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THE ORIGIN OF THE CUSSETA SAND

A dissertation submitted to the

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requirements for the degree of

DOCTOR OF PHILOSOPHY

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by

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I hereby recommend that the thesis prepared under my supervision by Norman C. Hester

entitled "The Origin of the Cusseta Sand"

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

Wayne A. Pryor

William F. Jenks

Form 668—Grad. School—1M—8-64

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THE ORIGIN OF THE CUSSETA SAND

Introduction

In defining a formation throughout its area of outcrop, the following criteria are generally used: lithology, genesis, unconformity and age. The use of unconformity to define the boundaries of the Cusseta Sand, for the most part, is invalid. The Cusseta Sand in nearly all sections studied, was gradational with the underlying Blufftown and overlying Ripley formations. Where unconformities were found at the "so-called" base of the Cusseta, they did not result from a transgression but rather as channels (fluvial, estuarine, or tidal) representing the upper phase of a positive prograding system. Because the unit is time transgressive (prograding east to west), age cannot be used. However, it can be thought of rather in terms of sequential time.

The use of lithology is also invalid since it changes radically east to west and in a vertical succession, particularly in Alabama. Lithologically, it may be defined only as a dominantly sandy unit generally becoming finer grained upward and westward and with gradational boundaries.

Genesis then may best define the Cusseta Sand, for it would give insight into the provenance, distribution, sedimentary environment, and general tectonic setting from which the paleogeography could be reconstructed. Only in this way can a sedimentary body be placed in its proper perspective in both time and space; thus, my thesis, "The genesis of the Cusseta Sand".

Purpose

The purpose of this investigation is to determine the origin of the Cusseta Sand and its spatial relationships with other (synchronous and diachronous) sediments of the upper Cretaceous of western Georgia and eastern Alabama. To accomplish this, two different approaches were undertaken.

First, the sediments were studied on a regional scale in an effort to determine the sediment dispersal patterns and provenance. This necessitated a combined study of mineralogy and lithostratigraphy, employing methods such as heavy, light and clay mineralogy, paleocurrent analysis, largest grain size analysis and surface and subsurface measured section analysis.

Secondly, detailed studies were undertaken for several vertical sections of the upper Blufftown, Cusseta and lower Ripley in an attempt to make environmental interpretation on a local scale. In addition to the methods used for the regional study, forminiferal micropaleontology, textural analysis and course fraction descriptions were incorporated.

Through integration of the environmental information, interpolated and extrapolated from the local scale into the regional picture, the paleogeography of this interval of geologic time was reconstructed.

ACKNOWLEDGEMENTS

The writer acknowledges the suggestions and criticisms offered by Professor W. A. Pryor, under whose direction this investigation was carried out. The writer wishes also to thank Professors Warren Huff, John Warren and Frank Koucky for their advice and suggestions. Thanks are extended to William Howard for writing the computer programs, to Jim Barr for invaluable aid in drafting and photography, to Bruce Bell for assistance in photography, to Duck Hee Lee for picking the foraminifera, to Richard Alexander for aid in foraminiferal identification, to Don Moore of the Alabama Geological Survey for unpublished subsurface information, and to Wanda Osborne for typing this manuscript. The writer is deeply indebted to the National Aeronautics and Space Administration for two years of financial support and to the Fenneman Fund for the Fellowship during the school year of 1967-68. My deepest thanks are to my wife, Ruth Ann, for her constant encouragement as well as her assistance in the laboratory and in editing this manuscript.

LOCATION

The location of the area of study occupies approximately two-thirds of southeastern Alabama and approximately two-thirds of southwestern Georgia. The outcop belt of the Cusseta Sand investigated extends from central Montgomery County, Alabama to just west of the Flint River in Crawford County, Georgia (Fig. 1).

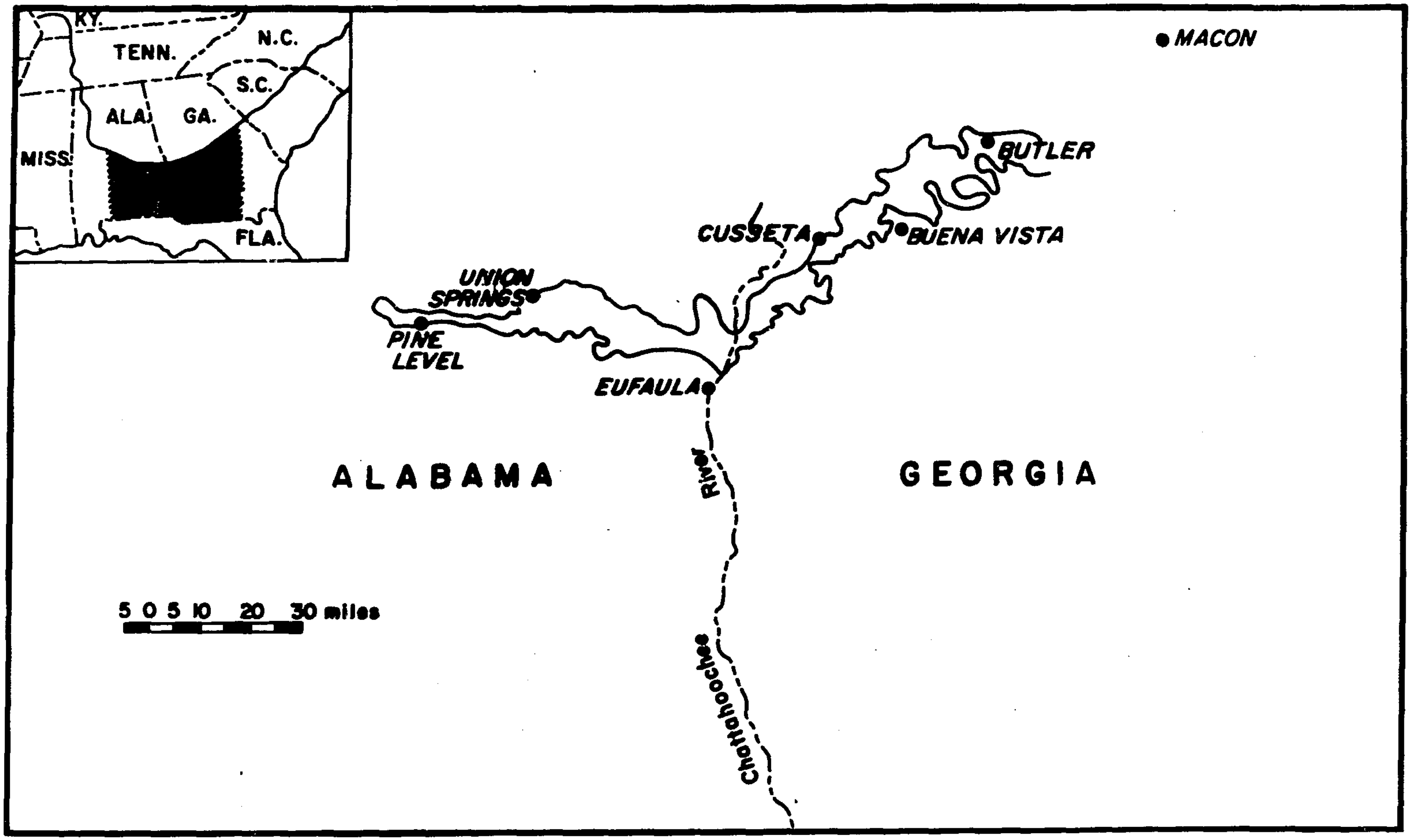


Figure 1 - Location map of study area, including areal distribution of Cusseta sand outcrop

STRATIGRAPHY

Previous Work

Stephenson (1914), Stephenson (1933), Stephenson and King (1942), Herrick and LaMoreaux (1944), Conant, et. al. (1947), Applin (1947), Monroe (1946), Eargle (1950) and Eargle (1955) made important contributions to the understanding of the Upper Cretaceous surface stratigraphy of Alabama and Georgia. The time zones defined by *Exogyra ponderosa* and *Exogyra costata* determined by Stephenson (1933) have served as a reference for all investigators to follow. Preliminary geologic maps by Monroe (1941) and Eargle (1950, 1955) served as the principle guide for the sample collection and section measuring for this study (Fig. 2).

Litho-Stratigraphy

The study of the Cusseta Sand is the preliminary purpose of this investigation. However, without gaining a general understanding of the units above and below the Cusseta unit, the time and space relationship of this unit in this sequence of geologic time could not be reconstructed. Therefore consideration is also given to the stratigraphy and lithologic description of the other units in the Upper Cretaceous, particularly the Blufftown, Demopolis and Ripley Formations. The stratigraphic relationships of these units are summarized in the columnar section of figure 3. The facies relationship of the Cusseta Sand to synchronous and diachronous units of the Upper Cretaceous is illustrated in figure 4.

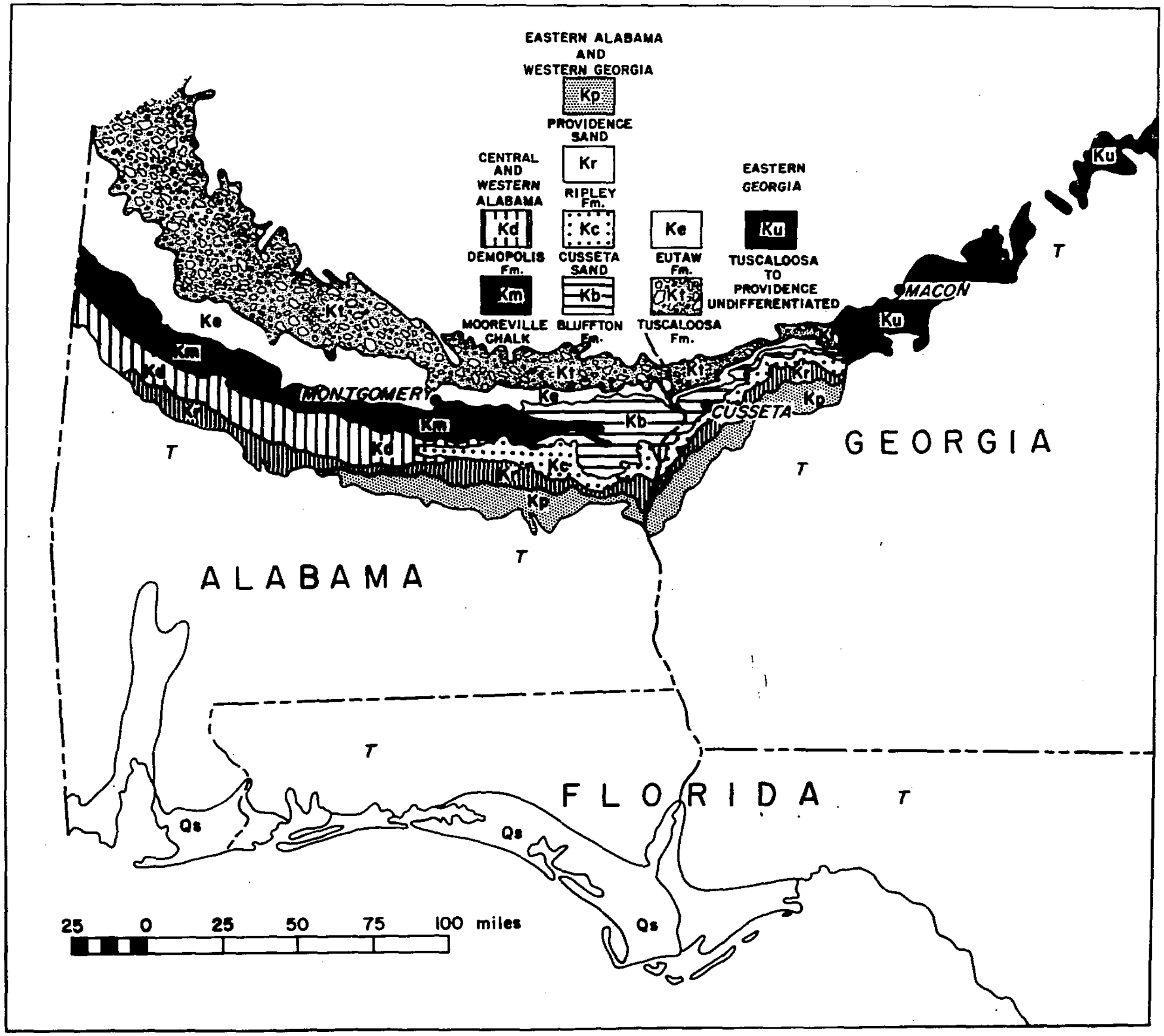


Figure 2 - Geologic map of Upper Cretaceous rocks of Ala. and Ga. (compiled from Eargle, 1950 and 1955)

The stratigraphic descriptions that follow are taken basically from the literature. Changes that are made in the description of the Cusseta Sand as a result of this study are treated in the conclusions.

Blufftown Formation

The Blufftown Formation, which extends from the approximate area of Union Springs, Alabama to Flint River, Georgia, is the eastern clastic facies of the Demopolis and Mooreville chalks of Alabama. This unit, which is very fossiliferous in the Chattahoochee River area, becomes less marine to the east until it takes on a complete nonmarine character in the Butler, Georgia area and eastward.

Demopolis Chalk

This formation in the outcrop area of this study is composed of silty, micaceous, carbonaceous, clayey marl. The Demopolis Chalk appears below the Cusseta Sand from the area of Union Springs, Alabama and west as a result of a facies change from Blufftown silty clays to silty clayey marl. The Demopolis appears above the Cusseta Sand from the area of Pine Level, Alabama west as a result of a facies change from Ripley sand to silty, clayey marl. Thus the Cusseta Sand splits the Demopolis Formation in Montgomery County, Alabama.

Cusseta Sand of Georgia

The formational name, Cusseta Sand, was proposed by Veatch, 1909, for nonmarine beds of Ripley age. The type locality was described at a railroad cut just west of Cusseta, Chattahoochee County, Georgia.

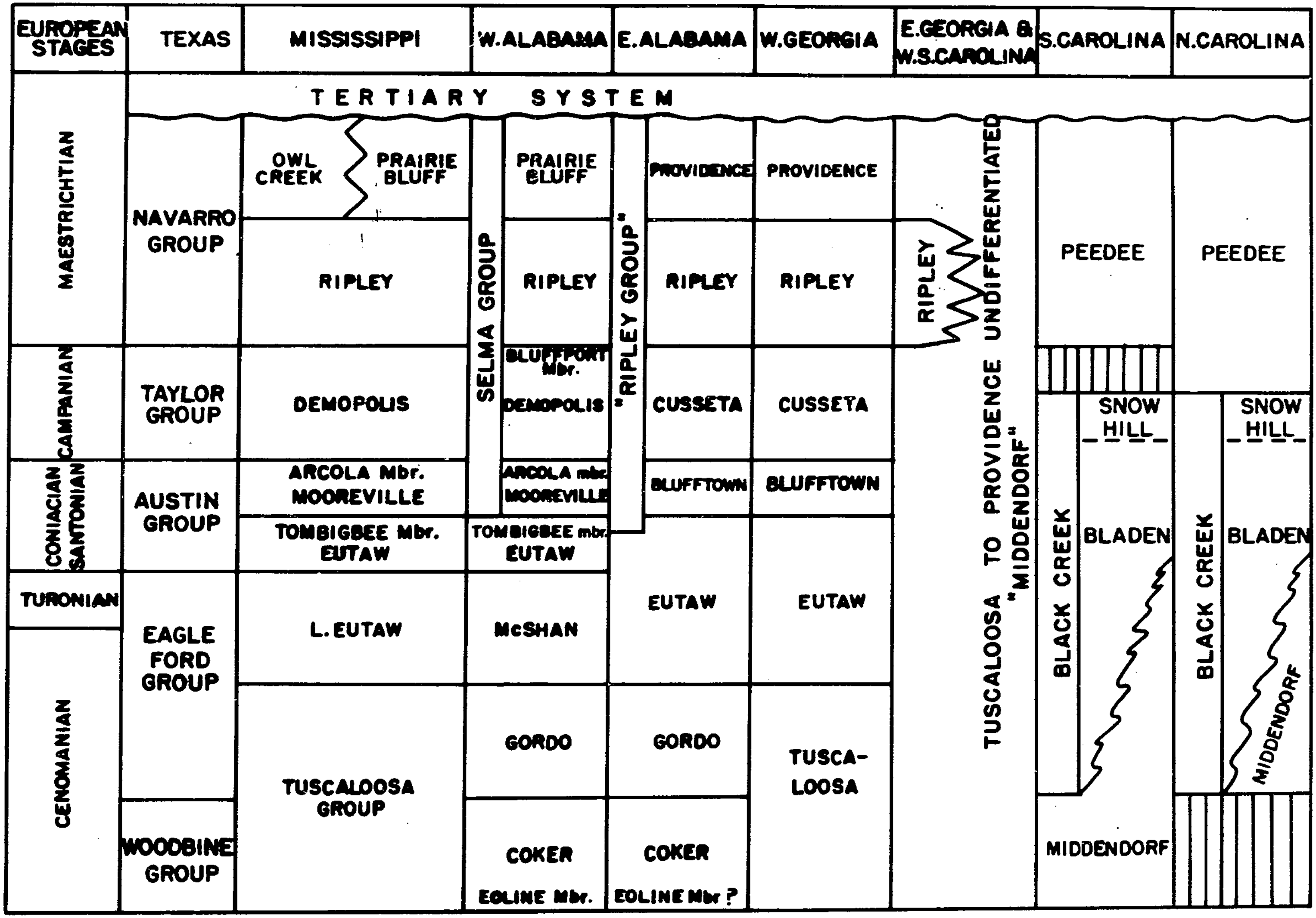


Figure 3 - Generalized columnar section of the Upper Cretaceous stratigraphy of the Gulf Coast (compiled from Jones, 1967, and Eargle, 1955, and Heron)

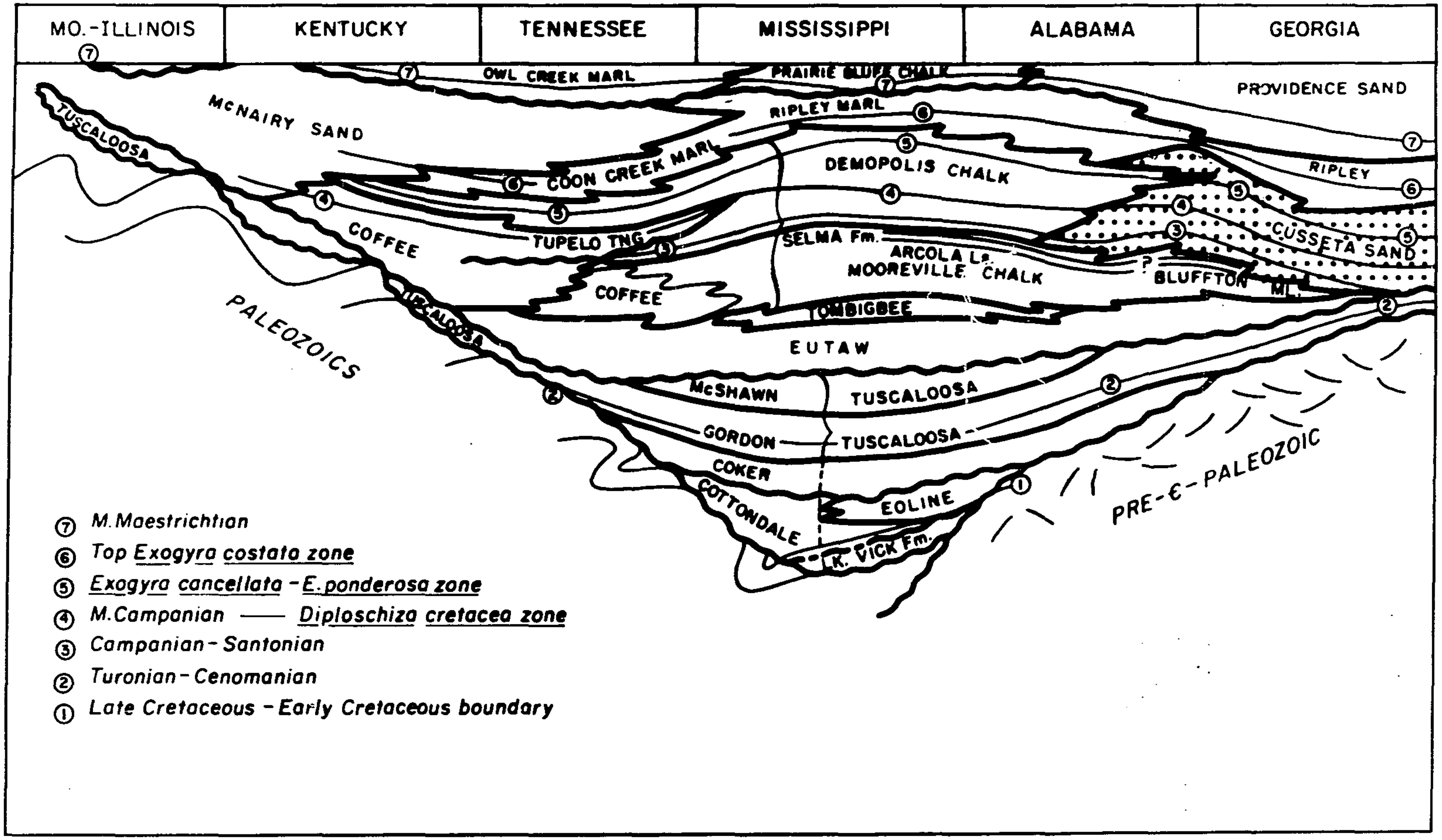


Figure 4 - Facies relationship of Cusseta sand with synchronous and diachronous Upper Cretaceous formations of the Gulf Coast and Mississippi Embayment (Pryor 1967, personal communication)

Stephenson (1911) described the Cusseta Sand as the basal member of the Ripley Formation. Stephenson and Monroe (1938) gave the Cusseta Sand formational rank because of marked lithologic difference from the overlying Ripley and a disconformity with the underlying Blufftown. In Alabama the Cusseta is considered the basal member of the Ripley because the boundary with the overlying Ripley is not distinct. In Georgia the Cusseta is considered by Eargle (1955) to be a mappable lithologic unit which can definitely be differentiated from the overlying fossiliferous Ripley Formation. Thus the Cusseta Sand in western Georgia has formational rank.

Areal extent

According to Eargle, the Cusseta Sand can be traced as a lithologic unit from the region of the Chattahoochee River as far east as Flint River. Here its lower boundary becomes indistinct with the underlying Blufftown which has taken on a coarse clastic character. The outcrop belt ranges from approximately 3 to 7 miles in width.

Lithology

The Cusseta Sand, according to Eargle (1955), lies unconformably on the fine sand and clay of the Blufftown formation. Near the Chattahoochee River workers from the past have reported that the basal Cusseta consists of a coarse glauconitic sand containing waterworn shells of *Ostrea pratti* and lignite fragments. Because of inundation of these localities resulting from the damming of the Chattahoochee River, these observations could not be made in this investigation.

Down-dip from Cusseta, Georgia, into the Chattahoochee River area of Quitman County, Georgia, the Cusseta sands take on a distinct marine character. Up-dip in the area of Cusseta, Georgia and east the Cusseta is chiefly coarse sand with kaolinitic clay galls and infrequent lenses of kaolinite. Generally the Cusseta Sand is differentiated from the underlying Blufftown on the basis that the Blufftown is characterized by fissile dark-gray, carbonaceous clay interbedded with fine to medium grained sand. Eargle (1955) states that in Marion County, Georgia "the coarse sand also contains white kaolinitic clay balls, scattered and in layers, and has conspicuous deltaic cross-bedding...". The base of the Cusseta Sand cannot be recognized east of Flint River nor can the upper boundary with the Ripley be recognized east of Macon. In this area the entire Upper Cretaceous has been defined as a coarse clastic and has been simply called "Upper Cretaceous Undifferentiated" by Eargle (1955, fig. 2). However, because this relatively thin sequence of fluvial material is lithologically so similar to the Middendorf Formation in South Carolina, it has been suggested by Snipes (1954) that the name Middendorf be applied to these sediments in central and eastern Georgia (Fig. 5).

Cusseta Sand of Alabama

In eastern Alabama the medium to coarse sand described as basal Cusseta grades upward into marine calcareous carbonaceous clays which are in turn overlain by fine-grained, fossiliferous, clayey sands of the Ripley. The medium to coarse sand in Russell and Barbour Counties, Alabama is apparently the western extension of the Cusseta Sand of Georgia.

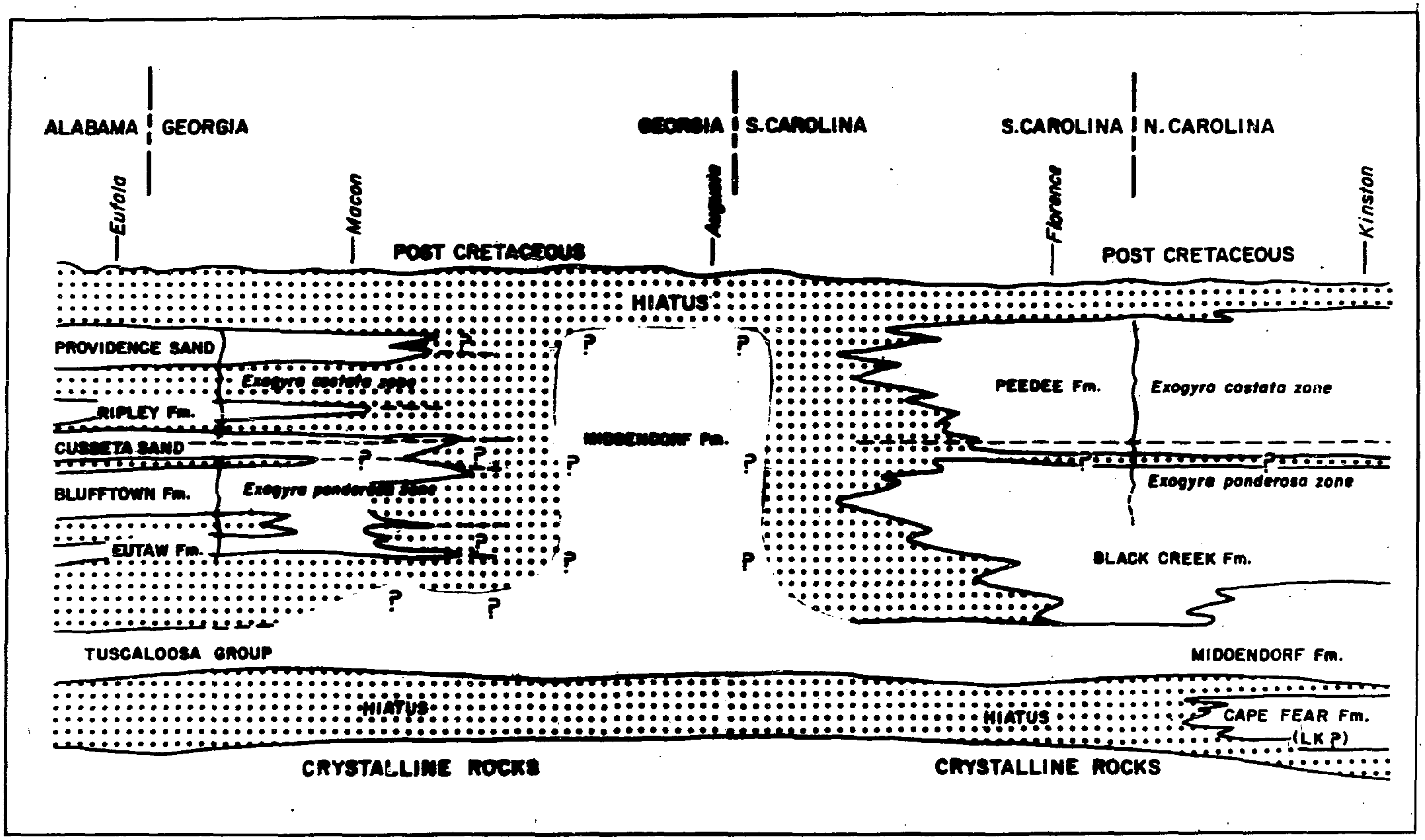


Figure 5 - Generalized stratigraphic relationship of the Upper Cretaceous formation from Alabama to North Carolina (Brett, 1967)

Farther to the west, however, the Cusseta sand loses its identity as a coarse, gritty, cross-bedded, non-fossiliferous sand and becomes marine in nature.

