	19.32
MgO	1.75	1.25	1.69	1.16	1.62	0.50
CaO	0.22	1.87	3.47	2.11	2.76	1.71
Na_2O	1.29	2.41	2.64	4.29	3.39	2.67
K_2O	0.45	0.43	0.32	0.63	1.32	0.65
SO_3	3.65	2.68	1.70	3.52	4.42	3.72
Ignition loss	2.00	2.00	2.00	2.00	2.00	2.00
Total	100.00	100.00	100.00	100.00	100.00	100.00

While these recalculated analyses are probably somewhat closer to the original composition of the tuffs, their silica percentages are misleading because they have been considerably increased in the recalculated analyses while the soda and potash and possibly lime, which have almost certainly suffered a great amount of leaching during the weathering of the rock are very slightly increased in the recalculations. Clarke[54] states that alumina and iron in weathered rocks ordinarily show slighter losses than do any of the other constituents, so there is a relative gain in these two constituents in most weathered rocks. In his analyses of fresh weathered igneous rocks there is, on the whole, about the same amount of potash lost as of soda. On account of the wide variations in the alteration of the same type of rock under different climatic conditions it is impossible to calculate with any certainty the probable original composition of the tuffs analyzed. Some of the tuffs have probably lost as much as 10% of silica but others (such as No. 3) have been enriched in silica by the redeposition of secondary opal in the pores of the rock as is proven by petrographic study of them. Ordinarily, lime is one of the first substances to be removed by weathering agencies and No. 1 has evidently lost lime. The rocks overlying and underlying the Gueydan contain considerable lime and No. 4 has certainly gained a large percentage of lime from those rocks, as is indicated by the fact that this lime is in the form of a carbonate cement in No. 4. It is, therefore, doubtful whether much lime has been lost from most of the Gueydan rocks except locally. The surprising fact is that these tuffs are not generally more calcareous than they are shown to be from their analyses as well as from effervescence tests with hydrochloric acid on a large number of samples.

The principal suggestive features brought out by the chemical analyses of these rocks are as follows:

(1) There is a considerable but not excessive variation in composition of Gueydan tuffs. No. 4, a rather thin horizon of greenish-gray tuff intercalated with the white tuffs of the lower Gueydan or Fant member, is slightly more basic than are the white tuffs, Nos. 1 and 3.

(2) The silica percentages of the original analyses are most similar to silica percentages of latites, trachyandesites, or acid andesites. The recalculated analyses show silica

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[54]Clarke, F. W., "The Data of Geochemitsry," U. S. Geol. Surv. Bull. 770, pp. 490–493, 1924.

percentages which range from those common to rhyolites in No. 3 to those reported for alkali-rich trachytes, quartz latites and certain dacites in other samples. However, No. 3 is impregnated with much secondary opal, and too much meaning should not be attached to the 74% silica of this sample. Most rhyolites contain over 70% SiO_2, though some varieties may contain as low as 65%. Therefore the Gueydan rocks cannot be definitely ruled out of the rhyolite class on the basis of silica percentage alone.

(3) From the light color of the tuffs and the scarcity of iron-bearing minerals in most of the tuff it is probable that by far the greater part of the combined iron and alumina in the analyses is alumina. The combined percentages of ferric oxide and alumina in the above analyses agree with the combined percentages of these oxides commonly found in trachytes, latites, dacites, and andesites. No. 3, which has a surprisingly low percentage even in the recalculated analysis, is an exception. In No. 3 the addition of considerable secondary silica, which has been noted in this rock, would lower the relative percentage of the other constituents, especially iron and alumina. However, the analysis shows this rock to contain about the same amount of soda as the other rocks analyzed and a higher percentage than the average of lime and magnesia, all of which should be lower than the average if the presence of additional silica of secondary origin is the explanation of the low iron and alumina content. A microscopic examination of this rock showed it to contain a small amount of secondary calcite. This is probably the explanation of the comparatively high lime percentage in No. 3. The soda and magnesia percentages in this sample are not easily explained and these must be somewhat higher than in the average weathered Fant tuff. If soluble salts are present in No. 3 they are not in sufficient quantity to be detected by the taste and are probably not present in appreciable amounts. It is likely that all these rocks originally had a higher iron-alumina percentage (14–24%) than is commonly found in rhyolites (14–16%).

(4) The significantly lower percentage of potash than of soda in all of the analyses is strongly suggestive that these rocks are not rhyolites, latites, dacites, or normal trachytes but that they may be soda-trachytes, trachyandesites, or even andesites.

(5) The lime and magnesia content is higher than the combined soda and potash in every sample analyzed. The analyses given by Clarke[55] show that a few latites, and a number of dacites and andesites but no rhyolites or trachytes contain more lime plus magnesia than soda plus potash. This is suggestive that the Gueydan rocks may have andesitic or trachyandesitic affinities but is by no means conclusive because a greater proportion of soda and potash may have been leached from these tuffs than of lime and magnesia. The present content of magnesia in the Gueydan tuffs, with the exception of No. 6, is higher than that of any rhyolite or granite tabulated by Clarke. The writer believes that their magnesia content alone furnishes a strong piece of evidence that the Gueydan tuffs are not rhyolitic.

Conclusions from chemical analyses.—The analyses of the Gueydan rocks taken as a whole are not unlike published analyses of soda-trachytes and trachyandesites, except that the alkali percentages should be at least 2% to 5% (of the total rock) higher than they are found to be in any of the Gueydan tuffs. It is quite possible that these tuffs may have lost proportionally much more of the alkalis than of the other constituents. On the other hand, these tuffs may also have lost as much lime and magnesia as soda and potash and may have been andesitic in nature. However, the silica percentages are believed to be too high for normal andesites, although some andesitic tuff strata probably occur in the Gueydan formation. It is unfortunate that more definite conclusions regarding the classification of these rocks cannot be drawn from these analyses. Additional petrologic data bearing on the classification are furnished by the petrographic study of the Gueydan rocks given in the following pages.

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[55] *Op. cit.*, pp. 439–458.

PETROGRAPHY OF THE GUEYDAN TUFFS

Texture.—The tuffs of the Gueydan are predominantly of the vitric type and, except where greatly silicified, show the typical ash or "bogen" structure. The glass fragments of which these tuffs are largely composed usually have a slightly concave, platy form, although filamentous and tubular glass particles or small pieces of pumice containing bubbles or steam cavities are quite common. A microphotograph of a thin section of a slightly silicified lower Gueydan tuff is found in Plate IX, Figure 1, showing very well the form of the cross-sections of the glass fragments and the general texture of the tuffs. Trifurcate grains composed of three plates branching from their line of union at angles of approximately 60 degrees are quite characteristic. These are shown in Plate IX, Figure 1. Pirsson[56] has carefully described the form of the glass fragments in vitric tuffs. The most common size range of the glass particles in the Gueydan tuffs is 0.01–4 mm. Occasional rounded to subangular pumice pebbles and lapilli up to 10 cm. in diameter are not uncommon in some strata. The deposits of pumice pebble conglomerate which are composed largely of coarse pebbles or lapilli of vari-colored pumice have been previously described. In some of the better silicified tuffs no glass fragments can be certainly identified but are believed to have been replaced by opal. It is possible that some of these are true crystal tuffs but this is not probable. In general, the fragments of crystals, such as feldspar, comprise less than 15% of the rock. As much as 20% of a few tuff beds consist of microcrystalline trachyandesite or acid andesite fragments but no examples of true lithic tuffs have been noted in the Gueydan.

The mineral and rock fragments are sharply angular in the true tuffs but are commonly subangular or even rounded in the tuffaceous sandstones and clays and volcanic conglomerates. In a few of the practically unconsolidated

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[56]Pirsson, L. V., "The Microscopical Characters of Volcanic Tuffs," Am. Jour. Sci. (4), pp. 191–211, 1915.

lower Gueydan sand-tuff samples, spherical pellets of hard, white tuff, 1 to 4 mm. in diameter, are found after the samples have been washed. E. Howe[57] has described the formation of "round clay pellets like buckshot" and believes they are due to the attraction of dust particles to globules of condensing steam which on falling would accumulate more and more dust, becoming hard clay pellets on reaching the ground. Similar pellets might be formed around rain drops at great distances from a volcano.

COMPOSITION

The principal primary constituents of the Gueydan tuffs, arranged in their order of abundance, are volcanic glass, soda-lime feldspar, alkali feldspar, and a small percentage of a ferro-magnesian mineral which is most commonly augite or diopside but is frequently biotite. In some rocks both biotite and augite are found. Apatite, zircon, magnetite, and ilmenite commonly occur as minor accessory minerals. In a few specimens of white Fant tuff some sharply angular grains of quartz which are evidently of primary origin are seen but, as a rule, quartz fragments are rare or absent from the Gueydan tuffs. The most unexpected and noteworthy mineral to be found in these tuffs is tridymite and in a few hand specimens tridymite comprises 1% to 5% of the rock. The principal secondary minerals are montmorillonite, barite, calcite, opal, limonite, and chlorite.

The most significant constituents of these tuffs will be discussed individually.

PRIMARY CONSTITUENTS

Volcanic glass.—Volcanic glass is the most abundant primary constituent in the Gueydan tuffs, comprising from 10% to 85% of these rocks. It ranges in color from light bluish-gray to colorless; but most of it has a gray tinge. The color becomes creamy-white on partial alteration. The

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[57]Howe, E., "The Tuffs of Soufrière, St. Vincent," Am. Jour. Sci., XXVIII, pp. 319–320, 1903.

luster is a characteristic bright vitreous to silky when fresh so that it can usually be recognized readily with a hand lens. The range in index of refraction of the glass from various strata and localities in the Gueydan formation is from 1.495 to 1.517. The glass with the lowest index of refraction is that from the white tuff of the Fant member. The common index of this glass is from 1.495 to 1.502. The glass with the highest index is found in the bluish-gray to greenish-gray tuff which occurs locally in the Fant member four miles west of Three Rivers. The glass in this tuff varies from 1.508 to 1.517$\pm$.002. The tuff from which this higher index glass comes is No. 2 of the chemical analyses given above. This is the tuff with the highest alumina and iron content. Moreover, its color indicates that a fair amount of iron is present, which may be responsible for the higher index. The glass from the Soledad tuff and tuffaceous sandstone has an index of 1.498 to 1.51, which is very slightly higher than that from the white tuffs of the Fant member. The index of the glass from the tuffs and tuffaceous clays of the Chusa member has practically the same range as that from the Soledad member. The glass in the Catahoula tuff has an index which ranges from 1.497 to 1.507. The refractive index of the glass in the Gueydan rocks was carefully determined on a large number of samples in the hope that it might settle the question of whether or not the pink and greenish-gray tuffs and tuffaceous sandstones and clays of the middle and upper Gueydan are petrologically distinct from the white tuffs of the lower Gueydan. It appears from the above refractive indices of the glass that either there is no marked difference in composition between these tuffs and also between the Gueydan and Catahoula tuffs or that the glass from the Soledad and Chusa members is only slightly more basic than that from the Fant white tuff. The greenish and bluish tuffs which occur locally in the Fant member appear to have approximately the same composition as the tuffs from the middle and upper Gueydan. It is worthy of note that there is a variation in refractive index of .001 to .005 in the different glass fragments from a single hand specimen of Gueydan tuff.

W. O. George[58] has made a study of the refractive indices of a large number of natural glasses and some of his results are given below in tabular form for the sake of comparison.

TABLE IV (p. 238)

Collector's or Author's Name of Rock.	Average n	Range of n recorded
Obsidian or Rhyolite Glass	1.492	1.48 –1.51
Pitchstone	1.500	1.492–1.506
Perlite	1.497	1.488–1.506
Pumice	1.497	1.488–1.506
Dacite	1.511	1.504–1.529
Trachyte	1.512	1.488–1.527
Andesite	1.512	1.489–1.529
Leucite Tephrite	1.550	1.525–1.580
Tachylite, Scoria, Diabase and Basalt Glass, Palagonite	1.575	1.506–1.612

These results apparently show that there is such a wide range in refractive index even in the glass of one rock type, such as andesite, that it is impossible to determine the name of a rock from the refractive index of its glass. The average indices are more significant but it is impossible to be sure that a given glass has an average refractice index for its particular species of rock. From their range in refractive index the glasses of the Gueydan tuff might be rhyolite, perlite, pumice, trachyte, or andesite. The average indices of the Gueydan glasses is approximately 1.499±.002 for the white tuff of the Fant member, 1.510±.002 for the greenish or bluish Fant tuff, 1.503±.002 for the Soledad and Chusa tuffs, and 1.502±.002 for the Catahoula tuffs. These glasses all have a slightly higher index than average rhyolite glass and a slightly lower index than average trachyte or andesite glass. They correspond more closely to pumice than to any other glass and since they are pumiceous glasses this would be expected.

George[59] does not give any refractive index determination

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[58]George, W. O., "The Relation of the Physical Properties of Natural Glasses to their Chemical Composition," Jour. Geol., Vol. 32, No. 5, pp. 353–373, 1924.

[59]*Op. cit.*, pp. 356–361.

on trachyte pumice but three values for andesitic pumice are given, as follows: Mont Pelée andesitic glass—1.4888; andesitic pumice, Bridge River district, British Columbia—1.506; andesitic pumice, Krakatoa, Straits of Sunda—1.488. It thus appears that andesitic pumice often has a considerably lower index than the average for andesitic glass. The Gueydan glass may thus be as basic as andesite if its refractive index alone is considered.

Feldspar.—Feldspar generally forms from 1% to 10% of the Gueydan tuffs but is greatly subordinate to glass except in the more altered tuffs and the silicified tuffs. By far the most common type of feldspar found in Gueydan rocks is albite-oligoclase or acid oligoclase. In some of the Fant tuffs and in many of the Soledad and Chusa tuffs this is the only feldspar present. The mean refractive index (β) of this feldspar commonly ranges from 1.535 to 1.540; the extinction angles on cleavage plates are from 0° to 10°; the optic axial angle is approximately 90° so that positive, negative, and neutral crystals are found; and the birefringence is .009. Some of the feldspar grains show very fine albite twinning striations but most of them appear to be untwinned. These are optical properties of a soda-lime feldspar containing approximately 90% of the albite molecule to 10% of the anorthite molecule, namely oligoclase-albite. In some of these tuffs this feldspar has an optic axial angle of not over 60° which is too small for oligoclase or albite, although the index of refraction is like that of albite-oligoclase. This feldspar with the small axial angle is probably a potash-oligoclase.

Sanidine is the dominant feldspar in a few of the Fant tuffs and is generally present as the subordinate feldspar in the Soledad and Chusa tuffs. True albite with a positive sign and all its refractive indices below 1.541 has also been identified in a few samples of Fant tuff.

In the Soledad and Chusa tuffs the most abundant feldspar is an acid to medium oligoclase but andesine is common and occasional grains of labradorite are noted. The more basic feldspar grains are practically always prominently twinned according to the albite law, unlike the acid oligoclase which is generally untwinned.

Quartz.—Sharply angular grains of quartz are found in only about 10% of the tuff samples examined but in none of these samples was quartz more than one-twentieth as abundant as feldspar. The crystalline grains which are present in these vitric tuffs evidently represent fragments of the phenocrysts in the original magma before eruption. Therefore, it appears that not more than 5% of the total phenocrysts in any of the Gueydan tuffs were quartz. Since there were a large number of successive eruptions of Gueydan pyroclastics, as indicated by numerous beds of interstratified fluviatile deposits, it seems quite unlikely that the tuffs are rhyolitic because in most series of rhyolitic eruptions at least a few strata contain over 10% of quartz phenocrysts. In many Tertiary rhyolitic tuffs which the writer has observed in the Coast Range and Sierra Nevada provinces of California quartz phenocrysts are as common as phenocrysts of feldspar. One rounded pumice pebble from the Gueydan near Simmons was found to contain one quartz phenocryst 1/16 inch in diameter as well as several sanidine phenocrysts. Porphyritic pumice fragments in the Gueydan are quite rare and this is the only one seen which contained quartz. The mineralogical composition of the Gueydan pyroclastics thus appears to indicate that these rocks are not generally rhyolitic.

Accessory minerals.—Ferromagnesian accessories are surprisingly scarce in any of the tuffs of the Gueydan formation, comprising less than 3% of the phenocryst minerals, or only a fraction of 1% of the rock. This is evidently due to the fact that most of the grains of these minerals have altered to limonite, serpentine, chlorite, argillaceous material, and other secondary products. In many samples, especially those of silicified tuff, no primary ferromagnesian minerals whatever are noted.

The commonest accessory is a light yellowish-green, nonpleochroic to faintly pleochroic augite or diopside or possibly aegirine-augite in some cases. This pyroxene is found only in small short prismatic or irregular grains which are commonly coated with limonitic and argillaceous material. Its alteration and its optical properties are more like those of augite than of diopside.

Scales and flakes of dark yellowish-brown biotite, which is often more or less bleached, are of frequent occurrence in the pinkish or greenish tuffs of the Soledad and Chusa members. Biotite, which under the microscope commonly has a reddish color on the basal cleavage plates and shows a much wider optic axial angle and stronger dispersion than most biotite, is found in some of the friable sand-tuffs of the Fant member and is fairly common in the indurated white tuffs in Webb County. It has been mentioned previously that the latter tuffs may possibly belong to the Fayette formation. The white mud-flow tuffs outcropping northeast of Webb County were not found to contain biotite, although it may have been present and has been since altered to chlorite and limonite. This probability is indicated by the presence of biotite in the intercalated friable sand-tuffs.

The minor accessories, magnetite, ilmenite, apatite, and zircon are found as minute grains which often exhibit fairly good crystal form. Zircon is rather rare.

Tridymite.—The most noteworthy mineralogical feature of the Gueydan tuff is the occurrence of tridymite. This high temperature form of silica has been identified in seven samples of the white "mud-flow" tuff of the Fant member from as many localities in Live Oak, McMullen, Webb, and Starr counties. The most widely separated occurrences of tridymite which have been noted are 135 miles apart. It has been seen only in the partially silicified, vesicular, white tuffs of the Fant member where it occurs as small, glittering, glassy plates lining the vesicles. In several hand specimens the vesicle walls are thickly studded with these crystals .02 to .10 mm. in breadth and the edges of the plates commonly project into the cavities at various angles. The tridymite crystals show a common tendency to be grown together with their basal faces parallel like a deck of cards stacked up so that in thin section the crystals look like very thick plates, or even prisms, with a well developed cleavage. In other occurrences the plates overlap one another like shingles on a roof. The tridymite is generally closely associated with botryoidal hyalite opal. Several occurrences of delicate tridymite plates completely inclosed in beautiful, transparent, botryoidal masses of opal were observed.

