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Figs. 1–6, December, 1969

HEAVY MINERALS AND SIZE ANALYSIS OF THE CITRONELLE FORMATION OF THE GULF COASTAL PLAIN[1]

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ABSTRACT

The heavy minerals of the Citronelle Formation and fluviatile terraces of Louisiana were examined to determine the source of these sediments. Examination of samples indicates that an East Gulf Province heavy mineral suite (kyanite, staurolite, zircon, tourmaline), typical of the Cretaceous and Tertiary sediments of the Gulf Coastal Province is present throughout the Citronelle and older Louisiana terrace deposits. A Mississippi River province suite (epidote, dolomite, amphibole-pyroxene, garnet), presumably derived from the glacial deposits of the northern United States, is present in the younger Louisiana terrace deposits: the Holloway Praire, Port Hickey, and Irene.

Based on previous work and heavy mineral and mechanical analysis data determined in this report, the Citronelle Formation appears to represent an alluvial apron formed by coalescing, braiding streams, in response to epeirogenic uplift of the continental interior during Late Pliocene to preglacial Pleistocene time. Encisement of the Mississippi River and other streams into Citronelle sediments has resulted in entrenched valleys containing fluviatile terraces which are mineralogically and lithologically similar to the Citronelle but are at lower elevations. Younger terrace deposits bearing a Mississippi River province heavy mineral suite are believed to have formed in response to fluctuating sea level during the Pleistocene.

INTRODUCTION

General Statement

Along the southern margin of the Gulf Coastal Plain, coarse sands and gravels cap stream interfluves, forming much of the highlands. These deposits were described by many early workers and were the subject of comprehensive mapping and discussion by Matson (1916), who named them the Citronelle Formation.

The age and origin of these deposits have been the center of much debate. At the present time, there are two main divergent hypotheses. The one elaborated by Fisk (1939b) states that Coastal Plain stream valleys were entrenched during Pleistocene glacial stages and that the sands and gravels were deposited during Pleistocene interglacial stages as fluviatile deposits in entrenched valleys and as deltaic plains along the coast; he believed the source of the sediments to be the glacial outwash deposits in the northern United States. The hypothesis of Clendenin (1896) and Doering (1956) suggests that the Citronelle represents a Late Pliocene to preglacial Pleistocene blanket fluviatile deposit, derived from the Cretaceous and Tertiary clastic deposits of the Gulf Coastal Plain and ultimately derived from the Appalachian highlands.

Enough work has already been done by other workers to indicate that the two suggested source areas possess completely different heavy mineral suites. The Gulf Coastal sediments are characterized by a nonopaque, heavy mineral suite dominated by kyanite, staurolite, zircon, and tourmaline. The glacial and Recent Mississippi River deposits are characterized by amphibole-pyroxene, dolomite, epidote, and garnet.

This information can be used to test the hypotheses in the following manner: if the sands and gravels were derived from glacial outwash, they should contain a heavy mineral suite dominated by amphibole-pyroxene, dolomite, epidote, and garnet; if, on the other hand, the sands and gravels were derived from the Gulf Coastal clastic deposits, then they should contain a heavy mineral suite dominated by kyanite, staurolite, zircon, and tourmaline.

This report presents the results of a comprehensive heavy mineral study of the Citronelle Formation from southwestern Mississippi to the Florida Panhandle and a brief examination of the heavy minerals of the Citronelle and the fluviatile terraces of Louisiana (fig. 1). The purposes of the investigation have been: (1) to describe the major suites of heavy minerals present in the Citrenelle and terrace deposits; (2) using the above information, locate the source of the sediment now comprising these deposits; (3) consequently, to suggest which of the above hypotheses can account for these deposits; and (4) additionally, to study the textural parameters of the Citronelle Formation in order to establish better the nature of its depositional agents.

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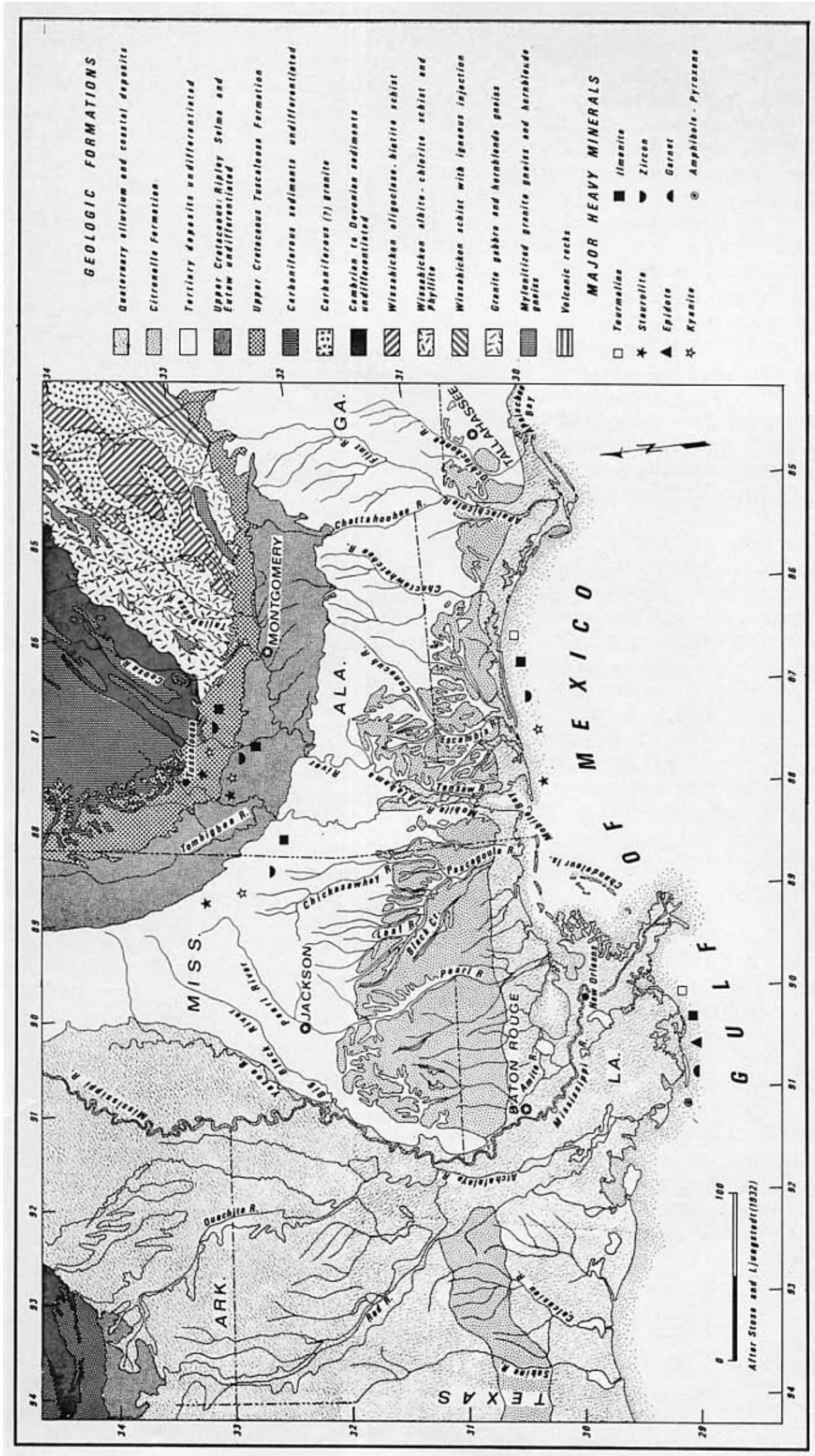