In northern Barbour County and in Russell County the basal sand grades upward into white fine sand which is followed by interbedded lenses of fine and very coarse sand (Eargle, 1950). In northern Barbour County and eastern Bullock County fine sands containing abundant Ophiomorpha borings and thin-shelled mollusks appear 40 to 50 feet above the base of the Cusseta. In central Bullock County just west of Union Springs, Alabama the basal Cusseta is reported by Monroe, 1941, as being fine-grained and containing waterworn shells of Ostrea pratti, shark teeth and bone fragments. Although west of this area, the basal sands grade into silty clays of the Demopolis Chalk, and other sands, some of which are glauconitic and fossiliferous, appear higher in the section and persist as far as Ada, in Montgomery County, Alabama. Here the Cusseta Sand changes facies to the Demopolis Chalk.

The Cusseta Sand was determined to be approximately 185 feet thick in the Chattahoochee River region of Georgia and approximately 125 to 135 feet thick (including the overlying calcareous silty clays) in eastern Bullock County, Alabama.

Ripley Formation

The Ripley Formation represents a marine transgression in both Alabama and Georgia which was probably one of the most extensive of the marine invasions of Georgia in Upper Cretaceous time; spreading conformably over the Cusseta Sand (Eargle, 1955). Its lithology is one of fine-grained, calcareous, often very fossiliferous, usually glauconitic, clayey, micaceous, calcareous, marine sand. In western Georgia this unit is approximately 100 feet thick.

Discussion of Stratigraphy

It has been determined from this study that the Cusseta Sand should not be considered as a basal unit of the Ripley Formation because it was not (for the most part) derived as a result of Ripley transgression. It is, rather, genetically related to the Blufftown Formation in such a way that the Cusseta Sand represents the uppermost phase of the positive deltaic cycle of the Blufftown. The unconformities at the "so called" base of the Cusseta Sand are overemphasized. Too often this unconformity is not present or distinguishable and where found does not occur as a result of transgression. To consider a coarse sand as thick as the Cusseta (185 feet thick in the Chattahoochee River region, Eargle, 1955) as the basal member of a transgressive phase is untenable. For most basal sands resulting from transgression are but a few feet in thickness.

The unconformities at the "so called" base of the Cusseta Sand, which are infrequent and discontinuous, occur as channels in some large outcrops where their dimensions can be observed (Pe-3a, Lg-1, Plate I, and Figs. 35 and 32). The channels commonly display coarse gritty, pebbly material, sometimes iron cemented sandstone slabs and angular fragments. The sand displays distinct by-modal cross-bedding at section Pe-3. At other localities the unconformities occur as coarse, gritty, poorly sorted sand overlying moderate to well sorted, fine to medium grained sand, often containing abundant Ophiomorpha borings and sometimes, as at Pe-3a Cusseta, Georgia, displaying a mode of cross-bedding diametric to that interpreted for the direction of sediment transport (Fig. 24).

Because of the position of the lower part of the Cusseta Sand with respect to the Upper Blufftown Formation, the basal Cusseta Sand is interpreted here as being channel-like in origin; tidal, estuarine and fluvial in a West to East direction. It is concluded, therefore, that the Cusseta Sand represents a terminal phase of a regressive sequence rather than the basal unit of a transgressive cycle.

Biostratigraphy

Correlation

A generalized investigation of the paleontology was made in order to establish the stratigraphic relationship of the Cusseta Sand with other units in the Upper Cretaceous of Alabama and Georgia. Most of the following information, especially the identifications and ranges were drawn from the literature. Particular reference is made to Stephenson (1914) and Cushman (1946).

Complete descriptions of the paleontology of the Selma, Coon Creek, Ripley, Mooreville, Demopolis and Blufftown are given by Stephenson (1914), Wade (1926), Cushman (1946), Stephenson (1956) and Loeblich and Tappan (1957).

Stephenson (1914) used three major faunal zones in the Upper Cretaceous of the Atlantic and Gulf Coastal plain for regional correlation: (1) Exogyra ponderosa zone, (2) Exogyra cancellata zone and (3) Exogyra costata zone (Fig. 6).

The Cusseta Sand and Demopolis Chalk in eastern Alabama are included entirely in the Exogyra ponderosa zone, while the Ripley Formation falls in the Exogyra cancellata and Exogyra costata zones. West of Union Springs, Alabama, Exogyra ponderosa is still found in the lower part of the Cusseta Sand (e.g. Dg 1-15 Pine Level, Montgomery Co., Ala., Fig. 25) however, in the upper Cusseta of sections Cg-la, Eg-1 and Fg-1 (Plate I and figures 26, 27, 28), Exogyra costata has been found by W. A. Pryor and the author. This suggests that the Cusseta Sand is very likely time transgressive to the west.

To further verify the stratigraphic position of the Cusseta Sand

Faunal Zone	European Type Section	American Stand. Section	Eastern Alabama
Exogyra costata	Maestrichtian	Navarro Group	Providence
			Ripley
Exogyra ponderosa	Campanian	Taylor marl	Cusseta Demopolis
	Santonian	Upper Austin Chalk	Blufftown

Figure 6 - *Exogyra costata* and *Exogyra ponderosa* zones of Stephenson and King, 1942 (modified from Monroe 1946)

in this area, the foraminifera from the Blufftown Formation, Demopolis Formation, Cusseta Sand and Ripley Formation were listed according to the Exogyra zone or zones in which they occur (table 1).

The bulk of the faunal evidence listed above illustrates that the Upper Blufftown, Upper Demopolis and Cusseta of Bullock and Montgomery Counties, Alabama were deposited during upper Taylor or upper Campanian time while the Ripley of Montgomery County, Alabama was deposited during lower Navarro or Maestrichtian time.

This biological evidence that the Cusseta Sand was deposited during upper Taylor time in the area of Pine Level, Alabama is important because this sediment undergoes such a pronounced facies change from western Georgia to Montomgery County, Alabama that lithologically it could easily be mistaken for the Ripley Formation. Thus the presence of Exogyra costata in the Cusseta Sand of Montgomery County, Alabama, observed by W. A. Pryor and the author, is probably a result of the convergence of these two zones. The lithology which occurs at the top of the Cusseta in the Pine Level area is probably an isopic facies of identical lithologies found lower in the Cusseta section to the east. This unit, then, in its migration westward, is transgressing time.

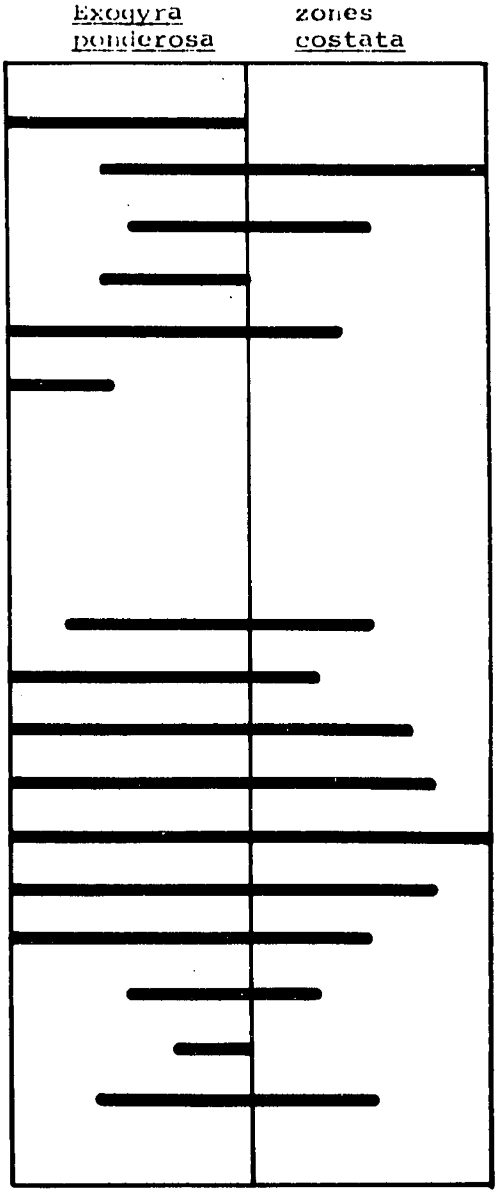
Table 1 - Faunal zones of Foraminifera from the Blufftown, Demopolis Cusseta and Ripley of Bullock and Montgomery Counties, Alabama

FAUNAL LIST

Phylum	Protozoa
Class	Sarcodina
Order	Foraminifera

Upper Blufftown Fm.

Conecuh Falls, Union Springs, Ala.



Kyphopyxa christneri

Robulus pondi

Robulus stephensoni

Robulus taylorensis

Vaginulina wadei

Valvulineria cf. *infrequens*

Upper Demopolis and Cusseta
Dgl-1 through Dgl-14
Pine Level, Ala.

Bolivina cretosa

Bulimenella carseyae

Bulimina kickapooensis

Bulimina reussi

Dentalina gracilis

Dentalina legumen

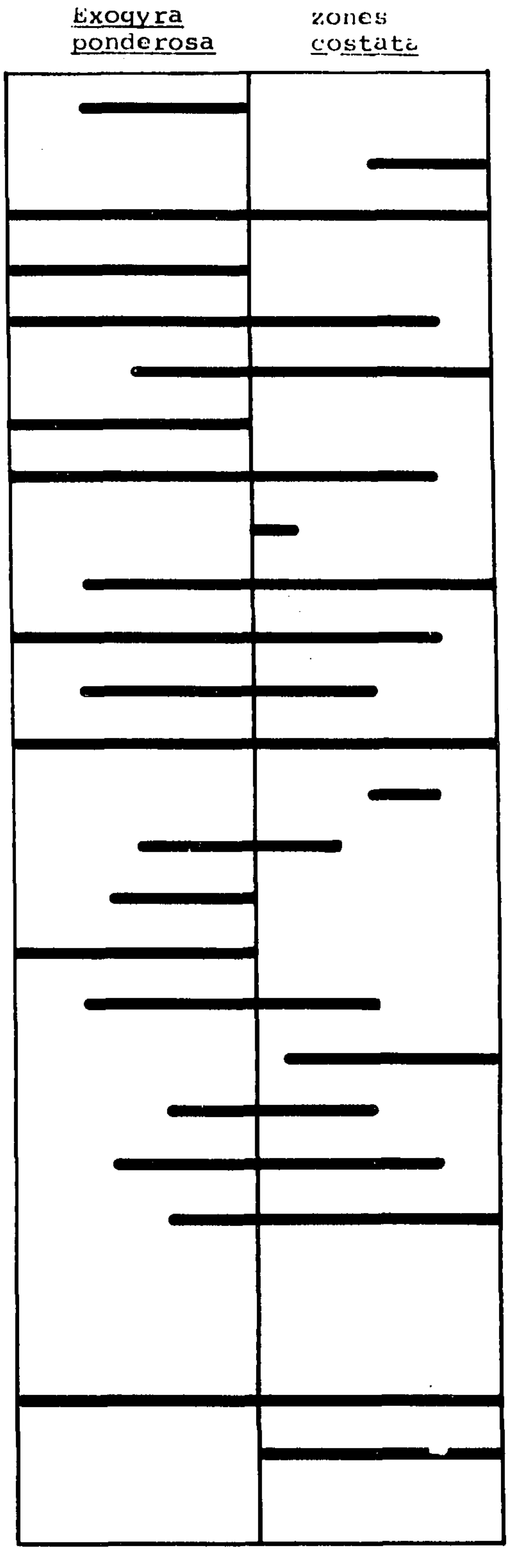
Dentalina lorneiana

Dentalina megapolitana

Dorothia concinna

Dorothia pontoni

Table 1 - (cont.)



Flabellammina compressa

Gaudryinella pseudoserrata

Globigerinelloides aspera

Globorotalia micheliniana

Globulina lacrima

Gumbelina costulata

Gumbelina pseudotessera

Gumbelina striata

Lagena vulgaris

Loxostoma plaitum

Neobulimina canadensis

Neobulimina spinosa

Nodosaria affinis

Nodosaria navarrona

Nodosaria obscura

Nodosaria probiscidea

Nonionella austinana

Nonionella cretacea

Nonionella robusta

Pseudopolymorphina incerta

Pullenia americana

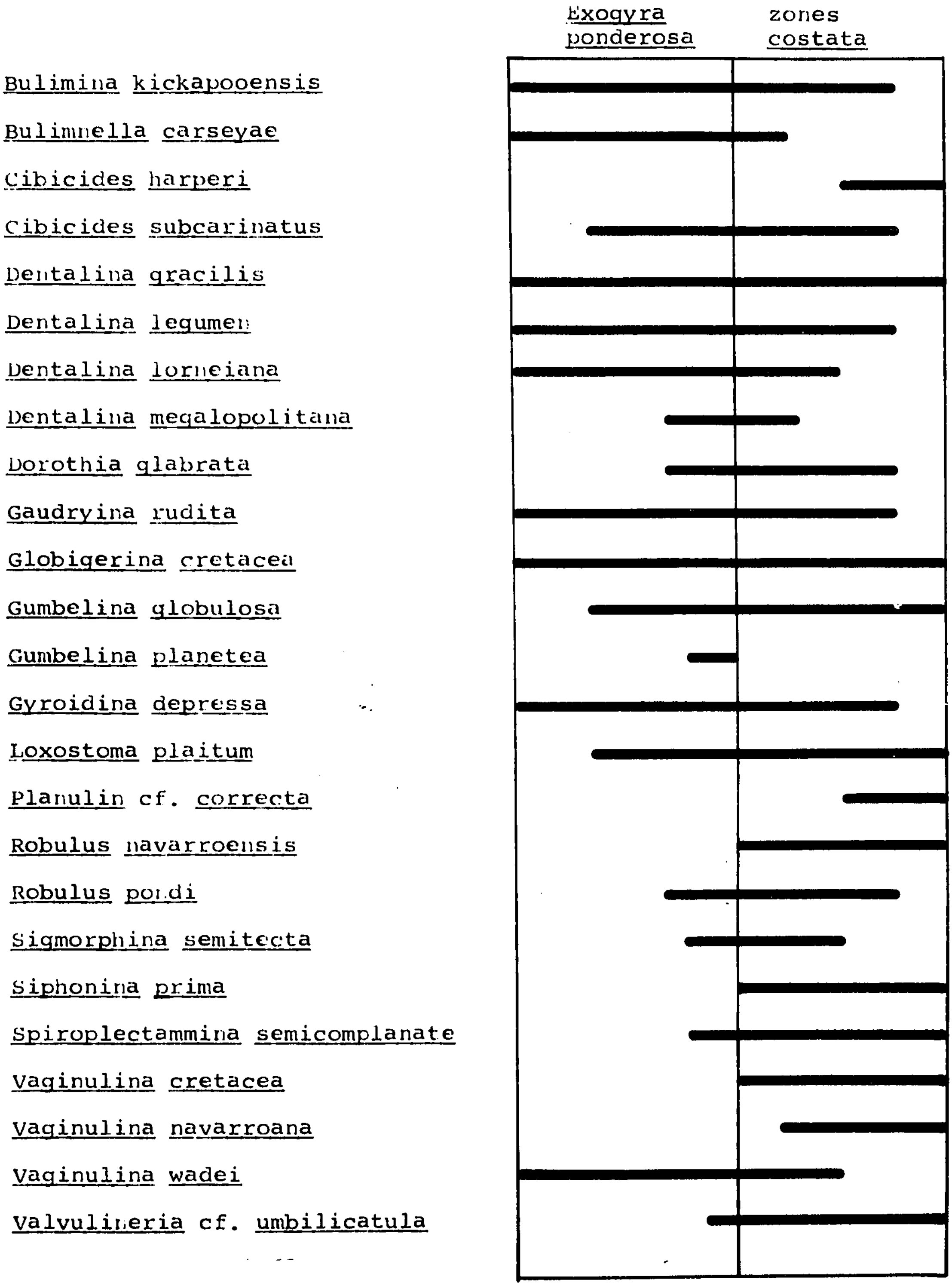
Spiroplectammina semicomplanata

Ripley Fm.

Anomalina nelsoni

Anomalina pseudopapillosa

Table 1 - (cont.)


Exogyra zones
ponderosa
costata
Bulimina kickapooensis
Bulimnella carseyae
Cibicides harperi
Cibicides subcarinatus
Dentalina gracilis
Dentalina legumen
Dentalina lorneiana
Dentalina megalopolitana
Dorothia glabrata
Gaudryina rudita
Globigerina cretacea
Gumbelina globulosa
Gumbelina planetea
Gyroidina depressa
Loxostoma plaitum
Planulin cf. correcta
Robulus navarroensis
Robulus pondi
Sigmorphina semitecta
Siphonina prima
Spiroplectammina semicomplanate
Vaginulina cretacea
Vaginulina navarroana
Vaginulina wadei
Valvulineria cf. umbilicatula

PALEOECOLOGY

Introduction

As a geologist attempting to reconstruct the depositional history of a sedimentary sequence it would be indeed "foolish" to ignore any parameter that would be of aid in meeting this end. Although it was not the original purpose of this sedimentary petrologist to become entangled in the cumbersome problems of biostratigraphy and paleoecology, it became apparent that in the marine western extension of the Cusseta Sand, parameters used in the area to the east for environmental interpretation would no longer suffice.

Even though studies of the clay mineralogy, dispersal patterns and basin geometry were adequate for making regional paleogeographic reconstruction, it was found necessary to use the fauna in order to make more detailed interpretations of sedimentary environment. The following will include brief discussions of the usefulness of micropaleontology (Foraminifera), macropaleontology and trace fossils for this purpose.

Micropaleontology

As a result of the detailed studies of the ecology and distribution of Recent Foraminifera afforded by Phleger (1955), Phleger and Parker (1951), Bandy (1956), Lowman (1949), Shepard (1956), Shepard and Moore (1954), Smith (1955), and Walton (1964), it has become possible to perform paleogeographic reconstruction based upon a careful study of the microfauna. By using the information of the above studies, paleoecological reconstructions of the Cretaceous sediments have been worked out by Clark and Bird (1966), Albritton et al. (1954), Brett and Wheeler (1961) and others. Of the above, only Brett and Wheeler (1961) made an effort to combine studies of the micropaleontology and the sediments.

It is here considered that only through a careful study of the sediments integrated with a study of the fauna entombed within them, can meaningful paleogeographic reconstruction be accomplished. It is the purpose of this section to discuss some of the advantages and disadvantages of various parameters used for reconstruction and to describe the method in which they were incorporated in this paper.

The generalized paleoecological interpretations drawn in this study are based on the premise that overall population characteristics and generic distributions are valid in sediments as old as the Cretaceous (Walton, 1964). Phleger (1960) clearly points out that sometimes there are problems in correlating Recent assemblages, which may be compounded when attempting to deal with ancient sediments. According to Phleger (1960, p. 255), most of the older assemblages are not similar to Recent ones which is apparently true for this study. Phleger also cautions that some genera from older sediments may have had an altogether different ecological setting than their present equivalents. Interpretation becomes particularly difficult when attempting to base reconstructions on extinct genera and species. Although differences of opinion exist concerning the usefulness of foraminifera for paleoecological reconstruction, certain generalizations can be made which are accepted as useful by most workers.

Parameters considered useful for obtaining ecologic information (according to Phleger, 1960) may be derived from studying:

(1) planktonic to benthonic ratio
(2) number of benthonic species and genera
(3) per cent of arenaceous specimens
(4) characteristic benthonic genera.

The most useful criteria for extrapolating modern environments into the geologic past (according to Walton, 1964) are:

(1) generic distribution
(2) generic dominance
(3) distribution of (most) dominant genera
(4) diversity of the fauna
(5) arenaceous or calcareous nature of the fauna
(6) abundance of planktonic forms.

In this study only the faunal dominance, planktonic to benthonic radio and number of benthonic genera were utilized as an aid in reconstructing the sedimentary environment.

Faunal Dominance

Faunal dominance is determined by calculating the percent of the most common benthonic foraminifera. Walton (1964) found the following depth relationships using this parameter.

% dominance	% restricted to depth in fathoms	
35%	entire fauna less than 10	
21-30%	36%	10 to 20
	31%	<10
	13%	20 to 50
11-20%	57%	>50
	18%	1 to 20
	20%	20 and 50

% dominance	% restricted to depth in fathoms	
<10%	92%	>50
	8%	20 and 50

Detailed study of the Pine Level, Alabama section (Dg 1, Plate I) illustrates that the dominant benthonic genera are represented by a single species. Therefore, this principle is equally applicable at the generic level (Alexander, 1968).

Planktonic to Benthonic Ratio

The percent of planktonic tests in the total foraminiferal assemblage is related to the proximity of an open marine environment (Phleger, 1960; Walton, 1964; Bandy, 1956; Smith, 1955). However, planktonic foraminifera are strongly controlled by various physical elements of sedimentary processes, particularly wind and current.

According to Phleger and Parker (1956) the following depth zonation can be derived from the percent of planktonic foraminifera.

% planktonic	bathymetric range in fathoms
< 10	< 25
11-30	25-50
31-50	50-250

Although depth is considered in general to be a measure of distance from the open sea, it must be remembered that the proximity to detrital source or relatively high run-off is what ultimately controls open marine conditions. Thus with little run-off and in the absence of detritus, open ocean waters can occur in very shallow, near-shore areas (Phleger, 1960). In sampling for foraminifera, in the area of Horn Island, in the northeastern Gulf of Mexico, Smith (1955) found no planktonic foraminifera landward of the barrier island which is approximately seven miles from the mainland. Yet, in a zone 1 to 2 miles seaward of and parallel to Horn Island, planktonic foraminifera were recovered from 12 of 21 samples. This suggests that open marine conditions are present in very shallow water in areas seaward of the barrier island. Currents or onshore winds are probably responsible for the presence of the planktonics in this environment.

Number of benthonic genera

The number of benthonic genera is related in general to bathymetric zonation. As marginal-marine conditions are approached, the environment becomes more variable and numbers of genera decrease. According to Phleger (1960), the following environments can be recognized using this parameter:

Zone	Depth in Meters	Number of Genera
Turbulent zone	0-20	< 5
Inner continental shelf	20-60	5-15
Outer continental shelf	60-100	20-30
Upper continental slope	100-1000	20-30

Bathymetric Zonation and Distribution

Genera found in significant abundance in the Cusseta Sand which range into the Recent are listed below with notes related to their distribution and ecology.

Bulimina	wide range from 10 to 100 fathoms (Lowman, 1949), Walton (1967) uses this genus as an indicator of

depth greater than 300 fathoms.

Buliminella	Shepard (1956) states that this genus is one of the indices of the Open Gulf environment. Phleger (1960) finds it as one of the most common forms on the inner continental shelf (10-30 fathoms).
Cibicides	shallow to deep, greatest abundance in depths less than 300 feet, make up more than 15% of assemblages in depths less than 20 fathoms (Lowman, 1949).
Epistominella	characteristic of depths of 30-100 fathoms (Walton, 1964); characteristic of open gulf east of the Mississippi delta (Shepard, 1956); deltaic marine (Phleger, 1960).

The absence of Bolivina in the Dg 1 Pine Level, Alabama section is anomalous, when it is found to be so common in Recent sediments from lower lagoon to lower slope. Yet, Bulimina, which is restricted to the upper continental slope and deeper (300 fathoms, Walton, 1964), is found in every sample of the Dg 1 section with the exception of Dg 1-1 and Dg 1-3. This certainly suggests that these genera no longer occupy the same zones as they did in Cretaceous time. This places doubt on their usefulness as paleoecological indicators. Genera that are extinct but have families ranging to the Present follow with notes on distribution.

Globigerinelloides	Globigerinid type, shallow to deep - 5% at 150', 40% at 500' (Lowman, 1949).
Anomalinoides	extinct, but belongs to the Family,

	Anomalinidae, which includes the following modern genus: *Anomalina*; for most part shallow water but not abundant in the Recent (Brett and Wheeler, 1961).
Neobulimina	extinct, but belongs to the Superfamily Buliminacea which includes the following modern genus: *Buliminella*; depth range of 2 to 10 fathoms (Walton, 1964). Phleger (1960) lists it as characterizing the inner continental shelf (10-30 fathoms).

Because *Neobulimina* and *Anomalinoides* belong to families with genera that are characteristic of relatively shallow water, this suggests that the sediments in which these forms are found were also deposited in shallow water.

Even though the family of the following genus is extinct it has been used by some workers for paleoecological interpretation.

Heterohelix	marine pelagic (Glaessner, 1963), found in shallow to deep water sediments (Brett and Wheeler, 1961). An assemblage of *Heterohelix*, *Bolivina*, *Anomalinoides* and *Neobulimina* was interpreted by Wall (1967) to indicate an outer neritic environment.

Megascopic Paleontology

Genera of the megafauna which range into the Recent are very useful as paleoecological indicators because of the studies of the habitat and occurrence of Recent genera by Parker (1956), Shepard (1956), Shepard and Moore (1955), Kauffman (1967), and others.

Unfortunately, while doing the field work for this study, only a limited number of the most abundant and easily identified genera were collected. However, collections and identifications by Monroe (1941) from the Blufftown, Cusseta and Ripley of Georgia and Alabama provides a list of the most common macrofauna present in the units (table 2). Only a very limited number of the forms which range into the Present were utilized for paleoecological interpretation. A list of the genera and comments concerning their occurrence is as follows:

Anomia: marine epifauna - intertidal or nearshore subtidal (Brett and Wheeler, 1961); 20-50 feet (Kauffman, 1967).

Ostrea: marine epifauna - intertidal zone and just off shore (Brett and Wheeler, 1961); 20-50 feet (Kauffman, 1967).

Cardium: marine infauna, near shore in shallow water Brett and Wheeler (1961) common near shore form (Kauffman, 1967).

Turritella: marine infauna, just off shore for most part, but range from 1-100 fathoms. (Brett and Wheeler, 1961) middle shelf clay facies (Kauffman, 1967).

Table 2

Some Diagnostic fossils of the Blufftown, Cusseta and Ripley of Alabama

- *Exogyro ponderosa*
- *Exogyra cancellata*
- *Exogyra costata*
- *Gryphaea mutabilis*
- *Gryphaea convexa*
- *Paranomia scabra*
- *Anomia argentaria*
- *Anomia tellinoides*
- *Ostrea plumosa*
- *Ostrea tecticosta*
- *Ostrea falcata*
- *Ostrea larva*
- *Ostrea subspatulata*
- *Ostrea battersis*
- *Ostrea pratti*
- *Terebratulina filosa*
- *Cardium* sp.
- *Turitella* sp.
- *Pecten* sp.
- *Gyrodes* sp.
- *Baculites* sp.
- *Inoceramus* sp.

Trace Fossils

Trace fossils occurring in the form of burrows are very useful tools as aids in making environmental interpretation because the types are directly related to the energy of the environment (Howard, 1966).

The ichnofossils of the Upper Cretaceous of the Book Cliffs and Wasatch Plateau were placed by Howard (1966) in four groups based upon the biogenic texture of the sediment. It is felt that this same general classification, with the exception of surface markings, can be applied to the marine Cretaceous sediments of this study.

The first group defined by Howard is a sediment with highly mottled texture in which the organisms have so profoundly altered the fine-grained clastic that primary structures are completely absent. This is characteristic of much of the Blufftown facies (e.g. Dg 1-1 through 3, Pine Level, Ala.) which is a clayey, sandy, very micaceous, highly carbonaceous, lignitic silt with abundant small pelecypods. This sediment is thought to be characteristic of a low energy environment where the water was turbid and slow-moving, allowing the fine organic material to settle. The presence of small burrowing pelecypods, low generic diversity of the benthonic foraminifera, the infrequent appearance of clean sorted sands and the absence of remains of filter feeders lends support to the interpretation of an environment in which the bottom conditions were not attractive to most bottom fauna, thus representing a restricted environment.