Under a binocular microscope several perfect crystals were pried from the vesicle walls of a sample collected in extreme east-central Webb County. They were found to possess the typical pseudo-hexagonal thin platy form of tridymite. The following optical properties were determined under the petrographic microscope:

(1) The refractive index of most of the crystals is slightly above 1.480 but some crystals show the normal index for tridymite, $1.471 \pm .002$; (2) the birefringence is very low, about .004 or even less so that individual plates appear nearly isotropic; (3) the characteristic twinning of tridymite with triangular areas of light and dark under crossed nicols is noted in some of the crystals; (4) the mineral is optically positive, has an observed axial angle of about 60° and *Bxa* is normal to *c;* (5) the mineral generally shows positive elongation although a few crystals which appear to have negative elongation are noted in a thin section of the tridymite-bearing rock.

The peculiar features of the above optical properties are the positive elongation, which should be negative in tridymite, and the slightly higher refractive indices than those reported for tridymite by Larsen.[60] It is possible that this mineral is a cristobalite paramorph after tridymite, such as has been suggested by Rogers[61] for certain California cristobalites, because its index of refraction is closer to that of cristobalite than that of tridymite. The mineral is insoluble in hydrochloric acid after prolonged boiling,

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[60]Larsen, E. S., "The Microscopic Determination of the Non-Opaque Minerals," U. S. Geol. Surv. Bull. 679, p. 206, 1921.

[61]Rogers, A. F., "The Occurrence of Cristobalite in California," Am. Jour. Sci. (4) XIV, pp. 222–226, 1918.

is fusible on thin edges only when subjected to a very hot blowpipe flame, and is etched by boiling sodium carbonate solution. The chemical properties thus agree with those of tridymite and the mineral is therefore determined as tridymite, although it may be an optically anomalous form of this mineral.

The opal which is associated with this tridymite has a refractive index of 1.44 but is faintly birefringent and has a radiating fibrous structure as shown by the appearance of a faint black cross under crossed nicols. The opal is, at least in part, younger than the tridymite for it frequently encloses the latter. The association of tridymite and opal from several localities is noted by Dana.

This is possibly the first record of the occurrence of tridymite in tuff. At least, the writer has found no mention of such an occurrence in the standard mineralogy texts, although an intensive study of the literature might reveal a previous description of such an occurrence.

Fenner[62] has made a detailed study of the inversion points of the various silica minerals and has reached the conclusion that tridymite is only formed at temperatures above 870° C. and cristobalite above 1470° C. However, from the results obtained by several French and German chemists, it appears that tridymite and probably cristobalite may be produced at considerably lower temperatures in the presence of water vapor. For example Königsberger and Müller[63] obtained tridymite quartz, opal, and a soda feldspar when powdered glass was heated to 300° C. with water. Also, tridymite is now forming in the spring of Plombières in France[64] and the temperature of this spring is only 73° C.

Since the tridymite in the Gueydan tuff is found only in the cavities or vesicles in the rock it is plain that the tuff, probably in the form of mud flows, had consolidated and

[62]Fenner, C. N., "The Stability Relations of the Silica Minerals," Am. Jour. Sci. (4) XXXVI, pp. 331–384, 1913.

[63]Königsberger, J., and Müller, W. J., Centralbl. Min. Geol. u. Pal. pp. 339, 353, 1906.

[64]Daubrée, Bull., Soc. Géol. Fr., vol. 4, p. 523, 1877.

the vesicles had thus been established before the tridymite was introduced. It is inconceivable that tuff which has settled through the atmosphere and had time for consolidation could have maintained a temperature of 870° C. or even 73° C. It is possible, however, that the material was transported by a "fiery cloud" of Pelean type. The lower portion of such a thick, quickly deposited accumulation might have remained hot enough to contain some steam or water vapor in its vesicles which attacked the volcanic glass of the tuff to produce tridymite. Lacroix[65] has established temperatures in excess of 200° C. for the finer material carried by the greatest "fiery clouds" from Pelée in 1902–1908, at distances of six kilometers from the crater. Because he found tridymite only in those rocks collected from Mont Pelée as late as six months after an eruption Lacroix[66] concluded that the tridymite was formed, after the partial cooling of the lava blocks, by the action of magmatic gases on the andesite paste. The tridymite of the Gueydan tuff was probably formed in a somewhat similar manner. Another hypothesis for the origin of the Gueydan tridymite is as follows: Fumaroles were established through the consolidated tuffs and the hot vapors rising along these vents attacked the tuff along the vent walls with the subsequent production of tridymite. This is a tenable hypothesis because most of the Gueydan tuffs having the same appearance as the tridymite-bearing tuffs contain no tridymite, thus apparently indicating a localization of this mineral. In either case the eruptive centers from which the Gueydan tuffs came could hardly have been more than twenty miles distant, and the occurrence of tridymite at such widely separated localities seems to indicate that there were two or more volcanoes or fumaroles in this region during Gueydan time.

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[65]Lacroix, A., "La Montange Pelée et ses Eruptions," Masson et Cie., Paris, pp. 212–215, 1904.

[66]Lacroix, A., Bull. Soc. Mineral., Vol. 28, p. 56, 1905.

SECONDARY MINERALS

Montmorillonite[67] *(Leverrierite)*.—An earthy to waxy, soft, argillaceous substance, which is determined as montmorillonite, commonly comprises from 10% to 60% of the tuffs in the Gueydan formation. This mineral is cream-colored, grayish-pink, grayish-green, white, light gray, or yellowish in color. The colored varieties are possibly stained with minute specks of hematite, limonite, and chlorite. By prolonged boiling of the harder white tuff fragments in balsam before grinding some of the montmorillonite can be obtained in thin sections. This mineral commonly shows a yellowish color in transmitted light. It looks very cloudy and often appears to be composed of wavy, thread-like bodies which show undulatory and often radiate (spherulitic) extinction along portions of each thread. The thread-like bodies are evidently cross-sections of platy or sometimes spherulitic aggregates, the flat surfaces of which are usually approximately parallel to the walls of vesicular cavities in which the larger masses of fairly pure montmorillonite are found. Most of this mineral occurs as tiny clay-like particles diffused through the tuff. When aggregates of this mineral from a dry sample of tuff are placed in water they quickly become plastic and break down into a thin doughy mass of tiny, often practically colloidal, platy particles. The principal optical properties are as follows: Refractive indices very variable, commonly 1.47–1.53; birefringence high (.02 or more) parallel to *c* axis, very low to isotropic perpendicular to *c*; 2V usually 0° to 20° and oriented perpendicular to the plate but good interference figures are rarely obtained; extinction straight or nearly straight; optically negative. These properties agree with those given by Larsen for the variable mineral, leverrierite,[68] although spherulitic

[67]Recently Ross and Shannon (Jour. Am. Ceram. Soc. Vol. 9, pp. 77–96, 1926), have found the clay minerals of bentonite to consist of two minerals (1) beidellite—n=1.517—1.549 (2) montmorillonite—n=1.484—1.527. It is probable that montmorillonite is dominant in the "leverrierite" of the Gueydan.

[68]Larsen, E. S., "The Microscopic Determination of the Non-opaque Minerals," U. S. Geol. Surv. Bull. 679, pp. 245, 247, 1921.

aggregates are not noted by him. Ross and Shannon have shown that Larsen's "leverrierite" consists of two or more mineral species. Montmorillonite is the mineral generally produced by the hydration of acid and intermediate vitric tuffs such as the Gueydan.

There can be no doubt that the Gueydan montmorillonite ("leverrierite") is produced by the alteration of volcanic glass, for the following reasons: (1) All glass fragments are coated with a thick to thin film of montmorillonite; (2) unbroken bubbles inclosed in the volcanic glass are lined with montmorillonite showing that this mineral could not have been introduced from the outside; (3) thin sections show a gradual transition from fresh, clear glass in the central portion of a given glass fragment to cloudy glass containing some montmorillonite and finally to pure montmorillonite at the margin of the fragment or grain. Many grains are completely altered to a cream-colored substance which is found to consist mainly of an aggregate of montmorillonite, although they still retain the original shapes of volcanic glass fragments.

Opal and Chalcedony.—Opal is present in all of the tuff samples examined. The chert-like silicified tuffs consist of preponderant opal, abundant montmorillonite diffused through the opal, a few angular feldspar grains, and occasional patches of fibrous chalcedony. The chalcedony occupies former vesicular cavities and some of these cavities are not completely filled. Gradations between tuffs containing only a few thin crusts of opal as a cement to completely silicified tuffs containing over 65% opal are observed. The opal in the silicified tuffs is finely botryoidal to massive but it frequently shows traces of the original vitric pyroclastic texture of the non-silicified tuff, indicating replacement. In index the opal ranges from 1.44 to 1.46. In many samples it is faintly birefringent in small irregular specks, patches, or fibers.

Other secondary minerals.—The other secondary minerals noted are limonite, hematite, kaolin (rather rare), chlorite, epidote, serpentine, and chabazite or gmelinite. Possibly other zeolites are also present. Minerals from veins or from the cement include barite (common), calcite (abundant only in certain localities), witherite (rare), gypsum (rather rare), pyrite, and marcasite.

Non-volcanic minerals.—Minerals of normal sedimentary origin, occurring in subangular to rounded grains, are rare in the true tuffs but are common in the tuffaceous clays and sandstones. The most abundant of these minerals and mineral aggregates are chert, quartz, orthoclase, and green hornblende. Partly rounded grains of andesine and labradorite are noted in many tuffaceous sandstones and clays. Worn tourmaline, epidote, titanite, hypersthene, and microcline grains are of rare occurrence.

PETROGRAPHIC DESCRIPTIONS OF PRINCIPAL TYPES OF GUEYDAN TUFFS

Brief petrographic descriptions of the more important types of tuffs and tuffaceous rocks occurring in the three members of the Gueydan are collected here in order to give the reader a more definite idea of the sizing of constituent fragments and of the approximate percentages of the occurrent minerals. The percentages are estimated except where stated otherwise. The consolidated (mud-flow) tuffs cannot be separated into their constituents without much attrition of the thin glass grains, therefore percentages of their constituents are not determinable except by estimate.

Fant member.—

DESCRIPTION OF TYPICAL LUMPY, WHITE TUFF FROM LANG CREEK, 2½ MILES NORTHWEST OF SIMMONS, LIVE OAK COUNTY

Sizing.—Grains 4 mm.–1/16 mm.—10–15%. Material below 1/16 mm.—85–90%. Grains larger than 1 mm. are partly altered pumice lapilli. Most of the "washed material" is composed of grains between ½ and ⅛ mm. Poorly sorted.

Composition of washed material (above 1/16mm.)—

Volcanic glass (n=1.495)—70%.

Soda-lime feldspar (mostly albite-oligoclase)—20%.

Sanidine—5%.
Quartz—trace[70] (rare).
Leverrierite aggregates (cemented with opal)—4%.
Opal (rounded grains which resemble isometric crystals, apparently formed by breaking apart of botryoidal spheres)—1%.
Magnetite—trace.
Marcasite—trace.
Zircon (colorless crystals)—trace.
Apatite—trace.
Chlorite—trace.
Serpentine(?)—trace.
Barite (from cement or veins)—trace.
Witherite (from cement or veins)—trace.

The matrix (material below 1/16 mm.) of this tuff is composed of glass, both fresh and in all stages of alteration to montmorillonite. Montmorillonite in abundance, and possibly as much as 5% of opaline cementing material. Very few feldspar and other mineral grains are below 1/16 mm. in length.

DESCRIPTION OF THIN SECTION OF TRIDYMITE-BEARING, PARTLY SILICIFIED TUFF FROM GATES RANCH IN EXTREME EASTERN WEBB COUNTY

Textural features.—The section shows this tuff to contain roughly oval-shaped or rounded lumps, best seen with a hand lens, from 2 mm. to 1 cm. or more in diameter which are composed of the same material as their matrix. Angular, often platy grains of volcanic glass and sharply angular grains (a few with crystal outlines) of feldspar and occasionally other minerals are all ½ mm. or less in length and most of them are between ¼ and 1/32 mm. Glass and mineral grains comprise about 35% of the rock; matrix of opal and montmorillonite 60%. No worn or rounded grains noted. Numerous vesicles are partly or completely filled with variously oriented tridymite plates and botryoidal hyalite opal intergrown.

Composition:

Soda-lime feldspar (mainly unstriated albite-oligoclase but includes some albite and oligoclase)—3%.

Sanidine and orthoclase (n below 1.53)—5%.

Volcanic glass—25%.

Augite (partly altered)—trace.

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[70]Trace=less than 1%.

Opal (both in matrix of rock and from botryoidal masses in vesicles)—40%.

Tridymite (from vesicles)—12%. (Plates are commonly grown together with their bases parallel or overlapping like shingles on a house, so that in section the mineral appears to show cleavage and seems to occur as rather thick crystals.)

Montmorillonite—15%.

This rock contained far more tridymite than any other sample found and the tridymite from this sample was subjected to qualitative chemical and blowpipe tests as well as the most detailed petrographic study.

DESCRIPTION OF BLUISH-GRAY TUFF FROM CHARLIE YORK CREEK AT THREE RIVERS-CALLIHAM ROAD, 4 MILES WEST OF THREE RIVERS

Sizing.—Portion left after prolonged washing until water shows no trace of clay in suspension is only 0.4% by weight. Examination of crushed unwashed sample indicates a considerably larger percentage of grains over 1/16 mm. than that obtained in the "washed material." Some grains containing bubbles probably floated off, while many others were evidently broken into tiny bits in the washing process and in the crushing of the sample before washing. Sizing of this washed material is estimated as follows: 1–½ mm.—trace; ½–¼ mm.—20%; ¼–⅛ mm.—40%; ⅛–1/16 mm.—40%.

Composition of washed material:

Volcanic glass (color bluish-gray, n = 1.508 to 1.512)—60%.
Albite-oligoclase (mostly unstriated)—25%.
Sanidine—7%.
Magnetite—trace.
Augite—trace.
Trachyandesite(?) fragments—trace.
Chlorite—trace.
Zircon—rare.
Opal (from cement)—6%.
Pyrite—trace.
Quartz (only worn, apparently sedimentary grains noted)—1%.
Chert (worn grains)—trace.

Matrix consists mainly of abundant montmorillonite, glass grains mostly .005 to .05 mm. in length and small particles of serpentine and chlorite(?). Opal in small, root-like or irregular, often branching bodies is not uncommon in the matrix.

DESCRIPTION OF THIN SECTION OF CHERT-LIKE, LIGHT GRAY SILICIFIED TUFF FROM NORTH BANK OF NUECES, 400 YARDS EAST OF SIMMONS BRIDGE

The thin section shows this rock to consist largely of opal mixed with considerable "leverrierite" which include variously oriented, sharply angular grains of sanidine and albite-oligoclase and a few augite grains ranging from .02 mm. to .25 mm. in length. The isotropic opaline matrix appears pale yellowish in transmitted light. It is traversed by numerous conchoidal fracture lines which extend in all directions, giving the section a faint net-like appearance. A very large number of tiny globular opaline bodies can be distinguished.

Composition is estimated as follows:

Opal—75%.
"Leverrierite"—15% (probably more but indistinguishable).
Albite-oligoclase—4%.
Sanidine—5%.
Augite—trace.
Chalcedony (in center of former cavities)—trace.

No glass is identified; it has been apparently replaced by opal.

DESCRIPTION OF THIN SECTION OF CREAMY-WHITE VESICULAR PARTLY SILICIFIED TUFF FROM MOST SOUTHERLY OUTCROP OF GUEYDAN, 6 MILES NORTH OF EL SAUZ, STARR COUNTY

Textural features.—This rock consists of angular volcanic glass and feldspar grains in a much more abundant matrix of opal and "leverrierite." Many cavities are partly filled with tridymite, occurring alone or associated with botryoidal opal. Most of the glass and feldspar grains are between .02 and .25 mm. in length but the sorting is poor.

Composition:

Volcanic glass (often partly replaced by opal)—10%.
Soda-lime feldspar (albite to acid andesine)—6%.
Sanidine—1%.
Opal—72%.
"Leverrierite"—10%.
Tridymite—1%.

DESCRIPTION OF THIN SECTION OF WHITE, DENSE-TEXTURED, SILICIFIED TUFF (POSSIBLY FAYETTE) FROM SECTION 854 WEBB COUNTY ABOUT 20 MILES NORTH OF MIRANDO CITY

The section shows this rock to be composed largely of pale yellowish opal intergrown with considerable montmorillonite, in which a few angular grains of albite-oligoclase, sanidine feldspar and biotite are imbedded. The mineral grains vary in length up to ¼ mm. but are mainly below 1/16 mm. The typical "bogen-structure" shows up beautifully in a very thin section and even some outlines of bubbles are preserved though now filled with opal. Very little of the original glass is left. The feldspar grains comprise about 2% of the rock and biotite flakes are found but comprise less than 1% of the rock. Possibly 15% of montmorillonite is present. The remainder of the rock is opal.

DESCRIPTION OF FRIABLE, GREENISH-WHITE, CALCAREOUS SAND-TUFF FROM LANG CREEK, 2½ MILES NORTHWEST OF SIMMONS

Sizing.—Washed material (coarser than 1/16 mm.)—51% by weight. The sizing of this washed material is estimated as follows: 2–1 mm.—3%; 1–½ mm.—3%; ½–¼ mm.—15%; ¼–⅛ mm.—40%; ⅛–1/16 mm.—39%. Most of the fine material (below 1/16 mm.) is "leverrierite." When a sample is placed in water it breaks down rapidly with a singing sound into its component grains. Only a few small lumps of calcareous cemented material fail to separate. A number of partly decomposed pumice pebbles or lapilli up to 5 mm. in diameter can be noted in the rock but these break into smaller fragments when the sample is washed. In the washed material about half the fragments coarser than 1 mm. are composed of roughly cylindrical bodies composed of crystalline calcite containing glass grains. About 30% of crystalline calcite is present in this rock. The cylindrical bodies probably represent calcite-filled "steam tubes."

Composition.—After the calcite is dissolved with cold hydrochloric acid the composition of the remaining washed material is approximately as follows:

Volcanic glass—80%.
Devitrified glass and fine-grained trachyandesite(?) fragments—10%.
Albite-oligoclase (often untwinned)—6%.
Sanidine—3%.
Biotite—trace (fairly common).
Quartz—trace (rather rare).
Orthoclase—trace.
Chlorite—trace.
Muscovite—rare.
Epidote—trace.
Magnetite—trace.
Ilmenite—trace.
Serpentine—trace.
Zircon—trace.
Apatite—rare.