FIG. 1.—Geology of East Gulf Coastal Plain (map after Stose and Ljungstedt, 1932).

DESCRIPTION OF THE CITRONELLE FORMATION

The Citronelle Formation extends from Alabama and Florida to Texas, generally near the seaward margin of the Gulf Coastal Plain; Doering (1960) has suggested that it is also present along the southern margin of the Atlantic Coastal Plain. The Citronelle is underlain by Tertiary silts and clays; this contact is marked by a regional unconformity that gains magnitude inland. The Citronelle has a surface thickness of about 150 feet (Doering, 1956, p. 1852), and dips southward beneath Pleistocene coastwise formations that overlap it unconformably. Fluviatile equivalents of the Pleistocene deposits extend northward as terrace deposits in major stream valleys, entirely across the Citronelle outcrop belt. Near the Mississippi River, deposits of loess unconformably mantle the Citronelle and older Tertiary deposits (Snowden, 1966).

The Citronelle consists of coarse- to fine-grained quartz sands, commonly with pebbles and granules. These deposits are generally massive but occasionally exhibit cross-bedding and other sedimentary structures. The boundaries between depositional units are either gradational within a short distance or erosional. The depositional units vary greatly in size; some extend horizontally across the outcrop but others terminate within the outcrop. Layers of sandy-clayey silt several inches thick are present but not common. These finer grained units display sharp upper and lower contacts and in some areas appear to be traceable for several miles from one exposure to another.

In fresh outcrops, the Citronelle sands and gravels are gray-white in color, but older, weathered outcrops are colored orange by secondary ferruginous stain and cement. Zones of hard pan several inches thick are also present in many of the older exposures. Generally, the hard pan is concentrated along the boundary between two depositional units of contrasting grain-size distribution.

No detailed studies of the pebbles of the Citronelle have been made, although field observations do indicate some type of regional variation in pebble lithology. A more complete description of pebble lithology can be found in Matson (1916), Fisk (1939a), Brown (1967), and Rosen (1968).

PREVIOUS WORK

Summary of the Term Citronelle

Matson (1916) mapped nonmarine sands and gravels that he believed to be Pliocene in age as the Citronelle Formation in the Gulf Coastal Plain. Matson selected the town of Citronelle, Alabama, as the type locality based on excellent exposures along the Gulf, Mobile, and Ohio Railroad north of the town. Previously, these deposits had been included in the Lafayette Formation; since 1915, however, the Lafayette has not been considered a valid formational term. A more complete discussion of the older nomenclature of these deposits can be found in Matson (1916) and Fisk (1938).

Age and Origin

In 1938, Fisk named and described four fluviatile terraces in the Red and Mississippi River valleys. From oldest to youngest, he named them Williana, Bentley, Montgomery and Prairie (fig. 2 and table 1). Although noting the difficulty in correlating terrace deposits with sediments in other regions, Fisk (1939b) made correlations between his fluviatile terraces and their coastal equivalents (i.e., deltaic plains). Fisk (1940, 1944) assigned Citronelle deposits to the Williana Formation, but a comparison of Fisk's (1944) and Matson's (1916) maps shows that he also included some Citronelle in the Bentley and Montgomery Formations.

Fisk postulated that glacial stages had been periods of erosion along the Gulf Coast as rivers entrenched in response to falling sea level. As sea level rose during the interglacial stages, rivers aggraded, filled their newly cut valleys, and formed deltaic plains as they entered the transgressing Gulf of Mexico. Downwarping of the Gulf Coast geosyncline was associated with structural uplift and tilting along its northern flank, where these deposits were transformed into fluviatile and coastal terraces. Fisk maintained that the oldest terrace, the Williana, was tilted and uplifted the most but the youngest terrace, the Prairie, was affected the least.

Since these studies, the fluviatile terraces and their coastal equivalents have been mapped in many other Louisiana parishes by various workers (e.g., Huner, 1939; Welch, 1942; Holland, Hough, and Murray, 1952; Martin, 1954; Varvaro, 1957; Andersen, 1960).

In 1956, Doering objected to Fisk's correlation of the Williana and Citronelle. Doering's figure 4 (p. 1834) indicated that if Fisk were correct, a large structural depression would be present in central Louisiana which could be eliminated if the Williana were equivalent to the Lissie Formation, which he considered younger than the Citronelle. Further, maps of the underlying Miocene deposits show no structural depression.