A second type of ichnofossil is found in the cleaner, better sorted, coarser sand and is characterized by the more coarsely mottled texture with distinct burrows (e.g. Dg 1-16 and 17 Pine Level, Ala.). The fauna, for the most part, is composed of detritus feeders and filter feeders (Howard, 1966). Based on the presence of filter feeders mixed with detritus feeders, the environment is interpreted as one with slightly higher energy, allowing for removal of much of the fine detrital organic material.

Another assemblage of organisms is represented by filter feeders only. These burrow building animals characterize an environment of high energy where the sediments are relatively well sorted (sands composing 85% of the sediment), free of organic debris and commonly cross-bedded. Examples of this environment have been observed at many of the localities, including Dg 1-28 and 29, where abundant borings of *Ophiomorpha* are found in clean, well-sorted sands.

Ophiomorpha is of particular interest in this paper (Figs. 7 and 8). This ichnofossil was first described by Lesquereux as *Halymenites major* but this name has since been found to be invalid. Later the name *Callianassa* was applied to this structure because the Recent decapod *Callianassa* constructs a seemingly identical burrow (Figs. 9 and 10). Because other decapod genera have not been known to survive over great lengths of geologic time it is doubtful that this name would apply to Cretaceous ichnofossils even though it is still in use today. The term *Ophiomorpha*, which was first used in Sweden, is now the accepted name (Toots, 1961). Weimer and Hoyt (1964) have illustrated the similarity of *Ophimorpha* to its modern counterpart *Callianassa major* (Say). Because *Callianassa* has been found only in the tidal and very shallow subtidal zone, *Ophiomorpha* is considered to be an excellent indicator of a very shallow marine environment. Personal observations of abundant borings of

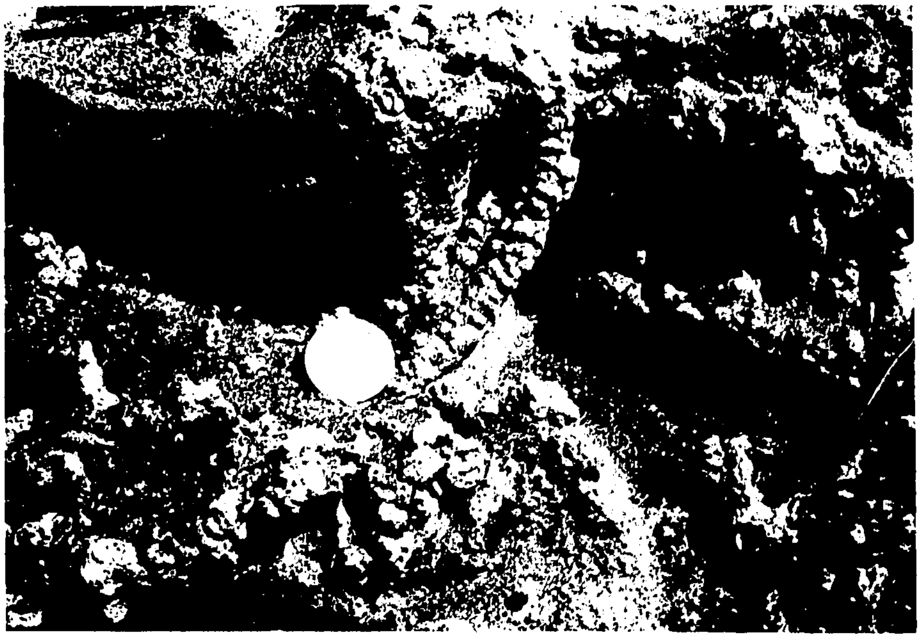


Fig. 7. Ophiomorpha borings from the Upper Cretaceous Cusseta Sand (Pine Level, Ala.). Note the "knobby" character of the boring.

Fig. 8. Ophiomorpha borings in an intensely weathered outcrop of the Cusseta Sand; particularly abundant in the lower left of photo.

Fig. 9. Opening to Callianassa tube surrounded by fecal pellets.

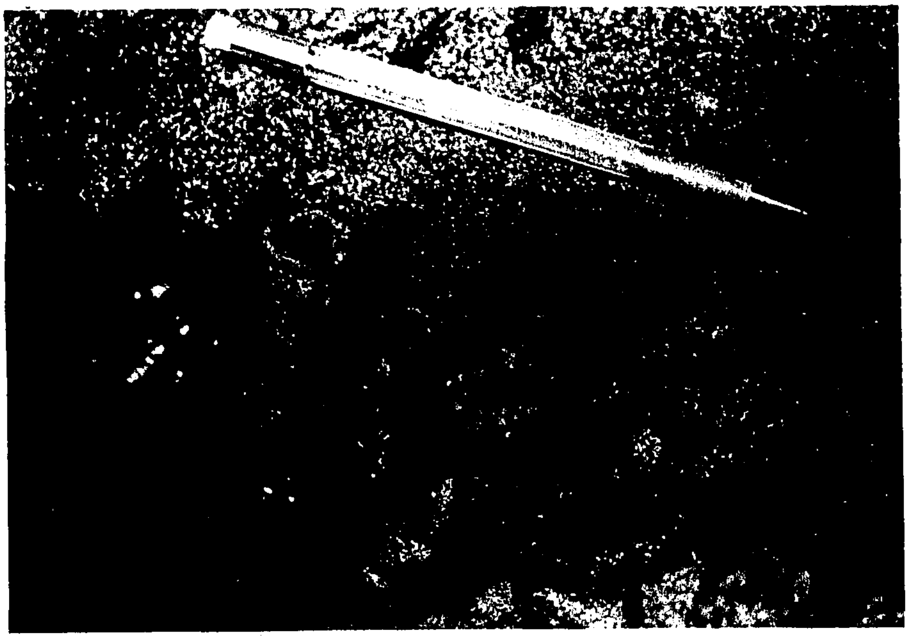


Fig. 10. Washed Callianassa boring (in place) illustrating "knobby" surface.

Callianassa by W. A. Pryor and the author on the beach fronts and backs barriers on the northeastern Gulf Coast (Figs. 11 and 12) certainly supports the interpretation by Weimer and Hoyt. Furthermore, because Ophiomorpha has been found (in this study) only in clean, rather well sorted sands, often displaying low and high angle cross-bedding, this trace fossil most likely characterizes high energy zones such as that represented by the beach or barrier environments. In this paper Ophiomorpha is used as a marker for the "Barrier Island" sand facies.

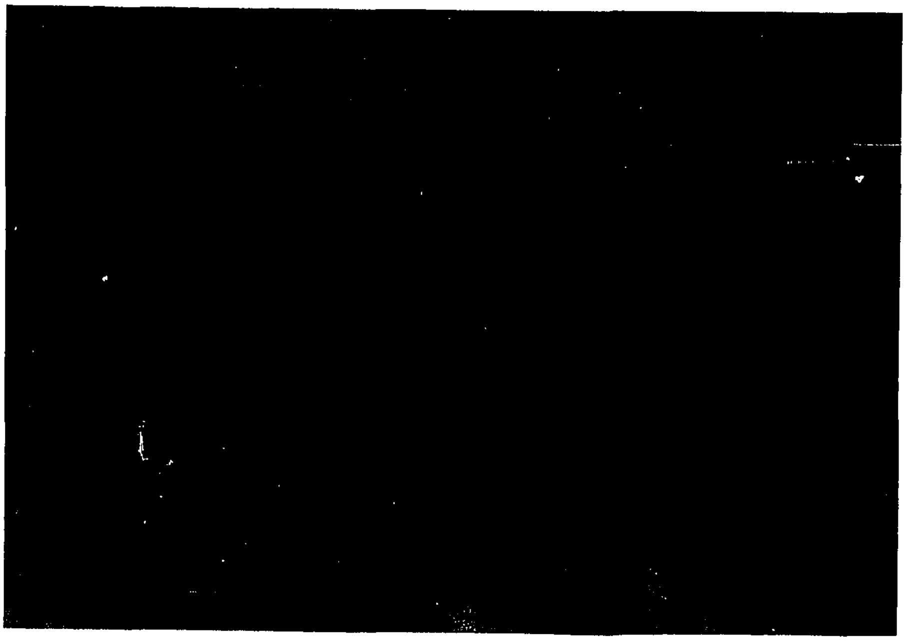


Fig. 11. Callianassa tubes in very shallow water partially exposed by action of surf.

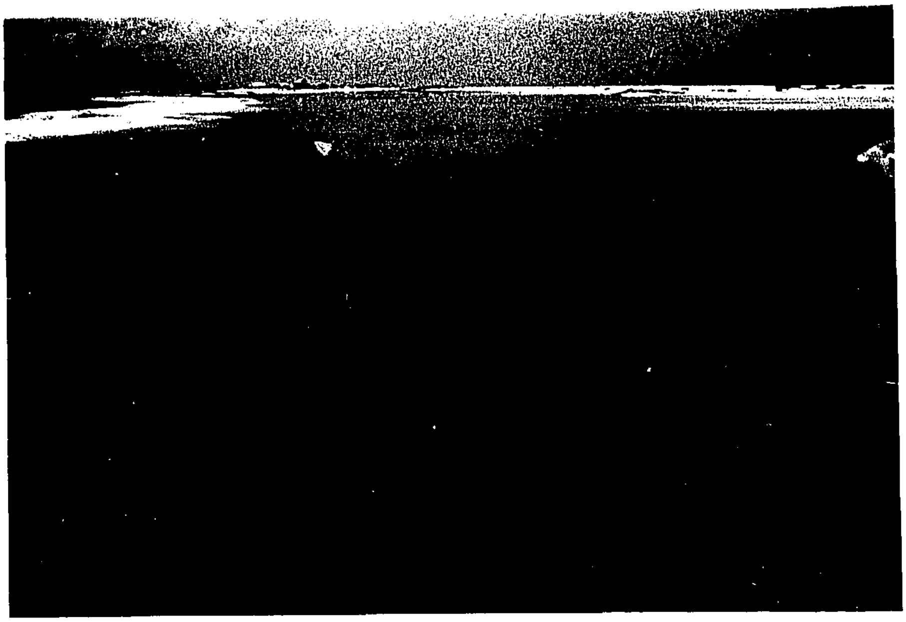


Fig. 12. Barrier bar environment where the Callianassa is found in abundance (Northeastern Gulf Coast, Ship Island).

PETROLOGY

Heavy Mineralogy

Purpose

In an effort to determine provenance and regional dispersal patterns of the Upper Cretaceous, the heavy minerals were analyzed by optical and X-ray methods. The X-ray method was investigated for the purpose of finding a rapid way of making general routine analysis of large numbers of samples. Actual mineral identification and percentage could then be determined by optical means for a relatively small number of samples. It was also thought that after knowing what minerals to expect, perhaps actual mineral identification could also be performed for the major constituents of a heavy mineral suite.

Sampling Methods

Samples were taken at 15-20 mile intervals in the vicinity of the Cusseta Sand outcrop (Plate 1). Samples in the upper part of the Upper Cretaceous, but not known to be of equivalent Cusseta age, were taken at less frequent intervals from Missouri around to North Carolina. Some samples of the Blufftown, Ripley, Providence and Tuscaloosa Formations were also incorporated to determine the general relationship of the Cusseta provenance of that of other units in the Upper Cretaceous.

In order to avoid problems such as the hydraulic factors of Rittenhouse or the granular variation of Van Andel, a "trench" sampling method was used. In this way the entire size range would be incorporated. This is termed "Normal Analysis" by Van Andel (1950).

Lab Methods

The sieve fraction between $\frac{1}{4}$ mm and 1/16 mm was utilized for heavy mineral separation. Bromoform with specific gravity 2.86 @ 25° C. served as the heavy liquid. After the first separation the heavy mineral fraction was boiled in concentrated HCl for 2 minutes after which the sample was again run in bromoform.

Before preparing petrographic and X-ray slides the sample was passed through the Franz separator at a setting of .45 amps and 20° side slope to separate the strongly magnetic minerals. This includes magnetite, pyrrhotite, limonite, garnet, olivine, chromite and chloritoid.

The remaining, less magnetic, sample was split on a micro splitter. One half was mounted in Hyrax (1.71) index of refraction) for petrographic study. The other portion was ground with agate mortar and pestle to less than 37 u, mixed in Duco cement and mounted on a glass slide for X-ray diffraction study. The material was mixed in Duco cement so as to avoid preferred orientation of the mineral grains.

The X-ray equipment used was the GE XRD-5 using copper radiation, 40 KV, 16 ma. The scan of the goniometer covered from 6° - 70° at 2 degrees per minute.

The petrographic analyses consisted of making line counts of 200 grains per slide. The tourmaline shapes were studied in order to determine the angularity to roundness ratio. The break between the subrounded and rounded classes of Powers (1953) was used to differentiate angular from rounded grains. The following minerals were recognized and counted: 1 - Rutile, 2 - Tourmaline, 3 - Zircon, 4 - Staurolite, 5 -

Kyanite, 6 - Epidote, 7 - Sillimanite, 8 - Hornblende, 9 - Titanite, 10 - Muscovite, 11 - Garnet, 12 - Monazite, 13 - Leucoxene, 14 - other (table 3).

Discussion

The reliability of the present heavy minerals assemblages actually being true provenance indicators must be considered in the light of certain factors which may modify the mineral association. These factors are (1) weathering, (2) abrasion, (3) selective sorting and (4) post depositional solution.

Because the Upper Cretaceous represents a time of relative tectonic quiescence and since the climatic conditions were rather hot and humid (Pryor, 1959), weathering and abrasion most probably had some influence on the heavy minerals made available for deposition. Thiel (1945) in a study of selective abrasion found that it is possible to arrange heavy minerals in an order of resistance to abrasion as shown in figure 1, column 1. Column 2 is a list of heavy minerals found by Stow (1939) in his study of the James River. The heavy minerals identified from this study are listed in column 3. With the exception of kyanite the larger part of the heavy minerals in column 3 appears to be present possibly as a result of their greater resistance to abrasion. However, the minerals reported from the James River, which drains the Appalachian sediments, igneous rocks of the Blue Ridge and Piedmont metamorphics provide a suite which is very similar to that found in this study. This suggests then that the absence of the minerals less resistant to abrasion occurs because they were never available. In a

Table 3 - Heavy mineral composition listed in % by count

SAMPLE LOCATION PLATE I	FORMATION	RUTILE	TOURMALINE	ZIRCON	STAUROLITE	KYANITE	EPIDOTE	SILLIMANITE	HORNBLENDE	TITANITE	MUSCOVITE	GARNET	MONAZITE	LEUCOXENE	OTHER	% ANGULAR TOURMALINE
Keownville, Miss.	Ripley	6.5	10.0	5.5	6.0	17.0	39.0	Tr	4.0	1.5	0.5	-	-	5.0	5.0	95
Pine Level, Ala.	Cusseta	25.0	19.0	23.0	11.5	4.5	2.5	-	-	1.5	2.0	-	-	5.5	5.5	87
Union Springs, Ala.	Cusseta	21.0	24.0	17.0	11.5	5.0	3.0	3.5	-	1.0	0.5	-	-	.5	13.0	94
Spging Hill, Ala.	Cusseta	11.5	29.0	10.5	12.0	11.0	1.0	5.0	Tr	0.5	3.5	-	1.0	10.0	5.0	93
Florence, Ga.	Cusseta	16.5	26.5	7.5	19.0	5.0	8.0	6.0	-	-	-	-	-	5.5	5.5	92
Cusseta, Ga.	Cusseta	11.5	41.0	5.5	18.0	12.0	0.5	3.0	1.5	-	0.5	-	-	6.0	0.5	
Tazewell, Ga.	Cusseta	30.5	22.5	12.0	5.0	14.0	1.5	0.5	-	1.0	1.0	-	1.5	6.5	4.0	100
Butler,	Cusseta	37.0	26.0	13.5	5.0	7.0	2.0	-	1.0	0.5	-	-	-	7.5	1.0	98
Macon, Ga.	Providence	27.0	17.5	14.5	15.5	1.0	2.0	-	-	-	1.0	-	-	13.5	8.0	99
Wrens, Ga.	Upper Tusc. Undiff.	6.0	24.5	3.0	58.5	-	2.0	-	-	-	3.0	-	-	1.0	1.0	99

Table 4

EFFECTS OF SELECTIVE ABRASION ON HEAVY MINERAL ASSEMBLAGES

After Thiel 1945 (from least to greatest resistance to abrasion)	After Stow (1939) H.M. Assemblage from James River, Virginia	Portion of H.M. Assemblage from this study
barite		
siderite		
fluorite		
goethite		
enstatite		
kyanite	kyanite	kyanite
bronzite		
hematite		
augite		
apatite		
spodumene		
hypersthene	hypersthene	
diallage		
rutile	rutile	rutile
hornblende	hornblende	
zircon	zircon	zircon
epidote	epidote	epidote
garnet	garnet	garnet
titanite	titanite	titanite
staurolite	staurolite	staurolite
microcline		microcline
tourmaline	tourmaline	tourmaline

study of the heavy minerals between Cairo, Illinois and the Gulf of Mexico, Russell (1937) found that abrasion had little effect on the over all mineral assemblage. Because rather complete heavy mineral assemblages are present in Upper Cretaceous of Southeastern United States which are very similar to those reported from the Appalachain Mountains area, it is concluded that modification due to abrasion was certainly not intense.

Weathering causes the decrease of less stable minerals such as augite, garnet, hornblende and epidote and a relative increase in kyanite, staurolite, rutile, tourmaline, and zircon, which represent the more stable constituents. By weathering, according to Van Andel (1959), it is conceivable to convert an association composed dominantly of hornblende-epidote into a kyanite-staurolite-zircon assemblage. In considering the effects of weathering in the source area on the modification of heavy mineral assemblages, Van Andel (1959) considers this to be negligible in basins with a moderate to rapid rate of deposition.

Brophy (1959) in his study of heavy mineral ratios of Sangamon till weathering profiles found that hornblende and garnet were depleted as a result of weathering, particularly in coarse-grained, open-textured outwash. In considering the possibility that post-depositional, subaerial weathering had altered the Cretaceous heavy mineral assemblage, nine samples from a profile along Highway 231 (Dg 1) near Pine Level, Alabama (Plate 1) were studied optically. It was found that garnet changed from a prominent constituent in Dg 1-15 and Dg 1-23, which flooded the assemblage, to complete absence at the uppermost portion of the weathered profile. Because of the strong dominance of rutile, tourmaline, zircon, staurolite, and kyanite and the relative absence of garnet, hornblende and epidote it is concluded that post-depositional, sub-aerial weathering did indeed modify the Cretaceous heavy mineral assemblage.

The control of sorting on heavy mineral assemblages seems to be problematical. Van Andel (1955) found in the Rhone delta that pyroxene was the characteristic mineral of the coarse fraction, hornblende dominated the intermediate position, and epidote was restricted to the finest fraction. Yet Van Andel (1959) reports that the Mississippi delta shows no difference in mineral composition between sandy and clayey deposits. In his study of the Gulf of Paria, Van Andel (1954) concluded that the heavy mineral associations found were not caused by the sorting of a single parent material but represented distinct sediment-petrographical provinces. In this study the effects of sorting (if present) would be obscured partially by the "trench" sampling method and by the fact that a wide range of sizes (0.062 and 0.25 mm) was used.

Because certain constituents occurred in strong percentages (e.g. 58% staurolite in the Wrens, Georgia sample, table 3) the effects of sorting were considered briefly in this study. It was thought that perhaps by measuring actual grain size of various members of the assemblage some light might be shed on why the staurolite appears as the dominant mineral. It is well known that certain minerals show a preference for specific size range such as zircon and rutile which are almost always smaller than the other species. With this in mind the shortest diameter of 32 grains of staurolite, tourmaline, zircon, kyanite and rutile were measured (Table 5). The following averages were found:

Table 5

AVERAGE SIZE OF CHARACTERISTIC MINERALS USING SHORTEST DIAMETER AND 10 POWER OBJECTIVE
(Sample from Florence, S. C.)

Staurolite	Tourmaline	Zircon	Kyanite	Rutile
1.7	2.6	1.5	1.5	1.1
1.6	2.1	1.2	1.3	1.6
2.4	2.0	1.7	1.2	1.5
1.5	2.0	1.8	1.2	1.0
1.9	2.2	1.6	2.7	1.7
1.2	2.6	1.2	2.8	2.1
1.8	1.5	1.2	1.0	1.5
1.8	2.1	1.4	2.2	1.4
2.2	2.9	1.8	2.0	1.1
2.6	2.5	1.4	1.5	1.5
2.0	1.8	1.5	1.3	.7
1.6	1.9	1.3	1.1	1.0
1.4	1.8	1.4	1.5	1.5
2.3	2.1	1.2	1.2	1.5
1.6	2.3	2.0	2.8	1.3
1.5	1.3	2.1	1.8	1.2
1.8	.8	1.4	2.5	2.0
1.4	.9	1.6	1.1	1.1
1.2	1.4	2.2	1.6	1.0
1.9	1.9	2.5	2.0	1.5
1.2	1.2	1.6	1.4	1.5
2.1	2.0	1.3	1.2	1.2
2.6	1.4	1.3	1.1	1.0
2.9	3.4	1.2	2.6	.7
1.2	1.3	1.5	.7	1.1
.9	1.0	.9	.7	2.1
1.4	.8	1.2	1.7	1.4
1.3	.9	1.5	1.8	1.5
2.0	1.4	1.0	1.0	1.5
1.8	1.7	.8	2.1	1.2
2.4	.7	1.3	2.6	1.6
1.3	1.2	1.3	1.9	2.2
1.76	1.74	1.47	1.66	1.38

staurolite 1.76, tourmaline 1.74, zircon 1.47, kyanite 1.66, and rutile 1.38. Because of the similarity in size of staurolite to tourmaline and kyanite it is concluded that sorting is definitely not responsible for the high percentage of staurolite.

Because it is thought that weathering, abrasion selective sorting, and post-depositional solution have relatively small effect on the over all heavy mineral assemblage it can be concluded that heavy mineral associations directly reflect the petrology of the source area.

The heavy mineral assemblage of the samples from Pine Level, Alabama to Fayetteville, North Carolina are very similar although percentages of individual constituents vary. The assemblage consists for the most part of the following (in order of abundance): rutile, tourmaline, zircon, staurolite, kyanite, epidote. Although grain size may in part contribute to the variation in the assemblages, the abnormally high percentages of staurolite in the vicinities of Wrens, Georgia and Florence, South Carolina possibly suggest a different petrographic province.

A different petrographic province is also suggested by the assemblage of the Ripley sample from Keownville. The dominant minerals in order of abundance are: epidote, kyanite, garnet, hornblende. This assemblage is very similar to that reported by Needham (1934) for the Tombigbee member of the Eutaw formation in eastern Mississippi.

Pryor (1959), in his study of the Upper Cretaceous heavy minerals of the Upper Mississippi Embayment, found the following assemblage in order of abundance: kyanite, staurolite, tourmaline, zircon, sillimanite, rutile. If the grain size is not responsible for this difference, then this is a different petrographic province from those above.

In the upper units of the Upper Cretaceous from Illinois to North Carolina, there exists at least three petrographic provinces and possibly more. They are (1) kyanite-zircon, (2) epidote, (3) zircon-tourmaline, (4) staurolite-zircon.

Light Mineralogy

The light mineral sand size fraction was studied optically in conjunction with the heavy minerals in an effort to determine the regional variations in mineralogy and relate these to provenance.

For the most part the Cusseta Sand was used for this study, however it was found necessary to study fresh samples from the Blufftown and Ripley Formations because it is believed by the author that sub-aerial weathering has slightly altered the mineralogy of the Cusseta Sand; particularly those outcrops appearing at deeply weathered, high elevations.

Method

In order to make point counts of the various constituents in the light mineral fraction, an artificial "rock" was made. Using one teaspoon of sand of the light mineral fraction, thoroughly mixed with an equal amount of bakelite, the sand was molded in an AB Specimen Mount Press. This method was finally chosen because: 1) it is rapid - 15 min/mount, 2) it is void of bubbles, 3) there is no need for fabricating containers, and 4) molds are adequate size for mounting on standard thin section slides.

After thin sections were made cobaltinitrite and rhodozonite were used for staining the feldspars following the method described by E. H. Bailey and R. E. Stevens (1960). As a result of etching with HF vapors, silicon is removed as a volatile fluoride, leaving the feldspar as a residue. It is this residue that becomes stained and not the feldspar grains.

In order to stain the potassium feldspar, the thin section is placed in a solution of sodium cobaltinitrite. Substitution takes place between sodium and potassium producing potassium cobaltinitrite which stains the potassium feldspar bright yellow.

Potassium rhodizonate serves as the staining agent for plagioclase (with the exception of pure albite (Na rich silicate)). In this process it it necessary to dip the sample in a barium chloride solution to obtain replacement of calcium with barium. With the application of potassium rhodizonate, cation substitution between barium and potassium produces the brick red stain; barium rhodizonate.

In the staining procedure a problem was encountered when staining with rhodozonite. It was observed that there was a conspicuously fewer number of yellow (potassium feldspar) grains after staining with rhodozonite than before. It was at first thought that perhaps the potassium cobaltinitrite was somehow "trapping" the rhodizonate stain, thus causing an orange color on many of the grains rather than a distinct yellow or red. In an attempt to solve this problem several thin sections were made of one sample (Dg 1) and point counts were carried out at various stages of the staining procedure. In the five thin sections studied the number of feldspars counted ranged in number from 10 to 11 in a count of

100 grains.

From the foregoing experiment it can be concluded that the staining method is reliable for determining the percent of feldspar present. It is often difficult to determine whether the feldspar is potassium feldspar or microcline or plagioclase because the residue largely prevents the transmission of light. It appears that since the relatively same number of feldspars were counted in the samples treated with cobaltinitrite only, and rhodizonate only, that the dominant feldspar is undoubtedly microcline. This is illustrated in a slide which was treated with both stained but uncovered. Here most of the stained grains are orange in color or reddish and yellowish streaked rather than being a distinct yellow or a distinct red. These grains were counted as microcline.

It is noted here that when using epoxy cement for mounting the cover glass, the cobaltinitrite stain appears to be destroyed for the most part and that the rhodizonate stain is partially destroyed. In this case microcline is distinguished by reddish blotches displayed in a somewhat linear fashion. Because the epoxy tended to destroy the stain, Lakeside was used as the cover glass mounting medium.

Using the line point count method, 200 grains of quartz, feldspar, muscovite and polycrystalline quartz were optically identified and counted. The analyses appear in table 6. A separate count was made on 100 quartz grains to determine the percent of angularity. During this count, general observations were also made on grain shape and secondary growth. The extinction qualities were not considered in this study because the author is in agreement with Bailey, Bell, and Ping

Table 6 - Light mineral composition in % by count

SAMPLE LOCATION PLATE I	FORMATION	% NUMBER OF GRAINS IN >.062 FRACTION					ELONGATION	% QUARTZ ANGULARITY
		QUARTZ	FELDSPAR	MUSCOVITE	POLYCRYSTALLINE QTZ	OTHER		
Keownville Miss.	Ripley	80	6	3	11	-	68	96
Pine Level Ala.	**Cusseta**	87	9	1	3	-	68	99
Union Springs Ala.	**Cusseta**	93	0	5	2	-	72	97
Spring Hill Ala.	**Cusseta**	90	0	7	3	-	70	100
Florence Ga.	**Cusseta**	94	3	0	3	-	71	96
Cusseta Ga.	**Cusseta**	94	2	[illegible]	0	-	65	99
Tazewell Ga.	**Cusseta**	98	Tr.	1	1	-	75	99
Butler Ga.	Cusseta	86	Tr.	10	4	-	74	99
Macon Ga.	**Middendorf**	90	0	4	6	-	56	100
Florence S.C.	**Peedee**	88	6	6	0	-	62	98
Fayetteville N.C.	**Middendorf**	99	0	0	1	-	76	99

Table 6 - (cont.)