DESCRIPTION OF VERY FRESH UNCONSOLIDATED, GRAYISH-WHITE, VITRIC SAND-TUFF OR FINE ASH FROM NORTH BANK OF NUECES RIVER 3½ MILES WEST OF SIMMONS

Sizing.—Coarser than 1/16 mm.—80% by weight. Most of the fine material is "leverrierite." The remarkable freshness of this rock is worthy of note. Sizing of washed material: 8–4 mm.—2%; 4–2 mm.—3%; 2–1 mm.—3%; ½–¼ mm.—12%; ¼–⅛ mm.—35%; ⅛–1/16 mm.—42%. About 75% of grains over ½ mm. are composed of bluish-gray, subangular to angular pumice lapilli. The remaining

25% is opaline material containing many glass grains. In the 2–1 mm. separate are found three spherical "mud balls" composed of interlocking volcanic glass grains held together by opaline and argillaceous material.

Composition—(washed material):

Volcanic glass—75%.
Devitrified glass or trachyandesite(?) fragments—10%.
Soda-lime feldspar (albite to oligoclase)—12%.
Sanidine—2%.
Biotite—trace (frequent).
Chlorite—trace.
Magnetite—trace.
Ilmenite—trace.
Zircon—trace (rare).
Opal—1%.

Soledad Member.—

DESCRIPTION OF RATHER FRIABLE, FINELY VESICULAR, SOMEWHAT SANDY, BROWNISH-PINK TUFF FROM EASTERN McMULLEN COUNTY, 4 MILES SOUTHWEST OF SIMMONS

Sizing.—Coarser than 1/16 mm.—60% by weight. Washed material sized approximately as follows: 2–1 mm.—1%; 1–½ mm.—3%; ½–¼ mm.—10%; ¼–⅛ mm.—38%; ⅛–1/16 mm.—48%. Most of the fragments above ½ mm. are gray pumice lapilli or pebbles.

Composition—(washed material):

Volcanic glass (n=1.50–1.508)—55%.
Soda-lime feldspar (albite-oligoclase to labradorite, mostly acid oligoclase)—20%.
Dark gray angular andesite fragments—20%.
Biotite—trace.
Magnetite—trace.
Orthoclase—trace.
Augite—trace.
Quartz—rare (worn grains).
Chabazite or gmelinite (colorless to yellow)—1%.
Zircon—trace.
Opal (from cement)—3%.

The matrix (fine material) is composed largely of montmorillonite but crusts of opaline and zeolitic material are common.

DESCRIPTION OF A VESICULAR, LUMPY, FRIABLE, BROWNISH-PINK, ARGILLACEOUS TUFF FROM RAY RANCH, 8 MILES SOUTH OF WENTZ, McMULLEN COUNTY

Sizing.—Coarser than 1/16 mm.—40%. Sizing of washed material about like preceding sample. About 15% of matrix consists of opaline cement. The remainder is mainly "leverrierite."

Composition—(washed material):

Soda-lime feldspar (mainly albite-oligoclase)—15% or more.

Volcanic glass (n=1.498–1.502)—68%.

Andesite and (or) trachyandesite fragments (red, brown and black)—10%.

Sanidine—4% or less.

Magnetite—1%.

Biotite—trace (frequent).

Quartz (all grains apparently worn)—1% or less.

Zircon—trace.

Opal—2%.

Calcite—trace.

Chusa Member.—

DESCRIPTION OF A POWDERY, SOMEWHAT PISOLITIC, LIGHT PINK, BENTONITIC TUFF OR TUFFACEOUS CLAY FROM TYPE LOCALITY OF GUEYDAN FORMATION (GUEYDAN RANCH) McMULLEN COUNTY

Sizing.—Coarser than 1/16 mm.—0.53% by weight. Sizing of washed material is approximately: 2–½ mm.—(consists entirely of white opaline crusts)—10%; ½–¼ mm.—15%; ¼–⅛ mm.—30%; ⅛–1/16 mm.—45%.

Composition—(washed material below ½ mm.):

Volcanic glass—(n=1.508)—10%.

Soda-lime feldspar (albite to andesine, mostly oligoclase)—60%.

Sanidine—12%.

Andesite or trachyandesite fragments—15%.

Magnetite—2%.

Biotite—trace.

Muscovite—trace.

Zircon—trace.

Quartz (angular and apparently primary)—trace.

Augite—trace.

Opal—1%.

Hematite and limonite—trace.

The matrix consists almost entirely of pinkish "leverrierite" and the sample breaks down fairly rapidly when placed in water.

DESCRIPTION OF A SAMPLE OF VERY FRIABLE, PISOLITIC, GREENISH-WHITE, ARGILLACEOUS TUFF FROM NORTH BANK OF NUECES RIVER, 3 MILES ABOVE MOUTH OF FRIO, LIVE OAK COUNTY

Sizing.—Washed material (below 1/16 mm.)—0.2%. Largest grain noted—¼ mm. About 75% of washed material between ⅛ and 1/16 mm.

Composition—(washed material):

Soda-lime feldspar (albite to acid andesine, mainly oligoclase, $\alpha=1.540$; $\gamma=1.548$)—65%.

Volcanic glass ($n=1.512\pm.004$)—20%.

Augite—trace.

Magnetite—trace.

Zircon—trace.

Opal—10%.

Calcite—5%.

Matrix consists mainly of an argillaceous substance ($n=1.50–1.52$) which does not break down in water like "leverrierite," probably on account of opaline cement in thin films. Most of particles in this rock range from .01–.05 mm.

PETROGRAPHY OF LAVA PEBBLES AND BOULDERS

The lava pebbles and boulders which are included in the Gueydan tuffs, tuffaceous clays and sands, and conglomerates range from an inch, or less, to more than one foot in diameter. Boulders two feet in diameter are observed only in a small area northeast of Loma Alto Mesa, but the one-foot boulders have a fairly wide distribution in McMullen, Live Oak, and Duval counties. These boulders or pebbles of eruptive rocks are practically always very well rounded, apparently by the action of water. Lava pebbles are far more abundant in the middle Gueydan (Soledad) than in the other members. In fact the Soledad conglomerate in western Duval County is composed almost exclusively of volcanic pebbles of a rather wide variety of types, including soda trachyte, leucite phonolite (?), trachyandesite, and acid to basic andesite. Andesite and trachyandesite are by far the most abundant petrologic types. Boulders and pebbles, and possibly some lapilli of reddish-brown vesicular andesite are also of common occurrence in the Soledad pinkish tuffs. Lava boulders, excluding pumice, are rare in the Fant member except in the extreme southwestern corner of McMullen County and the northwestern corner of Duval County, where reddish-brown and purplish pebbles and boulders of slightly porous to vesicular and amygdaloidal trachyandesite up to one foot in diameter are quite common in a pinkish or whitish tuffaceous clay or tuff near the base of the formation. A photograph of some of these boulders in the Fant member is given in Plate VII, Figure 1. Scattered boulders and pebbles of red to brown and dark gray, strongly vesicular andesite are found in the Chusa member; these boulders are quite abundant over areas a few acres in extent. The very large subangular and angular boulders of brownish-gray to red, acid andesite are present near the base of the Chusa member. They are coarsely porphyritic; the partially resorbed tabular andesine and oligoclase phenocrysts attain a breadth of three centimeters. Photomicrographs of thin sections of the Soledad fine volcanic conglomerate and volcanic sandstone are found in Plate XI, Figures 1 and 2 and Plate XII, Figure 1, which show the texture and appearance of some of the lava pebbles under the microscope. Photomicrographs of thin sections of chips from individual lava boulders are given in Plate X, Fgure 2 and Plate XII, Figure 2.

No chemical analyses of the lava boulders have been made and the rock types have been identified by the study of thin sections. The feldspar and some of the other minerals in these boulders were determined by immersing crushed samples in oils of known refractive index. A revision of the names of some of the lavas containing considerable glass may be necessary after chemical analyses have been made. Petrographic descriptions of some of the principal rock types found in the lava pebbles and boulders are given below.

PETROGRAPHIC DESCRIPTIONS OF LAVA BOULDERS FROM FANT MEMBER

1. Locality: Chapote ranch southwest corner of McMullen County.
   Megascopic character: Purplish-brown, somewhat amygdaloidal rounded boulder 1 foot in diameter.
   Texture: Felsophyric porphyritic. Groundmass cryptocrystalline to microcrystalline with a small amount of glass present.
   Phenocrysts: 40–50%. From 5–¼ mm. long. Phenocrysts are generally nearly equant, thick tabular, or irregular, due to much resorption. (See plate X, fig. 2.)
   Minerals—
   Oligoclase, probably potash-bearing (medium to acid) —80%.
   Augite or diopside (generally altered to limonite)—17%.

Apatite (euhedral, rather stout yellow prisms)—2%.
Magnetite—1%.
Unknown mineral (possibly a serpentine pseudomorph after pyroxene)—trace.
(This mineral is very light green to colorless, uniaxial, or biaxial with a 2V of 2°, positive, shows fairly high relief and a birefringence of .017 to .021, has extinction of 40°–45° and has a perfect prismatic(?) cleavage and a good rhombohedral parting.)

Ground mass: 50–60%.

The larger ground mass feldspars are mainly irregular to equant anorthoclase or (and) sanidine but some albite and albite-oligoclase is present. Numerous tiny, short, rod-like crystals of colorless or light green augite or diopside are noted and hematite and limonite specks are very common. Magnetite specks are also present. Not over 10% of the ground mass is glass. The colorless indeterminate constituents of the ground mass, probably glass, have a refractive index distinctly lower than 1.54. Small amygdules of radiating chalcedony and coarsely crystalline calcite are quite common.

Name: Trachyandesite (possibly trachyte).

2. Locality: Chapote ranch, McMullen County.

Megascopic character: Brownish-red, amygdaloidal, porphyritic, rounded boulder, having diameter of 8 inches.

Texture: Vitrophyric to granophyric porphyritic. Amygdules of chalcedony and calcite comprise fully 20% of rock.

Phenocrysts: 65%. From 10–⅛ mm. long. Phenocrysts are thick tabular or irregular with corroded surfaces.

Minerals—

Potash-oligoclase or albite-oligoclase (occasionally show almost ultramicroscopic cross-hatched twinning; extinction on 100 from X to 010=15°; 2V=60° approx.; negative; $\alpha=1.538$ and $\gamma=1.546$)—52%.
Albite—15%.
Orthoclase (possibly anorthoclase)—1%.
Apatite—1%.
Magnetite—1%.
Hematite and limonite mixed with argillaceous substance from alterations of augite(?) phenocrysts—30%.

Ground mass: 35%. Consists of partially formed untwinned feldspar microlites, hematite and limonite specks, glass and a few tiny crystals of apatite and magnetite. About half the ground mass is light brown glass. The ground mass feldspar appears to be mainly albite-oligoclase or potash-oligoclase and albite; some of it may be sanidine.

Name: Soda-trachyte or trachyandesite.

PETROGRAPHIC DESCRIPTIONS OF BOULDERS AND PEBBLES FROM SOLEDAD MEMBER

Pebble from Soledad tuff—

Locality: Near Live Oak-McMullen County line, 3½ miles west of Simmons.

Megascopic character: Brownish-red, extremely vesicular, subrounded pebble 3 inches in diameter.

Texture: Vitrophyric porphyritic, tendency toward hyalopilitic. Vesicular cavities occupy twice as much space as solid matter. Some vesicles partly filled with fibrous calcite, chalcedony and opal.

Phenocrysts: 15% of the solid matter. Crystals or microlites up to ⅛ mm. in length consist preponderantly of lath-shaped, striated feldspar.

Minerals—

Andesine to labradorite—13% (of rock).

Magnetite—2% (of rock).

Ground mass: 85%—Consists entirely of brown glass with refractive index of 1.55.

Name: Andesite(?)

BOULDERS AND PEBBLES IN SOLEDAD CONGLOMERATE FROM SOLEDAD HILLS

1. Megascopic character: Light purplish-brown, porphyritic, slightly amygdaloidal, rounded pebble 3 inches in diameter.

Texture: Vitrophyric porphyric with fine phanerocrystalline to microcrystalline imperfectly trachytic ground mass and some interstitial glass. A few round chalcedonic amygdules present.

Phenocrysts: 10%–15%. Tabular, plainly striated feldspar phenocrysts and a few rounded phenocrysts or amygdules of analcite(?).

Minerals—

Calcic oligoclase to andesine (indices between 1.54 and 1.56)—10% (of rock).

Analcite(?) (possibly primary but probably amygdaloidal)—2%.

Ground mass: 85%–90%.

Consists of predominant albite-oligoclase, sanidine and anorthoclase, abundant tiny, thick, rod-shaped, orange-red pseudomorphs of hematite and (or) limonite after pyroxene, and possibly 10% of interstitial glass. Tiny apatite prisms, magnetite crystals and a few irregular crystals of the unknown, uniaxial, positive mineral noted on page 137 with a low index and low birefringence are present.

Name: Trachyandesite or andesite.

2. Megascopic character: Brownish-gray, porphyritic, non-vesicular, rounded pebble 5 inches in diameter.

   Texture: Granophyric or imperfectly pilotaxitic, porphyritic.

   Phenocrysts: 30%. Thick rectangular phenocrysts of minutely striated oligoclase and andesine from 2 to ¼ mm. long which practically always show embayments produced by resorption. A few smaller euhedral phenocrysts of altered augite(?)

   Minerals—

   Oligoclase-andesine—90% of phenocrysts.

   Augite(?) (altered to red-brown, translucent, highly birefringent substance which shows pyroxene outlines. Probably a mixture of epidote and hematite).

   Ground mass: 70%. Consists of abundant short rod-like crystals of acid plagioclase and orange to yellowish altered augite (probably epidote and limonite or hematite), common euhedral octahedrons of magnetite and anhedral sanidine crystals and frequent apatite prisms. Possibly a trace of glass is present.

   Name: Andesite.

3. Megascopic character: Creamy-white, non-vesicular, porphyritic pebbles 4 inches in diameter.

   Texture: Hypocrystalline porphyritic with imperfectly trachytic ground mass.

   Phenocrysts: 20%. Tabular feldspar ⅓ mm. long.

   Minerals—

   Anorthoclase—50% of phenocrysts.

   Albite (shows good albite twinning)—50%.

   Ground mass: 80%. Consists of lath-shaped to equant crystals of singly twinned albite and sanidine and a few tiny crystals of magnetite and more or less aegirine in a glassy matrix. About 15% of glass with index of 1.50 is present. A small number of roundish grains of an isotropic mineral with a very low index, possibly analcite, are also noted. Less than 5% of ferromagnesian minerals present.

   Name: Soda-trachyte.

4. Megascopic character: Dark gray to black, non-porphyritic pebble 1 inch in diameter.

   Texture: Holocrystalline, even-grained, pilotaxitic to microdiabasic. Small phenocrysts of coarsely twinned labradorite and pale green augite are rare.

   Minerals—

   Andesine—preponderant.

   Labradorite—common.

   Augite (mostly altered to a red-brown substance which is probably a mixture of limonite and epidote)—very common.

Magnetite—common.
Apatite—frequent.

Name: Augite-andesite.

5. Megascopic character: Light red, non-vesicular, porphyritic, rounded pebble 3 inches in diameter.

Texture: Porphyritic with a hypocrystalline granophyric ground mass. Ground mass feldspar are mainly anhedral.

Phenocrysts: 15%. Tabular feldspar phenocrysts 1-5 mm. long and a few roundish leucite(?) phenocrysts up to ⅛ mm.

Minerals—
Sanidine (often shows Carlsbad twinning)—12% of rock.
Potash-oligoclase (with microscopic cross-hatched twinning)—2%.
Leucite(?) (euhedral crystals which are isotropic or altered to aggregatal orthoclase and zeolites; isotropic; $n=1.51$)—1%.

Ground mass: 85%. Small leucite(?) crystals and pseudomorphs after leucite(?) are very abundant in certain flow bands in the rock giving to these bands a net-like appearance.

Minerals—
Sanidine and albite—55%.
Glass ($n=1.50$)—20%.
Leucite(?)—8%.
Hematite (small specks)—2%.

Name: Leucite(?) phonolite(?).

6. Megascopic character: A rounded 8-inch boulder of light brownish-red, splotched with brownish-gray, amygdaloidal porphyritic lava.

Texture: Porphyritic with hyalopilitic ground mass.

Phenocrysts: About 20%. Composed of partly resorbed, tabular oligoclase and andesine crystals up to 7 mm. long and a few small subhedral to euhedral magnetite phenocrysts. Feldspar phenocrysts contain abundant irregular inclusions of the ground mass.

Ground mass: 80%. Contains abundant brownish glass with a refractive index below 1.539.

Minerals—Oligoclase to andesine (ground mass feldspar is untwinned; phenocryst feldspar shows very fine albite twinning)—predominant.
Glass—abundant.
Hematite (minute flecks)—abundant.
Magnetite—common.
Augite (light green and slightly pleochroic)—frequent.
Apatite—frequent.

Name: Andesite.

RELATIVE ABUNDANCE OF TYPES OF PEBBLES IN SOLEDAD CONGLOMERATE

Probably over 50% of the pebbles and boulders consist of acid to basic augite andesite. Augite trachyandesite boulders and pebbles much like those in the Fant member are also quite abundant and gradations between trachyandesite and andesite appear to exist. Possibly 10% of the lava pebbles and boulders consist of soda trachytes. Leucite phonolites (?) are rare. Dark gray pebbles which are doubtfully identified as leucite or analcite tephrite are of rare occurrence. A few pebbles of silicified tuff and chert are also found in the Soledad conglomerate.

PETROGRAPHIC DESCRIPTIONS OF BOULDERS FROM THE TUFF OF THE CHUSA MEMBER

1. Locality: 2 miles north of Loma Alto Mesa, McMullen County.
   Megascopic character: Brownish-red, vesicular and partly amygdaloidal, coarsely porphyritic, subrounded boulder 16 inches in diameter.
   Texture: Porphyritic with a hyalopilitic ground mass.
   Phenocrysts: 30%. Consist of partly resorbed, tabular, minutely striated oligoclase to acid andesine crystals up to 25 mm. in length and a few small (⅛ mm. and less) crystals of light green augite.
   Ground mass: 70%. Composed of abundant short feldspar laths and a few augite, magnetite and hematite crystals in a brown glass matrix.
   Minerals—
   Oligoclase—65% of rock.
   Glass (n=1.525)—25%.
   Augite—3%.
   Hematite—4%.
   Magnetite—3%.
   Apatite—trace.
   Amygdaloidal fillings of calcite, fibrous zeolites and opal are common.
   Name: Augite trachyandesite or acid andesite.
2. Locality: 2 miles east-southeast of Fant City, Live Oak County.
   Megascopic character: Exceedingly vesicular, brick-red, rounded boulder 7 inches in diameter.
   Texture: Vitrophyric porphyritic. (See Plate XII, fig. 2.)
   Phenocrysts: 15%. From 2–¼ mm. in length. Occur as euhedral or slightly resorbed broad laths of rather coarsely twinned plagioclase which sometimes show zoning.