Doering (1958) felt that the Citronelle represented an alluvial apron that formed as a result of preglacial epeirogenic uplift of the continental interior. A similar hypothesis had been sug-

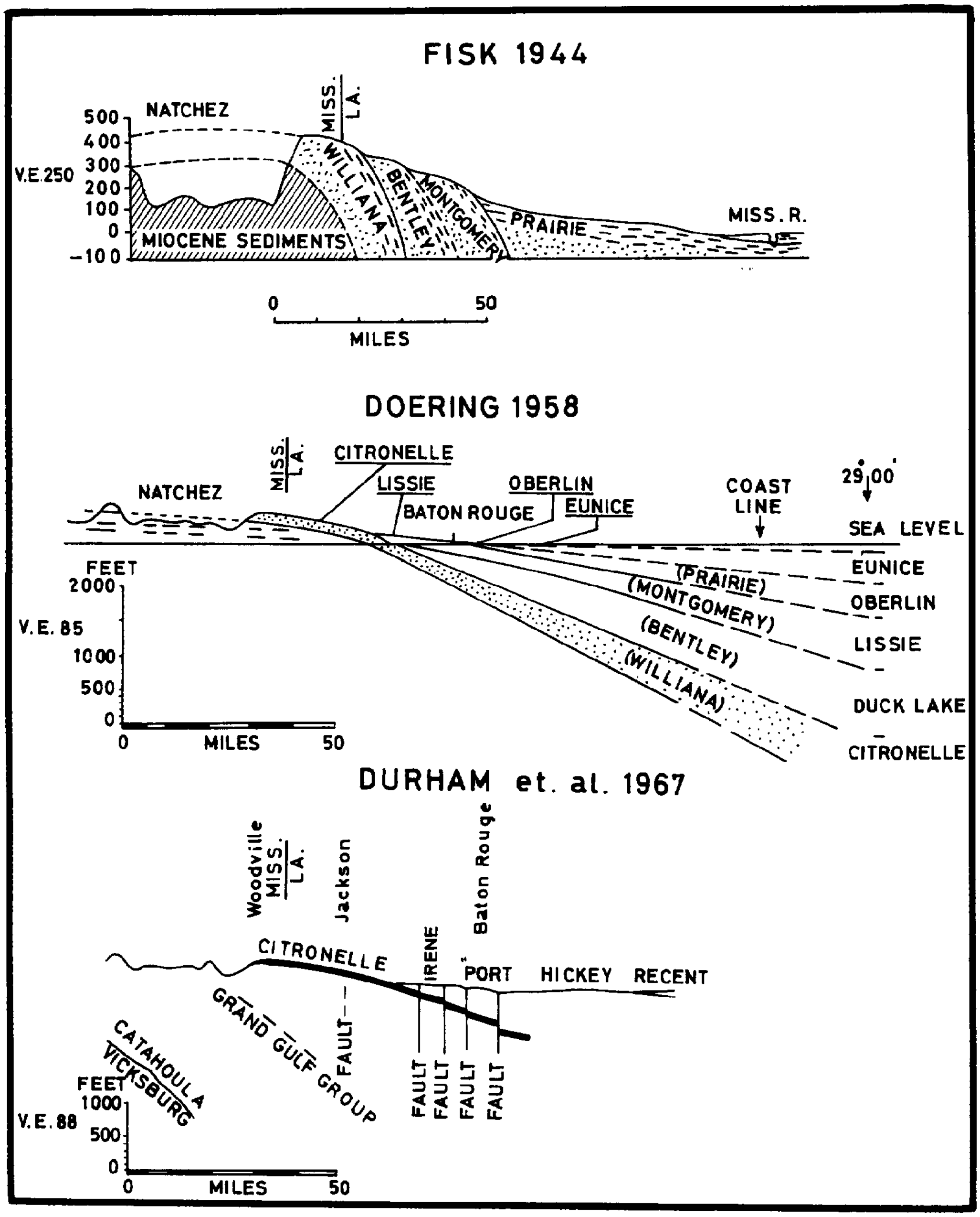

FIG. 2.—Contrasting concepts of terrace relationships shown by cross-sections from near Natchez, Mississippi, southward to south Louisiana (after Durham, Moore, and Parsons, 1967, Fig. 3).

gested by Clendenin (1896), who felt these deposits ranged from Late Pliocene to Early Quaternary in age and suggested that uplift in the continental interior resulted in stream rejuvenation, increased erosion, deposition of sands and gravels, and perhaps contributed to the onset of glaciation.

Doering's hypothesis received support from Parsons (1967) who traced the Citronelle Formation from southwestern Mississippi southward into Louisiana, an area which had been considered by Fisk (1939b) as Williana, Bentley, and Montgomery, and by Doering (1956) as Citronelle and Lissie (fig. 2). Because of the

TABLE 1.—*Revised correlation chart of Doering (after Doering, 1958)*

Red River Area	Doering (1956)	La. Coastal Area
(Fisk, 1940)		(Fisk, 1940)
Prairie	Holloway Prairie	—
Montgomery	Eunice	Prairie
Bentley	Oberlin	Montgomery
Williana	Lissie	Bentley
—	Citronelle	Williana

continuity of the deposits as shown from shallow subsurface information, obtained from closely spaced auger holes, Parsons felt that only one formation, the Citronelle, was present. He also suggested that the Citronelle represented an alluvial plain built by braiding, coalescing streams crossing a gently sloped plain.

The older workers were also in disagreement as to the significance of these sands and gravels. Clendenin's (1896) hypothesis was mentioned previously. Other ideas included Pleistocene glacial "southern drift" (Hilgard, 1866), Pliocene marine deposits (McGee, 1891; Harris and Veatch, 1899), and in part estuarine and in part shallow marine near the strand line where there was some wave action (Matson, 1916).

The age of the Citronelle has also been the subject of much disagreement. Matson (1916), Berry (1916), and Stringfield and LaMoreaux (1957) consider the Citronelle as Pliocene in age; Fisk (1938) and Roy (1939) consider the Citronelle as glacial Pleistocene in age; and Doering (1956, 1958) considers the Citronelle as preglacial Pleistocene in age. A complete discussion of the age problem can be found in Doering (1958).

Correlation Problems of the Younger Terraces

Similar correlation problems have been encountered in studies of the younger terraces in the Gulf Coast region. A complete discussion of these problems is beyond the scope of this report. However, because it must be determined when Mississippi River heavy minerals first entered the Gulf region, a brief discussion of these controversies in the Mississippi River area is presented.