SAMPLE LOCATION PLATE I	FORMATION	% NUMBER OF GRAINS IN >.062 FRACTION					ELONGATION	% QUARTZ ANGULARITY
		QUARTZ	FELDSPAR	MUSCOVITE	POLYCRYSTALLINE QTZ	OTHER		
Fg-2	Cusseta	71	21	3	5	-	62	95
Gf-3	Blufftown	83	9	8	0	-	67	97
Ni-1a	Cusseta	74	13	12	0	-	64	99
Pe -3a	Blufftown	80	10	10	0	-	69	99
Rd-2	Blufftown	76	12	10	2	-	56	96
Rd-2	Cusseta	80	13	3	4	-	70	96
Qe-5	Ripley	88	5	3	4	-	66	100

(1958) when they state that the quality of extinction is not valid as a criterion of origin. Also the degree of extinction is of little use in flat stage work which was utilized in this study.

Using the rock classification of Folk modified by Pryor (Fig. 13), the sands of the Cusseta, Blufftown, and Ripley Formations may be generally classified as sub-graywacke and sub-arkose with minor amounts of feldspathic sub-graywacke and orthoquartzite. The orthoquartzite was observed for the most part in the basal Cusseta Sands of Alabama.

Muscovite count presents a definite problem. Because of inclusions it sometimes settles in bromoform as a heavy mineral. If light mineral fraction is used an accurate percent is not obtained, partly because much of it is lost in handling. It could be considered ubiquitous and not counted, but this would affect the rock classification.

During field work and while sieving samples it was noticed that the coarser grained fraction seemed to contain less mica. In an attempt to verify this a sample was sieved using #230 and #60 sieves. From these two different fractions (one fraction greater than .25 mm, the other .25 mm to .062 mm) thin sections were fabricated.

The finer fraction of .062 to .25 mm was found to contain approximately 10 percent mica, while the coarser fraction showed only a trace; not showing up on a line point count.

There exists at least two possibilities that might help explain this: (1) the grain size of the mica in the source might start out in the size fraction .25 mm, (2) the time and distance of transport may have been such that the mica was broken down to a size of .25 mm.

The conspicuous absence of mica in coarse-grained, well-sorted

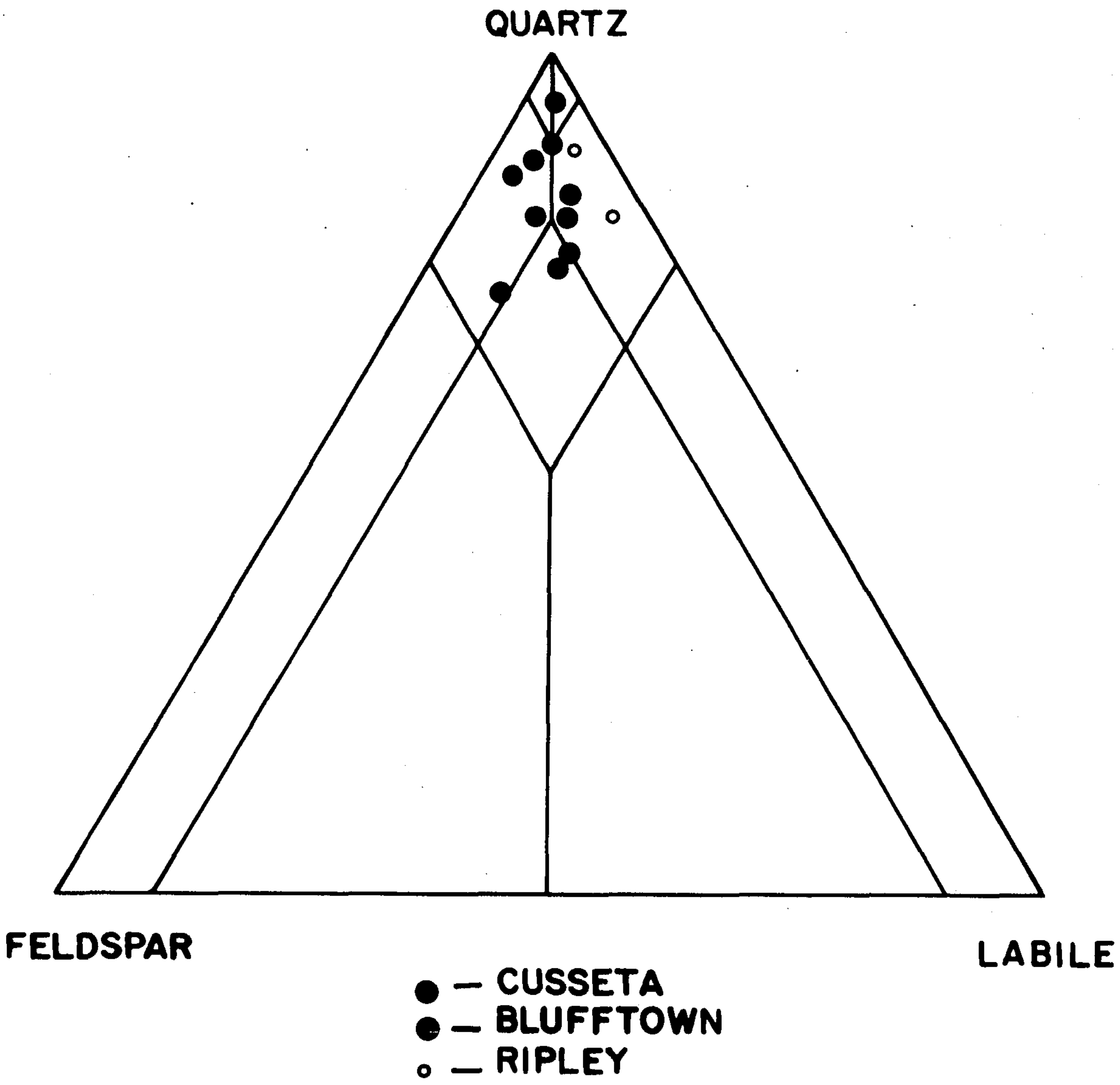


Figure 13 - Distribution of Cusseta, Blufftown, and Ripley light mineral analysis plotted on Ternary Diagram (rock classification from Folk, modified by Pryor,)

sediments is thought to be a result of winnowing. The abundance of mica in the Blufftown facies is considered a result of winnowing from a high energy environment and deposition in a low energy environment which the Blufftown facies represents. The conclusion is that the energy level is probably the one factor most responsible for the presence or absence of mica.

While making grain counts on the size fraction between .062 mm and .25 mm, polycrystalline quartz was found only as a trace or 1 percent at most. Size fraction apparently has no control because only a trace was observed in thin sections of the fraction greater than .25 mm.

It was observed that feldspar was totally absent at some localities, whereas at others, it was present in amounts as high as 13 percent. When checking the samples with no feldspar against their field locality, it was generally found that they were either taken at deeply weathered cuts or at high elevations. There seems to be at least two possibilities which may be responsible for this absence of feldspar; 1) prolonged sub-aerial, post-depositional chemical weathering may have removed the feldspar, 2) the samples may possibly represent Tertiary terrace deposits.

In order to check out the first possibility a profile of thin sections was made for known Upper Cretaceous sediments going from unweathered fossiliferous, glauconitic, calcareous sands to deeply weathered, fine, micaceous sands at the Pine Level, Alabama (Dg 1) locality using samples Dg 1-25 through Dg 1-31 (table 7).

Using Cobaltinitrite Only

Sample No.	Quartz	Feldspar	
Dg 1-31	195	5	
Dg 1-30	193	7	
Dg 1-29	189	11	
Dg 1-28	183	17	
Dg 1-27	183	17	
Dg 1-26	181	19	
Dg 1-25	174	26	1st count 11-9-67
	176	24	2nd count 11-13-67

Table 7. Thin section studies illustrating the depletion of feldspar in a road cut near Pine Level, Alabama

The effects of weathering are clearly illustrated by the depletion of feldspar from an average of 9.5% in samples Dg 1-25 through Dg 1-28 to an average of 4% in sample Dg 1-29 through Dg 1-31. The well defined boundaries to the fresh angular feldspar fragments of the Dg 1-25 to Dg 1-28 samples compared to the small altered (sericitized) feldspar fragments with poorly defined borders of the Dg 1-29 to Dg 1-31 samples strongly suggests that weathering is controlling the upward reduction in the percent of feldspar.

The presence of <u>Ophiomorpha</u> and the absence of an unconformity provides evidence that these sediments at Dg 1 are Cretaceous in age, thus the low percentage of feldspar cannot be attributed to Tertiary terraces. Although Tertiary terraces may explain the very low percent or absence of feldspar at infrequent localities, it is concluded by the author that weathering in situ is responsible for this anomoly in the majority of the weathered localities examined in this study.

Clay Mineralogy

The clay mineral assemblages of sediments both Recent and Ancient have been used by many workers as a tool for reconstruction of sedimentary environments, for locating source areas and determing the general direction of sediment transport. An investigation of the clay mineralogy was undertaken in this study to determine if this parameter was useful in making the above interpretations on a regional level. The validity of the use of clay mineral composition for this purpose was tested by integrating the results of this investigation with the regional lithostratigraphy, sedimentary petrology and paleontology as described by Pryor and Glass (1961).

When attempting to use clay mineral composition for environmental interpretation, consideration must be given to the origin of the clay minerals present. Two schools of thought are presently in vogue. Briefly stated some workers believe that the larger portion of clays found are authigenic, thus diagenesis is the most important factor controlling the clay mineral composition (Grim, 1955; Reynolds, 1966). Others maintain that clays for the most part are detrital, therefore their availability is controlled by the clay mineralogy of the source area and their distribution is strongly affected by preferred segregation due to various physio-chemical conditions in different depositional environments (Weaver, 1958; Milne and Shott, 1958; Pryor and Glass, 1961; Griffin, 1962).

Weaver (1958) contends that clay mineral lattice is inherited from the source rock and only slight modification takes place in the depositional sight. Although Weaver (1958) supports a detrital origin for clays he has not found that specific clays are restricted to specific depositional environments. Pryor and Glass (1961), found that clay minerals have a definite pattern of assemblage and occurrence in the Upper Cretaceous of the Upper Mississippi Embayment. They concluded that source area and depositional area played the major role in the occurrence of clay minerals. Weathering in the source area was found by Keller (1957) to exert the strongest control on the clays made available for the various environments. Milne and Earley (1958) state that climate in the source area may be the strongest factor controlling the ultimate clay mineral assemblage, however they contend that if the rate of sedimentation is slow enough illite may be formed in situ. The opposite was found by Biscaye (1965) in a study of approximately 500 Recent deep sea cores. Because the age-dates of illite clays of the deep-sea surface sediments were found to be very close to those of the ancient continental rocks, it was naturally concluded that the clays were indeed derived from the continent. In every case studied, Biscaye (1965) found a close correlation between the clay mineralogy of the ocean floor sediments and that of the adjacent continent.

Grim (1955, 1956) was one of the proponents of the diagenetic origin of clay minerals. However, in a more recent study in the Mississippi Delta area, Grim and Johns (1958) found that diagenesis played a minor role. Milne and Early (1958) also found that in areas of rapid deposition the diagenetic effect is subdued by the blanketing effect of of overlying clay material which probably reduces the chemical interaction.

In a recent study by Reynolds (1966) it was concluded that the origin of montmorillonite was diagenetic in the Pine Barren member of the Clayton Formation, lower clays of Porters Creek, the Grampian Hills member of the Nanafalia Formation and the Tallahatta Formation. This was based mainly on the fact that montmorillonite was found in association with clinophilotite, heulandite and cristobalite; minerals which are believed to have originated from the chemical alteration of fine-grained volcanic pyroclastics.

Pryor and Glass (1961) concluded that the clays were detrital in origin but that segregation in the depositional environment controls the variations in clay mineralogy. In studies of recent sediments of the Mississippi Sound Area, Milne and Shott (1958) concluded that the clays found are directly related to the source material. The increase from East to West in this area in montmorillonite-illite content of the sediments relative to a decrease in kaolinite is attributed to the influence of the montmorillonite-rich sediments of the Mississippi Delta.

Griffin (1962), in a study of regional clay mineral facies of the Northeastern Gulf of Mexico, concluded that the occurrence of the clay assemblages is a product of weathering versus parent-rock interplay in the drainage basins.

Parham (1966) in a review of studies of clay mineral assemblages from 1944 to 1965 was able to conclude that direction of sediment transport can be interpreted from lateral clay mineral variations. Of particular interest to this study is the works by Nelson (1960), Hirst (1962) and Porrenga (1965) on Recent sediments, Griffin (1962) on Eocene sediments and Heron (1959), Groot and Glass (1960), Pryor and Glass (1961), Weaver (1961) and Beall (1964) on Cretaceous sediments which all illustrate a reduction in kaolinite in a seaward direction while the montmorillonite increases in that same direction.

Procedure

Samples of clay were taken from clay galls, clay seams within sand bodies and formational clay of unweathered and relatively unaltered outcrops. According to Weaver (1961) lithology has a definite control over the percentage of kaolinite present. He states that kaolinite is commonly found to be more abundant in sandstones than in the adjacent shales. It has not been determined whether this segration takes place during deposition or whether it is due to post-depositional alteration by fluids. However, Glass (1960) found that much of the kaolinite formed after burial in permeable sediments.

In this study little difference in kaolinite percent was found in sands and adjacent shales if the outcrop was relatively unweathered. The opposite phenomenon is found in the Pine Level, Alabama (Dg 1) study. In going from clay Dg 1-10 through Dg 1-14) to sand (Dg 1-15 through Dg 1-17) the clay assemblage goes to a higher percent of montmorillonite. In the weathering profile and in weathered samples, there is seen a definite increase in kaolinite in the sands (Dg 1-26 through Dg 1-31). The increase in kaolinite correlates closely with a decrease in detrital feldspar. Perhaps weathering of the feldspar is partially responsible for the increase in the percent of kaolinite. This strongly suggests that the detrital loose clay in weathered sandstones is unreliable for clay analysis. For this reason clay samples from sand lithologies in this study were restricted to clay seams and clay galls in outcrops of deeply weathered sands.

Clay mineral composition for 156 samples was determined from oriented aggregates of the <2 micron clay by the X-ray diffraction method. In this study the XRD-5 operating with CuKx irradiation was utilized for most of the samples, however, the iron target cathode tube was used for the analyses of 45 samples. Each sample was irradiated untreated and treated with ethylene glycol and, where necessary to check for the presence of chlorite, some samples were heat treated. Montmorillonite and kaolinite were found to be the predominant clay minerals.

Montmorillonite in this study includes all clays that expand, with ethylene glycol treatment, to approximately 17 Å, thus degraded clay minerals and mixed layer are included with montmorillonite.

Illite is characterized by a slightly asymmetrical peak at 10 Å. Because of the ubiquitous nature of mica in the upper Cretaceous sediments, consideration is given to the problem of distinguishing between true illite and five grained muscovite.

Kaolinite is identified by peaks at 7.15 Å and 3.57 Å.

Chlorite, which is frequently confused with kaolinite, has characteristic peaks located at 7.1 Å and 3.5 Å. Distinction between the two can be readily obtained by heat treatment. Heating to 500° C will destroy the kaolinite and leave the chlorite unaltered.

A list of clay sample localities, clay sample types, compositions, and semi-quantitative percentages are outlined in table 8. Although

TABLE 8 CLAY MINERAL COMPOSITION (Cu Radiation)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION IN PERCENT		
				MONTMORILLONITE	ILLITE	KAOLINITE
Eg-1	Blufftown		Formation	37	8	55
Fg-1	Blufftown		Formation	31	11	58
Gg-4a	Blufftown		Formation	29	11	60
If-1	Blufftown		Formation	31	5	63
If-2	Blufftown		Formation	41	6	52
Kg-1	Blufftown		Clay Seam	36	4	60
Ln-1	Blufftown		Formation	59	0	41
Lg-1	Blufftown		Formation	46	7	48
Of-3	Blufftown		Formation	74	3	67
Pe-3a	Blufftown		Formation	83	0	17
Rd-2	Blufftown		Clay Seam	5	5	91
Rd-2	Blufftown	0-3'	Formation	94	0	6
Rc-2a	Blufftown		Formation	88	0	12
Wb-3	Blufftown		Clay Seam	0	0	100
Uc-1	Blufftown		Clay Seam	0	0	100
Cg-1a	Cusseta	Lower	Formation	38	5	57

TABLE 8. CLAY MINERAL COMPOSITION (Cu Radiation) (cont.)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION IN PERCENT		
				MONTMORILLONITE	ILLITE	KAOLINITE
Fg-2a	Cusseta	Lower	Formation	28	16	56
Gg-1	Cusseta	Lower	Clay Gall	0	0	100
If-1	Cusseta	Lower	Clay Seam	6	0	94
If-2	Cusseta	Lower	Clay Gall	72	0	28
Kg-1	Cusseta	Lower	Clay Gall	0	0	100
Lh-1	Cusseta	Lower	Clay Gall	0	0	100
Cg-1f	Cusseta	Upper	Borings	0	0	100
Eg-2	Cusseta	65-70'	Formation	63	6	31
Fg-4	Cusseta	Upper	Formation	33	9	58
Hg-1	Cusseta	Middle	Clay Seam	77	6	17
If-1	Cusseta	Lower	Clay Seam	82	9	8
Kg-2	Cusseta	Middle	Formation	47	7	46
Lh-1b	Cusseta	Upper	Formation	73	5	21
Mh-2a	Cusseta	Upper	Formation	67	9	24
Ni-1a	Cusseta	Upper	Formation	88	0	12
Ng-1	Cusseta	Middle	Clay Gall	72	6	22

TABLE 8 CLAY MINERAL COMPOSITION (Cu Radiation) (cont,)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION IN PERCENT		
				MONTMORILLONITE	ILLITE	KAOLINITE
Ng-1	Cusseta	13-18	Formation	70	6	25
Pg-2	Cusseta	Upper	Clay Seam	34	4	61
Pe-1	Cusseta	Upper	Clay Gall	0	0	100
Pe-1	Cusseta	25-30	Clay Seam	9	6	85
Rd-3	Cusseta	Middle	Clay Gall	0	0	100
Pg-1	Cusseta	-	Clay Seam	27	6	67
Pe-3	Cusseta	Lower	Clay Gall	0	0	100
Pe-3a	Cusseta	-	Formation	17	0	83
Qd-1	Cusseta	-	Clay Gall	0	0	100
Rd-2	Cusseta	21-29	Clay Gall	57	0	43
Rd-3	Cusseta	Middle	Clay Gall	0	0	100
Sc-1	Cusseta	Lower	Clay Gall	0	0	100
Tb-1	Cusseta	-	Clay Gall	0	0	100
Ub-1	Cusseta	-	Clay Seam	0	0	100
Wb-1	Cusseta	-	Clay Seam	0	0	100
Xa-2	Cusseta	-	Clay Seam	0	0	100

TABLE 8 CLAY MINERAL COMPOSITION (Cu Radiation) (cont.)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION IN PERCENT		
				MONTMORILLONITE	ILLITE	KAOLINITE
Dg-1a	Ripley	-	Formation	0	0	100
Hh-1	Ripley	-	Formation	74	13	14
Kh-2	Ripley		Formation	91	0	9
Mh-2b	Ripley		Formation	27	15	57
Nh-1	Ripley		Formation	75	4	21
Ni-2	Ripley		Formation	15	13	71
Pe-1a	Ripley		Formation	61	0	39
Kh-3b	Ripley		Formation	18	14	68

TABLE 8 **CLAY MINERAL COMPOSITION** (Fe Radiation) ' **(cont.)**

(Treated with Ethylene Glycol)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION IN PERCENT		
				MONTMORILLONITE	ILLITE	KAOLINITE
Eg-1	Demopolis		Formation	.35	.05	.60
Gg-4a	Blufftown		Formation	.38	.08	.54
If-1	Blufftown	19.5-20	Clay Seam	.62	Tr	.38
Lg-1	Blufftown	0 - 3	Formation	.35	.07	.58
Lg-1	Blufftown	9 -12	Formation	.71	Tr	.29
L. -1	Blufftown	3 - 6	Formation	.48	.04	.48
Rd-2	Blufftown	10' below sand	Clay Seam	Tr	Tr	1.00
Rd-2	Blufftown	9 -12	Formation	.71	Tr	.29
Rd-2	Blufftown	20 -20.5	Clay Seam	.63	Tr	.37
If-1	Cusseta	47 -48	Clay Seam	Tr	.06	.94
Kg-2	Cusseta	6 - 7.5	Clay Seam	.54	.04	.42
Jn-1	Cusseta	Upper	Clay Seam	1.00	Tr	Tr
Ng-1	Cusseta	10 -13	Clay Seam	.69	Tr	.31
Rd-2	Cusseta	31.5-38	Formation	.44	.03	.53

many different clay percentage combinations are present, three distinct associations are conspicuous (Fig. 14). These are: 1) approximately equal amounts of montmorillonite and kaolinite illustrated by sample If-1 of the Blufftown Formation, 2) predominant kaolinite as found in the Pe-1 sample of the Cusseta Sand, and 3) predominant montmorillonite which is shown by the Ripley Formation sample number Mh-2b.

Using montmorillonite, kaolinite and illite as three end members, the semi-quantitative clay percentages of various facies were plotted by computer method on ternary diagrams (Fig. 15).

Of the 23 samples analyzed for the Blufftown Formation, 18 fall in a general zone of approximately equal amounts of montmorillonite and kaolinite. Because of facies changes that take place in the Cusseta Sand both vertically and laterally, it was found that it was possible to break this formation down into four different facies based on clay mineral composition. Analysis of ten samples from the lower Cusseta of eastern Alabama range in composition from approximately equal quantities of montmorillonite and kaolinite to approximately 100 percent kaolinite. Fourteen samples from the middle and upper Cusseta Sand of eastern Alabama and the Chattahoochee River area are composed chiefly of montmorillonite, as were the seven samples analyzed from the lower Cusseta Sand in central Alabama. The fifteen samples analyzed from western Georgia were found to be dominantly kaolinite. Analysis of eight Ripley Formation samples shows a range in composition from dominant kaolinite to dominant montmorillonite.

Based upon the field description of the sediments associated with these clays, stratigraphic position, and coarse fraction studies, it was

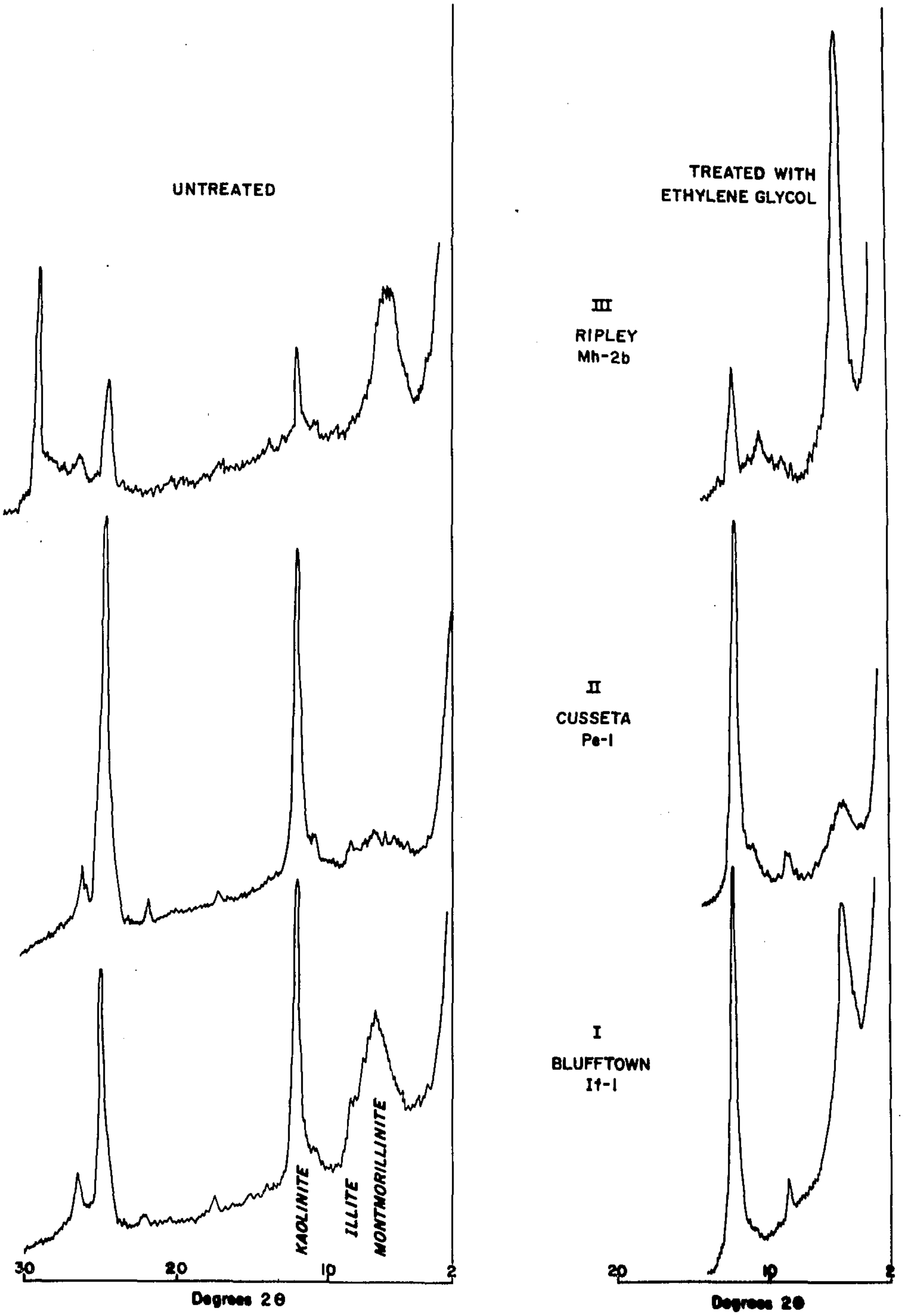
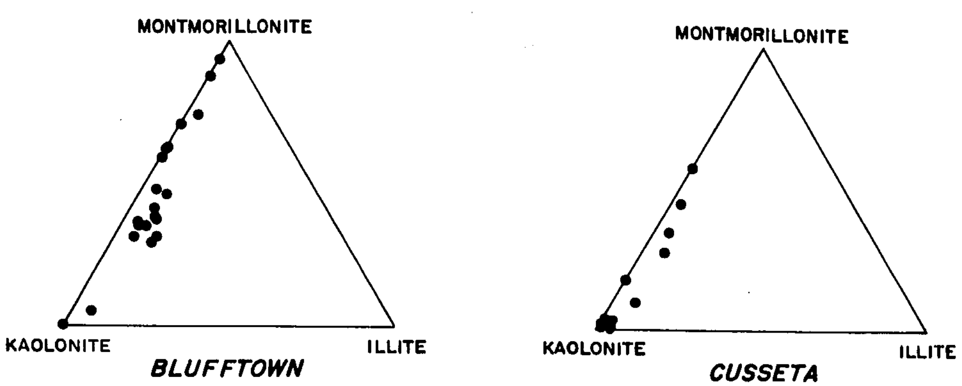
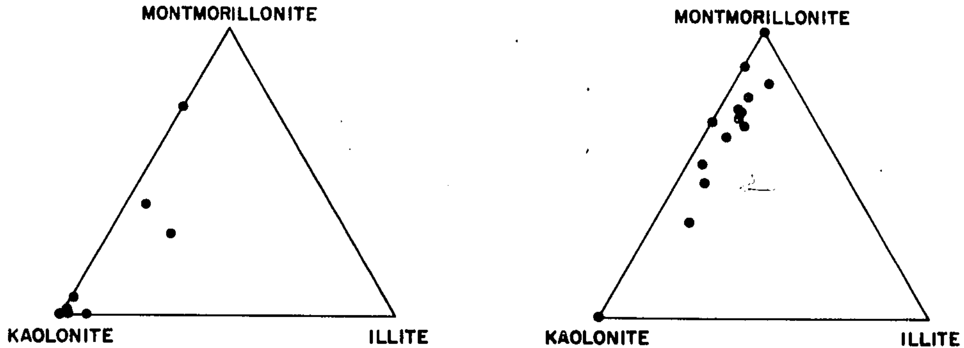


Figure 14 - Characteristic peaks of the clay mineral assemblages



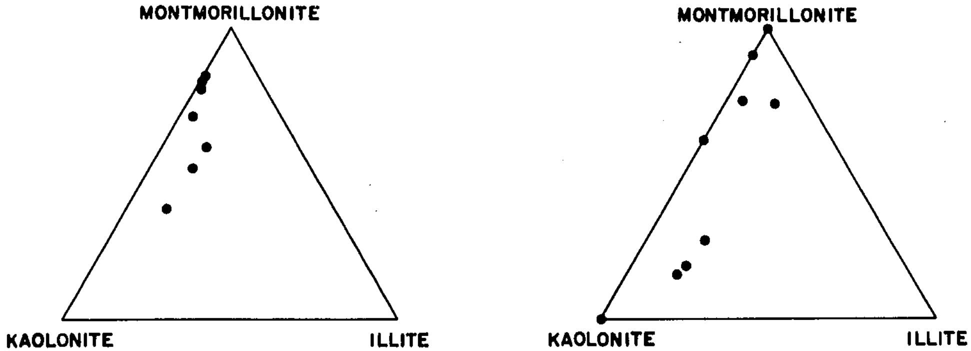
BLUFFTOWN

CUSSETA
Western Georgia
Macon to Cusseta



LOWER CUSSETA
Chattahoochee River Area
Eastern Alabama and Western Georgia

MIDDLE AND UPPER CUSSETA
Alabama and Chattahoochee River Area



LOWER CUSSETA
Central Alabama

RIPLEY

Figure 15 - Ternary diagrams of the clay mineral assemblages for Blufftown, Cusseta and Ripley

found that the various clay mineral assemblages were diagnostic of certain environment (Fig. 16). Most of the clay analyses that were dominantly montmorillonite represent the pro-delta, outer neritic, open marine environment. The clays which have a rather equal mixture of montmorillonite and kaolinite are interpreted as being representative of the delta front, inner neritic, somewhat restricted environment. The analyses which illustrate a predominance of kaolinite represent the upper delta, barrier bar, or fluviatile environment.