Ground mass: 85%. Consists of 70% glass and scattered, variously oriented microlites. Ground mass appears red on account of abundance of hematite specks.

Minerals—

Glass—55% of rock.

Andesine to labradorite—30%.

Hematite—11%.

Magnetite—1%.

Augite—trace.

Limonite—1%.

"Leverrierite(?)"—(cloudy yellowish material)—2%.

The rock also contains coatings of calcite and opal inside the vesicles.

Name: Vesicular andesite(?).

3. Locality: 2 miles east-northeast of Loma Alto Mesa, near contact of Soledad and Chusa.

Megascopic character: Black, vesicular, coarsely porphyritic, subangular boulder 2 feet in diameter. This is the largest boulder seen in the Gueydan formation.

Texture: Vitrophyric porphyritic.

Phenocrysts: 30%. Tabular, minutely striated, partly resorbed oligoclase crystals 1 cm. across comprise fully 85% of the phenocrysts. These feldspar phenocrysts contain abundant, very irregular shaped inclusions of brown glass. Other phenocrysts ¼ mm. or less in length consist of pale yellowish-green augite and magnetite. Rare phenocrysts of light yellow to colorless apatite are present.

Ground mass: 70%. The ground mass consists of abundant glass in which are included variously oriented, slender laths of feldspar, short rods of augite, rounded crystals of magnetite and occasional slender prisms of apatite.

Minerals—

Oligoclase—35% of ground mass.

Glass—53%.

Augite—10%.

Magnetite—2%.

Apatite—trace.

Titanite (reddish-orange)—trace.

Unknown mineral (like that in No. 1 of Fant member)—trace.

Some calcite is present as amygdaloidal fillings.

Name: Augite trachyandesite or acid andesite.

PETROGRAPHY OF NON-PYROCLASTIC ROCKS OF THE GUEYDAN-CATAHOULA

Petrographic descriptions of many types of the fluviatile sandstones and clays of the Gueydan have been given under the description of samples from the Hicks No. 1 well on pages 94–100. The non-pyroclastic rocks of the Gueydan were found to contain variable quantities of volcanic glass, andesite(?) grains, feldspar, montmorillonite, and other constituents of volcanic origin as well as chert, quartz, and a few other minerals derived from sedimentary rocks. Some of the other fluviatile rocks of the Gueydan, particularly those from Gonzales County where the Gueydan grades eastward along its strike into beds of the Catahoula facies, are described here. Some unquestioned Catahoula rocks from eastern Texas are also described, in order to show their similarity to the Catahoula rocks from Gonzales County.

DESCRIPTION OF A SAMPLE OF YELLOWISH-GREEN, FRIABLE, TUFFACEOUS SANDSTONE FROM NAVES RANCH, 3¾ MILES SOUTHEAST OF FANT CITY, LIVE OAK COUNTY. (Middle Gueydan)

Sizing.—Sand (above 1/16 mm.)—79% by weight; silt and clay—21%. The sizing of the sand is estimated as follows: 1–½ mm.—trace; ½–¼ mm.—15%; ¼–⅛ mm.—65%; ⅛–1/16 mm.—20%.

Rounding.—Sharply angular with the exception of a few beautifully rounded and polished quartz and plagioclase grains.

Composition of washed material—

- Volcanic glass (n=1.498-1.508)—25%.
- Plagioclase (mostly oligoclase and andesine)—15%.
- Sanidine—3%.
- Quartz—5%.
- Calcite (from cement)—30%.
- Trachyandesite(?) grains (possibly includes some chert)—20%.
- Magnetite—2%.
- Biotite—trace.
- Chert—trace.

The green color of this rock is due to abundant chloritic(?) material in the argillaceous matrix.

DESCRPTION OF A GRAYISH-WHITE, OPAL-CEMENTED, TUFFACEOUS SANDY CLAY FROM VICTORIA ROAD, 4½ MILES EAST OF GILLETT, KARNES COUNTY. (Gueydan)

Sizing.—Washed material comprises about 25% of sample. The sizing of washed material is estimated as follows: ½–¼ mm.—30%; ¼–⅛ mm.—45%; ⅛–1/16—25%.

Rounding.—About 15% of rounded to subrounded grains. Remainder angular to subangular.

Composition of washed material—

Plagioclase (oligoclase to andesine)—25%.
Sanidine and orthoclase—5%.
Volcanic glass—35%.
Trachyandesite fragments—5%.
Quartz—12%.
Opal (from cement)—10%.
Chert—8%.
Augite—trace.
Magnetite—trace.

Many of the coarser grains are rounded and polished and often coated with a thin film of opal; these grains resemble grains of rice. "Rice sands" are very common in the Catahoula and in this sample there is a mingling of the Gueydan and Catahoula materials. This sample comes from the most southwesterly locality at which such a mingling of the Gueydan and Catahoula materials may be discerned.

DESCRIPTION OF A RED AND ORANGE SPLOTCHED, LIGHT CREAMY-GRAY, INDURATED, OPAL-CEMENTED, JAROSITE-BEARING, QUARTZ SANDSTONE FROM 8½ MILES DUE SOUTH OF SMILEY, GONZALES COUNTY. (Gueydan-Catahoula)

Sizing.—About 10% of argillaceous material present. The sizing of the washed material is estimated as follows: ½–¼ mm.—45%; ¼–⅛ mm.—40%; ⅛–1/16 mm.—15%.

Rounding.—Grains largely subangular to subrounded. About 20% of rounded grains.

Composition of washed material—

Quartz—70%.
Plagioclase (albite to labradorite)—3%.
Chert—5%.
Orthoclase and sanidine—1%.
Zircon—trace (common).
Magnetite—trace (common).
Hornblende—trace (rare).
Jarosite (occurs in cavities as tiny, orange-colored hexagonal plates with a habit typical of this mineral)—1%.
Volcanic glass—trace (rare).
Hematite (from weathering of jarosite)—trace.
Opal (from cement)—20%.

This sample resembles very closely some beds in the typical Catahoula (*cf.* description following) of eastern

Texas. The rock is quite porous, the pores having been produced by the weathering out of certain grains, possibly volcanic glass.

DESCRIPTION OF AN INDURATED, LIGHT YELLOWISH-GRAY, OPAL-CEMENTED SANDSTONE FROM ¼ MILE NORTHWEST OF ROCKLAND, TYLER COUNTY, EAST TEXAS. (Upper Catahoula)

Sizing.—About 20% of clay and silt present. The sizing of the washed material is estimated as follows: 1–½ mm.—trace; ½–¼ mm.—50%; ¼–⅛ mm.—35%; ⅛–1/16—15%.

Rounding.—About 5% of the grains are well rounded. Most of grains more or less worn.

Composition of washed material—

Quartz—30%.
Plagioclase (mainly andesine)—28%.
Chert—25%.
Orthoclase and sanidine—4%.
Microcline—1%.
Magnetite—1%.
Biotite—trace.
Volcanic glass—trace.
Muscovite—trace.
Zircon—trace.
Opal (from cement)—11%.

This rock is quite porous; some of the pores may have been formed by the decomposition and removal of volcanic glass grains. This sample shows marked similarity to the preceding sample in physical and mineralogical characters.

DESCRIPTION OF A MASSIVE-BEDDED, FRIABLE, GRAYISH-WHITE, SILICEOUS "RICE" SANDSTONE FROM 5 MILES SOUTHEAST OF SMILEY, GONZALES COUNTY.—(Catahoula)

Sizing.—About 5–10% of argillaceous material is present in the white, porcelain-like, siliceous cement of this rock. The washed material is sorted as follows: 8–4 mm.—trace; 4–2 mm.—2%; 2–1 mm.—28%; 1–½ mm.—50%; ½–¼ mm.—16%; ¼–⅛ mm.—3%; ⅛–1/16 mm.—1%.

Rounding.—The majority of the grains are subangular to subrounded and about 10% are well rounded. Even the subangular grains are usually nicely polished. This polished appearance of the grains together with the thin films of opal which coat them have given rise to the descriptive term "rice sand." Some of the quartz and feldspar grains are etched.

Composition of washed material—

- Quartz (many grains exhibit wavy extinction or even partial granulation and many contain apatite prisms. These features suggest granitic and metamorphic source rocks) —65%.
- Chert (mostly translucent light gray)—5%.
- Plagioclase (mostly albite-oligoclase)—1%.
- Orthoclase—5%.
- Silicified wood fragments—trace.
- Tourmaline—trace.
- Zircon—trace.
- Magnetite—trace.
- Cement fragments (consist of porcelain-like, opaque to translucent, angular fragments composed of a mixture of opal, chalcedony and argillaceous material which shows irregular fibrous extinction)—24%.

This sample comes from the most westerly locality of typical Catahoula sandstone and the beds from which this sample is taken grade southwestward along their strike into beds of the Gueydan facies.

A sample of typical friable, grayish-white, somewhat pebbly Catahoula sandstone from a large quarry four miles northeast of Rockland, Tyler County, is found to be almost identical to the above sample. The Tyler County rock has the same white porcelain-like, siliceous cement as the rock from Gonzales County; its sizing is very similar, although a few more small pebbles are present; its mineralogical composition is almost identical except that a few grains of volcanic glass and some small pebbles of porcelain-like, silica-impregnated, argillaceous material, resembling the cement are noted. There can be no real question of the identity of the source of the material and conditions of deposition of the two samples.

AGE OF THE GUEYDAN

The age of the Gueydan deposits cannot be determined from their fossil content because of the extreme paucity or nearly complete absence of fossils. The only fossils which have been found in this formation, so far as known, are a very few silicified logs or wood fragments and one or two imperfect leaf impressions which are too poorly preserved for specific determination.

The upper and lower age limits as fixed by stratigraphic relations has already been discussed on pages 49 to 51. It is definitely proven that the Gueydan is post-Upper Eocene and pre-Upper Miocene in age from the abundant invertebrate and vertebrate fossils found in the Fayette and Oakville formations respectively. That an appreciable period of time elapsed between the Gueydan and the Oakville is proven by the unconformity at the base of the Oakville. (See p. 52.)

Since the Gueydan can be traced into the Catahoula it is, at least in part, equivalent in age to the Catahoula. Berry[70] has studied the fossil flora from the Catahoula of Trinity County in East Texas and has identified it as Oligocene and not younger than Oligocene. He states also that "it must be regarded as the most tropical flora known from the Tertiary formations of the Southern States." Some of the most recent work on the Catahoula of Louisiana and eastern Texas was done by Matson. He states[71] that the Catahoula is in part the equivalent of the Chattahoochee and in part the equivalent of the Vicksburg Oligocene, also that the lower part of the Fleming clay, which overlies the Catahoula is apparently of Upper Oligocene age and may be correlated with the Alum Bluff marine clay in Florida.

The light green, pisolitic clays and tuffaceous clays of the upper Gueydan (Chusa), when traced northeastward are found to overlie, apparently conformably, the typical Catahoula sandstone of Gonzales and Lavaca counties. These green clays of the Chusa member thus occupy a similar stratigraphic position to the partly marine Upper Oligocene and Lower Miocene Fleming clays of East Texas. It is, therefore, quite possible that a part or the whole of

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[70]Berry, E. W., "The Flora of the Catahoula Sandstone," U. S. Geol. Surv. Prof. Paper, 98M, pp. 227–252, 1917.

[71]Matson, G. C., "The Catahoula Sandstone," U. S. Geol. Surv. Prof. Paper, 98M, pp. 209–226, 1916.

the Chusa member of the Gueydan may be of Lower Miocene age. The Soledad and Fant members, and possibly the entire Gueydan, are apparently correlatives of the Catahoula formation of Oligocene age.

MINERAL VEINS IN THE GUEYDAN (LOS PICACHOS HILLS)

Los Picachos Hills are situated in extreme north-central Duval County, five miles southwest of Loma Alto Mesa, McMullen County. The topographic form of the hills has already been described on page 27. These elongated hills owe their relief to the resistance to erosion of a series of parallel, more or less lenticular, massive veins of varicolored opal and chalcedony and veins of banded white and light brown columnar to fibrous calcite, probably recrystallized aragonite. In the most southerly hill these veins have a maximum aggregate thickness of about fifty feet. They strike N. 42° E. and dip 72° N.W. on the average. There are three principal steep-sided hills which rise thirty to sixty feet above the surrounding country and the middle hill was determined, with a hand-level, to be slightly higher than the south hill, while the north hill is only about half as large or high as the other two. The veins in all the hills have approximately the same strike and dip, so far as can be determined. Northeast of these main hills is a low ridge formed of boulders of chalcedony and opal vein rocks. The approximate arrangement of the veins in these hills is indicated in Figure 2a.

The veins are best exposed in the south hill, but even here their outcrops are more or less obscured by loose fragments. The siliceous veins which are located on the west side of this hill vary considerably in thickness within a short distance, but individual veins are commonly from one to fifteen feet across. These siliceous veins are separated from each other by beds or partings of fine-grained, more or less silicified, light yellowish-green to white, argillaceous tuff or tuffaceous clay containing angular grains of feldspar and volcanic glass. The tuff partings are from an inch to a few feet thick. The siliceous veins consist of an irregularly splotched and mottled milky-white, bluish-gray and light gray to brownish-yellow, microcrystalline to amorphous textured rock with a waxy to pearly-vitreous luster. The rock breaks with a prominent conchoidal fracture. Under the microscope the vein rock is seen to be composed of about two-thirds opal and one-third chalcedony, although the ratio of the two minerals varies from place to place. Extremely irregular, minute to large areas of transparent chalcedony are distributed through the imperfectly translucent, yellowish, isotropic opal. Some of the chalcedony consists of long to short radiating fibrous crystals and all gradations are found between this variety and a cryptocrystalline or very finely microcrystalline type. The opal and chalcedony can be readily distinguished in thin section by their difference in color in plane polarized white light. At and near its contacts with the partings of argillaceous tuff the siliceous vein material is irregularly diffused through the tuff and consists of waxy, mottled and streaky opal of highly variegated bright red, yellow, purple, brown and black colors. These colors are apparently due to included oxides of iron and manganese. In many places between the normal green tuff and the highly colored margins of the siliceous veins are zones of nearly pure white, coherent, pisolitic, bauxite-like tuff from which the iron and, possibly, some of the silica has been leached. A microscopic examination of this white pisolitic material shows that it consists of a mixture of opal patches and a very weakly birefringent argillaceous mineral with an index of refraction of $1.51 \pm .003$. The latter mineral may be halloysite, "leverrierite," or a similar hydrous aluminum silicate. It is practically insoluble in hydrochloric acid. Qualitative tests show that it contains aluminum. The rock will not "slake" in water but the opaline material would prevent this even if the mineral be montmorillonite (leverrierite).

The fibrous calcite vein has the same dip and strike as the siliceous veins. It is about six feet thick at its widest point, but the thickness varies greatly. This vein is separated from the siliceous veins by about twenty feet of light green, argillaceous, pisolitic or pseudo-pisolitic, upper

Gueydan (Chusa) tuff or tuffaceous clay which apparently has the same dip and strike as the veins.

On the eastern side of the south hill, only seventy-five feet east of the main calcite vein, are a series of beds of greenish-white, slightly indurated but often pulverulent, Chusa tuffaceous clay cut by numerous small calcite veins. This rock is well stratified (unlike its usual massive character) in beds from four to ten inches thick. These beds dip 20° to 40° southeast about 100 feet southeast of the main fibrous calcite vein. The dip rapidly decreases toward the southeast. Close to the calcite vein is another small exposure of this tuffaceous clay. Here the beds are practically vertical or even dip in the same direction (northwest) as the vein. These beds also contain a great number of banded fibrous calcite veinlets, one-fourth to two inches thick, which are roughly parallel to the main vein. The beds containing these veinlets are greatly sheared so that they have a schist-like appearance. This shearing is evidently produced by faulting.

The veins in the other hills are similar to those of the south hill except that no fibrous calcite veins or vari-colored opal are noted. In the middle hill the main vein is composed of crypto-crystalline chalcedony which is full of numerous very irregular cavities up to three feet across. Some parts of the veins contain numerous irregular patches of coarsely crystalline calcite with well developed rhombohedral cleavage. The cavities in the chalcedony have been evidently formed by the solution of similar calcite as shown by cavities containing calcite linings. A thin section of the chalcedony-calcite rock shows the presence of a number of small, angular inclusions of silicified wall-rock tuff. The chalcedony is apparently replacing the calcite.

On the southeast side of the middle hill, associated with large loose blocks of chalcedony-calcite vein rock, are a number of great boulders and some small outcrops (which appear to be in place) of very hard quartzite-like sandstone. This sandstone is composed of angular to rounded quartz sand grains of fine to medium size in a larger amount of matrix of whitish chalcedony and opal, which show botryoidal surfaces where they line cavities. The attitude of the siliceous sandstone beds is doubtful but beds of this material appear to grade into the chalcedony-calcite rock. Therefore these beds probably have the same attitude as the veins.

Origin of Los Picachos veins.—The prominent gouge-like shear-zone developed in the tuffaceous clay strata and the abnormally steep dip which becomes vertical or even overturned next to the chalcedony and calcite veins in the south hill, leave no doubt that a fault passes through this hill, the steep dips having been produced by drag. In fact the succession of parallel veins alone strongly suggest a fault zone. On account of the transitional nature of the contact between the partings and beds of tuffaceous clay and the siliceous and calcareous veins and because of the extremely irregular and embayed inclusions of silicified tuffaceous clay in the chalcedonic vein rock, these veins are believed to have been formed, at least in part, by replacements of the tuffacous clay by silica and carbonate from waters circulating along fault planes or fissures. The quartzite-like sandstone may well have been produced by the replacement of a sandy horizon in the tuffaceous clay series. On the other hand it may be a sandstone dike or block of Oakville sandstone which has been dragged down by the faulting and included in the fault zone. It resembles the Oakville sandstone in composition and texture more than the sandy strata of the Gueydan. The faulting here appears to be of the reverse or high-angled thrust type. The faulting will be more fully discussed under "Structural Geology."