In southwest Louisiana, Doering (1956) concluded that because Fisk's coastwise Prairie terrace is higher in elevation and has a steeper slope that Fisk's fluviatile Prairie terrace, the coastwise terrace is older and should be correlated with Fisk's Montgomery fluviatile terrace. Consequently, he renamed the fluviatile type Prairie the Holloway Prairie, and the coastwise Prairie the Eunice (which he correlated with the fluviatile Montgomery; see table 1). Progressively older coastwise terraces, the Oberlin, and Lissie, were correlated with the fluviatile Bentley and Williana, respectively.

In southeast Louisiana, Doering also mapped Lissie, Oberlin, and Eunice coastwise terraces south of the Citronelle terrain. The Eunice-Oberlin contact, however, is actually the Baton Rouge fault escarpment of Durham and Peebles (1965). Parsons (1967) recognized only two post-Citronelle coastwise terraces in the area. Realizing the uncertainty that was still present in regional terrace correlations, Durham, Moore, and Parsons (1967) suggested using local terminology for these two terraces. They informally named the older terrace Irene and called the widespread younger surface the Port Hickey, a name used first by Matson (1916) for these deposits. For additional information, see Doering (1956) and Durham, Moore, and Parsons (1967).

HEAVY MINERAL STUDIES IN GULF COAST PROVINCE

Studies of the heavy minerals of various deposits in the Gulf Coastal Plain and the Mississippi Embayment have been done in the past. Figure 1 summarizes the distribution of heavy minerals in units in or near the area under study and indicates the two contrasting suites present: the Mississippi River province assemblage and the East Gulf province assemblage.

Mississippi River province assemblage.—Russell (1937) has described the heavy minerals of Recent Mississippi River deposits; the minerals found are summarized in pie diagram form in figure 3. Analyzing Recent sediments in the northern Gulf of Mexico, Goldstein (1942) has distinguished four major heavy mineral provinces, one of which is the Mississippi River province assemblage. This assemblage is found from the Chandeleur Islands (about Long. 88° 45′) westward to Vermillion Bay (about Long. 92° 30′), encompassing the Recent Mississippi River deltaic deposits. The Chandeleur Islands represent reworked sands of the Mississippi River St. Bernard subdelta whose outer margin represents the most eastern extent of Recent Mississippi River deltaic deposition; the western boundary is marked by the Salé-Cypremort subdelta. This assemblage is also summarized in pie diagram form in figure 3. It should be noted that dolomite, which is an important member of this assemblage, is not included because all samples used in this study had to be treated with acid.

Wilman, Glass, and Frye (1963) reported the heavy minerals of the glacial deposits of Illinois as dominantly amphibole-pyroxene, epidote, and garnet (fig. 3). As Potter and Pryor (1961)

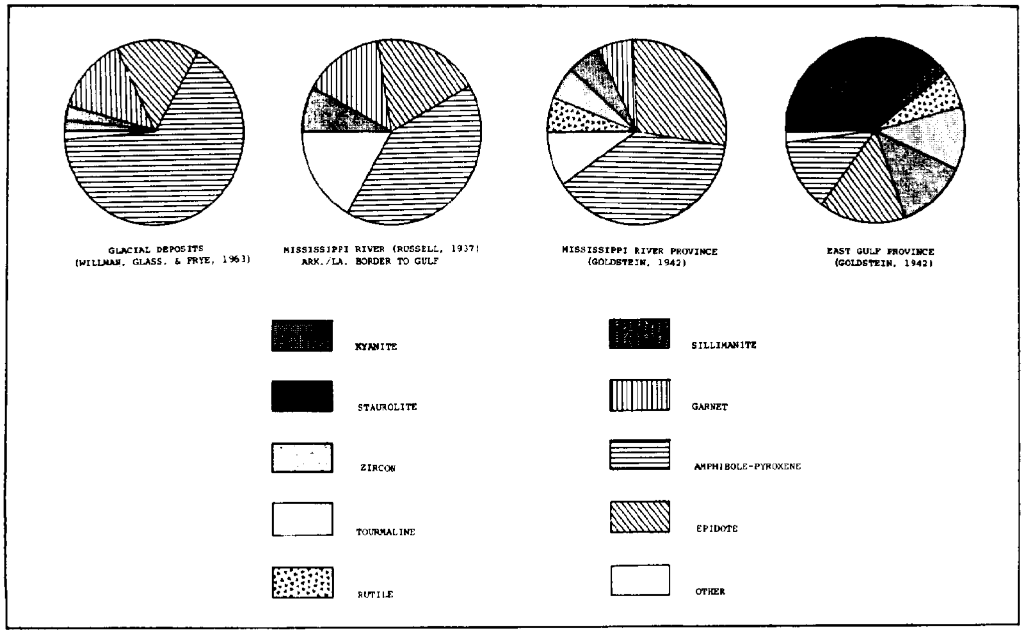

FIG. 3.—Pie diagrams of contrasting source area heavy mineral suites.

have indicated that the Paleozoic rocks that the Mississippi River drains contains a limited suite of zircon, tourmaline, and some garnet, the glacial deposits may be assumed to be the main source of heavy minerals for the Mississippi River.

East Gulf province.—The East Gulf province assemblage was first defined by Goldstein (1942) and includes the area east of the Chandeleur Islands to at least Long. 86°. The metamorphic heavy minerals that characterize this assemblage are summarized in pie diagram form in figure 3.

The most comprehensive report of the heavy mineral zones of the Tertiary of western Louisiana and eastern Texas is by Cogen (1940). Cogen has recognized four heavy mineral zones that transect formational boundaries; three zones are in the subsurface and only one, the kyanite zone, is present in the surface Tertiary deposits of western Louisiana. This zone is characterized by kyanite, staurolite, zircon, tourmaline, and rutile. Work by Levert (1959) and Dixon (1963) indicates that the kyanite zone is present in all of the surface Tertiary deposits of Louisiana.

The Tertiary deposits east of the Mississippi River have been studied for heavy minerals by Grim (1936), Sun (1954), and Blankenship (1956). The basic assemblage reported by these workers is dominated by kyanite, staurolite, ilmenite, zircon, and tourmaline; lesser quantities of sillimanite and rutile are present. Garnet is present in some samples but it is generally absent or less than one percent.