The presence of these different clay mineral assemblages or ratios is attributed for the most part to source area contribution and in part to segregation in the various sedimentary environments as described by Van Andel and Postma (1954), Pryor and Glass (1958, 1961), Groot and Glass (1961), Heron, et al. (1964) and others.

Montmorillonite definitely characterizes the middle and upper Cusseta of Alabama, and the entire Cusseta Sand of the Pine Level, Alabama locality with the exception of the upper few feet. It is found to make up approximately 50 percent of the Blufftown Formation in most localities. Its presence presents a definite problem. There seems to be no source for it to the northeast if it is a detrital mineral. The heavy mineral study and paleocurrent data (from this investigation) indicate the ultimate source for the clastic sediments of the Blufftown, Cusseta and Ripley to the northeast in the Appalachians. According to Griffin (1964) the present clays availabe in this source rock are dominantly kaolinite with small amounts of illite. No mention is made of montmorillonite. Studies off the Atlantic coast show that kaolinite, chlorite and illite are supplied as detrital clays from the

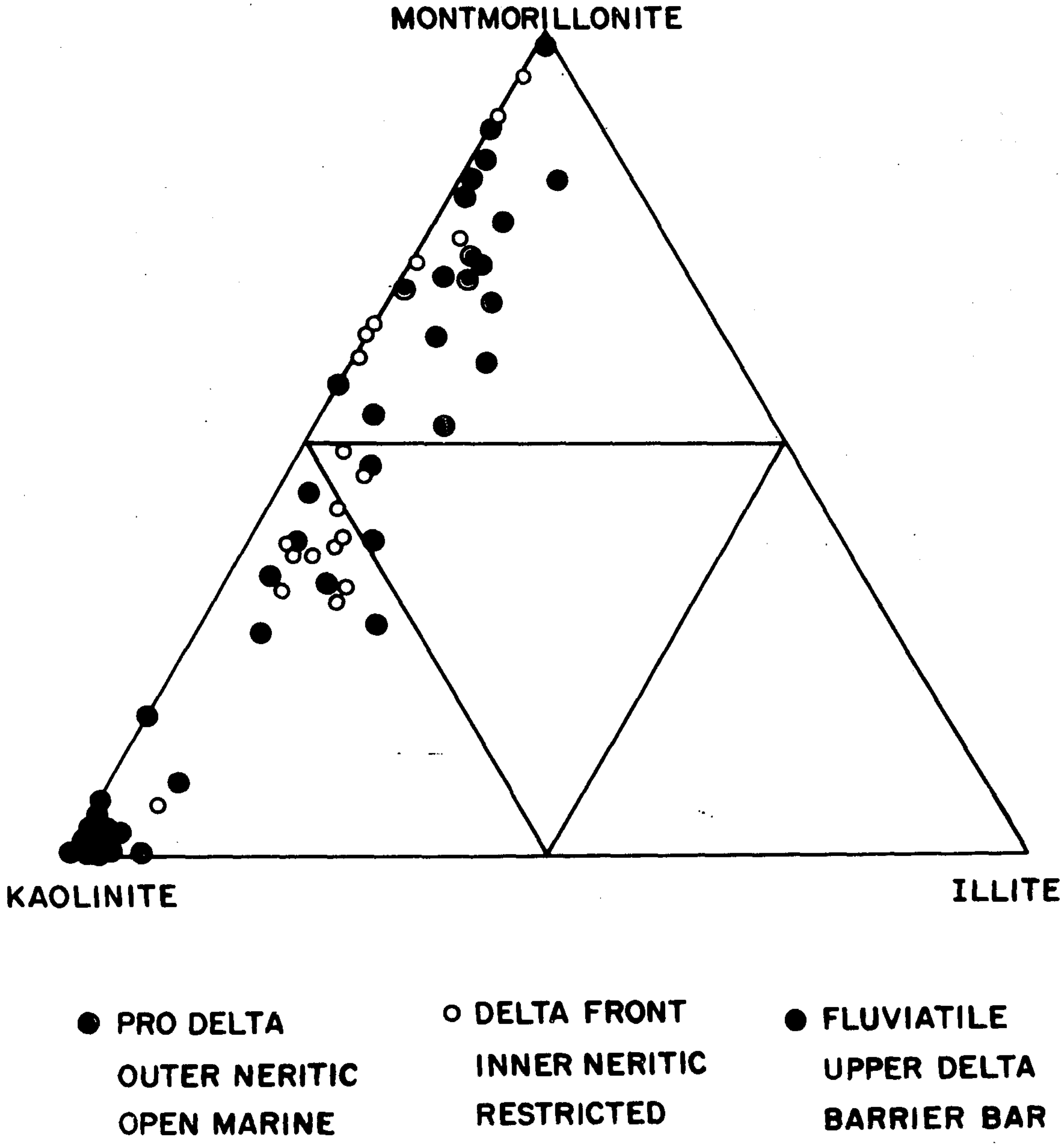


Figure 16 - Environments determined from clay mineral assemblages

eastern continental United States.

If the montmorillonite was not carried as part of the detrital sediment from the northeast, then possibly the montmorillonite is a result of post-depositional, sub-aerial weathering. Brophy (1959) and Johnson (1964) found, in their studies of weathering profiles in glacial till, that the original chlorite and illite altered almost completely to montmorillonite as a result of oxidation. In considering post-depositional, sub-aerial weathering as a cause for the presence of montmorillonite in this area the clay percentages of a number of calcareous unaltered, and leached, oxidized and altered outcrop localities were studied (table 9). There was found to be no definite relationship between the presence of montmorillonite and the degree of weathering. However, some of the oxidized and weathered samples did produce some of the sharper montmorillonite-like peaks. The detailed study of the outcrop profile Dg-1 near Pine Level, Alabama gives conclusive evidence that there is no increase in montmorillonite with the increase of weathering.

The possibility that the montmorillonite originated from the weathering of illite during transport or after deposition in a marine environment was also given consideration. Sample Kh-2a which is a marine non-calcareous, leached sand was treated to a solution of potassium hydroxide. According to Weaver (1958) montmorillonite, that has originated from the weathering of muscovite (illite), will fix potassium and contract to the 10Å peak. Although more samples should be analyzed in order tomake this evidence conclusive, this does suggest that the montmorillonites are not a result of the weathering of muscovite.

Table 9 - Effect of weathering on Mont/Kaol. ratio

SAMPLE LOCATION (PLATE I)	FORMATION	TYPE SAMPLE	MONTMORILLONITE / KAOLINITE RATIO	WEATHERING CONDITION OF SAMPLE
Eg-2	Cusseta	Formation	2.03	Calcareous
Fg-4	Cusseta	Formation	.57	Calcareous
Kg-2	Cusseta	Formation	1.02	Leached, oxidized
Mn-2a	Cusseta	Formation	2.79	Calcareous
Ni-1a	Cusseta	Formation	7.33	Non-calcareous, unoxidized
Ng-1	Cusseta	Formation	3.27	Leached, oxidized
Jn-1	Cusseta	Formation	> 10	Calcareous, unoxidized
Ng-1	Cusseta	Formation	2.23	Leached, oxidized
Hn-1	Ripley	Formation	5.29	Leached
Mn-2b	Ripley	Formation	.47	Calcareous-unaltered
Ni-2	Ripley	Formation	.21	Calcareous-unaltered
Pe-1a	Ripley	Formation	1.56	Leached-oxidized
Kh-3b	Ripley	Formation	.26	Leached-oxidized
Eg-1	Blufftown	Formation	.67	Oxidized-leached
Fg-1	Blufftown	Formation	.53	Calcareous
Gg-4a	Blufftown	Formation	.48	Calcareous-Fresh

Table 9 - (cont.)

SAMPLE LOCATION (PLATE I)	FORMATION	TYPE SAMPLE	MONTMORILLONITE KAOLINTE RATIO	WEATHERING CONDITION OF SAMPLE
Kg-1	Blufftown	Clay seam	.60	Oxidized
Ln-1	Blufftown	Formation	1.44	Leached-oxidized
Of-3	Blufftown	Formation	3.22	Calcareous
If-1	Blufftown	Clay seam	1.63	Non-calcareous
Lg-1	Blufftown	Formation	.60	Non-Calcareous, unoxidized
Lg-1	Blufftown	Clay seam	2.45	Non-calcareous
Rd-2	Blufftown	Clay seam	1.70	Non-calcareous

If the montmorillonite-type clay would contract with a mild treatment of KOH, then it is very unlikely that it was deposited in a marine environment, unless possibly, deposition was so rapid that equilibrium with the surrounding potassium-rich sea water was not reached. In Weaver's investigation only one of 40 formations containing expanded 2:1 clays demonstrated appreciable 10 Å contraction.

Since volcanism was very active during the Upper Cretaceous, it seems very possible that the montmorillonite could have resulted from the alteration of volcanic ash. This possibility was discounted by Pryor and Glass (1961) on the basis that no montmorillonite was found in fluvial sediments and volcanic shards do not occur as a common constituent of the Upper Cretaceous sediments in the Upper Mississippi Embayment. Weaver (1958) however, states that stripped mica or illite-montmorillonite supplies only a small portion of the total clay fraction to the Northwest Gulf of Mexico whereas volcanic-montmorillonite derived from the Cretaceous sediments is the dominant mineral present.

The presence of montmorillonite in this study could be a result of the mixing of two sources. The kaolinites are coming from the NE in the Appalachian area whereas most of the montmorillonite has its origin to the northwest where montmorillonites are so prevalent in most of the marine sediments. These clays would have been carried into this area from the northwest as a result of southeastward trending deltaic sedimentation overriding the western margin of this area of study. This then would be analagous to the situation found by Griffin (1964) in the Northeastern Gulf Coast and by Milne and Shott (1958) in the Mobile Bay areas. In both cases kaolinite is the dominant clay mineral carried down from the northeast and montmorillonite has a strong presence only as a result of an influx of sediments from the Mississippi Delta area which overrode the northeastern gulf coast. The only real problem is that if longshore drift is carrying sediments to the northwest as illustrated by cross-bedding studies in this study and by Tanner (1955), it may be difficult to bring clays down from the northwest.

Conclusions

There are at least three possibilities to consider for explaining the presence of the abundant montmorillonite: (1) mixing with clay source from the Cretaceous Mississippi Embayment, (2) volcanism, (3) source in the southern Piedmont Plateau.

The first consideration may explain the presence of montmorillonite in the western portion of this study area (Bullock and Montgomery Counties, Alabama). However, this is not an adequate explanation for the presence of montmorillonite in the Upper Cretaceous of North and South Carolina (Heron, et al., 1964).

Volcanism could be a logical explanation except that the montmorillonitic clays are so thick (Mooreville Formation, Blufftown Formation, Demopolis Formation, Selma Chalk and Ripley Formation of Alabama) and so persistent through Upper Cretaceous.

In considering statement number 3, it has been found that there is presently no source for montmorillonite to the north in the Piedmont Plateau (Griffin, 1962; Neiheisel and Weaver, 1967). According to Keller (1957), however, the kaolinite and montmorillonite may occur as weathering products of the same parent material. A change in weathering conditions, from acid to alkaline, will cause a change in the clay weathering product from kaolinite to montmorillonite.

When one considers that volcanism has taken place erratically during recorded history while weathering conditions have been so persistent, it seems much more feasible that the weathering conditions would be the one most likely to continue, relatively unchanged, through the Upper Cretaceous and Tertiary.

Changes in climate which took place at the onset of the Pleistocene probably explains the presence of kaolinite rather than montmorillonite in the Piedmont Plateau today.

It is concluded that the source for the montmorillonite was to the north in the Piedmont Plateau and that the distribution probably resulted from segregation in the depositional environments as a result of various physic-chemical conditions. It can also be concluded that the montmorillonite to kaolinite ratio is a useful aid in reconstructing sedimentary environments and determing general direction of transport.

Textural Analysis

Although many studies have been made concerning textural analysis, the geologic significance of the various measures is still not fully understood (Folk, 1959).

One of the purposes of this investigation is to determine if some generalizations might be drawn on a regional scale concerning grain size analysis. For this study 20 samples were taken from distinct sedimentary units (table 10). These were for the most part restricted to cross-stratified sands or clean sands between laminated clays. A standard sieving technique was used.

The conclusions drawn from this study were that there was a general, but seemingly not significant reduction in mean grain size in going from east to west. Following Folk and Ward (1957) the sands were found to be moderately to poorly sorted. The only sands that came near to being well sorted were samples Pe-1 and Ng-3, which are located in a down dip direction from the typical medium to coarse grained sands of the updip areas of Georgia.

Another purpose of the textural study is to determine the sand-silt-clay ratio and apply this to the environmental interpretation of the Pine Level section (Dg 1, Plate I, Fig. 25). Following the classification by Shepard (1954) this proved to be a very useful parameter which will be discussed later. To gather this information both the sieve and pipette techniques were employed. Mean size, coarsest grain size and standard deviation were also determined for this study.

Mean grain size is a function of the size range of the material provided and the amount of energy made available to the system. This

Table 10 - Textural analysis of distinct sedimentary units of the Cusseta Sand

SAMPLE LOCATION (Plate I)	MEAN	STANDARD DEVIATION	SKEW	SAND/MUD RATIO	SHEPARD CLASS	COARSEST GRAIN (mm.)
Hg-1	*4.29	1.74	.84	2.51	5	1.8
Hg-1a						1.4
Ng-1	.98	1.63	.31	14.78	1	5.0
Ng-2						6.0
Ng-3	2.38	.68	.27	17.84	1	1.3
Ni-2	*7.16	3.07	-.58	0.58	8	1.4
Og-1						4.0
Pe-1	.80	.59	.03	38.65	1	4.0
Pe-2	*1.77	2.00	1.00	6.37	1	4.0
Pe-3	1.37	1.22	.39	12.57	1	2.3
Pe-3a	*2.38	1.58	1.47	6.14	1	2.1
Pe-3b	2.60	2.24	1.13	4.45	1	4.0
Pf-2	*2.60	1.15	2.26	9.97	1	1.5
Qe-2	*2.13	1.52	1.69	7.68	1	2.8
Qe-3						4.0
Qe-3						1.7
Rc-1	1.85	.94	.03	34.91	1	3.0

Table 10 - (cont.)

SAMPLE LOCATION (Plate I)	MEAN	STANDARD DEVIATION	SKEW	SAND/MUD RATIO	SHEPARD CLASS	COARSEST GRAIN (mm.)
Td-1	.97	.78	.11	39.03	1	5.0
Ua-2	.22	1.08	.37	21.45	1	6.5
*Xa-2	1.02	1.84	1.66	9.74	1	6.0
Recent Beach Sand	2.35	.31	-.04	83.05	1	

* moment measures

parameter proved useful for determining when shallower water and subsequent higher flow regime was beginning to influence the environment.

For eleven sections throughout the outcrop area 42 samples were analyzed by the Emory Settling Tube method (Emory, 1938) (table 20). For these samples mean grain size, standard deviation, sand/mud ratio and coarsest grain determinations were made.

Textural maturity

The textural maturity index of Folk (1951) is a useful tool because it provides information concerning the physical nature of the depositional environment. Thus, one may deduce that immature sediments are deposited in areas where winnowing, sorting and abrading are ineffective, such as neritic, lagoonal or floodplain environments, while beach sands, for example, would be characterized by the mature sediment.

If the rock has over 5% clay it is immature. With the exception of a few beach samples and the *Ophiomorpha* facies, the Cusseta sand for the most part is angular and poorly sorted and is best described as immature. The sands of the *Ophiomorpha* facies are classed as sub-mature and the beach samples (Mh-3 and Ng-1, Plate I) are mature. Folk and Mason (1958) found that beach sediments have standard deviation values that range from .30 to .35. Samples Mh-3 and Ng-1 are the only samples from this study which illustrate a mean size close to this value. However, it is considered by the author that many other localities would show a significantly lower mean if it were not for the presence of *Ophiomorpha* borings and fragments of borings. These borings are very rich in clay in an otherwise clay poor sediments. The method by which these organisms acquired the clay for their tubes presents somewhat of a problem, although it seems possible that they probably filtered it from the water.

DISTRIBUTION, DISPERSAL, AND SOURCE OF SEDIMENTS

Basin Geometry

An investigation was made to determine the thickness distribution and facies relationships of the Upper Cretaceous sediments in the subsurface. This was carried out in order to reconstruct the basin geometry and regional lithofacies, so that the sediment distribution could be determined.

Thickness of Sediment

Figure 17 shows the isopach map of the Upper Cretaceous for Alabama and Georgia. Unfortunately not enough subsurface information was availabe to draw an isopach on the Cusseta Sand. The isopach for Georgia was adapted from Herrick and Vorhis (1963). The isopach for Alabama was constructed from well information from the Alabama Geological Survey. The discontinuity between the isopach thickness lines for each state was unavoidable because the author was able only to obtain subsurface information in Alabama on the top of the lower Tuscaloosa. In Georgia no distinction is made between upper and lower Tuscaloosa. In this interpretation, the post Tuscaloosa, Upper Cretaceous thickness was utilized for Georgia and the post lower Tuscaloosa, Upper Cretaceous thickness was used for Alabama. This, however, has no affect on the interpretation.

A trough shaped body trending east-west through southern Georgia and Alabama contains sediments approximately 1600 feet in thickness in Georgia. These sediments increase in thickness through Alabama until

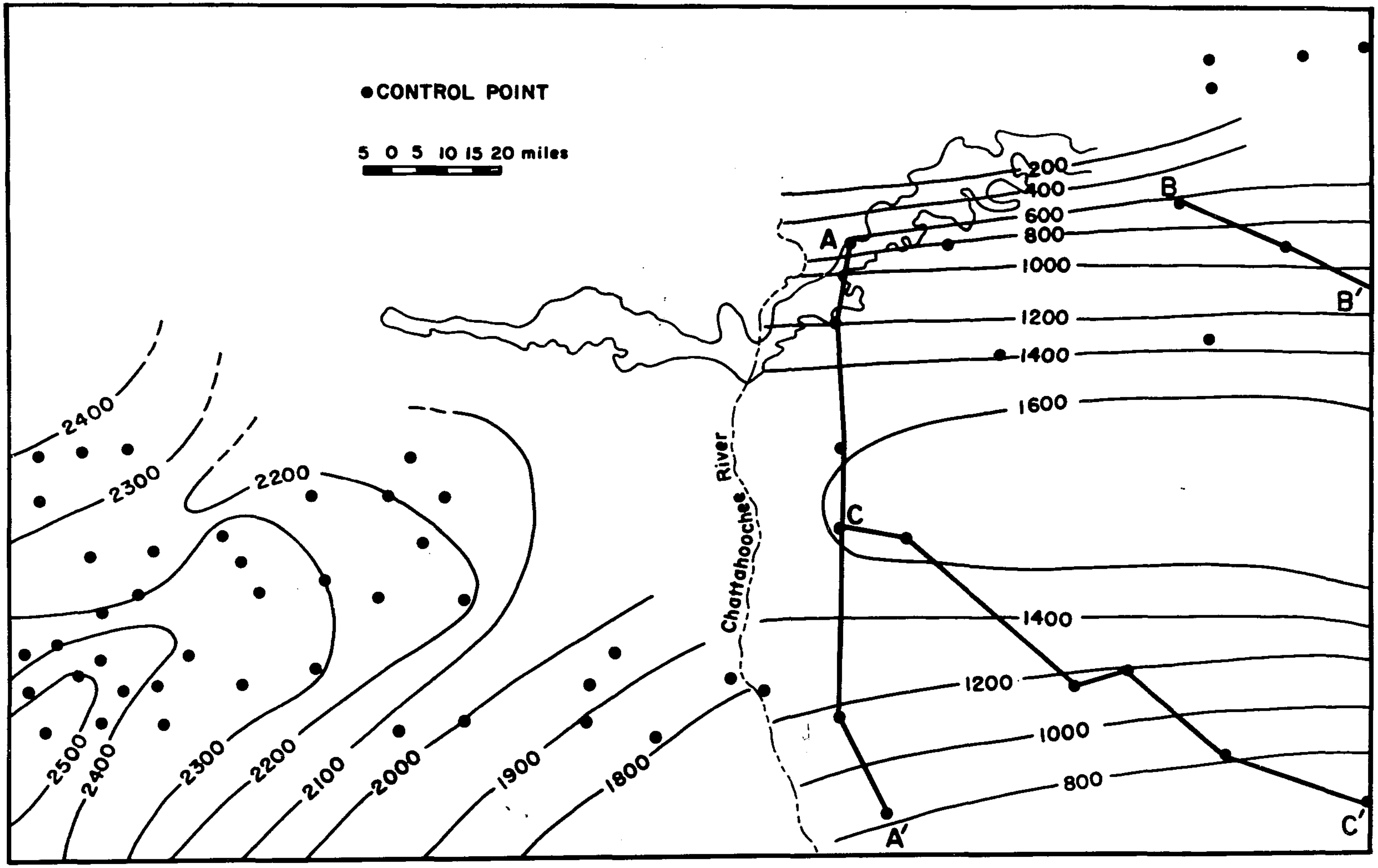


Figure 17 - Isopach of post-Tuscaloosa Cretaceous of Georgia and the post-lower Tuscaloosa Cretaceous of Alabama (Isopach map of Ga. from Herrick and Vorhis, 1963)

a thickness of 2500 feet is reached in the southwestern corner of this area of study.

Reconstruction of the "depo-centers" of Georgia from Tuscaloosa to Recent was made in an effort to determine what relationship could be drawn between Cretaceous clastic dispersal systems on those on the present coasts of southeastern United States. From Figure 18 it can be seen that during times, I, II and III the "depo-center" migrated to the southeast. During times IV and V no conspicuous centers are present. During time VI there is a definite split in the dispersal system, probably resulting from initiation of the Ocala uplift which persisted through time VIII. Time VIIIb is represented by the Present Appalachicola delta. This suggests that it is very possible that the deltaic system responsible for the development of the "depo-center" at time I migrated, at least in part, gulfward to the position of the Present Appalachicola delta.

Subsurface Lithostratigraphic Sections of Georgia

Section A A' (Fig. 19) illustrates that the entire clastic section in Chattahoochee County changes facies down dip into a completely marine section made up predominantly of chalk. The deltaic clastic wedge made up of the Blufftown Delta front facies and the overlying Cusseta upper delta facies persists at least as far as Stewart County.