Deussen[72] has drawn a sketch map and section of Los Picachos but his section indicates that the veins are vertical and no fault is mapped or mentioned. He does not show the tuffaceous clay partings between the several siliceous veins but draws these all as one chalcedony vein; nor does he indicate the character or the dip of the material between the siliceous veins and the calcite vein. The sketches (Figs.

[72]Deussen, Alex., U. S. Geol. Surv. Paper, 126, p. 122, 1924.

2a and 2b) represent the writer's interpretation of the structure at Los Picachos.

The writer is not entirely certain that the bedding planes in the tuffaceous clay between the siliceous veins and the

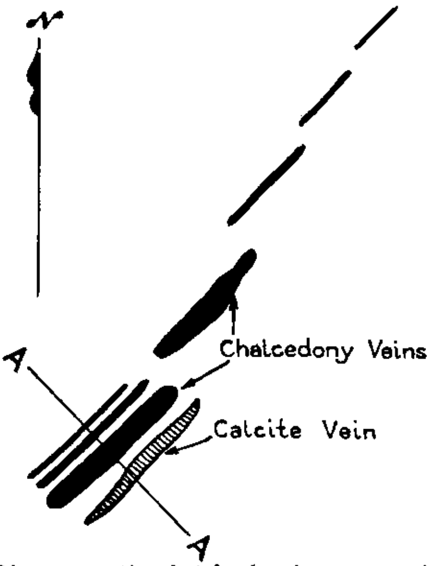

FIGURE 2a.—Diagrammatic sketch showing approximate plan of vein outcrops at Los Picachos Hills.

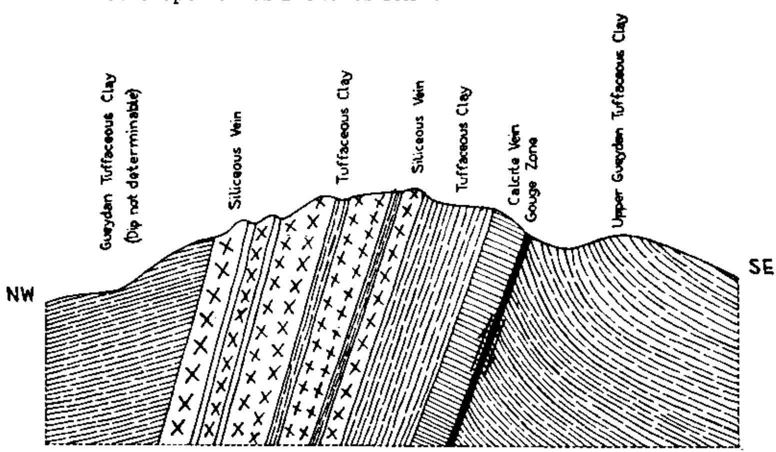

FIGURE 2b.—Diagrammatic sketch of south hill of Los Picachos along line A-A′ in Fig. 2a.

calcite vein, and the clay partings between the various siliceous veins actually parallel the vein walls but believes this to be the most logical interpretaion from the data available. No dip was determinable in the tuffaceous clays exposed west of the siliceous veins and it is possible that the dip there is southeast, instead of northwest as indicated in Fig. 2b.

It is possible that this reversed faulting which is so rare in the coastal plain was produced by the movement of molten magma at a slight depth below the surface, as Dr. G. D. Louderback[73] has suggested as a possibility.

SILICEOUS KNOBS

The siliceous knobs found at several places in McMullen, Duval, and Webb counties are generally composed of the same type of opal-chalcedony rock or quartzitic sandstone as that which composes the siliceous veins at Los Picachos. These knobs are situated both on the outcrop of the Chusa member of the Gueydan and on the western margin of the Oakville outcrop. It is possible that some of these knobs have a structure similar to Los Picachos but this appears to be improbable. The siliceous knobs are usually quite circular in plan and rounded conical in profile while the Picachos are elongated ridge-like hills. No steeply inclined partings or beds of clastic wall rock were found in these knobs. Instead, the siliceous rock of these knobs shows a semblance of horizontal bedding. Such horizontal joints or bedding planes can be noted at Tendita Knob in extreme southeastern McMullen County, three miles southeast of La Chusa Mesa, and at the two Sermosa Hills, in western Duval County, two miles southeast of the south end of Soledad Hills. In the former knob there appears to be a gradation from siliceous Oakville sandstone into massive, gnarly, irregularly banded, dark to medium gray or whitish, opal-chalcedony rock. No suggestion of steep dips was noted in the beds of Chusa tuff or Oakville clays outcropping

[73]Oral communication, May, 1926.

around these knobs. However, the outcrops of the surrounding strata are largely obscured by the presence of blocks of chalcedonic rock from the knobs so that the dip is very uncertain. Loose rounded blocks up to five feet in diameter of desert-varnished, chalcedony-opal rock and silicified sandstone, which appear to be identical to the rocks in these knobs, are found resting on the outcrop of the Chusa tuffaceous clays one-quarter mile east of the center of Loma Alto Mesa and fully two miles west of Paint Hill, the nearest of the siliceous knobs. There is a broad valley between Paint Hill and these blocks which would prevent any rolling boulders from Paint Hill from reaching this locality. These blocks are apparently residuals of a former silicified Oakville sandstone cap that has been undermined and removed by erosion leaving these blocks. From the foregoing evidence the writer is inclined to regard the rounded siliceous knobs as residuals of the better silicified portions of formerly more extensive Oakville sandstone beds. Such strongly silicified portions of the Oakville possibly represent parts of former channels for silica-bearing waters which circulated through this sandstone and deposited a quantity of siliceous cement or even replaced most of the sand grains in this rock.

INTRUSIONS IN THE GUEYDAN

Serpentine.—In the Hawley well, located about the middle of the Gueydan belt in Live Oak County two miles southeast of Fant City, at a depth of 230 feet, a peculiar, very light green serpentine cut by veins of fibrous calcite up to one inch in thickness was encountered. The serpentine shows the characteristic slickensiding of that rock and the optical properties of its principal constituent agree with those of antigorite. Another sample of similar serpentine containing smaller calcite stringers, numerous small pyrite cubes, and rounded, pebble-like masses of fine-grained white limestone was obtained from 235 feet. These were the only samples of serpentine seen by the writer. The driller reports twenty feet of this rock.

The limestone pebbles which are included in the serpentine show many irregular embayments along their borders and are cut by minute sinuous, vein-like masses of serpentine. These features strongly suggest that the serpentine was intruded into a limestone conglomerate. It is posssible that the irregular reëntrants of serpentine in the limestone were produced by plastic flow of the serpentine under pressure generated by the hydration and consequent expansion in volume of a basalt or basalt tuff from which the serpentine may have formed. However, no shearing can be noted in the limestone, although such shear cracks may have been obliterated by being later filled with fibrous calcite stringers which cut both the limestone and the serpentine. If this is really an intrusive serpentine, instead of a hydrated basic tuff, the intrusive body is evidently a sill, a thin laccolith, or an inclined dike because Gueydan, Frio, and Fayette tuffs and sediments are found beneath the serpentine.

The nearest known intrusive bodies are the nepheline and melilite basalt and phonolite volcanic necks and laccoliths in Uvalde County, more than 100 miles northwest of the Hawley well. The nearest known mass of serpentine rock is that encountered between 1,150 and 1,450 feet in the Lytton Springs oil field, in the northern corner of Caldwell County, about 110 miles north of the Hawley well. The serpentine rock from Lytton Springs has been examined by the writer and is entirely different in texture from that in Live Oak County. No pseudomorphs after olivine crystals are seen in the Live Oak County serpentine but such pseudormorphs are very abundant in the Caldwell County serpentine. The Caldwell serpentine is an altered basaltic volcanic breccia or agglomerate composed of angular fragments of several types of hydrated basalt. The Live Oak serpentine shows no suggestion of agglomeratic texture.

ORIGIN OF THE GUEYDAN

From the foregoing descriptions and discussions it is evident that the Gueydan formation is a series of land-laid pyroclastics interbedded with fluviatile sediments. Many of the latter are composed principally of material derived from pyroclastic rocks including variable amounts of pebbles and boulders of lava rocks. The question now arises: Where is the neck or stump of the volcano which threw out such enormous quantities of debris?

Source of the material.—From the character of the material it is evident that a large part of the Gueydan deposits were erupted from one or more volcanoes in a number of great explosive eruptions. To date no volcanic cone or neck has been found in the vicinity of the Gueydan outcrop. Since this was an Oligocene or Lower Miocene volcano it is not surprising that difficulties are encountered in locating the exact position of the volcano or volcanoes.

No lava flows have been found in the Gueydan or adjacent formations although boulders and pebbles of lava rocks are very abundant in McMullen and Duval counties and common or frequent over a much more extensive territory. Since lava flows are far more resistant to erosion than any of the rocks now exposed in this part of Texas it is probable that no lava flows of Gueydan age were ever present within the area of the Gueydan outcrop or the adjacent region. The pebbles of lava rock can be more naturally explained as more or less comminuted and eroded volcanic blocks or bombs ejected by explosive eruptions instead of fragments from lava flows which have been entirely eroded or covered. Such purely explosive eruptions have been quite common among modern volcanoes (*e.g.* Krakatoa, Vulcano, Mont Pelée, and other Antillean volcanoes). The Gueydan eruptions belong, probably in toto, to the Vulcanian or Peléan types of volcanic eruptions according to Lacroix's classification.[74] The presence of widely distributed tridymite in the tuffs might be interpreted to mean that the ejectamenta, at the time of deposition, were at high temperatures comparable with the temperatures of the fiery clouds (nuées ardentes) of Mont

[74]Lacroix, A., "La Montagne Pelée après ses Eruptions," Masson et Cie, Paris, pp. 75–83, 1908.

Pelée which have been so admirably described and carefully studied by Lacroix.[75]

After the Gueydan tuffs were deposited they were partly or entirely covered by Upper Miocene and younger continental sediments, the land surface was tilted gulfward, and the whole Tertiary series including the Gueydan was truncated by erosion.

The present problem of locating the source of the Gueydan material is difficult because the apparent point of greatest thickness only can be located along the present outcrop, in a comparatively narrow northeast-southwest belt. This belt of outcrop is little better than a random cross-section of the formation and the actual point of greatest thickness may be situated at a considerable distance to either side of the belt at its point of greatest thickness now exposed. As many lines of evidence as possible have therefore been followed in order to try to ascertain the source of the Gueydan pyroclastics.

What may be the circumstances which have baffled attempts to discover the volcanic source of the Gueydan pyroclastics? Three hypotheses are submitted as follows:

(1) The source is distant, *e.g.* located 100 miles or more from the nearest point on the present outcrop of the Gueydan.

(2) The old volcano is situated within the present outcrop of the Gueydan formation; but erosion has planed off the ancient cone without yet uncovering the lava pipe; and the portion of the cone and neck now at the surface is composed of pyroclastic material so similar to the surrounding Gueydan tuff that it has not been distinguished.

(3) The stump of the ancient volcano is situated near the Gueydan belt but is now hidden under a covering of sediments younger than the Gueydan.

Each of these hypotheses will now be tested by all the evidence available in order to determine which hypothesis agrees best with the facts.

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[75]Lacroix, A., "La Montagne Pelèe et ses Eruptions," Masson et Cie, Paris, pp. 163–209, etc, 1904.

Evidence for a distant source.—Under the first hypothesis the source is distant and it is, therefore, useless to expect to find the remains of the volcano in the vicinity of the Gueydan outcrop. If this ancient volcanic vent is located farther inland than the Gueydan belt, it should be exposed as a volcanic plug, because the formations outcropping farther inland are older than the Gueydan and a volcanic pipe would have had to pass through these formations in order to deposit the eruptive debris on top of them. On the other hand, if this volcano is situated at a considerable distance nearer to the Gulf than the Gueydan belt it would be covered by several thousand feet of post-Lower Moicene sedimentary deposits and could be discovered only by drilling.

The evidence for a distant source is as follows:

(1) The bulk of the Gueydan pyroclastics consists of fine particles, below one millimeter in length. This does not necessarily indicate a distant source because volcanoes erupting pumiceous material similar to the Gueydan tuffs often throw out the debris in a series of violent explosions which comminute this debris into tiny particles. Krakatoa is an extreme case of this type of volcano.

(2) Negative evidence is furnished by the failure to discover volcanic necks or parts of cones in the immediate vicinity of the tuff outcrops.

(3) A number of volcanic plugs are exposed in Uvalde, Kinney, and Travis counties, 100 miles or more from the nearest Gueydan exposures and these would furnish a convenient source for the Tertiary tuffs provided there were no conflicting evidence. Jones[76] evidently believes that the volcanic boulders he has noted in northwestern Duval County came from the Uvalde County volcanoes, although he gives no facts in support of his statement. The volcanic necks have been described by Vaughan[77] in the Uvalde Folio

[76]Jones, R. A., "The Relation of the Reynosa Escarpment to the Oil and Gas Fields of Webb and Zapata Counties, Texas," Bull. Am. Assoc. Petro. Geol., Vol. 7, No. 5, pp. 544–545, 1923.

[77]Vaughan, T. W., "The Uvalde Folio," U. S. Geol. Sur. Folio No. 64, pp. 1–7, 1900.

and the petrography of their rocks has been described by Whitman Cross in the same folio. The Uvalde County necks consist of nepheline basalt grading into limburgite, nepheline-melilite basalt, olivine basalt, and phonolite. All these rocks contain either nepheline or olivine. The nepheline basalts generally carry little or no feldspar. The feldspar is labradorite in the olivine basalts and alkali feldspar, generally sanidine, in the phonolites.

This assemblage of rocks is utterly different in mineralogical composition from the Gueydan tuffs or lava pebbles and boulders. In fact not a single crystal of either nepheline or olivine has been found in any of the Gueydan rocks. Vaughan maps a few necks of augite-andesite in Uvalde County but Cross does not describe or mention any andesites in his petrographic descriptions of the igneous rocks of the Uvalde folio. The entire dissimilarity in composition of the Uvalde and Gueydan rocks is a strong objection to the assumption that the Uvalde volcanoes were the source of the Gueydan. Hinds[78] and others have called attention to the fact that eruptions of nepheline- and melilite-basalts and even trachytes may come from the same volcanoes which normally erupt basaltic and andesitic lava. However, the Gueydan has been produced by a large number of successive eruptions and at least a few crystals of nepheline or altered nepheline in the tuff or a few pebbles of nepheline-bearing rocks in the volcanic conglomerates would be expected if the Uvalde County necks were the source of the Gueydan. Another objection to these necks as the source of the Gueydan is their distance from the tuffs. The basis of this objection will be discussed later.

The same objections hold for the Travis County and Kinney County necks. These necks, so far as known, also consist of basalts and limburgites. The largest of the Travis County necks has been described by Hill[79] who believes that

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[78]Hinds, N. E. A., "Melilite and Nephelite Basalt in Hawaii," Jour. Geol., Vol. 33, No. 5, pp. 537–538, 1925.

[79]Hill, R. T., "Pilot Knob, a Marine Cretaceous Volcano," Am. Geol., Vol, 6, pp. 286–292, 1890.

its eruptions occurred during Cretaceous time as indicated by the title of his paper. The writer has also examined Pilot Knob and has noted the basaltic tuffs (of an entirely different character from the Gueydan) which surround Pilot Knob. These tuffs are intercalated with abundantly fossiliferous, Upper Cretaceous marls; this proves that at least part of the eruptions of this volcano occurred in Cretaceous time. If the Pilot Knob tuffs are representative of the type of pyroclastics produced by the basaltic necks found in the neighborhood of the Balcones fault in Uvalde, Travis, and Kinney counties, the Gueydan tuffs were evidently not erupted by these volcanoes. Although it cannot be absolutely proven that these old volcanoes are not the source of the Gueydan tuff the weight of evidence is directly opposed to such a conclusion.

Evidence for a proximate source.—The following data are strongly suggestive, if not indicative, of a proximate source for the Gueydan volcanic materials:

(1) Many beds of tuff of evident mud-flow origin are present, especially in the Fant member. The data in support of this conclusion are the presence of beds showing a ropy surface and definite flow structure (see Plate VI, Figure 2), the prevalence of well developed sun-cracks in many of the Fant tuff beds, the wavy bedding planes and the strong resemblance of these rocks to rocks of certain mud-flow origin. Mud flows, like lava flows, do not move a great distance from their parent volcanoes unless the land surfaces on which they are deposited have a high gradient. The unconformity at the base of the Gueydan, if a true unconformity exists, is a minor one, because there is no definite difference in the dip and strike of the Gueydan from the dip and strike of the underlying Frio. The Frio rests conformably on the marine Fayette and the latter shows ripple-marks, current bedding, lignite beds and other evidence of a shoal water and littoral origin. The Fayette and Frio were therefore not deposited on steeply inclined surfaces. The Gueydan was apparently deposited on the same kind of gently sloping

surface, probably on a recently upraised and slightly dissected coastal plain.

(2) The presence of the high temperature mineral, tridymite, in the Gueydan tuff in at least five localities, the most distant of which are 135 miles apart, strongly favors the idea of vulcanicity in the immediate neighborhood of the tuff containing the tridymite. It is probable that the tridymite was not formed at excessively high temperatures but may have been formed around hot springs, comparable to the Spring of Plombiéres, the temperature of which is 73° C., or around solfataras. The presence of a number of hot springs at that time is itself suggestive of proximate contemporaneous vulcanicity or vulcanicity only a short time prior to the tridymite formation. On the other hand, the tridymite-bearing tuffs may have been deposited at high temperatures from fiery clouds. The occurrence of this tridymite at such widely separated localities favors the idea that the Gueydan came from two or more volcanoes of the same general type.

(3) Fifty or more acid andesite boulders, between one and two feet in diameter, and a great number of smaller boulders are found within the confines of a few acres, two miles north of Loma Alto Mesa in McMullen County. These boulders occur near the middle of the Gueydan outcrop in a flat area covered by brush. The boulders show a tendency to be arranged in a line parallel to the strike of the Gueydan. Pinkish Chusa tuffaceous clay outcrops at several points within a radius of half a mile from the boulder locality and the boulders have apparently weathered out of this tuffaceous clay. A number of these boulders are subangular and resemble in form the volcanic blocks which are commonly found on cinder cones. On account of their great size and weight and their subangular form it is difficult to imagine how they could have been transported in such numbers by rivers from a volcano situated over a hundred miles away. The boulders may have been concentrated by river action but were in all probability carried only a few miles. They may also be residual boulders from a large mass of tuff. Rounded boulders from an inch or less to a foot in diameter

are frequently found on Gueydan tuff exposures at several other localities in Live Oak, McMullen, and Duval counties.