Pryor (1960) described the heavy minerals of the basal Gulfian (Cretaceous) deposits of the Mississippi Embayment and reported an East Gulf province heavy mineral suite. Farther southeast, the only Cretaceous heavy mineral study was by Needham (1934) on the Tombigbee Sand; he reported epidote, garnet, and tourmaline. Pryor believed these minerals to be typical of all Cretaceous deposits in this region, apparently because no study reported otherwise. The writer collected sand samples along a traverse from Centerville southward to Marion, Alabama, from the Tuscaloosa Formation, the McShan Formation, the Eutaw Formation, and the Tombigbee Sand. The heavy minerals present in all of the samples are quite similar and belong to the East Gulf province metamorphic assemblage. The writer knows of no explanation for Needham's results.

APPLICATION OF HEAVY MINERAL ANALYSIS

The intention of this study to utilize heavy mineral assemblages in determining source area for the Citronelle and the terraces has already been mentioned. However, the variation of heavy minerals in a sediment is a function of several factors, and it is necessary for this study to eliminate all of these factors except one: variation associated with source area (provenance). Besides provenance, some of the other factors which must be considered are: (1) differential physical stability during transport, (2) differential chemical stability to weathering and intrastratal solution, and (3) physical sorting of mineral species having differing specific gravity and size distributions. Fisk (1951, p. 342) has suggested that these factors make the heavy minerals in these deposits useless for reflecting their source. The following discussion, however, indicates that this statement was unnecessarily pessimistic.

Possible effects of differential physical stability can be estimated by comparing mineral hardness with mineral abundance. The data presented in the following sections indicate that the hardest mineral is not the most abundant; hence, this factor apparently has not significantly affected the heavy mineral assemblage.

Differential chemical stability can be examined by comparing the estimated chemical stability of heavy minerals present (e.g., Milner, 1962, p. 434) with their abundance, by examining the heavy minerals from unweathered localities with the heavy minerals from weathered exposures and by examining heavy minerals present for chemical attack. In the Citronelle, the most abundant heavy minerals are not the most stable chemically. Of the approximately 130,000 nonopaque grains examined, tourmaline showed the greatest amount of attack in one or two grains per slide, but these grains are at least third cycle.

Supporting evidence of the unimportance of this factor on these deposits is found in the studies of the other units in the Gulf Coast region. The presence of garnet and epidote (the latter in the subsurface of Louisiana) in the Tertiary sediments of this region makes it unlikely that weathering or intrastratal solution have removed these minerals completely from the younger deposits. The inability of intrastratal solution to remove hornblende from a friable Claiborne sand has been noted by Callender (1958). In addition, it must be noted that other workers in this region (e.g., Goldstein, 1942; Todd and Folk, 1957; Potter, 1955; and Pryor, 1960) agree that the heavy minerals of the units that they have studied have been relatively unaffected by secondary changes. Therefore, the assumption seems justified that the heavy minerals in the Citronelle Formation and the terrace deposits have not been appreciably affected by this factor.

The third factor is of vital importance if statistical procedures are to be applied to the heavy mineral data but is of lesser importance if only comparison of heavy mineral suites is desired. For the latter, it is necessary to determine if any heavy minerals are present in one size fraction but not in another. Examination by the writer of 0.5ϕ and 1.0ϕ size fractions in samples of the Citronelle and younger terrace deposits indicates that although the mineral species percentage does vary with the size range examined, the mineral suite present does not change. Therefore, for the purposes of this report, this factor is not deemed of critical importance.

FIELD PROCEDURE

In the Citronelle terrain east of the Mississippi River, a series of east-west and north-south lines of localities were established with an approximate distance of 5 to 10 miles between localities. In Louisiana, an attempt was made to collect from pertinent terrace localities of various ages so that this procedure was not always followed. Because of the large area, only road cuts and gravel pits were examined.

At all exposures, the surface of the outcrop was first scraped clean and an attempt was made to distinguish sedimentation units that were homogeneous with respect to grain size and primary structures. Channel samples of each different unit were taken. To insure that all particle sizes were represented, the quantity of sample taken varied with the size of the largest particles present. No material was taken from zones of hard pan.

The younger fluviatile deposits, in part derived from the Citronelle Formation, look much like fresh Citronelle exposures. Most of the natural Citronelle exposures, however, are stained red and can be easily distinguished from younger material. When confusion could exist between fresh Citronelle and younger deposits, no samples were taken.

LABORATORY PROCEDURE

Mechanical Analysis

For unconsolidated samples, the most commonly used methods for determining grain-size distribution are sieve analysis of the sand fraction and pipette analysis of the silt and clay fraction. Because secondary iron causes some induration, however, it was necessary to treat samples with acid before analysis could be made. Since the acid affected some of the clay minerals, the true grain-size distribution of the fine fraction could not be determined with any degree of reliability.

To estimate the importance of the silt and clay fraction (material less than 4ϕ), three iron-free samples of obviously different grain-size distribution were dry sieved. The results from all three tests indicated that the silt and clay fractions comprise less than 4.0% by weight of any fresh sample. In addition, it was noted that the amount of material less than 4.0ϕ in size was related more to the degree of weathering of the outcrop than to the grain size of the deposit. (Parsons, personal communication, reached the same conclusion from his study.)

With the above factors in mind, the following procedure was used.

The material coarser grained than -2.0ϕ (4 mm) was washed, dried, and then sieved through a nested sequence of sieves ranging from -5.0ϕ to -2.0ϕ, using a CENCO-Meinzer sieve shaker for 15 to 20 minutes at an intensity setting of 6 to 8. Each sieve fraction was then weighed ± 0.05 gm. Any material passing through the -2.0ϕ sieve was then added to the sand fraction.