In the subsurface of the sections along BB' (Fig. 20) the environment is dominated by fine to coarse sands, containing kaolinitic clay lenses, and alternating sand and laminated clay. This section is interpreted as a mixture of fluvial and upper delta sediments from

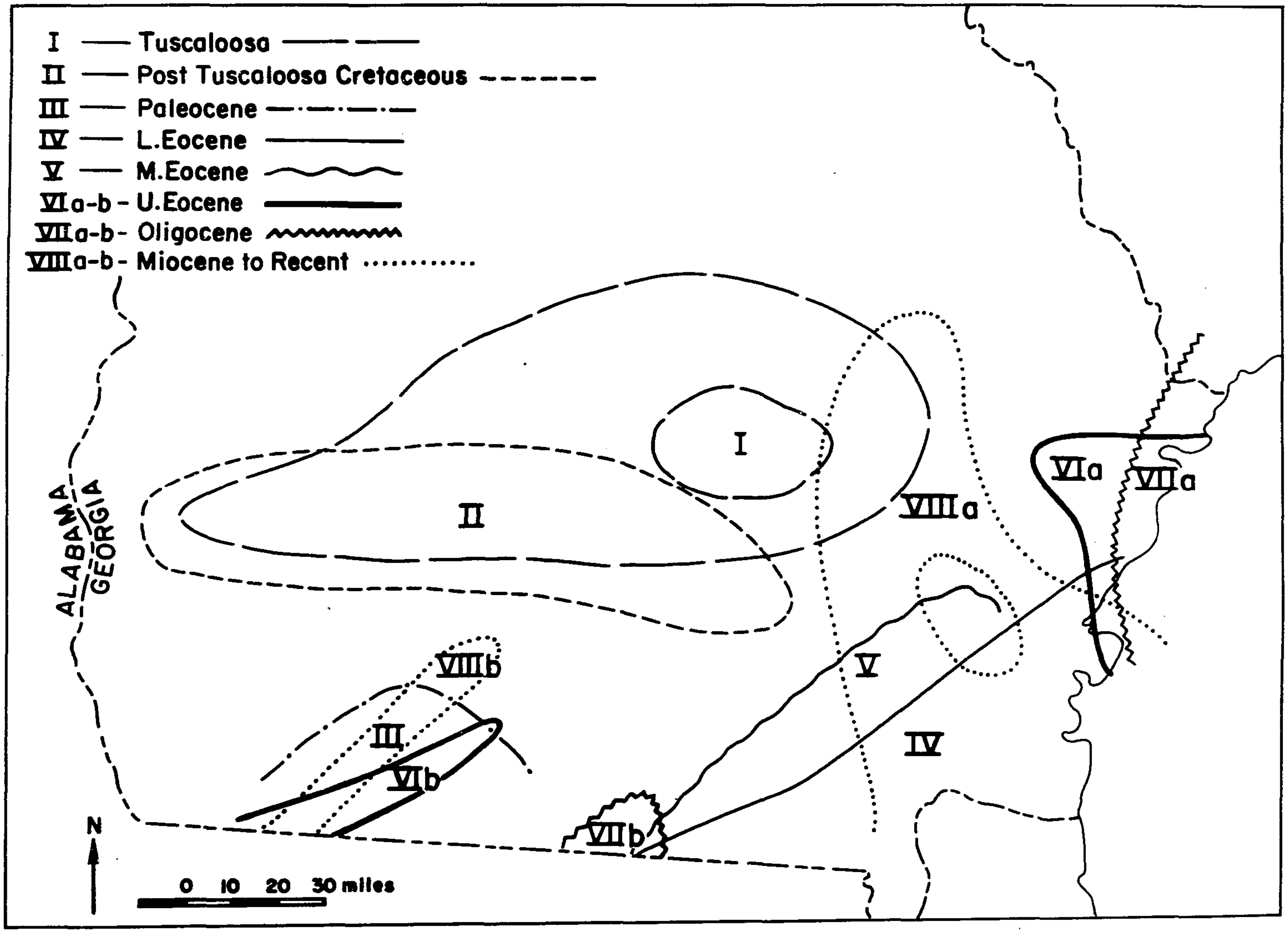


Figure 18 - Distribution of "Depo-Centers" from Tuscaloosa time to Present (compiled from Herrick and Vorhis, 1963)

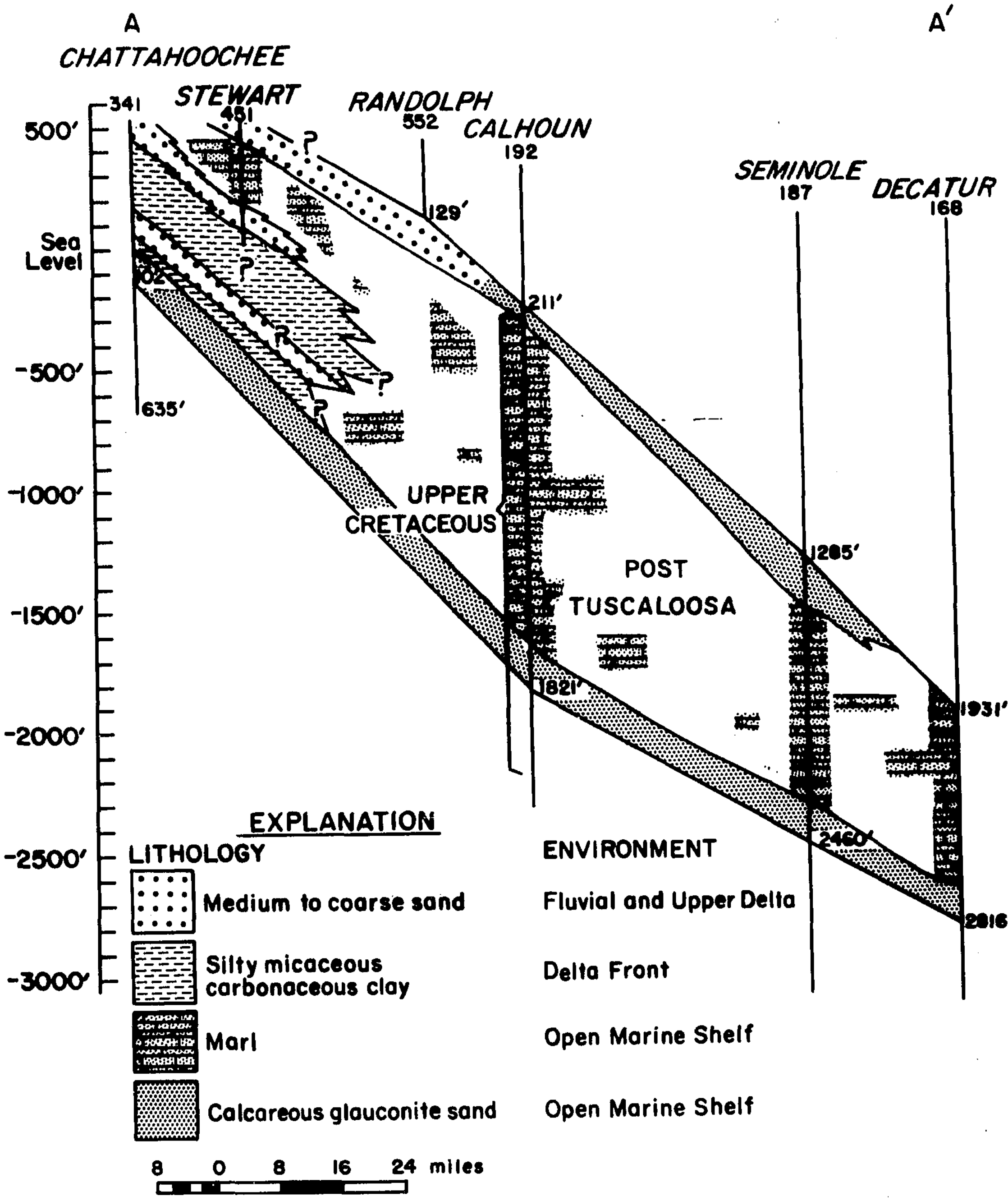


Figure 19 - Cross-section A A' (see fig. 17) from Chattahoochee County to Decatur County, Ga. (depths from Herrick and Vorhis, 1963)

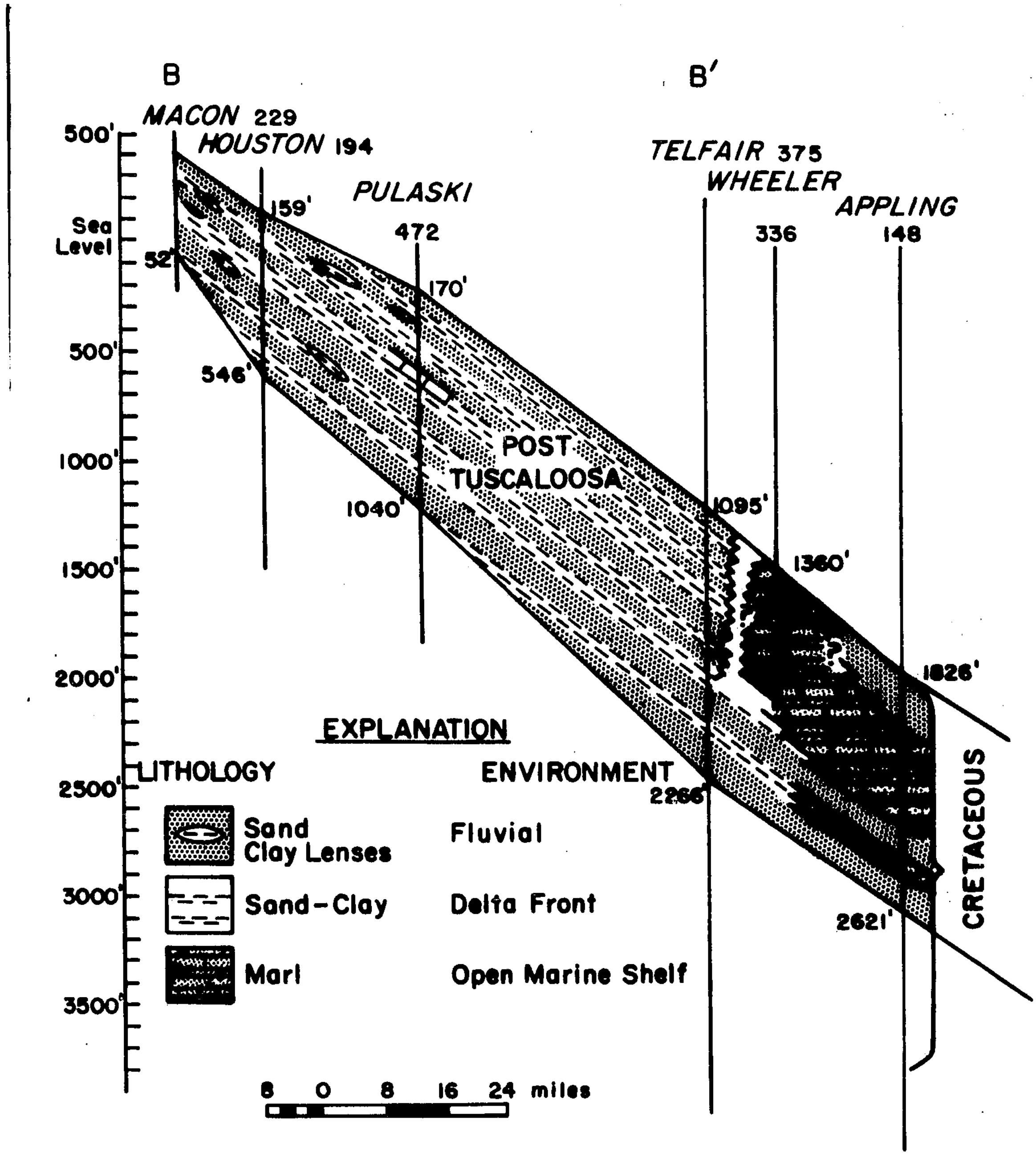


Figure 20 - Cross-section B B' (see fig. 17) from Macon County to Appling County, Ga.

Macon County to Telfair County. Off the map to the southeast an anomalously sharp facies change takes place in going from fluvial and delta front sediments to those of an open marine shelf environment.

Section CC' (Fig. 21) shows that the entire section is composed of open marine shelf sediments. Marl with stringers of marine fine sands continue to dominate the section in this area which is rather far removed from the source to the north and northeast.

Subsurface of Alabama

Electric logs from some wells of the Upper Cretaceous of Alabama give some insight into the downdip facies relationships.

In well number 719 in western central Butler County (Plate I in pocket), a definite sand facies occurs in the upper portion of the Upper Cretaceous. The remainder of the section is silty, shaly, chalk, as are the sediments from wells in northern Covington County.

In Covington and Geneva Counties, the logs suggest that the Upper Cretaceous sediments are dominantly shaly chalk. In Houston County well number 238, the upper part of the Upper Cretaceous section is very sandy. The section that is interpreted as being correlative to the Cusseta Sand is slightly sandy in this well (Don Moore, Alabama Survey, personal contact).

In Crenshaw County well number 500, the upper portion of the Upper Cretaceous displays a well developed sand which is probably equivalent to the Providence Sand.

The entire upper portion of the Upper Cretaceous is sandy or slightly sandy in Coffee County well number 489. Thus it seems probable that the

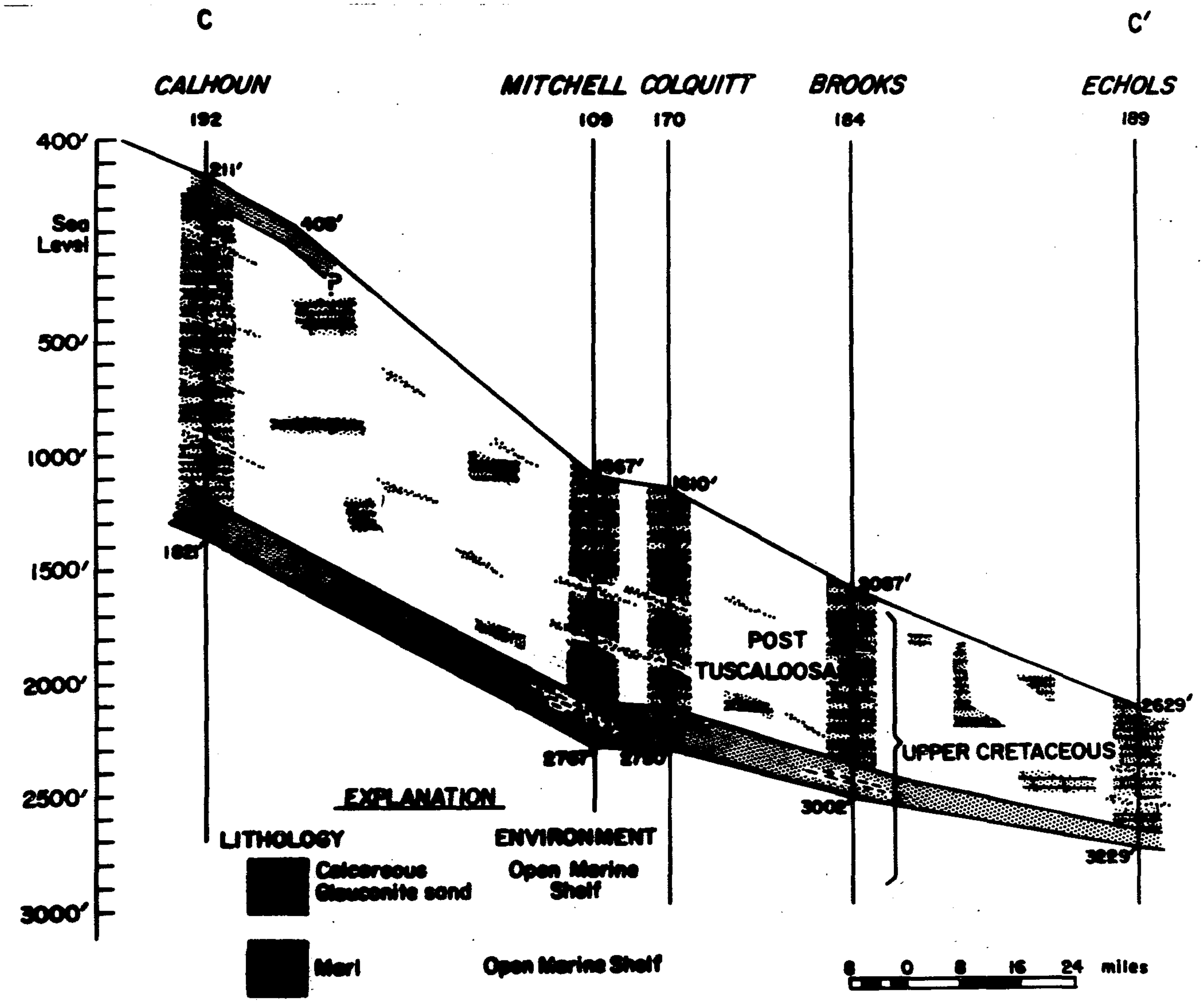


Figure 21 - Cross-section C C' (see fig. 17* from Calhoun County to Echols County, Ga.

Cusseta Sand, Ripley Formation and Providence Sand persist into the subsurface as dominantly sandy units, at least as far as Coffee County.

Paleocurrent Study

A cross stratification study was undertaken with the purpose of using the data derived as an aid in reconstructing the paleoslope, direction of transport, depositional conditions and possibly the source area. The basic assumption is that the dip direction of the cross-bedding represents the direction of current flow. Potter and Pettijohn (1963) thoroughly treat the subject of cross-bedding. The author might add here, however, that by using an inclinometer (Pryor, 1958) and a little extra time at an outcrop, this very meaningful information can be gathered with little effort.

In Georgia, cross-bedded sands were very abundant (Figs. 22 and 23). However, in Alabama, cross stratification became the exception rather than the rule. It is thought that perhaps much cross-bedding was possibly overlooked because it was of the low angle beach type. Intense sub-aerial weathering has a tendency to produce "liesegang" which tends to obliterate the true cross-bedding. Where absolute distinction could not be made, readings were not taken.

The data was treated statistically by a program written by William Howard of the University of Cincinnati Computer Center (table 11).

It was determined from this work that although the computer method is extremely accurate, it does not always yield information which is useful. It may even provide information which is misleading, particularly when attempting to reconstruct paleogeography.

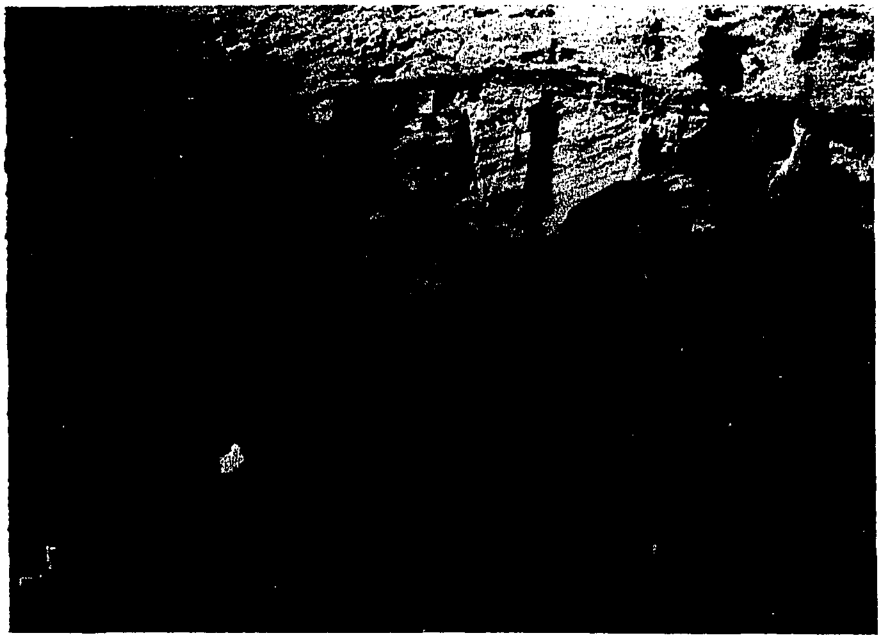


Fig. 22. Tidal cross-bedding in the Cusseta Sand near the type locality; Cusseta, Georgia.

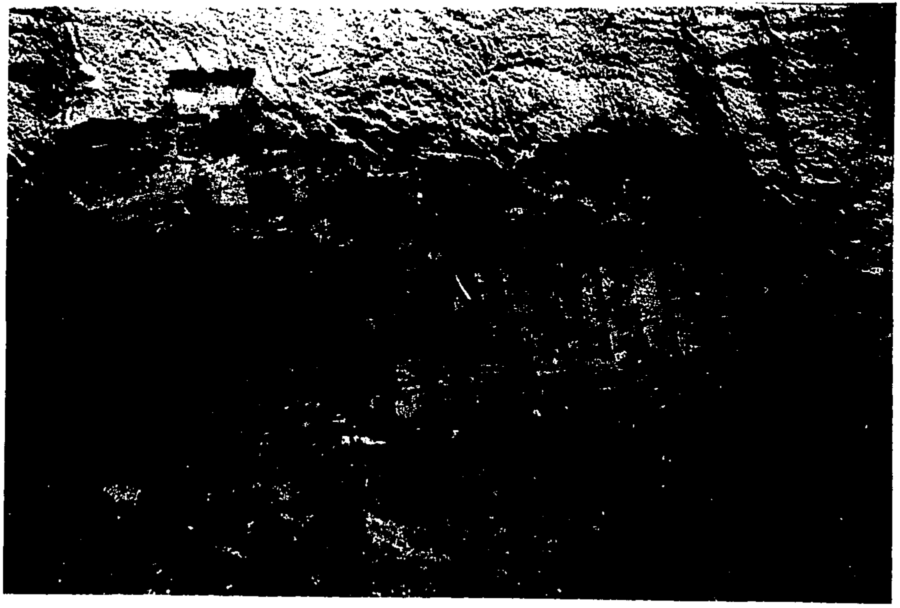


Fig. 23. Cross bedding in the Cusseta Sand; Florence, Georgia.

TABLE 11 CROSS-BEDDING DATA

LOCATION PLATE - I	NUMBER OF OBSERVATIONS	VECTOR MEAN	STANDARD DEVIATION	CONSISTENCY RATIO
If-2	5	193	106.75	2.2
Kg-1	4	269	26.58	3.4
Lg-1	8	259	25.28	6.7
Lg-1	10	256	36.52	6.9
Lg-2	6	174	137.57	1.1
Mr-3	3	179	43.59	2.0
Mh-1	2	304	21.21	1.9
Lg-4	4	62	47.87	2.3
Ng-1	6	224	30.56	4.7
Ng-2	4	221	88.35	0.2
Ng-3	7	156	28.94	5.6
Og-1	7	209	104.74	0.4
Of-2	5	90	44.22	3.1
Of-1	10	166	104.33	0.2
Pf-2	7	248	56.18	2.7
Pe-2	6	183	61.21	2.5

TABLE 11 CROSS-BEDDING DATA (cont.)

LOCATION PLATE - I	NUMBER OF OBSERVATIONS	VECTOR MEAN	STANDARD DEVIATION	CONSISTENCY RATIO
Pe-1	10	197	90.04	0.8
Pe-3	9	175	99.86	0.2
Qe-1	6	164	86.40	0.7
Qe-2	5	192	20.80	4.5
Td-1	9	152	38.01	6.1
Rd-1	5	183	60.35	2.0
Qe-3	8	203	96.69	1.4
Pe-3	9	169	99.23	0.3
Sd-1	5	215	59.41	1.9
Sc-1	5	176	64.77	1.8
Rc-1	9	212	94.08	0.2
Qd-1	6	155	110.43	0.2
Rd-2	4	172	84.21	0.5
Rd-3	5	213	79.17	0.8
Rc-2	8	166	89.15	0.5
Tb-1	7	187	47.42	3.8

TABLE11 CROSS-BEDDING DATA (cont.)

LOCATION PLATE - I	NUMBER OF OBSERVATIONS	VECTOR MEAN	STANDARD DEVIATION	CONSISTENCY RATIO
Tc-1	2	197	45.96	1.4
Ub-1	8	133	109.63	1.5
Wb-1	10	222	84.07	2.4
Va-1	4	278	45.35	2.5
Uc-1	3	84	25.00	2.6
Xa-2	10	236	54.22	4.1
Kg-1	4	269	26.58	3.4
If-2	5	254	106.75	2.2

Thus, simple observations of modes often prove much more useful for recognizing secondary effects of long shore drift along with down slope cross-bedding. When statistical analysis is applied to bi-modal cross-bedding which is 180° out of phase, the possibility of a tidal interpretation is completely masked out. However, if paleoslope is the net result desired from cross-bedding data, computed data is very simply and rapidly acquired.

Vector mean was computed for each outcrop locality and this data was plotted (Fig. 24). The average azimuth direction of transport for 243 readings is approximately 185°.

However, by plotting two different rose diagrams a slight difference in average direction is noted between the area toward central Georgia and that from the Chattahoochee River area. The Chattahoochee area has an average azimuth vector of approximately 195. More important than this, however, is the conspicuous mode to the WNW, suggestive of long-shore drift.

A plot of the coarsest grain (Fig. 24) displays little difference in this parameter in Georgia, suggesting that the transport direction is probably to the south. The coarsest grain size is however distinctly smaller in nearly all of the Alabama outcrops sampled for this parameter.

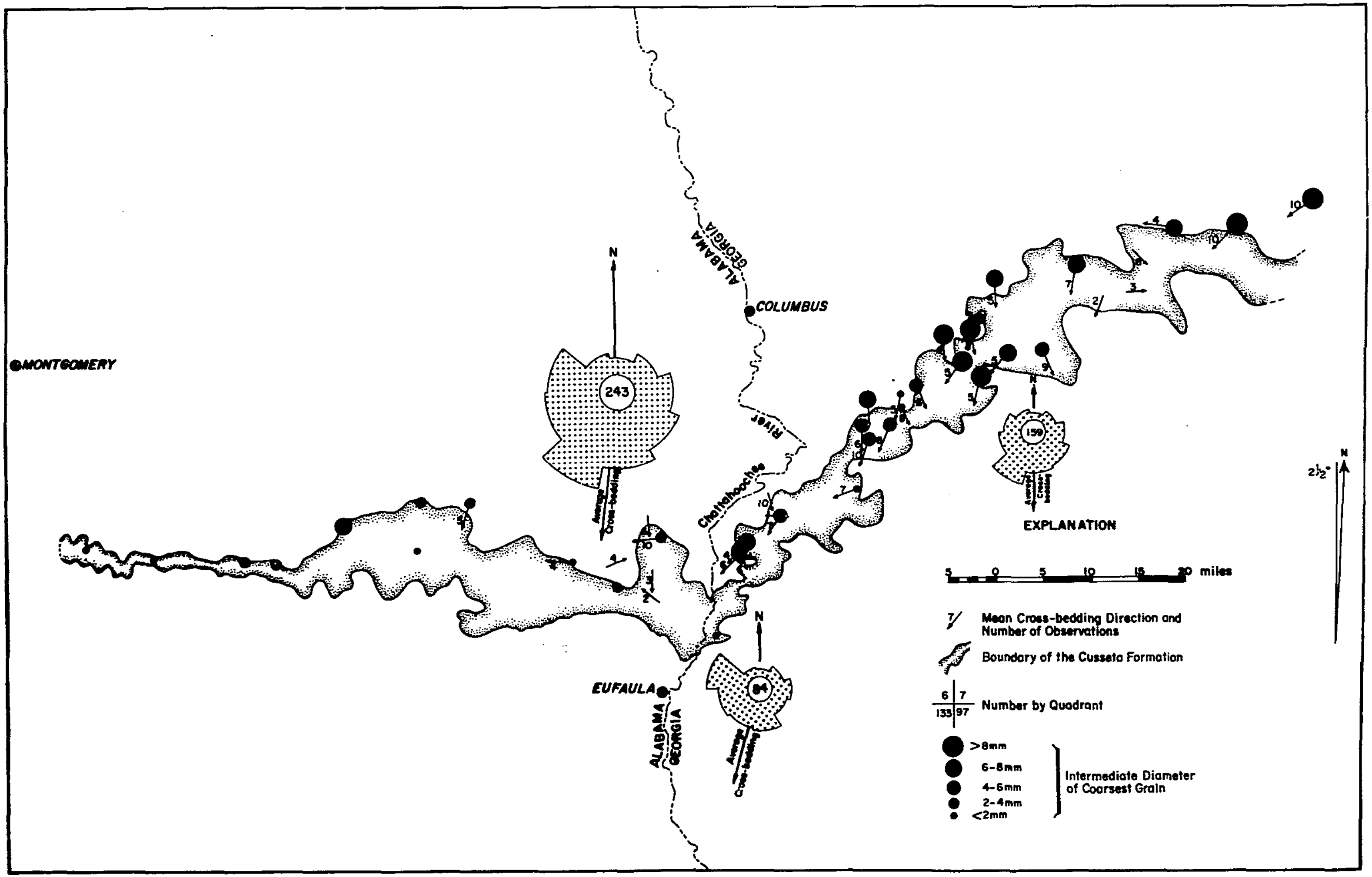


Figure 24 - Cross-bedding and coarsest grain size distribution for the Cusseta sand of Georgia and Alabama

Source of Sediments

Direction of Transport

From a study of the stratigraphic relationships of the Cusseta Sand with other upper Cretaceous units it was determined that this sand was changing facies in a general direction of south, southwest and west, from fluvial to delta-front to pro-delta. This strongly suggests that the source is to the north or northeast.

Analysis of the clay mineralogy demonstrates that there is an overall reduction in kaolinite with an increase in montmorillonite in going from east or northeast to west or southwest. This has been used by various workers (Parham, 1964) to demonstrate that the kaolinite was generally related to a nonmarine, continental environment and the montmorillonite generally represented a marine environment. This suggests that the general direction of transport (in outcrop sediments) is to the west and southwest. Because transport direction is generally related to the source, this would suggest that the source area for the clays was to the east or northeast.

Cross-bedding analysis and a coarsest grain size study suggests that transport direction was to the south and southwest. This indicates that the source of coarse clastics is to the north and northeast particularly in Georgia.

Mineral Composition of Source Rock

The Cusseta Sand is classified as ranging from sub-graywacke, sub-arkose, to orthoquartzite. It is an immature sediment which demonstrates an almost complete absence of roundness in the quartz and tourmaline grains.

This indicates a source composed largely of crystalline rocks. The immaturity and angularity suggest that little of this sediment was derived from pre-existing sedimentary rocks.

The presence of angular microcline and orthoclase feldspar indicates an igneous or metamorphic source. The abundance of mica indicates that schists were probably strong contributors to the sediment.

Heavy minerals provide reliable information concerning the ultimate source area. Table 12 lists the heavy minerals identified in this study and the probable type of source rock. The rather consistent presence of kyanite, staurolite, epidote, muscovite, points to high-rank metamorphic rocks as the dominant source of material. The presence of titanite, muscovite, biotite, monazite in rather insignificant percentages suggests acid igneous rocks as a minor source area. Pre-existing sedimentary rocks are also considered as minor contributors.

A heavy mineral study by Stow (1939) of the James River in Virginia, illustrated that the sediments were derived principally from the igneous rocks of the Blue Ridge and metamorphics of the Piedmont Plateau. The assemblage that Stow identified is very similar to the suite of this study (table 4). Studies of accessory minerals of the crystalline rocks of the Blue Ridge and Piedmont Plateau and southern Appalachians by Bloomer (1955), Furcon and Teague (1945), and Kesler (1944) illustrate that the heavy minerals from these areas are very similar to those found in the Upper Cretaceous sediments of Alabama and Georgia.