(4) The extraordinary rarity of pebbles and boulders, other than lava, in the Soledad conglomerate at Soledad Hills in Duval County is difficult to explain unless the parent volcanic blocks were close by at the time the conglomerate was formed, thus allowing only a slight adulteration of the lava pebbles with the chert pebbles which are generally predominant in other conglomerates of the Texas coastal plain. In fact the Gueydan conglomerate itself, except in western Duval County, contains more chert and quartz pebbles than lava pebbles. This latter fact proves that abundant chert and quartz pebbles were available to the streams of that time and furnishes excellent evidence that a volcanic cone existed in the immediate neighborhood of the present Soledad Hills during middle Gueydan time. These blocks could not have been thrown more than a few miles from a volcano even if swift-moving "fiery clouds" assisted in their transportation. Therefore it is reasonable to suppose that at least one of the Gueydan volcanoes was situated in proximity to the Soledad Hills.

(5) The presence of twenty feet of apparently intrusive serpentine in the Hawley well in Live Oak County, only 230 feet below the surface, is another indication that an ancient volcano once existed in the vicinity of the Gueydan outcrop. If this serpentine dike or sill was connected with the magma which rose to the surface to produce the Gueydan pyroclastics, the serpentine must be an ultrabasic differentiate from this magma, because it is entirely unlike the Gueydan tuffs or lava pebbles in composition.

Only a quarter of a mile north of the Hawley well in a cliff of upper Gueydan pulverulent, pink, tuffaceous clay are found two vertical dike-like bodies. These bodies consist of brick-red, somewhat indurated, tuffaceous clay and are cut along their center planes by thin vertical streaks of light greenish, extremely vesicular, slag-like material. The surface of the slaggy streaks is very smooth and has a luster like that on highly glazed pottery. A similar glaze is present on the inside surfaces of the vesicles. This glazed slaggy material passes gradually into the brick-red, partly fused, tuffaceous clay mentioned above and the later grades into normal tuffacous clay. Such a fusion of the tuffaceous clay may have been produced by hot ascending vapors of volcanic origin. On the other hand, the phenomenon may be readily explained by the burning of escaping natural gas which is known to be present only a few miles west of this locality at depths of 500 or 600 feet. It is impossible to determine which is the correct explanation, at present, but this phenomenon, probably unique in the Texas coastal plain, is worthy of record.

Evidence for several volcanoes.—Were all the Gueydan pyroclastics ejected from one volcanic vent or from two or more vents? The widely separated occurrences of tridymite have already been mentioned as evidence for more than one volcano. If a single volcano be assumed to have been situated near the center of the space between the most distant tridymite localities these localities would yet be sixty-seven miles from the volcano. This seems to be an excessive distance and favors the hypothesis that two or more volcanoes, arranged in a line roughly parallel to the Gueydan belt as now exposed, existed.

The widespread distribution of fairly large lava boulders along the strike of the formation lends strength to the supposition that there was more than one volcano.

That the assumption of several volcanoes in a northeast-southwest belt is not merely a product of the imagination is strengthened by the known occurrence of such a row of volcanic necks in a northeast-southwest belt in Uvalde, Travis, and Kinney counties. These necks are all situated in the vicinity of the Balcones fault zone, which line of weakness is evidently responsible for their arrangement. Field study proves the existence of a parallel zone of faulting (see geologic map) in the proximity of the Gueydan outcrop.

Conclusions as to location of volcanoes.—After taking into account the data discussed above, what conclusions can be formed as to the most plausible location for the Gueydan volcano or volcanoes? One center of volcanic activity was probably located in southwestern McMullen or western Duval County for the following reasons:

(1) The largest (two foot) volcanic boulders in the Gueydan are found in southwestern McMullen County.

(2) The Gueydan formation is thickest in McMullen and Duval counties.

(3) The Soledad volcanic conglomerate is thickest and contains fewest non-volcanic pebbles and boulders in western Duval County.

Of the three possible hypotheses outlined on page 157, the hypothesis that the old volcano or volcanoes were located near the Gueydan belt but are now covered by post-Gueydan sediments, possibly accords best with the facts. In other words the ancient volcanic stumps or necks are hidden by Oakville, Reynosa, or terrace deposits, or even by the upper Gueydan tuffaceous clays. Future borings for oil or water may discover these ancient volcanoes, and wells which are drilled in the vicinity of the Gueydan outcrop should be diligently watched for the occurrence of volcanic rocks. The writer's conclusions as to the source of the Gueydan are, therefore, provisional, and convincing evidence in favor of another source for the Gueydan will be readily accepted.

STRUCTURAL GEOLOGY

A glance at the geologic map shows that the major structure of the southwestern Texas coastal plain is that of a very gently gulfward-dipping homocline. The regional dip is southeast, north of Webb County, and east, south of that county. The change from southeast to east is gradual as can be seen from the swing in the strikes of the formations in Webb County. The angle of regional dip ranges from about 100 feet to the mile in the Fayette formation to about 20 feet in the Reynosa.

This large homocline, concave toward the Gulf, is cut by a number of strike, dip, and oblique faults with displacements which range from a few feet to 300 feet or more. Several flat anticlines, faulted anticlines or anticlinal noses, and synclines relieve the monotony of the general homoclinal structure. The folding in this regicn involves such slight upwarping and downwarping that the anticlines may be detected only by slight to fairly pronounced gulfward bulges in the formational contacts and the synclines by similar landward bulges. The dips on the flanks of the folds are rarely in excess of two or three degrees and satisfactory outcrops are so scarce that is is rarely possible to follow a given bed for a distance of a mile. Also, the rarity or absence of continuous, easily distinguished marker beds renders the interpretation of structural details a very difficult problem. The detailed structure cannot be worked out without a very painstaking study of the petrology of the clastic rocks. An exceedingly small number of folds or faults have been described in any of the publications on the region. Neither Deussen[80] nor Trowbridge[81] indicates a single fault within the area with which this paper deals, nor is any mention made of faults in this area. Deussen has ably described the broad Torrecillas uplift which crosses the southern portion of the region. This is a recent arch and was discovered by the use of physiographic data. It has been previously discussed on page 20 of the present paper. Deussen also described Los Picachos Hills, noting the abnormal dip in the rocks east of the veins there, but he made no reference to a fault. Jones[82] has cited the presence of siliceous knobs, and veins in Webb, Zapata, and Duval counties as evidence of faulting and has mentioned subsurface evidence of faulting in the Webb-Zapata county oil fields. Several other writers have discussed the probability of faulting as the *raison d'être* of the Webb-Zapata oil fields but no geologic maps showing the traces of any faults in detail have been published so far as known to the writer, although some outline maps indicating hypothetical faults have appeared.

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[80]Deussen, Alex., U. S., Geol. Surv. Prof. Paper, 126, Plate VIII, 1924.

[81]Trowbridge, A. C., U. S. Geol. Surv. Prof. Paper 131D, Plate XXVIII, 1923.

[82]Jones, R. A., Bull. Am. Assoc. Petr. Geol., Vol. 7, No. 5, pp. 532–545, 1923.

FAULTS

The main purpose of this paper is not to work out in detail the structure of the region of the Gueydan outcrop, because the area covered is too large to be dealt with satisfactorily within the few months available for field work. Nevertheless, while the Gueydan formation was being traced the writer detected a number of important faults which have never been mapped or described before. Some of these faults were actually seen but the existence of others was inferred from geologic mapping. Several of the faults found exposed were first approximately located from mapping evidence; a later search along the banks of streams near the points where they should cut the suspected faults disclosed the outcrops of the fault planes and their gouge zones. Certain faults were located only approximately and more detailed work will doubtless necessitate a number of changes in the geologic map. It is also quite probable that additonal faults will be discovered.

The accessory geological features which are found to be more or less indicative of faulting in this region are as follows:

(1) Abnormally steep dips (15° or more) which have evidently not been produced by landsliding are found. Such abnormal dips, which may become practically vertical next to the trace of the fault plane, are due to drag; such drag zones may attain a width of several hundred feet in the slightly consolidated rocks of this territory. A prominent drag zone is exposed in a bluff near the Nueces River, two miles west of Oakville.

(2) Veins of fibrous calcite or aragonite are commonly found either along the fault plane itself or in the fractured rocks adjacent to the fault plane. Some of these calcite and aragonite veins are two or three feet wide. The best examples of these are exposed in the bed of the Nueces River, two miles west of Oakville, and at Los Picachos Hills.

(3) Veins of opal and chalcedony are also commonly associated with faults. The opal which occurs along fault zones frequently shows brilliant yellow, green, orange, and

red colors and is sheared in many places, the shear planes paralleling the fault plane. The best example of siliceous veins was seen at Los Picachos Hills. Another good example of a green and yellow opal vein is exposed in a small outcrop on the west side of Tornillo Hill on the Karnes-Atascosa line. However, many of the largest faults in the region are not accompanied by veins of any kind and veins are occasionally found along fractures where no appreciable displacement has occurred.

(4) Salt springs or creeks containing salt water are associated with some of the largest faults in eastern Live Oak County. The long fault which is clearly exposed in the cut made by a small salty tributary of Sulphur Creek, eight miles southeast of Fant City, is an example of this association. Sulphur springs occur in the vicinity of some faults and Sulphur Creek derives its name from the presence of such springs.

(5) Although no suggestions of fault scarps were seen in this region, the presence of faults which are located at the contact between an overlying resistant and an underlying non-resistant formation can sometimes be detected from a different type of topographic evidence. This can be presented best by a comparison of the topography along the Oakville-Gueydan contact in McMullen County with that along the same contact in central Live Oak County. In McMullen County there is no fault at the contact and the resistant Oakville sandstone rests almost horizontally on top of the friable upper Gueydan clays. As a result of this relation erosion has produced a number of long, topographically prominent salients and steep-sided mesas. In central Live Oak County along this same contact the topography is quite different. Here the Gueydan is in contact with the Oakville along a vertical fault and no salients or mesas are found. The resistant Oakville is on the downthrown side of this fault and enough erosion has taken place since the faulting to obliterate completely the former fault scarp and, in addition, to remove so much of the soft upper Gueydan material from the upthrow side that the more protected Oakville-covered downthrow side is now topographically

higher. This is a reversal of the topographic relations which evidently existed shortly after the faulting occurred. The Oakville here forms a nearly straight line of rather gently sloping, asymmetrical hills instead of the numerous steep-sided, flat-topped salients and mesas of McMullen County.

Character of displacements.—The downthrown sides of the great majority of the strike faults are on the southeast or east; those of the dip faults and oblique faults (cross faults) are usually on the south or southwest. Normal faults are more common than reverse faults and a few of the faults exposed are vertical. Successive fault blocks are generally displaced in the same direction but a few horsts and grabens are found. Cross-faulting plays a prominent rôle in Karnes and southern Gonzales counties but is apparently of minor importance southwest of Karnes County. It is evident, from the foregoing discussion, that the structure of the Gulf Coastal Plain of Texas is not so simple as it is generally believed to be.

DESCRIPTION OF PRINCIPAL FAULTS

Gonzales County.—Nopal Fault—Three miles northwest of Nopal, in a small road-cut about one-half mile east of Rocky Creek School, a fault contact between the sandstone of the Oakville and crumbly, light green, porous, sandy tuffaceous clay of the Gueydan is exposed. As measured at the outcrop the fault plane strikes N. 20° W. and dips 55° S.W. At this locality it is a normal fault—the plane of the fault dips southwest and the southwest side is downthrown. No measurement of the displacement could be made but judging from the small amount of offset produced in the Gueydan-Oakville contact it is probably not more than fifty feet. Since the Gueydan-Fayette contact is apparently offset in the opposite direction from the Gueydan-Oakville contact this fault must be a rotational fault with the southwest side upthrown at the northwest end of the fault and downthrown at the southeast end.

It is probable that a strike fault forms the contact between the Fayette and Gueydan between the northwest end of the Nopal fault and the Karnes County line. Another cross-fault offsets the Gueydan toward the southeast in northern Karnes. As a result, there is a triangular block in extreme southern Gonzales County which is surrounded by faults and has apparently undergone rotational tilting. More detailed field work must be done here before the character of the faulting movements can be accurately determined and a revision in the geologic mapping may be necessary.

Karnes County.—Faulting appears to play a more important part in Karnes County than any other portion of the area. With the exception of the small fault at Tornillo Hill on the Karnes-Atascosa line the Karnes County faults were located by mapping evidence or by tracing them from Live Oak County where they were found exposed. The strike faults in Karnes County are approximately parallel and extend N. 25–35° E. One of these faults is perhaps responsible for the falls in the San Antonio River below Falls City. With the exception of the Tornillo Hill fault the downthrow side is to the southeast. The Tornillo Hill fault is exposed in a small, nearly horizontal outcrop on the northwest side of Tornillo Hill. Along the fault is a vertical vein of yellow, green, and gray opal about eight inches wide. East of the fault, silicified Fayette sandstone outcrops. This sandstone has produced Tornillo Hill owing to its resistance to erosion. West of the fault a white or light tan, tuffaceous shale, which generally occurs at the top of the Fayette in this region, is exposed. Since the siliceous sandstone is probably older than the white shale the northwest (or white-shale) side of the fault is probably downthrown. It is impossible to be sure of the relative displacement from the outcrop of the fault.

Three cross-faults offset contacts in Karnes and extreme southeastern Atascosa counties. The cross-fault in northern Karnes County has apparently offset the Gueydan-Oakville contact about five miles. Taking the average dip of the

Oakville at sixty feet per mile, the displacement along this fault is about 300 feet.

Live Oak County.—The faulting in central and northern Live Oak County has been more carefully worked out than elsewhere because a greater amount of detailed field work was done in this county. The fault at the contact of the Gueydan and the Oakville in Live Oak, northeastern Bee, and southern Karnes counties continues for a distance of thirty-five miles.

Sulphur Creek Faults—At least three and possibly more faults cross Sulphur Creek between Fant City and Oakville. These faults are not far apart and are grouped under the term "Sulphur Creek Faults." The most westerly of these faults is more easily traceable because along this fault the Oakville sandstone is in vertical contact with the upper Gueydan tuffaceous clay. This contact appears to be a fault contact from Kittie Station in central Live Oak County almost to Karnes City in Karnes County, a distance of approximately thirty-five miles. The fault is clearly exposed in the east bank of a salty tributary of Sulphur Creek, one and one-half miles west of Sulphur Creek, and one mile southeast of the Live Oak County Demonstration Farm. The vertical fault plane strikes N. 35° E. and about eight feet of it are exposed. Slickensides are well developed and a three-foot gouge and breccia zone, composed of a mixture of angular fragments of Oakville sandstone and plastic green tuffaceous clay of the upper Gueydan, is present. Drag is not prominent at this exposure, although the beds are bent down toward the southeast enough to disclose plainly the direction of movement without the aid of stratigraphic evidence. The Live Oak Basin Oil Association's 32,000,000 cubic feet gas wells three miles east of Three Rivers evidently obtain their gas from the breccia zone along this same fault because the producing wells are located in a line striking N. 35° E. and are situated along the faulted Oakville-Gueydan contact.

The other two faults occur within the Oakville belt of outcrop and appear to unite near the Nueces River, two miles west of Oakville. The easterly fault of this pair is exposed in the bed and north bank of the Nueces River. Here the sandstone and conglomerate beds are almost on end or dip southeast at high angles and are cut by a fibrous calcite vein six inches thick and a number of smaller veins. This fault strikes N. 43° E. Along the east bluff of a small tributary of the Nueces River just below the outcrop of the eastern fault is exposed the western fault of the pair. The latter strikes N. 35° E., parallel to the main Sulphur Creek fault. The beds of Oakville sandstone have been steeply tilted by the drag along this fault for a distance of 300 feet or more.

Fant City Faults—In a railroad cut one mile northwest of Fant City the lower Gueydan tuff and the underlying Frio clay dip northwest at angles of 10 to 15 degrees. This abnormal dip is probably caused by a strike fault with the downthrow on the northwest side. The displacement on this fault is probably not over fifty feet because the basal Gueydan is repeated for only a quarter of a mile or less northwest of the fault.

On the west side of the Atascosa River four to four and one-half miles south of Fant City the beds of lower Gueydan white, pumice-pebble conglomerate in several exposures show northwest dips of 10 to 40 degrees. A few exposures of green gypsiferous clay resembling Frio are also found in this locality, although the main Frio-Gueydan contact is situated a mile west of here. The fault is poorly exposed four and one-half miles south of Fant City in the bluff of a small gully. From the drag and apparent duplication of some of the lower Gueydan beds the downthrow side must be to the northwest. The amount of throw is estimated to be 100 feet. The straight course of a portion of Weedy Creek is possibly a result of this fault but no outcrop of it was found on Weedy Creek.

Since the Fant City faults are downthrown on the northwest and the Sulphur Creek faults on the southeast the block lying between them is a horst. This is designated as the Three Rivers Horst because the town is situated thereon. The presence of a number of shallow gas wells and a few small oil wells in the vicinity of Three Rivers constitutes additional evidence that an uplift exists in this district. A certain amount of doming in addition to the opposing drag dips on the two sides may also have occurred in this upthrown block, but such a horst without the doming might serve to trap and imperfectly concentrate petroleum and natural gas.

McMullen County.—San Caja Fault—On account of the steep dips in the Gueydan strata north of San Caja Mesa and the decided tilt to the Oakville cap of the mesa itself, a fault, probably of small displacement is believed to pass a short distance north of San Caja Mesa. If the fault is assumed to have a strike approximately parallel to that of the dragged beds, the strike of the San Caja fault is N. 80° W. That the downthrow side is on the south is indicated by the fact that the strata on San Caja are tilted in that direction.

Duval County.—Los Picachos Fault Zone—Los Picachos Hills with their massive siliceous and fibrous calcite (recrystallized aragonite) veins have been described under "Mineral Veins." These veins, the steep southeast dips of the Gueydan strata outcropping southeast of the veins, and the gouge zone along the calcite vein together furnish proof that a fault passes through these hills. Since the veins in successive hills are arranged *en échelon* it is probable that this is a fault zone instead of a single fault. The fault exposed in the largest and most southerly hill strikes N. 42° E. and dips 72° N.W. Since the fault plane and its attendant veins appear to dip northwest and since the drag produced by the fault is toward the southeast, this must be a reversed or compressional fault. This type of fault is uncommon in the Texas coastal plain. It indicates that the territory adjacent to Los Picachos has been subjected to compressional forces or possibly to the upward thrust of unexposed magma from below. It is impossible from surface exposures to ascertain the amount of displacement produced by this fault because Gueydan rocks of similar character outcrop on both sides of the fault and exposures are scarce in this vicinity. From the width of the drag zone it is probable that this is an important fault. The strata on the northwest side of the fault are too poorly exposed for the direction of dip to be determined and it is, therefore, impossible to ascertain without excavations or borings whether this is a faulted anticline or a fault unaccompanied by folding.