The sand fraction was then split with an Otto-type sample splitter. Each split was resplit and quarters from the right and left were recombined to reduce bias. In this manner, the sample was reduced in size until two replicate samples of each unit, weighing 300 to 700 gm, were obtained. Each replicate was placed in HCl (diluted 1:3) and heated to boiling. After cooling, the acid was neutralized and the finer than 4.0ϕ material was removed by wet sieving. After drying, the replicate samples were sieved through a series of nested screens at 0.5ϕ intervals, using a CENCO-Meinzer sieve shaker as described above. Each residue was weighed as described previously and the 2.0–2.5ϕ and the 2.5–3.0ϕ splits were retained for heavy mineral analysis. Cummulative curves were constructed following standard procedures. Because the weight of the material on the sieves greater than -2.0ϕ represented the total weight collected in each sample, the weight of the residue on these sieves was successively divided by two for every split of the sand fraction.

HEAVY MINERAL PROCEDURE

An initial survey of 16 samples on an east-west line from western Mississippi to Florida was made to determine which assemblage of heavy minerals is present in the Citronelle. These samples were treated as described under mechanical analysis except (1) replicate samples were not analyzed, (2) the samples were sieved into three size classes (3.0–4.0ϕ, 2.0–3.0ϕ, 1.0–2.0ϕ). Eighteen samples of the terrace deposits were then examined to determine heavy mineral content. These samples were treated as described under mechanical analysis except that replicate samples were not studied; the size classes 2.0–2.5ϕ and 2.5–3.0ϕ were examined. To insure that the data from the initial survey of the Citronelle material was correct, the samples from which mechanical analysis data have been derived were also checked for heavy minerals. In 15 of these samples, the heavy minerals of each 0.5ϕ size class were examined; in the other samples, only the heavy minerals in the 2.0–2.5ϕ and 2.5–3.0ϕ size classes were examined.

The heavy minerals were separated from the 'light' fraction using bromoform, following the procedures outlined in Krumbein and Pettijohn (1938). The heavy minerals were mounted on glass slides with Lakeside 70. If more residue was present than could be mounted on a single slide, a micro-sample splittler was used in the same manner as described for splitting of samples under mechanical analysis. The slides were point-counted using a mechanical stage and the first 200 non-opaque grains (not including mica) were identified with the aid of a petrographic microscope. To insure that no grain was counted twice, the distance between points on a traverse and between traverses across a slide was slightly larger than the longest dimension of the largest nonopaque grain on the slide.

PRESENTATION OF DATA

Textural Data Analysis

Depositional environments previously suggested for the Citronelle Formation range from near the strand line to fluviatile. The use of textural parameters to distinguish sedimentary depositional environments is a common technique (see Folk, 1966, and Friedman, 1967, for summaries). The parameters used are generally based on mean grain size, standard deviation (sorting), and the asymmetry of the curve about the mean (skewness) because these parameters are believed to reflect the nature of the depositional agent.

Because different sedimentary environments yield overlapping values for any single parameter, Friedman (1967) tried scatterplots of two parameters. Although overlap was not eliminated it was greatly reduced, and Friedman found 12 combinations useful for distinguishing beach and river deposits. None of the 12 appeared to the present writer to be more effective than another, and for this study two plots were selected as representative of the method for use in plotting data derived from mechanical analysis. These are (1) inclusive graphic skewness (SK_I; Folk and Ward, 1957) versus graphic standard deviation (σ_I; Folk and Ward, 1957), and (2) simple skewness measure (α_s; Friedman, 1967) versus simple sorting measure (SO_s; Friedman, 1967). The formulas for calculating the various parameters can be found in the above-mentioned citations. Figures 4 and 5 are

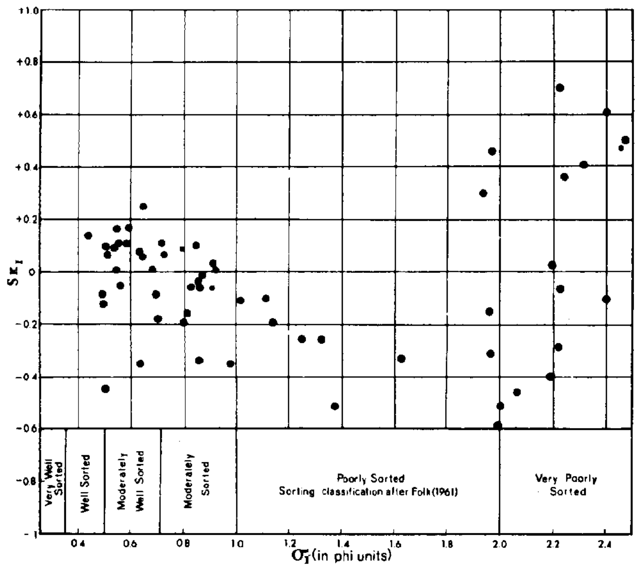

FIG. 4.—Scatterplot of SK_I versus σ_I.

scatterplotts of SK_I vs σ_I and α_I vs SO_s, respectively.

Figure 4 shows two clusters of points. In one the sediments range from moderately well sorted to moderately sorted and $SK_I = \pm 0.25$. The second cluster is characterized by a wide range of skewness values and are very poorly sorted; the two clusters appear to be connected by a scattering of points in the poorly sorted region of the plot. Folk (1961, p. 45) notes that most Texas river deposits range in sorting from 0.4ϕ to 2.5ϕ, a range matched by the Citronelle data. Friedman's (1967, p. 340) figure 15 plots SK_I vs σ_I for known beach and river deposits. Although there is a small overlap, a river-beach boundary is indicated; almost all of the Citronelle data plot on the river side of the boundary. The very poorly sorted cluster does not show on Friedman's diagram as he plotted values of σ_I only to 1.40. Figure 5 yields much the same information and may be compared to Friedman's (p. 342) figure 18. The above scatterplots indicate that the Citronelle represents fluviatile deposits.