From the studies of directional properties and light and heavy minerals it is concluded that the source area for the Cusseta Sand is the Blue Ridge and Piedmont Plateau of the southern Appalachian region.

Table 12

SOURCE ROCK OF UPPER CRETACEOUS HEAVY MINERALS OF ALABAMA AND GEORGIA

		reworked seds.	low rank meta	high rank meta	acid igneous	basic igneous	peg
*Rutile		X				X	
*Zircon		X			X		
*Staurolite			X	X			
*Kyanite				X			
**Epidote			X	X			
**Hornblende (bl-grn)				X			
Titanite					X		
Muscovite			X	X	X		X
Biotite				X	X		
Sillimanite				X			
Corundum							
Spinel							
Garnet				X			X
Monazite					X		X
Leucoxene		X	X			X	
*Tourmaline	rounded	X					
	brown euhedra		X				
	blue						X

*Stable
**Unstable

(Adapted from Pettijohn, 1957)

Environmental Interpretations from Studies of Vertical Sections

Introduction

A wealth of geologic information has been gathered in the past few years concerning the processes and products of Recent sedimentary environments, particularly in the Gulf Coastal regions of the United States, by Scruton (1955), Moore (1955), Shepard (1956), Fisk (1961) and others. The purpose of these extensive studies was to gain better knowledge of the Recent so that it may be possible to use the law of uniformitatianism to interpret environments in ancient rocks. Judicious application of this law has proven most useful in the environmental interpretations of ancient sediments by Brett and Wheeler (1961), Weimer (1961), Wermund (1965), Fisher and McGowan (1967) and others.

The objective of this investigation, as the second half of this thesis, is to study in detail a sequence of Upper Cretaceous sediments in a number of sections, and relate this information to that obtained from studies in the Recent Gulf Coast in an effort to interpret the environments under which these sediments were deposited. Through integration of the environmental information gathered from local areas into the regional picture, the detailed paleogeography of the Cusseta Sand is reconstructed.

Methods

Because interpretations based on one or two parameters or methods are at best tenuous, consideration was given to a number of factors in order to make a better estimate of the environments. The methods employed in this study were detailed lithologic field description, coarse fraction description, clay mineralogy, textural analysis, megapaleontology and micropaleontology.

Field description

Samples were collected at five foot intervals at which time detailed field description was made. A trench method was utilized in an effort to obtain a representative sample from the entire 5 feet. At contacts, adherence to this method was not maintained, but rather, detailed sampling was made on each side of the contacts.

Coarse Fraction Study

A split was made of the fraction coarser than 0.62 mm. and examined under the binocular microscope (Shepard and Moore, 1954). Percentage estimates were made of the more significant constituents, including foraminifera, ostracods, shell fragments, glauconite, mica and lignitic material.

Clay Mineralogy

Oriented slides of clay aggregates, using the less than 2 micron fraction, were prepared for analysis with X-ray diffraction. Following work by Griffin (1963), consideration was given only to the montmorillonite (15.3 Å) to kaolinite (7 Å) ratio for the environment study.

Textural Analysis

Samples collected at the Dg-1 section (Pine Level, Alabama) were disaggregated and wet sieved through 230 mesh (.062 mm) sieves, and the fraction greater than .062 mm was analyzed by standard sieving methods. The size fraction less than .062 mm was analyzed by the pipette method at 1/2 ϕ intervals up to 6 ϕ after which whole ϕ interval readings were taken to 10 ϕ. For the remaining eleven sections textural analysis was performed on only the size fraction greater than .062 mm through the use of the Emory Settling Tube (Emory, 1938). All calculations were made by computer technique. The original program was obtained from the University of Pennsylvania, but in order to make it better fit the needs of this study, William Howard of the University of Cincinnati Computer Center, modified the program.

Statistical parameters utilized were the mean and standard deviation. The sand-to-mud ratio (Shepard classification) and the coarsest grain measurement were also used for general description of the sediments.

Megapaleontology

Megafossils were treated in a very general manner, in that notes were only made of the presence of large Mollusca, particularly Ostrea and Turritella, the presence (when abundant) of a small unidentified pelecypod cast, and the presence of various types of trace fossil-bioturbate structures and particularly Ophiomorpha.

Micropaleontology

Samples were washed through the 230 mesh (.062 mm) screen. A split was made of the fractions coarser than .062 mm, and the foraminifera were picked, counted, and identified to genus. The parameters given consideration were planktonic to benthonic ratio, faunal dominance, and number of benthonic genera. Unfortunately most of the samples were void of microfossils, as a result of sub-aerial weathering.

DETAILED STUDY OF SECTION DG 1, PINE LEVEL, ALABAMA

A detailed study of one area was undertaken to determine what parameters would be most useful for reconstructing the ancient environment, and to serve as a reference for correlation in the nearby sections studied. It was fortuitous for the author that new road cuts for US 231 near Pine Level, Alabama were being made during the summer of 1966, when most of the field work was carried out. These road cuts provided an excellent section (which is seldom found in this area) exposing approximately 65 feet of the Demopolis and approximately 100 feet of the Cusseta Sand (Fig. 25).

Discussion of Dg 1 Section

The sediments mapped as Cusseta in this area are dominantly marine. However, to the east they take on characteristics which look less and less marine, until in central Georgia, the sediments are very coarse clastics, conglomeratic in part, and associated with conspicuously thick lenses of kaolinite. An isopach map showing the thickness distribution of post-Tuscaloosa and pre-Paleocene sediments defines a "depo-center" located in south-central Georgia. The Cussets Sand is here interpreted as a clastic wedge of this Upper Cretaceous delta complex which projected west and southwest into Alabama. The Cusseta Sand in Montgomery County may not be exactly equivalent in time to the Cusseta of Georgia, but it may be considered as a portion of the interval of time necessary for the development of this facies sequence.

If it can be assumed that the same physical elements influenced the sediments in the Upper Cretaceous Gulf that operate in the Present, the obvious place to concentrate our search for analogous environmental conditions is on the Present Gulf Coast. Since two distinct deltaic complexes were active in the northeast Upper Cretaceous Gulf - one the "McNairy" delta (Pryor, 1960) and the other the "Middendorf delta" (Cusseta) of Georgia and South Carolina - the present day Mississippi Delta and the Appalachicola Delta respectively, may be considered their contemporary equivalents. The area of concentration for locating a present day analogy of the facies sequence observed in the Upper Cretaceous in the Pine Level, Alabama area (which is situated midway between the Cusseta and McNairy deltas) is in the zone of intermixing between the Mississippi and Appalachicola deltas.

The description and interpretation of the Pine Level section (Dg 1, fig. 25) follows.

Table 13

SUMMARY OF FEATURES FOR FACIES I (Dg 1-1 through Dg 1-9, Fig. 25)

Sediment	Fauna
very poorly sorted	Bioturbate structures
5 - 31% sand	abundant small pelecypods
very carbonaceous	relatively common ostracods
very micaceous	foraminiferal faunal dominance average of approximately 50%
average mean grain size 7 ∅	*Neobulimina* dominant genus
relatively low Mont/Kaol ratio	*Anomalinoides* second most abundant
SAND-SILT-CLAY RATIO	*Heterohelix* third
clayey silt, sandy silt and sand-silt-clay	*Buliminella* fourth
	Planktonic to Benthonic ratio less than 1

The sedimentological description compares very favorable to the delta front silts and sands described by Scruton, 1955. The low diversity organisms suggest a restricted environment or one that is in some way not open marine. The abundant presence of *Neobulimina*, although extinct, suggests a rather shallow water environment. *Buliminella*, which belongs to the same superfamily, has a present-day depth range of 2-10 fathoms. Foraminiferal faunal dominance of 50% strongly suggests that the water is less than 10 fathoms in depth. The planktonic to benthonic ratio of approximately 0.1 indicates that the water was less than 25 fathoms in depth. *Anomalinoides* was used by Brett and Wheeler (1961) as an indicator for shallow water. Phleger would place this environment in the Innter Continental Shelf at 20-60 meters depth.

Table 14

SUMMARY OF FEATURES FOR FACIES II (Dg 1-10 through Dg 1-14, Fig. 25)

Sediments	Fauna
Clay predominates ranging from 62 to 80%	scattered small pelecypods
	Foraminifera
carbonaceous	Planktonic to Benthonic ratio from .3 to .8
very calcareous	Diversity of population 7.0
SAND-SILT-CLAY RATIO	Faunal dominance average approximately 25%
	order of most abundant genera
	Anomalinoides
	Heterohelix
	Bulimina

Based on the abundance of clay, this facies would be equivalent to the off-shore clays. These clays most likely have their source to the east as the Blufftown pre-delta silts and sands, only farther from the source. To the west these clays grade into transitional sands and the open platform chalks of the Demopolis.

A higher planktonic to benthonic ratio, a greater number of genera, and a lower faunal dominance, suggests that this is an environment which is more open marine than Facies I. The foraminiferal assemblage, particularly *Bulimina* and the abundant extinct planktonic form *Heterohelix*, suggests that the water is very deep, possibly as deep as 300 feet. However, this is considered unreliable because the underlying and overlying facies are shallow marine sediments, probably less than 60 feet, but, the presence of these two genera does suggest that this interval is more transgressive than the underlying and overlying facies.

Table 15

SUMMARY OF FEATURES FOR FACIES III (Dg 1-15 through 19, Fig. 25

Sediment	Faunal
67 to 83% sand	presence of distinct burrows
coarsest grain size largest for entire section 1.5 mm	high diversity of mega fauna
	Anomia and *Ostrea* (Dg 1-17)
better sorted and mean grain size is larger than underlying facies	*Exogyra* scattered in area of Dg 1-15
SAND-SILT-CLAY RATIO sand and clayey sand	faunal dominance of benthonic foraminifera approximately 7.0
abundant glauconite	Planktonic to Benthonic ratio approximately .20
	Anomalinoides and *Cibicides* dominate

Facies III is a sand which is typical of marginal deposits. This sand consists of dominant sand size particles, with clay and a conspicuously small amount of silt. Bioturbation, layers with abundant megafossils, coarseness of grain size, and olive gray color are all characteristics that compare favorably with the marginal sand deposits of Recent sediments described by Scruton, 1955. These sediments, according to Scruton, are deposited rather slowly and are actually derived from nearby sand bodies which were formed during a period of inactivity of a previous regression. This may represent the termination or reduction of terrigenous supply observed in Facies I.

Abundance of glauconite is generally associated with inner neritic environments containing oxygenated water of normal marine salinity (Wermind, 1961). The presence of these sands, which are much better sorted than the underlying facies, suggests that there was considerable influence of ocean currents or wave action. Trace fossils suggest the same conditions in changing from a highly mottled texture in facies I to sediments with distinct burrows in Facies III.

The presence of marine epifauna, consisting mainly of Anomia and Ostrea, place a depth range of 20-50 feet on this facies (Kauffman, 1967). Brett and Wheeler (1961) interpret these forms as represented intertidal and just off shore environments. According to Kauffman (1967), the large shelled Exogyras are specifically adapted to the high energy, shallow, nearshore zone of marine sheet sands.

The foraminiferal benthonic faunal dominance of 30% and the lower (.20) planktonic-to-benthonic ratio suggests that this environment is very likely shallower than Facies II.

Table 16

SUMMARY OF FEATURES FOR FACIES IV (Dg 1-20 through Dg 1-25, Fig. 25)

Sediments	Fauna
increases upward in sand from 6-63%	abundant small pelecypods in lower part
mean and largest grain size increase upward	distinct burrows in zone from Dg 1-22 through Dg 1-24
SAND-SILT-CLAY RATIO averages around sand-silt-clay	6 inch fossiliferous layer made up dominantly of Ostrea in Dg 1-25
carbonaceous in lower part	Planktonic to Benthonic ratio high in lower part
high Mont/Kaol. ratio	
glauconitic in upper part	dominant genera increases from approximately 25% to approximately 35%. Anomalinoides, Heterohelix, and Cibicides are dominant.

According to Shepard and Moore (1955), this type of sediment is found seaward of the (approximate) 30 foot contour. The lower portion of this facies is probably a renewal of the underlying Facies II which would represent another minor transgression.

The high montmorillonite/kaolinite ratio, high planktonic to benthonic ratio and lower generic dominance at the lower portion of this facies suggests that this environment was open marine. The presence of distinct burrows, which are associated with higher energy levels, than the underlying intensely mottled beds, and the increase in mean and largest grain size suggests that the environment was becoming shallow enough to be affected by wave energy. The presence of Ostrea restricts Dg 1-25 to a bathymetric zone of 20-50 feet.

The open marine environment, at the lower part of this Facies, is better explained by being isolated or far removed from a detrital source or a source of high continental run-off, rather than being associated with deep water.

Table 17

SUMMARY OF FEATURES FOR FACIES V (Dg 1-26 through Dg 1-31, Fig. 25)

Sediment	Fauna
75 - 93% sand	infrequent gastropods
SAND-SILT-CLAY RATIO sand	abundant Ophiomorpha Dg 1-29 and 30
shows much better sorting than any other facies	(foraminifera absent)
Dg 1-30 and 31 mod. well sorted	

The presence of clean moderately well sorted sand with abundant Ophiomorpha strongly suggests either a beach facies (Toots, 1961), tidal or subtidal environment (Weimer and Hoyt, 1964), shallow turbulent environment (Waage, 1967), or nearshore sands (Kauffman, 1967). The depth of water was probably less than 10 feet. Pryor (personal communication, 1968) found Callianassa limited to a depth of approximately 6 feet of water off the beach front of Ship Island, northeastern Gulf of Mexico.

This continued increase in sand content suggests the migration of barrier islands into the area, which is similar to conditions found by Shepard and Moore (1955), on the open water side of island barriers of the central Texas coast. The open shelf character of the fauna and sediments of the section below the high energy Ophiomorpha facies lends strong support to the barrier island interpretation. Because barrier islands are so commonly many miles seaward of the mainland coast, an open marine environment would be much more easily obtained than in the zones of mainland beaches. Another point to consider is the position of this section with respect to the major deltas. The inter-deltaic position is characterized in the Recent Gulf Coast by large barrier islands.

Facies V represents an environment where the energy is high enough to remove fine material and organic detritus to a point where the only organisms which can establish themselves are the filter feeding infauna, _Ophiomorpha_. _Ophiomorpha_, according to Weimer and Hoyt (1964), represents an environment in the tidal or subtidal zone.

Sandstone bodies, very similar to Facies V, found in the Fox Hills Sandstone of Wyoming are also described by Weimer (1961) as barrier islands. Harms _et al_. (1965) object to this interpretation in that these sediments show no abrupt shoreward change into a lagoonal facies, and the erosion surface, commonly found in the lower portion of the sand, separating fine sand below from coarse sand above with steep cross-bedding in a predominantly seaward direction, has not been recognized in Recent barrier island sequences.

The absence of the lagoonal facies in the regressive sequence above and shoreward of the barrier facies in the section described in this paper can be explained in two ways. If what we now see in the outcrop represents the lower portion of the "barrier" facies, subsequent destruction by the transgressing Ripley sea eroded and reworked the upper barrier facies and the lagoonal facies.

Since the Cusseta strand line is parallel to outcrop and parallel to the basinal hinge line, change in dip, due to seaward subsidence, from an original 4-5 feet per mile to 23-25 feet per mile (Herrick, 1961) has caused truncation of most of the littoral sediments. There is no unconformity in the barrier facies in this section, but these disconformities, where present, probably formed as a result of migrating inter-barrier tidal channels which partially destroy the "island barrier".

The cross-bedding which shows a predominant seaward vector component (Weimer, 1961; Harms, et al., 1965) can also be explained by sedimentological processes associated with inter-barrier tidal channels. A detailed bathymetric map of the Gulf Coast between Dauphin and Ship Islands shows distinct tidal deltas that build seaward. A possible explanation for this follows.

Because the area behind the barrier is much shallower (maximum of 18 feet), higher velocities are generated, causing a considerable amount of sediment to be carried in suspension and as a traction load through the tidal channel with the outgoing tide. When this sediment-loaded water meets the open ocean, a rapid decrease in velocity takes place, causing the sediment to be deposited at the crest of and down the foreset slope of the tidal delta. The incoming tide has a tendency to scour the tidal channel because of the constriction, therefore picking up some of the sediment that was carried out. However, because the velocities do not become high enough to effectively scour the bottom until they reach the immediate area of the channel, the sediment that was deposited on the foreset slope with outgoing tide is not returned shoreward. Thus, cross-bedding with a seaward vector component would be preserved.

Sedimentological Method for Determination of Water Depth

The determination of the depth of water is a problem that plagues nearly every sedimentologist or paleontologist in his attempt to reconstruct ancient sedimentary or paleoecological environments. From the observations made in this study, it is the contention of this author that there is no one parameter which is completely reliable for making such determinations. However, the factor which should prove to be most reliable is one that is affected by the least number of variables. Of course, any parameter that is chosen over another is going to prompt heated argument from opposing points of view.

It has been well illustrated by large numbers of investigations that through the study of the distribution of foraminifera, reliable ecological zonations can be constructed. However, zonation does not always carry with it depth connotation, for this is where the problems with variables are most pronounced. Distance from a detrital source or from shore is too often correlated with depth. Such a generalization is not warranted, because it depends upon where the environment is with relation to the detrital source. Between areas of active deposition (deltaic) and areas of slow deposition (inter-deltaic) the same fauna are characterized by different depths because, as Bandy (1956) and Phleger (1960) point out, the chemistry of the water (in this case salinity) plays an important role in dictating the type of faunapresent.

In areas of relatively high runoff, abnormally low salinites are felt great distances from shore. On the other hand, in areas of low runoff, normal marine salinities are found much closer to shore and in considerably shallower water. Phleger (1960) observed that in areas where no distinct coastal waters exist (e.g., off northern Baja California), little difference is found in the planktonic foraminifera shoreward. This seems to be particularly true for areas associated with off-shore barriers. The barriers are often far from the mainland (as much as 15 miles), yet the depth of water seaward of the barrier is extremely shallow and the environment is that of an open marine situation. In this environment a mixture of nearshore and open-ocean benthonic foraminifera may occur (Phleger, 1960). Wall (1967) attributed the presence of planktonic foraminifera, in otherwise shallow water sediments, to favorable oneshore currents and to conditions of minimal turbidity. From this brief discussion it can be concluded that variables such as distance from detrital source, proximity to zones of fresh water runoff, and presence and direction of currents present problems in utilizing foraminifera as absolute depth indicators. However, this does not mean that these organisms are not useful for depth zonation, for they are much more sensitive to chemical changes than are the sediments.

The one factor affected by the least number of variables is the sediments, when considered simply as detrital material "infilling" a basin. Careful observation of a stratigraphic sequence of sediments and its response to sedimentological processes, particularly flow regime, probably provides the most meaningful depth interpretations.

In a number of the sections studied (Dg 1-20 through 31, Eg-2, If-1, Lh-1, and Pe-3a (Plate I, figure)) a distinct coarsening upward was observed, which is accompanied by better sorting and a transition from an absence of primary structures to distinct laminated bedding and finally to a sequence dominated by cross-bedding. In this same upward direction bioturbate structures resulting from detritus feeding burrowing infauna, slowly but completely are replaced by a burrow-building, filter-feeding infauna. These characteristics are attributed to a change from low to high flow regime which is associated with shallowing of the water resulting from "infilling" by detrital material.

In order to give more absolute rather than relative values to the depth, it is imperative to establish a reference figure. Stringent limits can be established for the cross-bedded, well-sorted uppermost unit based upon the following facts:

(1) the well sorted sands commonly displaying alternating low and high angle cross-bedding suggests that the environment was affected by tides or wave energy. The maximum depth at which Recent sediments are influenced by wave energy in the Gulf Coast area is approximately 35 feet (Shepard and Moore, 1955). Because plants which grow in the photic zone, may inhibit sorting of bottom sediments by wave energy, the depth at which well sorted sands occur is most likely much shallower than 35 feet.

(2) the presence of Ophiomorpha (previously discussed) provides rather conclusive evidence that these sediments were deposited in the tidal or subtidal area of the littoral environment.

The section considered for this discussion is the upper Cusseta (Dg 1-20 through Dg 1-31, Plate I) of Pine Level, Alabama (Fig. 25). Accepting a maximum of 35 ft. for the depth at which the sediments of sample Dg 1-29 were deposited, sample Dg 1-20, 45 feet below Dg 1-29, would have been deposited in a marine environment little deeper than

80 feet. However, since the water content of clays and silts is as great as 60%, allowance must be made for compaction due to dewatering. Allowing a maximum of 60% compaction for Dg 1-20 (% clay) and Zero compaction for Dg 1-29 (% sand), the total compaction for this 45 foot section would be 30%. This would make the original thickness approximately 58.5 feet and place the maximum depositional depth for Dg 1-20 at 93.5 ft. However, if subsidence continued in the Upper Cretaceous at the same time (but not necessarily at the same rate) that sedimentation was taking place, as it does along the present Gulf Coast, the original depth of sedimentation at any specific time was probably less than is indicated strictly by representative thickness. Simply stated a "hole" is not just becoming filled with sediment.

Uplift has not been seriously considered as an explanation for the shallowing conditions because the dominant tectonic influence on the present Gulf Coast is one of subsidence. Long periods of non-deposition could also alter the above depth interpretation, but since no unconformities or lag deposits were observed in this section from Dg 1-20 to Dg 1-31, this "positive" sequence is interpreted as representing one continuous period of deposition.

To project this interpretation any farther down into the section is considered to be tenuous. However, sedimentological and stratigraphic observations suggest that the sediments of this section were deposited in water of a depth shallower than 100 feet.

Vertical and Composite Sections

The same method of study, as used for section Dg 1 was utilized for eleven other composite sections (Fig. 26 through 36; Cg, Eg, Fg, Gg, If, Kg, Lg, Lh, Ng, Pe, Rd - Plate I). Although these sections were studied in considerably less detail than section Dg 1, it is felt that adequate information is provided for environmental interpretation. The coarse fraction analyses (table 18), montmorillonite to kaolinite ratio (table 19) and textural analyses (table 20) appear on the following pages.

The major environments (delta front sills and sands, offshore clays, marginal shelf sands and barrier island sands) observed in the Dg 1 section, were found in almost every composite section from Cg (the western most outcrop) to Ng (the Chattahoochee River area). Close correlation for the lithologies and major environments was observed for sections Cg, Dg, Eg, and Fg (Fig. 25, 26, 27, 28). In all of these sections the environment is shallow marine with the barrier island facies occurring at the top of the Cusseta Sand. For section Gg (Fig. 29) no Ophiomorpha were observed, however, a barrier island sand facies was determined which was based upon the presence of interpreted tidal channel deposits and clean, moderately well sorted sands with scattered small pelecypod casts. The presence of alternating layers of nonfossiliferous clean sands and kaolinitic clays, underlying the tidal channel deposits, lends support to the above interpretation.

In section If (Fig. 30) the Ophiomorpha facies (barrier island sand facies) occurs in the lower portion of the Cusseta Sand section. It is overlain by cross-bedded, fine to coarse sand which is interpreted as

Table 18 - Coarse fraction analysis

SAMPLE LOCATION (PLATE I)	INTERVAL	FORAMS		OSTRACODS	SHELL FRAGMENTS	GLAUCONITE	MICA	LIGNITIC MATERIAL	$\frac{\text{SAND}}{\text{MUD}}$ RATIO
		PLANK.	BENT.						
Cg-1a	9-15'	P	A	P	P	P	P		
Cg-1f						P	P		4.37
Cg-2			A	P		P	P		
Eg-1						P	P		
Eg-2	6-11'	P	A		P	A	P		
Eg-2	50-55'		P			P	P		
Eg-2	65-70'		P		P	P	P		
Eg-2	92-97'						P		6.77
Eg-2	102-107'						P		22.71
Eg-2	107-113'						P		21.17
Fg-1							A	P	
Fg-2a							A		
Fg-3	5-10'		P			A	P		
Fg-4		P	A	P		P	P	P	
Fg-6							P		100% sand
Gg-4	0-3'					P			7.03
Gg-4	20½-22½'	P	A	A		P	P	P	
Gg-4a		P	A	A		P	P	P	
If-1	1-3'	P	A	A			A	P	
If-1	7½-10'						P		17.78
If-1	14-15'		P			P	A	P	
If-1	17-19½'						P		4.45
If-1	20½-22½'		P	P			P		
If-1	31-35'						A		
If-1	41-47'						P	P	3.10
Jh-1		P	A			P	A	P	

Table 18 - (cont.)

SAMPLE LOCATION (PLATE I)	INTERVAL	FORAMS		OSTRACODS	SHELL FRAGMENTS	GLAUCONITE	MICA	LIGNITIC MATERIAL	SAND/MUD RATIO
		PLANK.	BENT.						
Kg-1	0-3'						A		3.63
Kg-1	25-28'						P		5.94
Kg-2	4½-6'						A		
Kg-2	7½-10'					P	A		
Kg-2	12-15'					P	P	P	3.98
Kg-2	16½-20'						P		
Kh-2							P		
Kh-4						P	P		
Lg-1	0-3'		P	P			A	P	7.17
Lg-1	12-14'						A		
Lg-1	14-17'						P		
Lh-1	0-3'								
Lh-1	3-6'					P	P	P	3.99
Lh-1	15-18'					P	P		6.36
Lh-1	24-25'					P	P		6.10
Lh-1	29-33'						P		10.93
Lh-1	38-44'						P		9.31
Lh-1	46-49'					A	P		
Lh-1b						P	P		
Lh-1c							P		5.91
Mh-2a							A	P	
Mh-2b		P	A	A		P	P		
Mh-3							P		23.39
Ng-1	0-3'						P		21.82
Ng-1	10-13'						P		17.59
Ng-1	13-18'					A	P		

Table 18 - (cont.)

SAMPLE LOCATION (PLATE I)	INTERVAL	FORAMS		OSTRACODS	SHELL FRAGMENTS	GLAUCONITE	MICA	LIGNITIC MATERIAL	$\frac{\text{SAND}}{\text{MUD}}$ RATIO
		PLANK.	BENT.						
Ni-1a							A	A	
Ni-2		P	A	P		A	P		
Pe-1	0-5'						P		100% sand
Pe-1a							A		
Pe-3a	0-3'		P			P	A	A	
Pe-3a	12-15'					P	P		4.17
Pe-3a	33-36'					P	P		4.47
Pe-3a	36-38'					P	P		3.47
Pe-3a	38-42'						P		11.46
Pe-3a	42-45'						P		8.67
Rd-2	10' below samp. sec.						P		100% sand
Rd-2	12-15'						P		
Rd-2	21-23'						P		21.30
Rd-2	26-29'						P		17.83
Rd-2	35-38'						A		
Rd-2	38-45'						A		100% sand

A - Abundant

P - Present

Table 19 - Montmorillonite/Kaolinite ratios of clays from sections Cg through Rd

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION (Peak Heights)		
				MONTMORILLONITE	KAOLINITE	MONT./KAOL. RATIO
Cg-1a	Cusseta	9 -15	Formation	90	120	0.8
Cg-1f	Cusseta		Borings	0	100	0.0
Cg-2	Demopolis		Formation	50	60	0.8
Eg-1	Demopolis		Formation	38	68	0.6
Eg-2	Cusseta	6 -11	Formation	65	33	2.0
Eg-2	Cusseta	65 -70	Formation	85	52	1.6
Eg-2	Cusseta	86 -92	Formation	35	19	1.8
Fg-2a	Demopolis		Clay Seam	32	43	0.7
Fg-3	Cusseta	5 -10	Formation	55	40	1.4
Fg-4	Cusseta	Upper	Formation	23	25	0.9
Gg-4a	Blufftown		Formation	34	55	0.6
Gg-2	Cusseta		Formation	18	60	0.3
If-1	Blufftown	1 -3	Formation	40	47	0.9
If-1	Blufftown	4 -4.5	Clay Seam	17	38	0.5
If-1	Blufftown	14 -15	Clay Seam	48	60	0.8
If-1	Blufftown	19.5-20	Clay Seam	48	52	0.9
If-1	Blufftown	31 -35	Formation	65	60	1.1

Table 19 - (cont.)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION (Peak Heights)		
				MONTMORILLONITE	KAOLINITE	MONT./KAOL. RATIO
If-1	Cusseta	47-48	Clay Seam	5	58	0.1
Kg-1	Blufftown	0-3	Formation	34	17	2.0
Kg-1	Blufftown	24-25	Formation	Tr	45	0.0
Kg-2	Cusseta	6-7.5	Clay Seam	55	55	1.0
Kg-2	Cusseta	20-20.5	Clay Seam	68	38	1.8
Jh-1	Cusseta	Upper	Clay Seam	90	0	10
Kn-2	Ripley		Formation	45	7	6.4
Lg-1	Blufftown	0-3	Formation	50	95	0.5
Lg-1	Blufftown	9-12	Formation	65	43	1.5
Mh-2a	Cusseta	Upper	Formation	55	35	1.6
Mn-2b	Ripley		Formation	15	28	0.5
La-1	Blufftown	3-6	Formation	58	65	0.9
Lh-1	Cusseta	29-32	Clay Seam	68	41	1.7
Ln-1	Cusseta	38-44	Clay Gall	10	43	0.2
Ln-1	Cusseta	46-49	Formation	45	66	0.7
Lh-1b	Cusseta	Upper	Formation	27	5	5.4
Ng-1	Cusseta	3-4	Clay Seam	60	28	2.1

Table 19 - (cont.)