Webb County.—A two-foot vein of green and red-brown, banded opal and opal-impregnated clay is poorly exposed in a gravel pit one-half mile N. 15° E. of Mirando City along the front of the Reynosa escarpment. The middle Gueydan conglomerates which are exposed for a few feet along this vein appear to be standing nearly vertically, but the dip is uncertain on account of the poor stratification of the material. This vein may be located along a fault plane but the same kind of conglomerate is found on both sides of the vein so that the displacement is small if there is a fault here.

There may be one or more important faults in the vicinity of the Reynosa escarpment in Webb and Zapata counties but the writer saw little definite evidence of important faults in either Webb or Zapata counties. On account of the extreme paucity of exposures, faults and other structural features can only with great difficulty be delineated.

Starr County.—A fault is clearly exposed in the bank of Los Olmos Creek, six miles north of Rio Grande City. The fault plane strikes N. 10° W. and dips west approximately 80 degrees. The throw, which is approximately the total displacement, can be determined by the relative position of a heavy bed of Oakville sandstone on the two sides of the fault plane. This throw is about thirty-five feet. The west side is downthrown and the Oakville beds are vertical next to the fault.

Another fault with the downthrown side to the south (indicated by steep south dips) apparently cuts the north-south fault only a few hundred feet north of the point where the first fault is exposed. The dragged strata along the second fault strike N. 70° E. and dip south about 30 degrees, and it is probable that the strike of the fault is the same as the strike of the strata. The displacement along this fault could not be determined.

FOLDS

Torrecillas Arch.—The broad and gentle Torrecillas arch, centered near Mirando City in southeastern Webb County, is so recent that it is reflected in the present topography. This uplift hat been fully discussed by Deussen.[83]

Anticlines of Webb, Zapata, and Jim Hogg counties.—A row of small, gentle and ill-defined, anticlinal folds or crumples in the large Torrecillas arch extends from east-central Webb County southward along the front of the Reynosa escarpment into northeastern Zapata and northwestern Jim Hogg counties. At least six small petroleum and natural gas fields have already been discovered in this territory. Some of the fields are situated at the foot of the escarpment and others are on top of the escarpment. On account of poor exposures and the covering of Reynosa which lies unconformably on the folded beds these folds are difficult to detect and only in two cases were westerly dips observed by the writer.

One and a half miles southwest of Mirando City or one-half mile west of the Mirando City-Ojuelos oil field, a wall-like bed of silicified sandstone, probably Oakville, strikes N. 38–75° E. and dips 10–60° N.W. The steep dips may have been produced by drag along a fault having the west side downthrown. A similar bed of Oakville sandstone dipping eastward at a low angle outcrops on the east side of the Ojuelos field beneath the Reynosa capping. The Gueydan conglomerates and tuffs appear to have low-angled opposed dips on the two sides of the Ojuelos oil field but these dips are uncertain on account of poor exposures and indistinct bedding planes. In the vicinity of this oil field

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[83]Deussen, Alex., U. S. Geol. Surv. Prof. Paper 126, pp. 124–126, 1924.

a group of rolling hills projects westward for a mile or more beyond the Reynosa escarpment. Such rounded hills (not mesas) are also present west of the Schott-Aviators field, four miles south of Mirando City, but are rarely present at other points along the Reynosa scarp. The topography and the scanty geologic evidence obtainable from exposures thus suggest small anticlines with north-south axes at the Ojuelos and Schott-Aviators fields in southeastern Webb County.

Gentle opposing tilts of the siliceous sandstone cappings of the mesas which partially surround the Mirando Valley oil field in northeastern Zapata County indicate the presence there of a small dome or nearly equidimensional anticline.

The large reëntrant in the Reynosa scarp near Randado, in northwestern Jim Hogg County, with an extensive eastward projection of older rocks into the reëntrant, suggests the presence of an anticline in this region. An oil field has been discovered in northwestern Jim Hogg County since the writers last visit, which furnishes confirmatory evidence of such a structure.

Faulting may have played a minor rôle in the causation of petroleum and natural gas accumulation in the Webb-Zapata and Jim Hogg county fields but the surface evidence points to small anticlines or, as Sellards[84] suggests, anticlinal noses as the important agencies in the accumulation of petroleum and natural gas.

The widening of the Gueydan outcrop and the broad reëntrant of Gueydan in the vicinity of Moglia, in east-central Webb County, suggests the existence of a north-south structural terrace or of gentle anticlinal and synclinal folding in this region. Important additional evidence of folding here is afforded by the predominance of north dips of 1–5° at the northern margin of this reëntrant of Gueydan. The Carolina-Texas gas wells west of Moglia may owe their existence to one of these inferred structural features. Some doubt is cast on the validity of folding in this region by the

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[84]Sellards, E. H., "Notes on the Oil and Gas Fields of Webb and Zapata Counties," Univ. Texas Bull. No. 2230, pp. 5–29, 1922.

uncertainty of the correlation of the white tuff beds, which outcrop fourteen miles west of Moglia, with the Gueydan and the possibility that the white tuffs may belong to the older Fayette formation.

Duval County Folds.—Government Wells Anticline(?)—The following facts suggest the existence of an anticline or anticlinal nose with a northeast-southwest or north-south axis located about two miles north-northwest of Government Wells settlement in northwestern Duval County:

(1) Persistent southwest or west dips can be observed in the vicinity of the Cotulla road, about three miles north-northwest of Government Wells. It is possible that these dips may have been produced by cross-bedding but they appear to be too regular and persistent for that.

(2) The Soledad green volcanic sandstone, although its thickness was nowhere observed to exceed thirty feet, outcrops prominently in the northwestern part of Government Wells; one-half to one mile northwest of Government Wells; and at localities three miles north-northwest of that settlement.

This green sandstone horizon locally interstratified with brown sandstones and conglomerates can be traced for over fifty miles in Duval, McMullen, and Live Oak counties and in no locality has more than one horizon of the unusual sandstone been identified. If the disconnected outcrops near Government Wells all represent approximately the same stratigraphic horizon there must be a repetition of certain beds, thus indicating folding, or faulting with the downthrown block on the west side.

McMullen County Folds.—Calliham Faulted Anticline—The small oil field located just west of the town of Calliham in eastern McMullen County apparently owes its existence to the presence of a faulted anticline. The axis of this anticline, as revealed by the alignment of producing wells, trends practically east-west and a fault having the north side downthrown apparently parallels the axis of folding. The existence of a fault is indicated by the straight and sharp northern limit of productive wells. The broad salient of the Fayette formation along the Frio River east of Calliham, also suggests the presence of an anticline.

Wentz Anticline and Syncline.—The two pronounced bowings of the formational contacts in the vicinity of Wentz are strongly suggestive of anticlinal and synclinal folding. This folding may possibly be associated with faulting. The friable, greenish-gray to buff sandstone which outcrops a mile or two south of Wentz is lithologically very similar to the upper Fayette sandstone exposed on the banks of the Frio River, four miles east of Calliham. *Ostrea georgiana,* a common Fayette fossil, is also reported by residents to be found a mile southwest of Wentz. It is on the basis of this evidence and the peculiar bends in the outcrops of the basal Gueydan silicified white tuff that an anticline is believed to exist here. Outcrops are disconnected so that there is chance for error in the mapping. If the geologic mapping in this vicinity is essentially correct, an anticline, with an east-west alignment, having an approximate length of two miles and a width of one mile, is situated south of Wentz. The salient of younger Gueydan into the outcrops of the older Frio and Fayette formations a fraction of a mile east of Wentz indicates the presence of an adjacent syncline. This fold has about the same dimensions as the anticline and its axis also extends east-west. The axis of this syncline is situated about two miles north of the axis of the Wentz anticline.

Live Oak County Folds.—The mapping of the Gueydan-Frio contact west of Simmons suggests the occurrence of a gentle anticline and syncline or anticlinal and synclinal noses. These parallel, and are similar to, the Wentz folds, except that they do not appear to be quite as pronounced. The presence of south dips (as high as 5°) in the vicinity of Lang Creek, two and one-half miles northwest of Simmons furnishes additional evidence of folding in this vicinity. The axis of the anticline probably crosses the Nueces about one mile south of Simmons. The syncline lies between this anticline and the Calliham anticline.

No evidence of folding was noted northeast of Live Oak County but a more intensive field study may demonstrate the existence of folding in Karnes and Gonzales counties, in addition to the faulting.

SUMMARY AND CONCLUSIONS

The name "Gueydan formation" is assigned to a group of strata exposed in the southwestern Texas coastal plain, which are composed of volcanic tuffs interbedded with fluviatile deposits which have been derived mainly from these tuffs. The Gueydan formation occupies a stratigraphic position between the Frio clay (redefined by the writer) of uppermost Eocene age and the Oakville sandstone of Upper Miocene age. It is correlated with the Catahoula formation (Oligocene) of eastern Texas. The tuff and bentonite beds in the Catahoula evidently represent the more distant deposits of the same great explosive eruptions which formed the much thicker Gueydan pyroclastics. On account of the marked difference in facies between the Gueydan and Catahoula the former merits a separate formational name.

The Gueydan formation is separable into three members: (1) Fant member, (2) Soledad member, and (3) Chusa member. The Fant member is composed essentially of a number of beds of indurated, creamy-white, mud-flow tuff, which commonly shows sun-cracks, interstratified with friable, grayish-white, air-deposited tuffs, and greenish-gray or purplish-pink, fluviatile clays and sandy clays. Petrologically, the Fant tuffs apparently range from trachytes to acid andesites; trachyandesite is probably the principal petrologic type. Among the unaltered constituents of these tuffs volcanic glass fragments and small pumice lapilli comprise over 65 per cent; feldspar (mainly albite-oligoclase) comprises most of the remainder; augite and biotite are the ferromagnesian minerals noted. The secondary bentonitic minerals and opal generally comprise as much as half of most tuff samples. In several localities vesicles in the mud-flow Fant tuffs are lined with tiny plates of tridymite or with tridymite and botryoidal opal.

The Soledad member consists of interbedded friable, grayish-pink, trachyandesite or acid andesite tuffs, pumice-pebble conglomerates or lapilli beds, coarse to fine volcanic conglomerates and volcanic sandstones and tuffaceous sandstones. The opal-cemented volcanic conglomerates and sandstones which locally consist almost entirely of water-worn boulders, pebbles and sand grains of grayish-brown trachyandesite and other lavas are the most noteworthy rocks in this member. In southern McMullen County fifty or more subangular boulders of acid andesite up to two feet in diameter are exposed over a small area. These boulders are too large and do not show enough evidence of wear to have been transported for a great distance.

The Chusa member consists primarily of friable tuffaceous clays and impure bentonites which have evidently been formed by the action of streams on the Soledad and Fant tuffs and other rocks.

From the evidence discussed previously, the following conclusions are made: (1) The Gueydan tuffs were deposited by a succession of explosive volcanic eruptions. (2) Two or more volcanoes arranged in a northeast-southwest line contributed to the formation of these pyroclastic strata. (3) These volcanoes were located within a few miles of the present outcrop of the Gueydan but have not been discovered because the remains of their cones have been covered by the Chusa tuffaceous clays or younger sediments.

Taking into consideration the length of the present outcrop, the average thickness and the probable area formerly covered, a minimum estimate of the volume of material ejected by the Gueydan volcanoes is 150 cubic miles.

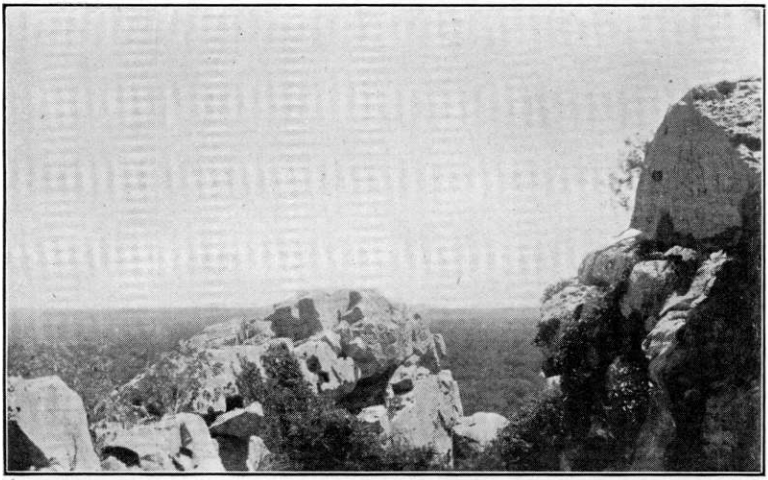

Figure 1. Fissure in Oakville quartzitic sandstone on east side of San Caja Mesa showing cut in Rosalier Hills in alignment with it.

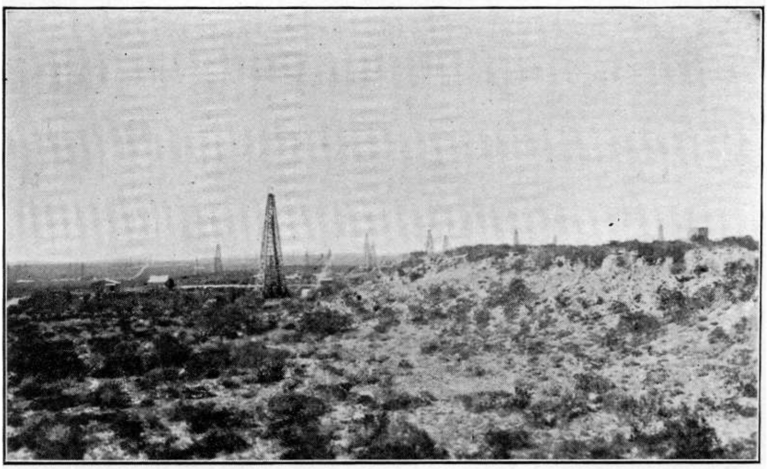

Figure 2. Reynosa Escarpment at Mirando City Oil Field, Webb County, Texas, 40 miles east of Laredo.

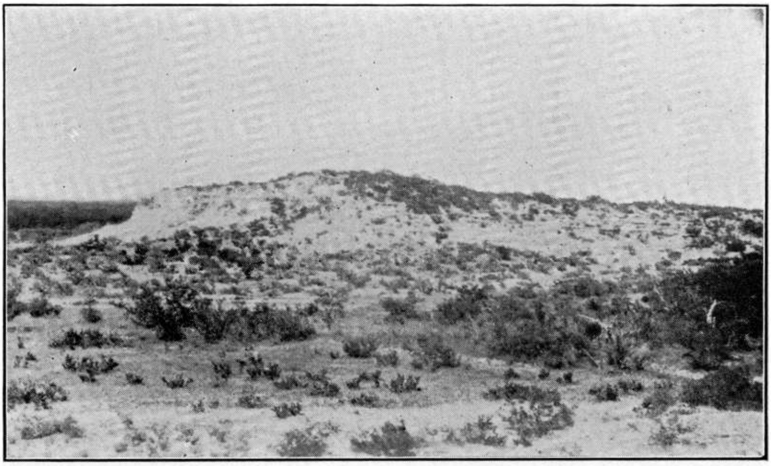

Figure 1. A Gueydan tuff cuesta scarp, looking northeast along strike. "Chalk Bluffs" on Ray Ranch in McMullen County, Texas. Note automobile at base of scarp.

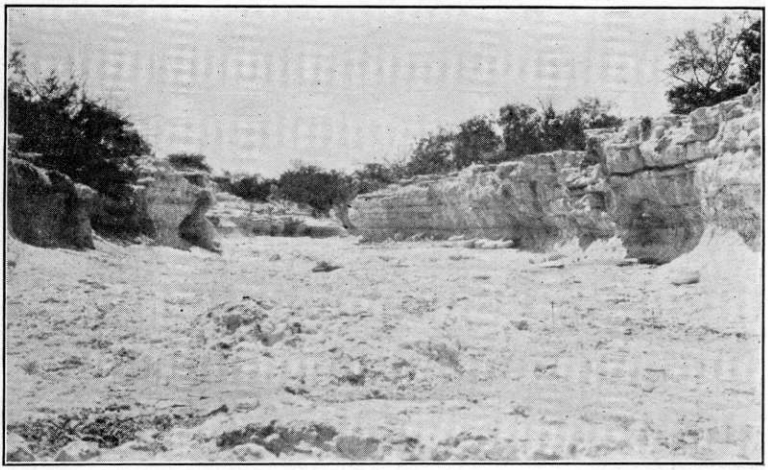

Figure 2. Exposure of Fant trachyandesite tuff in bed of creek, and massive-bedded, greenish-white, sand-tuff in banks of Lang Creek, 2½ miles west of Simmons, Live Oak County.

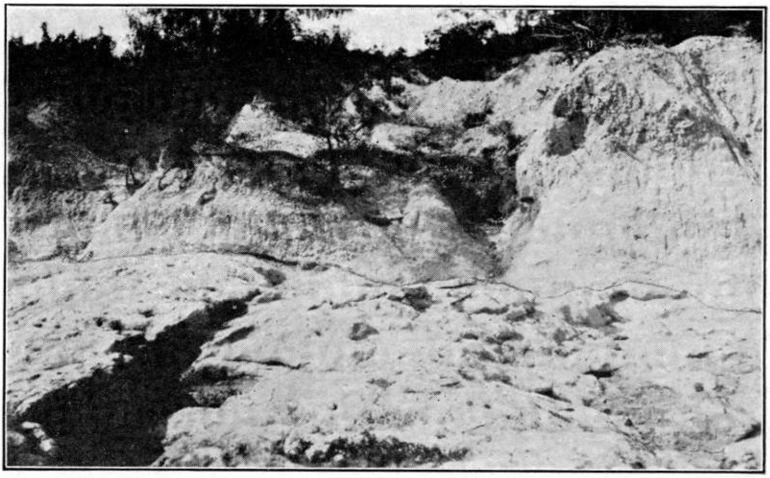

Figure 1. Unconformity in Gueydan near road bridge, 1½ miles west of Simmons. Reworked, light green, sandy, tuffaceous clay above and even-bedded sand-tuff below unconformity.