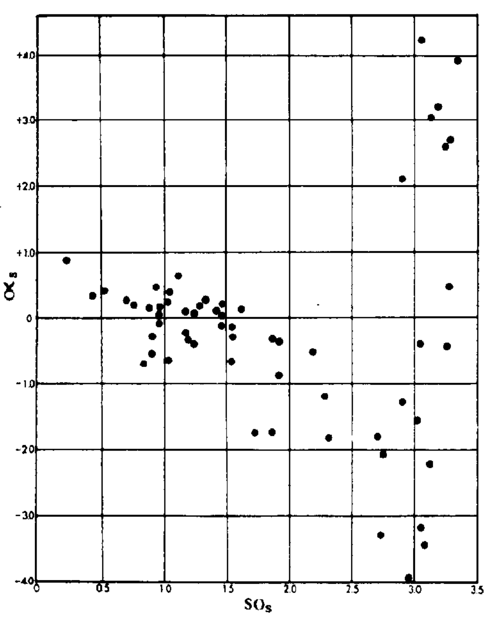

FIG. 5.—Scatterplot of α versus SO_s

Description of Heavy Minerals

Examination of all Citronelle samples indicate that the heavy minerals present belong entirely to the East Gulf province assemblage of Goldstein (1942). Figure 6 shows in pie diagram form the nonopaque minerals present in the 2.0–3.0ϕ size fraction. Examination of the Louisiana samples indicate a similar assemblage in samples from the Citronelle and three older terraces as defined by Fisk (fig. 6). The heavy minerals of this assemblage in approximate order of abundance are: ilmenite, mica, kyanite, staurolite, zircon, tourmaline, rutile, and sillimanite; magnetite content fluctuates greatly but it is never really abundant. Other minerals that are present but not common include andalusite, garnet (spinel?), amphibole, pyroxene, epidote, sphene, and monazite. A description of the heavy minerals follows.

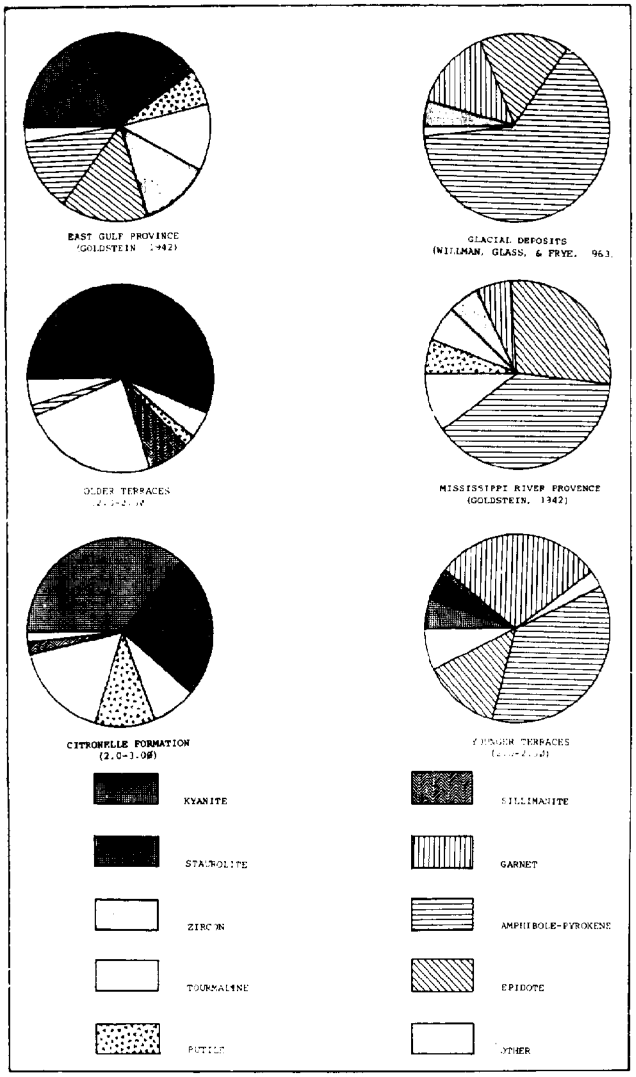

FIG. 6—Citronelle and Louisiana terrace heavy mineral suites compared with suggested source area heavy mineral suites.

Ilmenite.—Ilmenite is the dominant heavy mineral in all Citronelle samples. Ilmenite occurs as opaque grayish-black, subrounded to subangular, equidimensional grains. Most grains are coated with a white alteration product, leucoxene. A reddish-orange color can be seen in the thin edges of some grains.

Rutile.—Deep reddish-brown, generally rounded grains and deep yellow, subrounded to angular prisms and crystals of rutile are present. Deer, Howie, and Zussman (1962, p. 38) report rutile as a common alteration product of ilmenite and other titaniferous minerals. In the Citronelle and older terrace samples, the alteration of ilmenite to reddish-brown rutile can be seen in some grains. It is not clear, however, whether all of the reddish-brown rutile has formed by this process or whether the alteration that is present has occurred before or after deposition. The deep yellow variety is always free of inclusions and is certainly detrital.

Kyanite.—Most kyanite grains are typically bladed and range from angular to subrounded in habit; however, some are short, stumpy, and rounded. Some grains show anomalous extinction, probably due to air trapped along cleavage planes.

Staurolite.—Staurolite grains may be equidimensional but more commonly are crudely prismatic to, sometimes, almost bladed. These grains range from reddish-brown to yellowish-brown to straw yellow. The degree of pleochroism varies from moderate in the more colored grains to almost none in the straw yellow grains. Most grains have no inclusions, but grains containing carbonaceous material or quartz and other minerals (i.e., 'Swiss cheese' texture) are common too.

Zircon.—Zircon grains range from well rounded equidimensional to angular prisms; the former are the only type present in the larger size grades and the latter are very common in the smaller size grades. As xenotime is indistinguishable from colored zircon under the microscope (Milner, 1962, p. 202–203), some xenotime may also be present.

Tourmaline.—Tourmaline is present as subangular to rounded prisms to nearly equidimensional grains. The most common forms are pleochroic yellowish-black to black and pleochroic reddish-brown to black; other forms are present but not common.

Sillimanite.—Sillimanite most commonly occurs as fibrous grains but slender arcuate prisms and short, stubby prisms are not uncommon. The latter type resemble kyanite but are distinguished by their lower relief and parallel extinction.

Mica.—Almost all of the mica present is muscovite; grains of phlogopite are rare. The quantity of mica varies considerably in the samples examined, being very abundant in some and almost absent in others.