Figure 2. Sun-cracks in Gueydan tuff, near north bank of Nueces River, 4½ miles southwest of Simmons, McMullen County.

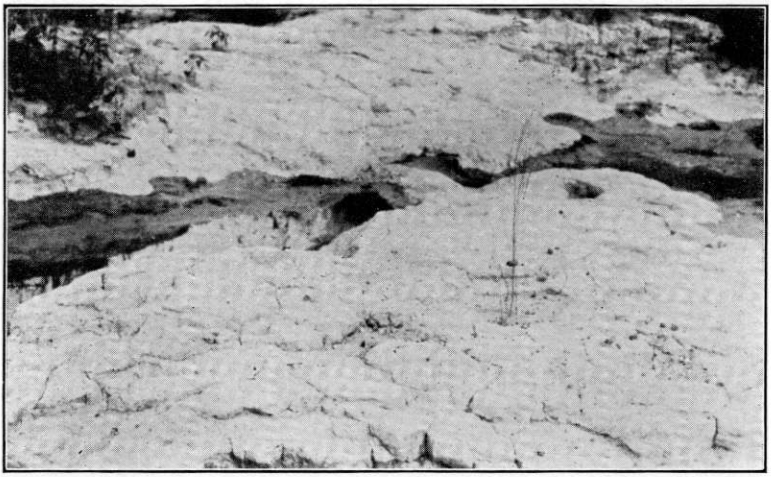

Figure 1. Sun-cracks in trachyte tuff in bed of Charlie York Creek, 4 miles west of Three Rivers.

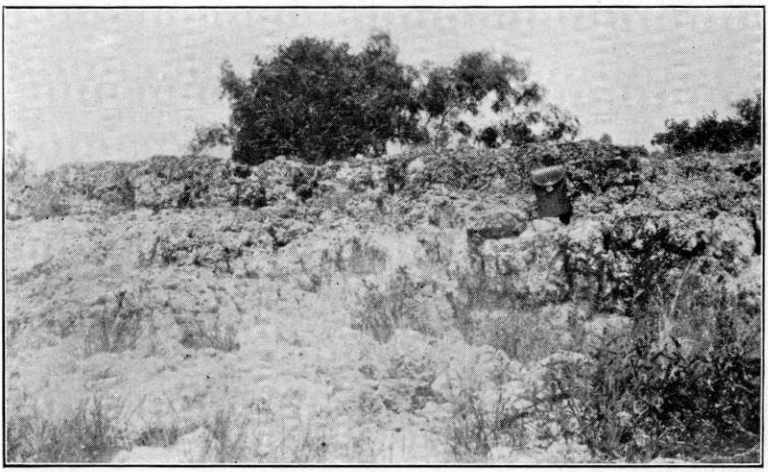

Figure 2. Exposure of trachyte tuff ½ mile south of Fant City, showing rugged character of outcrops.

Figure 1. Outcrop of Gueydan tuff, 4 miles west of Three Rivers, Live Oak County.

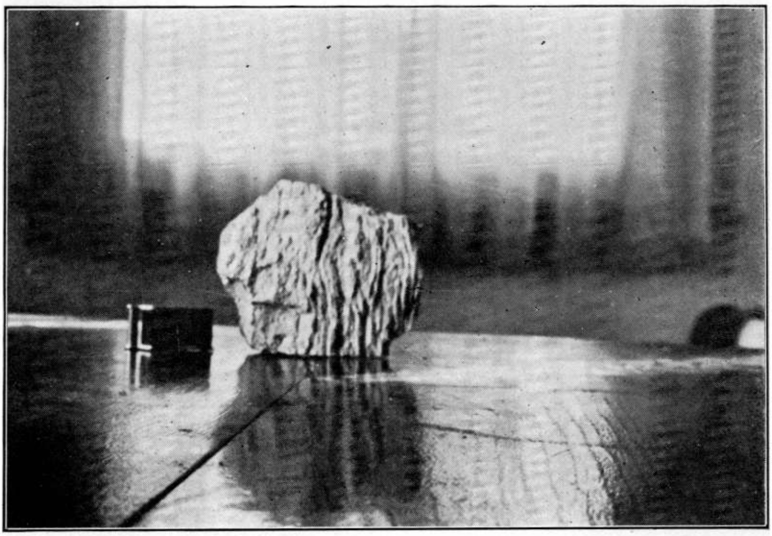

Figure 2. Fragment from slab of tuff showing ropy flow structure. "Chalk Bluffs" on Ray Ranch, eastern McMullen County.

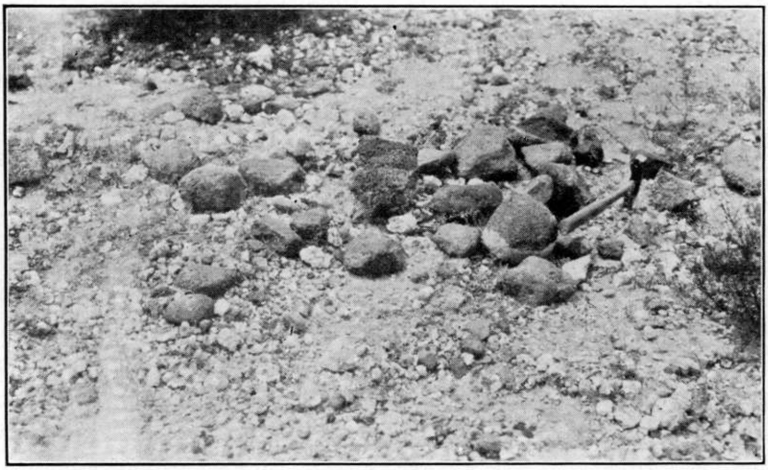

Figure 1. Andesite boulders in Gueydan tuff. Southwest corner of McMullen County.

Figure 2. Soledad conglomerate containing a number of lava pebbles on La Mesa, at Mirando Valley Oil Field, northeastern Zapata County.

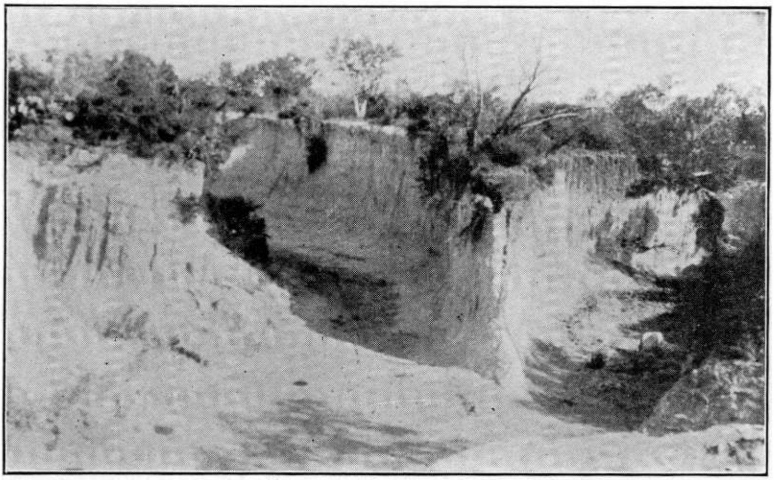

Figure 1. Loess-like outcrop of Chusa tuffaceous clay at junction of White Creek and a tributary, 4 miles above mouth of White Creek, Live Oak County.

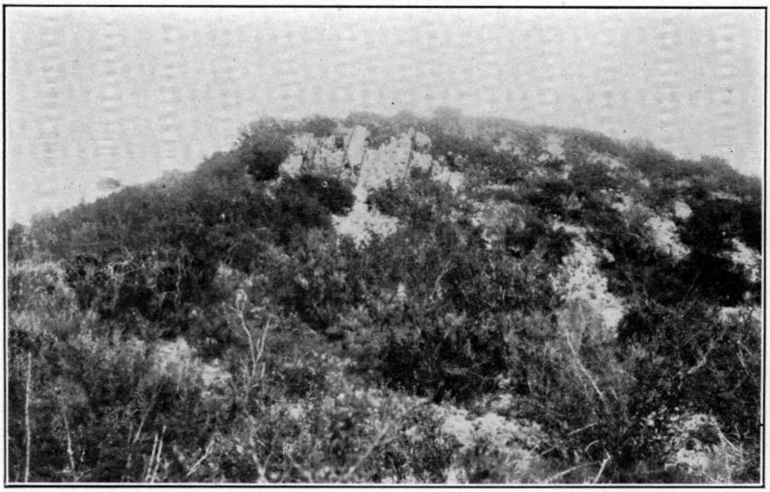

Figure 2. View of south side of main Picachos Hill showing outcrop of thick chalcedony veins. Note dip of veins to left (west). Duval County.

Figure 1. Thin section of massive, very lumpy, vesicular, mud-flow tuff from "Chalk Bluffs" on Ray Ranch, McMullen County. X 25. Large, white elongated spot is hole in section.

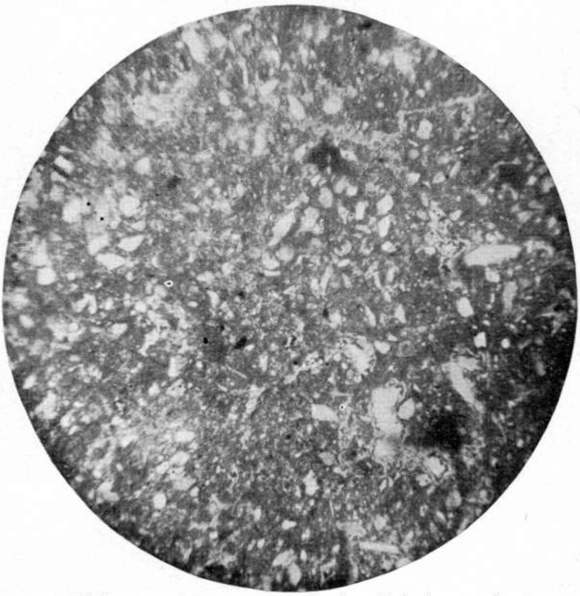

Figure 2. Thin section of silicified, slightly vesicular tuff from ½ mile northeast of Wentz, McMullen County. Contains tridymite in cavities. X 25.

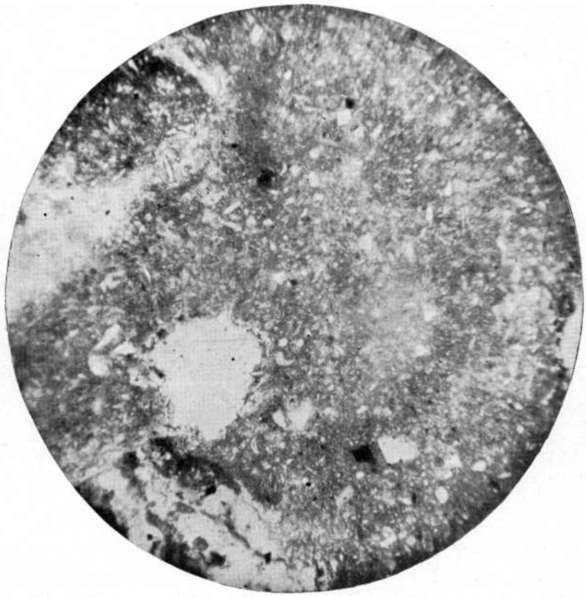

Figure 1. Thin section of fairly hard, dense-textured, vesicular, white tuff containing tridymite crystals in cavities, from Charlie York Creek, 4 miles west of Three Rivers. X 25.

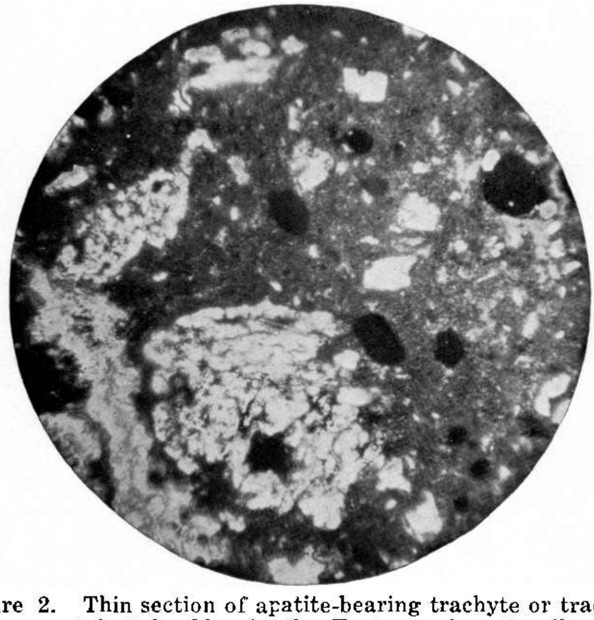

Figure 2. Thin section of apatite-bearing trachyte or trachyandesite from a 1-foot boulder in the Fant member, 2 miles west of Chapote Ranch, McMullen County. Shows large resorbed oligoclase phenocrysts containing glass inclusions. Dark spots are limonitized pyroxene and magnetite. The two light-colored hexagonal crystals on each side of largest pyroxene crystal are yellow apatite. X 25.

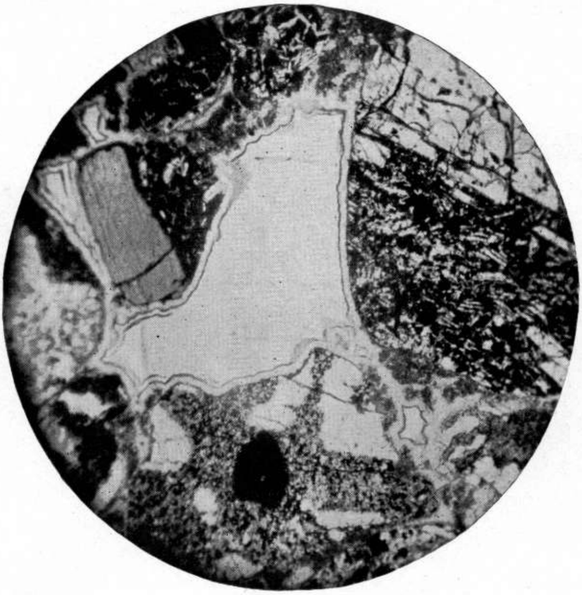

Figure 1. Fine-grained Soledad volcanic conglomerate from south end of Soledad Hills, Duval County. Clear areas are chalcedony surrounded by a band of opal. Phenocryst with high relief is augite, black phenocryst is altered augite. Other phenocrysts are albite-oligoclase and oligoclase. Plane polarized light. X 25.

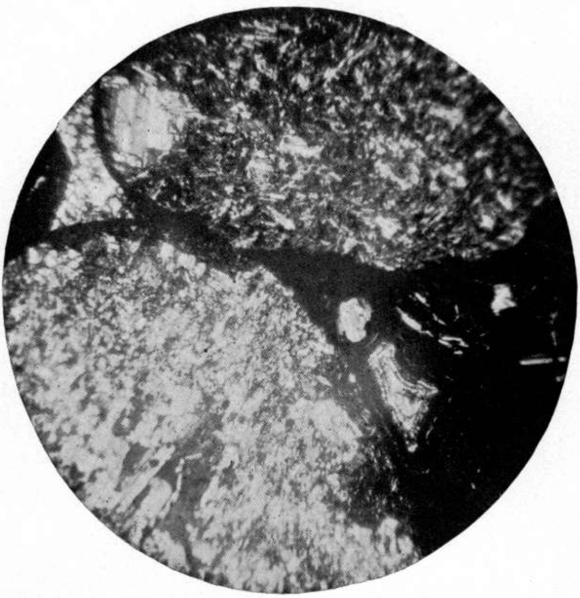

Figure 2. Fine-grained volcanic conglomerate from south end of Soledad Hills, Duval County. Dark areas are opal. One pebble is trachyte and the other is andesite. Crossed nicols. X 25.

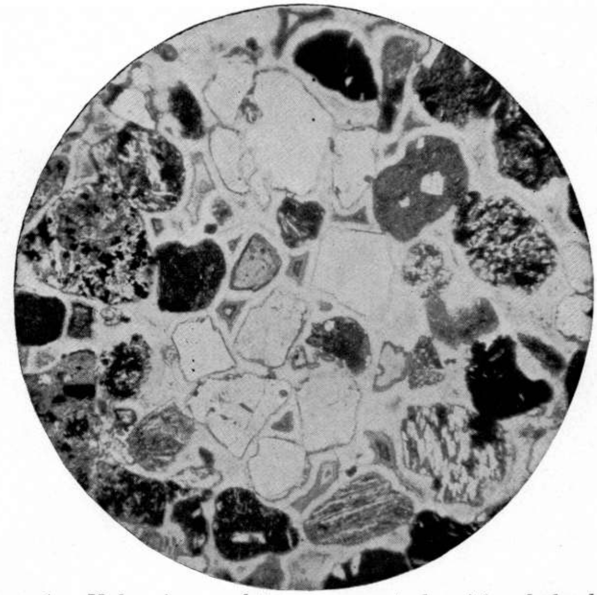

Figure 1. Volcanic sandstone cemented with chalcedony and opal from outcrop 2¼ miles northwest of Government Wells, Duval County. X 25.

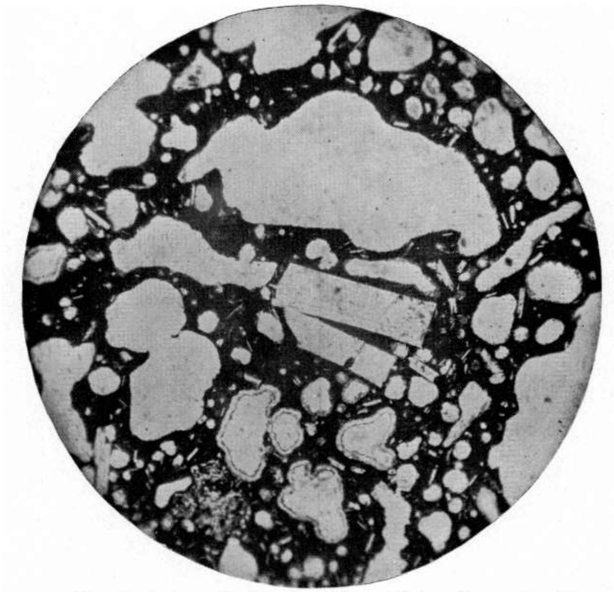

Figure 2. Vesicular andesite boulder 8″ in diameter from upper Gueydan, 2 miles east-southeast of Fant City. X 25.

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