Although this was to be only a survey of the younger Louisiana terrace deposits, an attempt was made to collect from other pertinent localities. Thus samples were taken from the Avoyelles Prairie, Fisk's fluviatile Prairie type locality, where Pleistocene Mississippi River meander scars clearly indicate the source. These samples contained a Mississippi River province heavy mineral suite that is summarized in pie diagram form in figure 6. A sample of the Port Hickey fluviatile terrace, taken at St. Francisville, Louisiana, on the east side of the Mississippi River valley, and a sample of the Irene terrace from Irene, Louisiana, possessed little or no material in the 2.0–3.0ϕ range; the suite present in the 3.0–4.0ϕ range, however, is the same shown in the younger terraces pie diagram. A very small amount of East Gulf province heavy minerals present in the younger terrace deposits suggests reworking from older deposits. Again, the absence of dolomite in the diagram is due to acidizing of samples; dolomite is present in untreated samples. The other heavy minerals, however, are so diagnostic and different from the East Gulf province suite that there can be little doubt that the younger terrace deposits sampled contain the Mississippi River province heavy mineral assemblage whereas the older terraces (and Citronelle) do not.

It should be noted that more work remains to be done on the younger terraces, especially in connection with auger drilling. A more complete discussion of some of the sampling problems encountered can be found in Rosen (1968, p. 42).

A brief description of the important heavy minerals of this assemblage follows.

Augite.—Augite occurs as green, rounded to angular, prismatic grains and, rarely, as irregular, cleavage fragments. Most grains appear fresh.

Hornblende.—Hornblende occurs as dark green, slightly pleochroic, rounded to subangular grains. Most grains appear fresh.

Epidote.—Epidote occurs as rounded to subrounded, equidimensional grains. Epidote is characterized by its pistachio green color and the brilliant green-purple-red (ringed) interference tints observed in many grains.

Garnet.—Garnet occurs as red to reddish-orange, irregular, sometimes fractured, generally well rounded grains that show no crystal faces. A colorless variety of garnet is present but not common.

INTERPRETATION

Interpretation of data presented in this report and from previous work indicates that three types of deposits have been examined: (1) the Citronelle Formation, containing an East Gulf province heavy mineral suite; (2) an older terrace deposit also containing an East Gulf province heavy mineral suite (i.e., Doering's Lissie fluviatile terrace which in some places is 100 feet or more lower in elevation than the adjoining Citronelle); and (3) Mississippi River terrace deposits which possess a Mississippi River province heavy mineral suite.

It is evident that the hypothesis advanced by Clendenin (1896) and Doering (1958) that the

Citronelle represents deposits of preglacial, coalescing, braiding streams in response to epeirogenic uplift of the continental interior best explains the known facts about the Citronelle Formation.

If Fisk's theory of the origin of these deposits were correct, (1) the material eroded during the glacial stage of entrenchment would not have been deposited in the valleys but would have been flushed out to sea, and (2) the material which forms the terraces (i.e., Citronelle or Williana) along the Mississippi River would have to have been derived from glacial outwash. Fisk (1951, p. 341) implies this fact in stating,

"All the terraces can be traced directly up the Upper Mississippi and Ohio River Valleys, thus proving that the sediments of all the terrace formations came from the same general source area."

From the data presented, this is certainly not true of the terraces as defined by Fisk.

The presence of the Lissie fluviatile deposits in Grant and LaSalle parishes, Louisiana (the type area for Fisk's Williana, Bentley, and Montgomery terraces) at elevations in some cases more than 100 feet lower than the Citronelle can be explained by lateral planation, a process completely rejected by Fisk (1939b) as an explanation for his terrace concepts. Durham (1961) has suggested that scour and fill associated with lateral planation during glacial times can account for the formation of the entrenched Mississippi and Red River valleys in Louisiana and thick alluvial valley fill simultaneously. The box-shaped cross-section, truncation of spurs, and indentation of the valley walls by arcuate meander scars support this theory.

If Durham is correct, then deposits that resemble the Citronelle could be formed by the Mississippi and Red Rivers at lower than expected elevations whenever the river encised against the Citronelle sediments; thus, this could account for the Lissie fluviatile deposits. The lack of glacial heavy minerals in the Lissie fluviatile deposits can be explained in one of three ways: (1) these deposits represent a Pliocene period of entrenchment (or preglacial Pleistocene); (2) the deposits are Kansan in age so that no glacial deposits had yet been eroded; or (3) terraces of at least two glacial cycles are present but glacially derived heavy minerals did not arrive until, perhaps, as late as Irene time.

The younger terrace deposits appear to be clearly related to fluctuating sea level during Pleistocene glaciation. Their relationship to the modern Mississippi River deposits is well illustrated by (1) their common heavy mineral assemblage, and (2) the presence of Mississippi River meander scars on the surface of these terrace deposits. More thorough work is needed to relate the terminology of Doering (1956) in southwestern Louisiana with the revised terminology of Durham, Moore, and Parsons (1967) in eastern Louisiana.

CONCLUSIONS

The most probable explanation for the Citronelle Formation is that it represents an alluvial apron formed by braiding, coalescing streams as postualted by Clendenin (1896), Doering (1956), and Parsons (1967). Epeirogenic uplift of the continental interior as envisioned by Clendenin (1896), Doering (1956), and perhaps Matson (1916), caused a time of increased stream activity and erosion and deposition in the entire Gulf Coast region. The uplift resulted in the erosion of Cretaceous clastic deposits which, as evidenced by outliers of Cretaceous rocks in the southern Appalachians, once extended farther north than at present; very likely, the Tertiary sands also extended farther north and served as a source for some of the material in the Citronelle east of the Mississippi Valley and probably all of the Citronelle west of the Mississippi Valley.

After deposition of the Citronelle, progressive encisement by the Mississippi River and other streams, associated with uplift and tilting along the northern flank of the Gulf Coast geosyncline, formed entrenched valleys containing fluviatile deposits. Deltaic plains, equivalent to these fluviatile deposits, were similarly uplifted and tilted to form coastwise terraces. In some areas, associated faults have been misinterpreted as terrace scarps.

The oldest of the fluviatile terraces are identical lithologically and mineralogically with the Citronelle Formation. The Mississippi River heavy mineral suite has been recognized in younger terrace deposits: the Holloway Prairie, the Port Hickey, and the Irene. These deposits are believed to be related to fluctuating sea level associated with Pleistocene glaciation, but additional field work is needed before this can be proven positively true.

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