SAMPLE LOCATION PLATE I	FORMATION	INTERVAL	TYPE OF SAMPLE	CLAY MINERAL COMPOSITION (Peak Heights)		
				MONTMORILLONITE	KAOLINITE	MONT./KAOL. RATIO
Ng-1	Cusseta	10-13	Clay Gall	60	33	1.8
Ng-1	Cusseta	13-18	Formation	35	15	2.3
Ni-1a	Cusseta	Upper	Formation	53	12	4.4
Ni-2	Ripley		Formation	35	33	1.1
Pe-1	Cusseta	Upper	Clay Seam	Tr.	90	0.0
Pe-1a	Ripley		Formation	26	33	0.8
Rd-2	Blufftown	10' below Sand	Clay Seam	5	80	0.1
Rd-2	Blufftown	9-12	Formation	55	40	1.4
Rd-2	Blufftown	20-20.5	Clay Seam	46	44	1.0
Rd-2	Cusseta	31.5-38	Formation	32	47	0.7

Table 20 - Textural analysis for sand from sections Cg through Rd

SAMPLE LOCATION (Plate I)	INTERVAL	MEAN	STANDARD DEVIATION	SKEWNESS	SAND/MUD RATIO	COARSEST GRAIN (mm.)
Cg-1f		3.41	1.78	1.49	4.37	0.9
Eg-2	91-97	2.96	1.11	1.88	6.77	1.2
Eg-2	107-113	1.37	.78	1.18	21.17	3.0
Eg-2	102-117	1.95	.67	.46	22.71	1.7
Fg-6		1.84	1.01	.41	100% sand	1.9
Gg-4	0-3	3.16	1.02	1.86	7.03	0.45
Gf-1	27-30	2.87	.92	2.08	10.74	0.40
If-1	7.5-10	3.12	.79	[illegible]	17.78	1.0
If-1	17-19	2.98	1.46	1.46	4.45	0.8
If-1	41-47	4.13	1.65	1.08	3.10	1.0
If-1	56-61	1.97	1.64	1.28	5.54	
Kg-1	0-3	3.51	1.89	1.17	3.63	1.3
Kg-1	25-28	2.60	1.43	1.22	5.94	3.5
Kg-2	12-15	3.88	1.60	1.32	3.98	1.1
Lr-1	3-6	3.88	1.59	1.36	3.99	1.3
Lr-1	15-18	3.58	1.01	1.72	6.36	.35
Lr-1	24-25	3.48	1.07	1.67	6.10	.65

Table 20 - (cont.)

SAMPLE LOCATION (Plate I)	INTERVAL	MEAN	STANDARD DEVIATION	SKEWNESS	SAND/MUD RATIO	COARSEST GRAIN (mm.)
Lh-1	29-32	1.75	1.21	1.42	10.93	3.5
Lh-1	38-44	1.15	1.22	1.65	9.31	5.5
Lh-1c		1.86	1.74	1.23	5.91	6.0
Lg-1		2.29	1.47	1.01	7.17	
Mh-3		2.44	0.46	1.74	23.39	1.6
Ng-1	0-3	2.67	0.46	1.42	21.82	1.1
Ng-1	10-13	1.47	0.94	0.95	17.59	5.0
Pe-3a	12-15	3.11	2.02	1.15	4.17	1.4
Pe-3a	33-36	3.12	1.43	1.28	4.47	1.2
Pe-3a	36-38	3.10	2.22	0.93	3.47	4.0
Pe-3a	38-42	2.20	1.16	0.63	11.46	4.5
Pe-3a	42-45	1.78	1.07	1.86	8.67	5.5
Pe-1	0-5	1.25	0.74	0.61	100% sand	3.0
Rd-2		1.11	0.76	1.10	100% sand	2.1
Rd-2	21-23	1.42	0.89	1.01	21.30	5.0
Rd-2	26-29	1.90	1.01	0.46	17.83	4.0
Rd-2	38-45	2.26	0.43	-0.63	100% sand	1.6

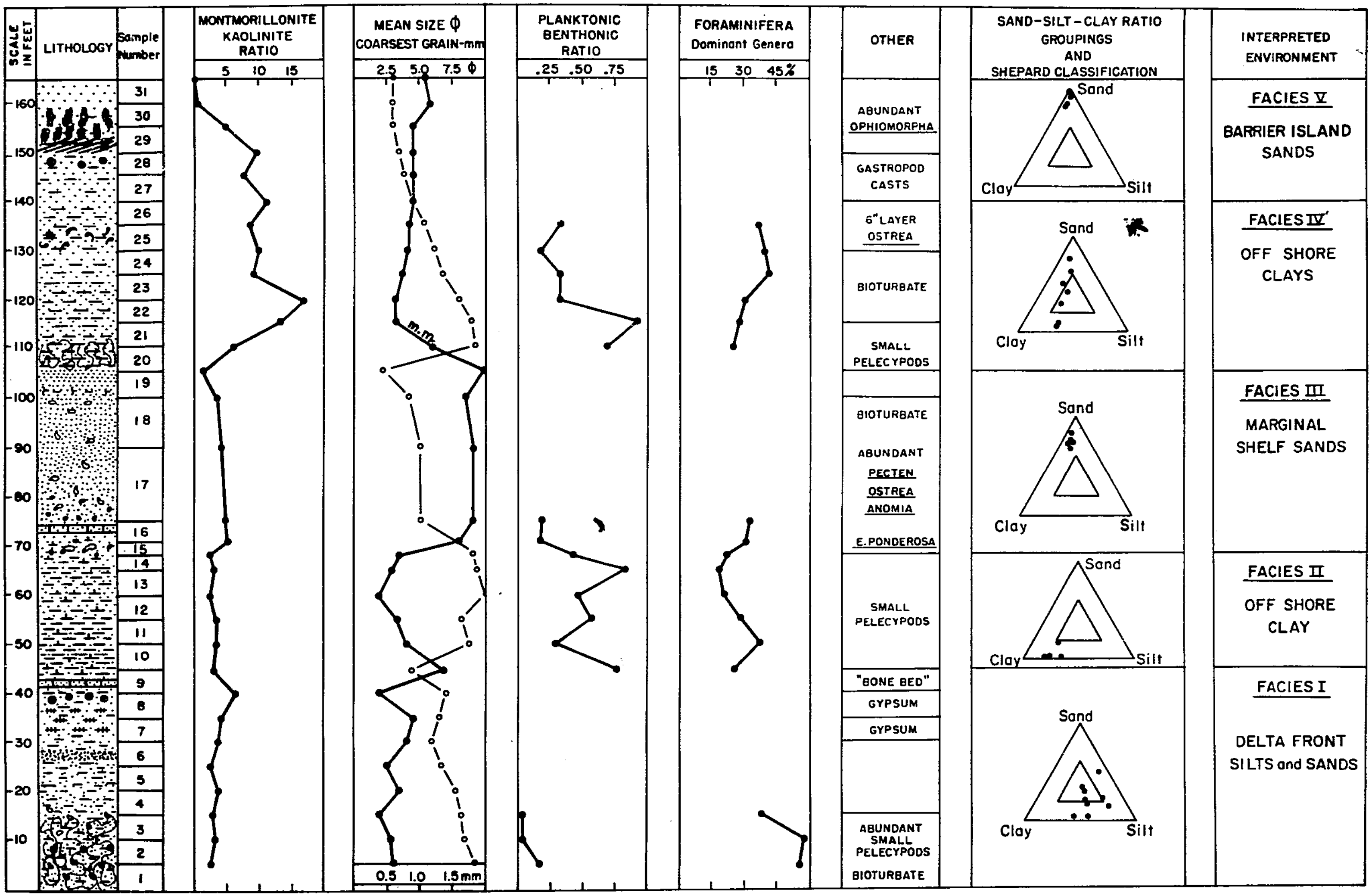
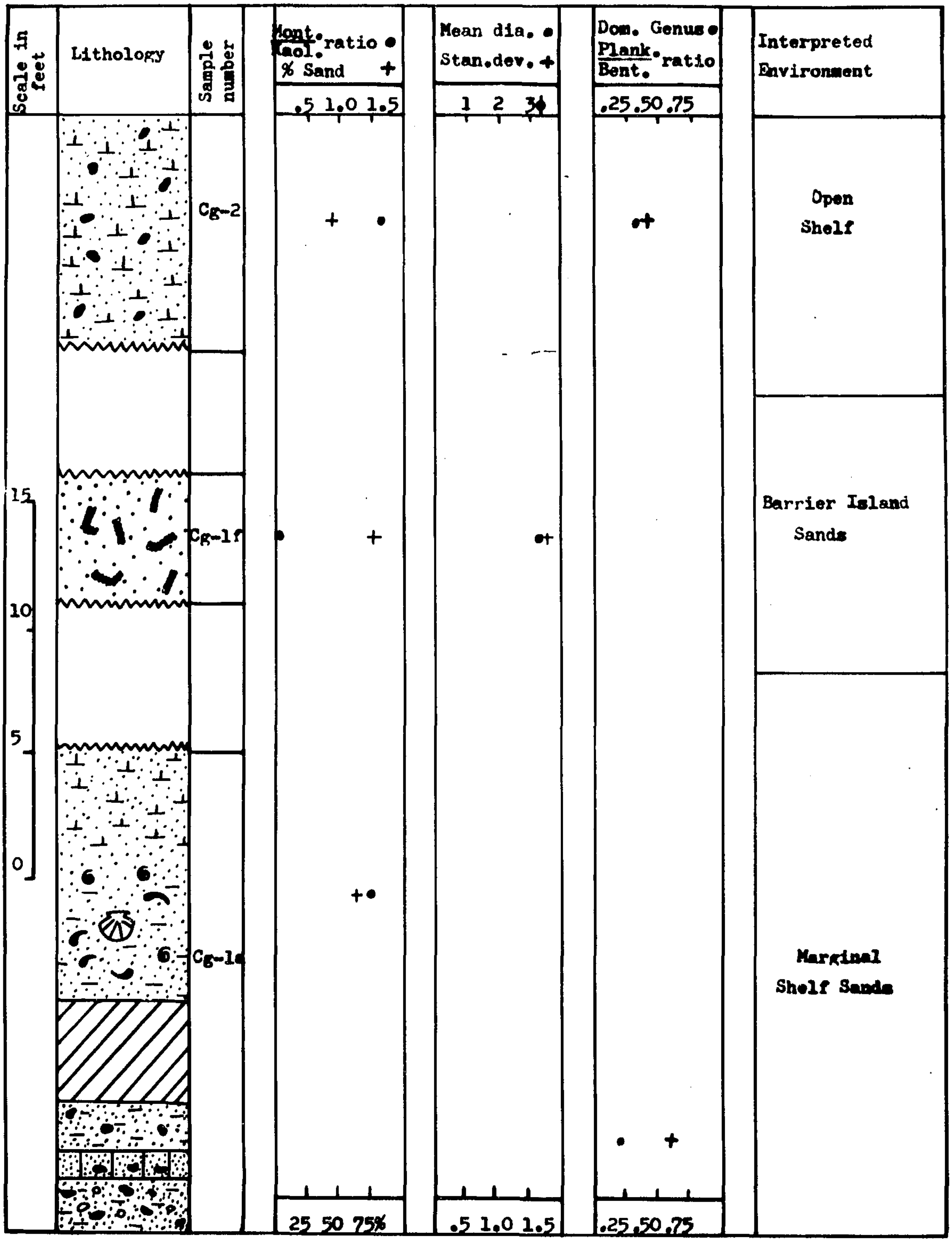


Figure 25 - Detailed study of section Dg 1, Pine Level, Ala.

Figure 26 - Section Cg Series



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(For Figures 25 Through 36)

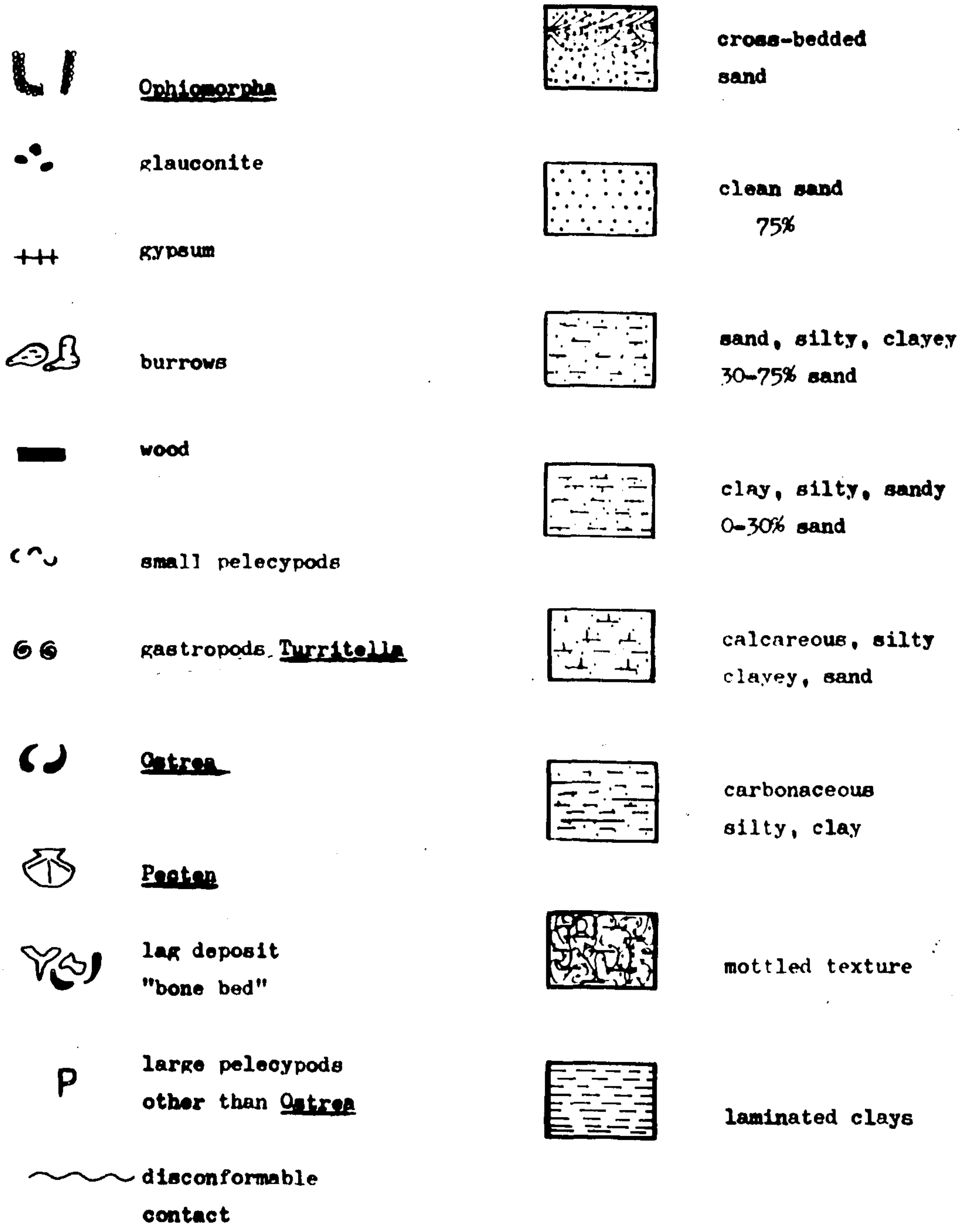


Figure 27 - Section Eg Series

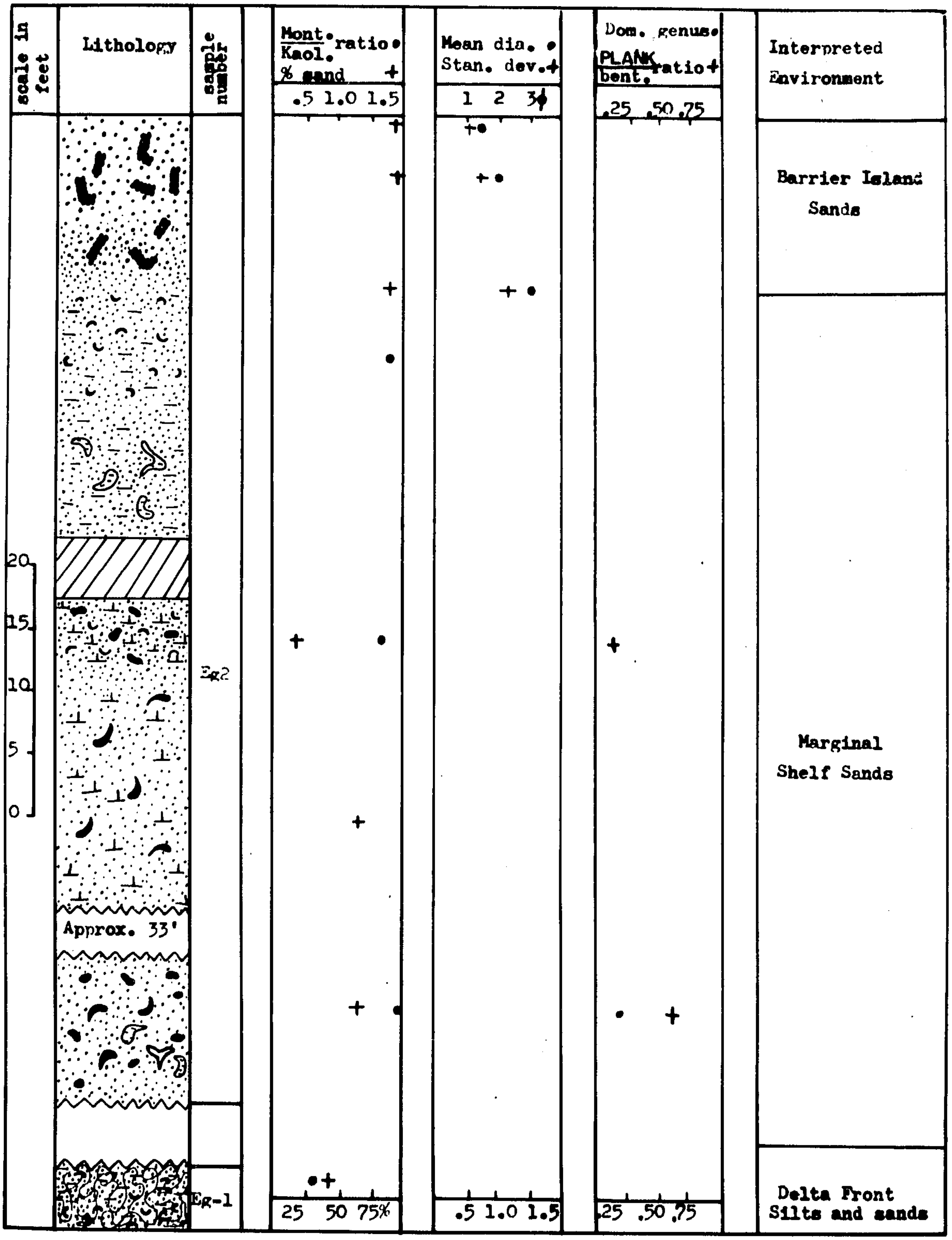


Figure 28 - Section Fg Series

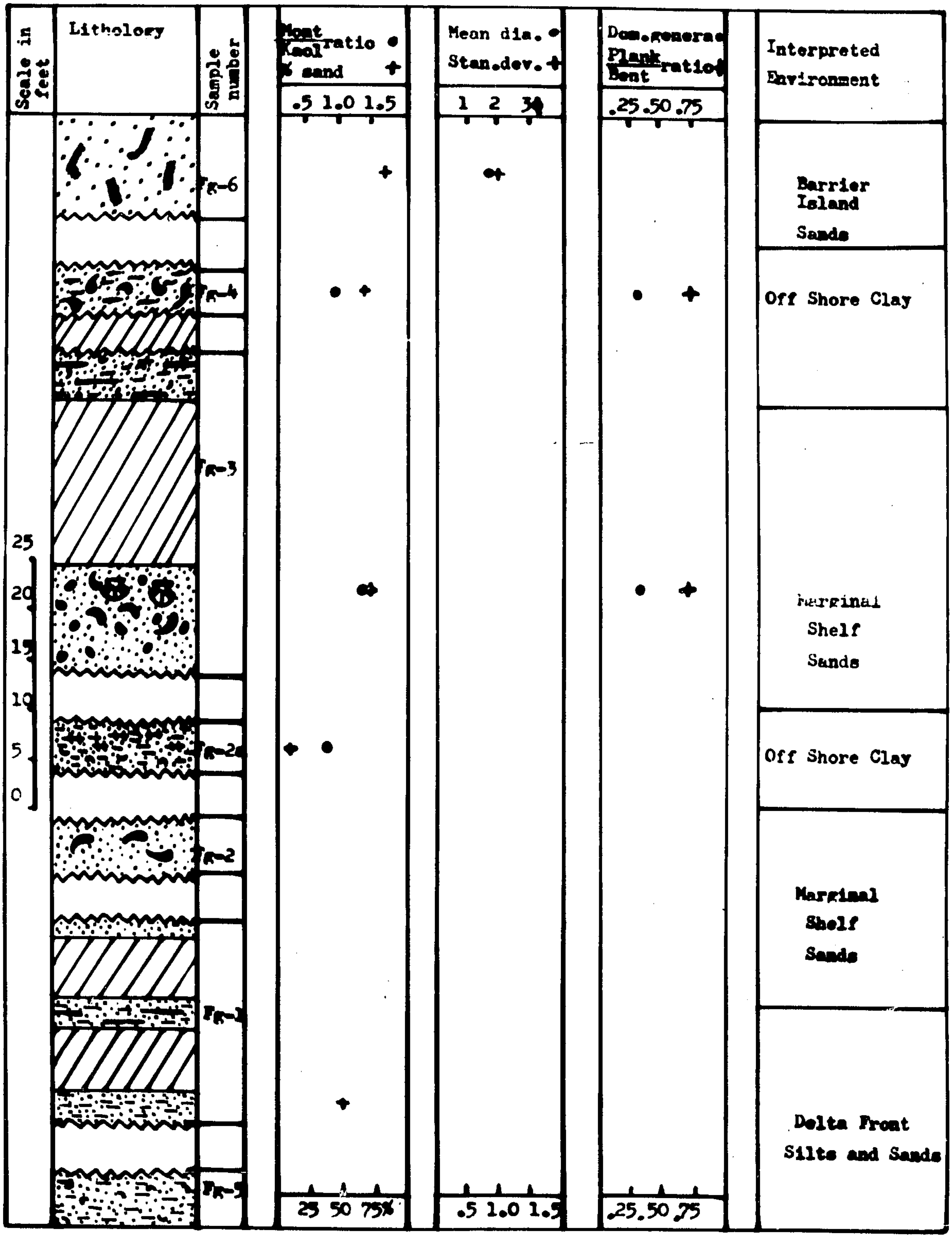


Figure 29 - Section Gg Series

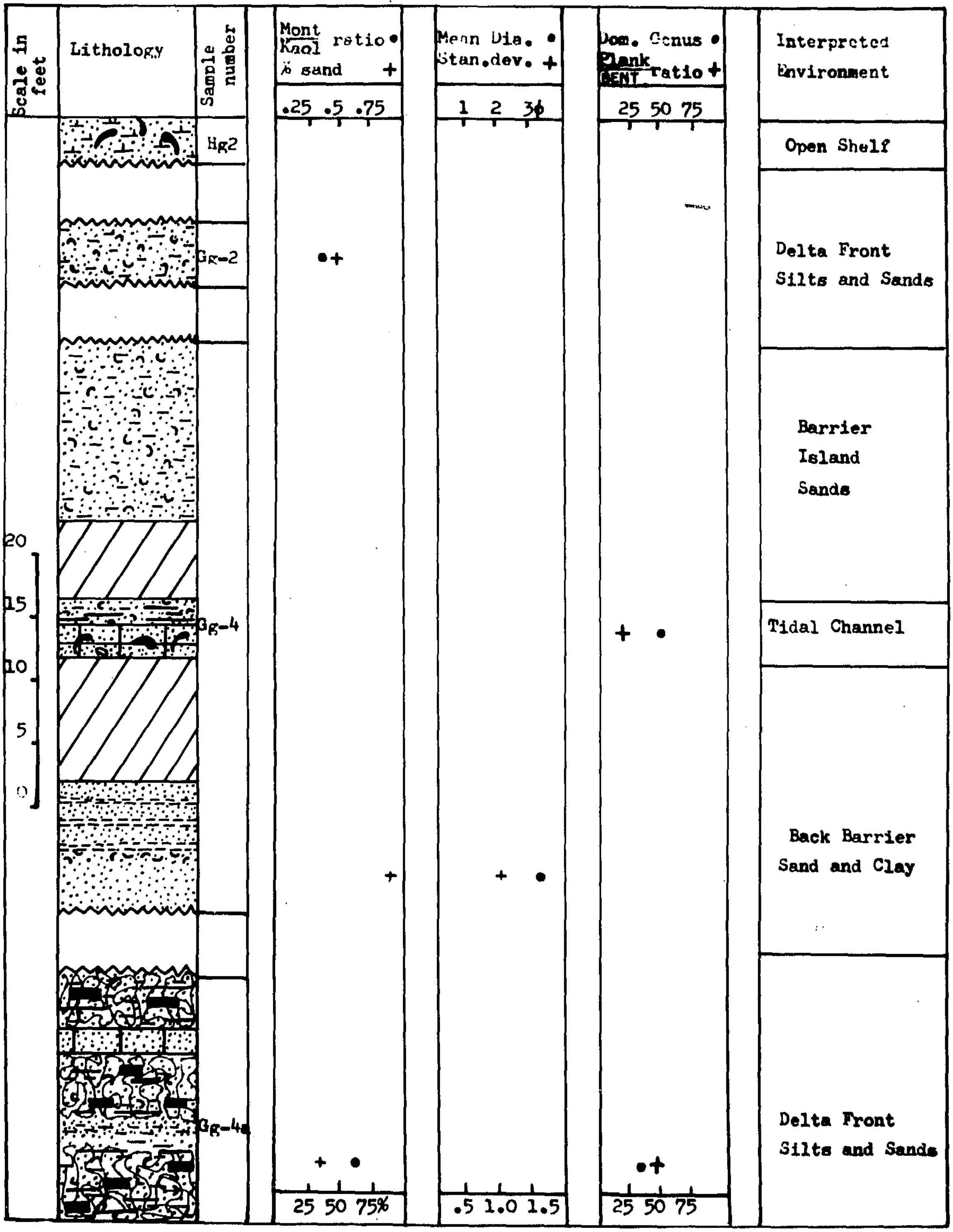
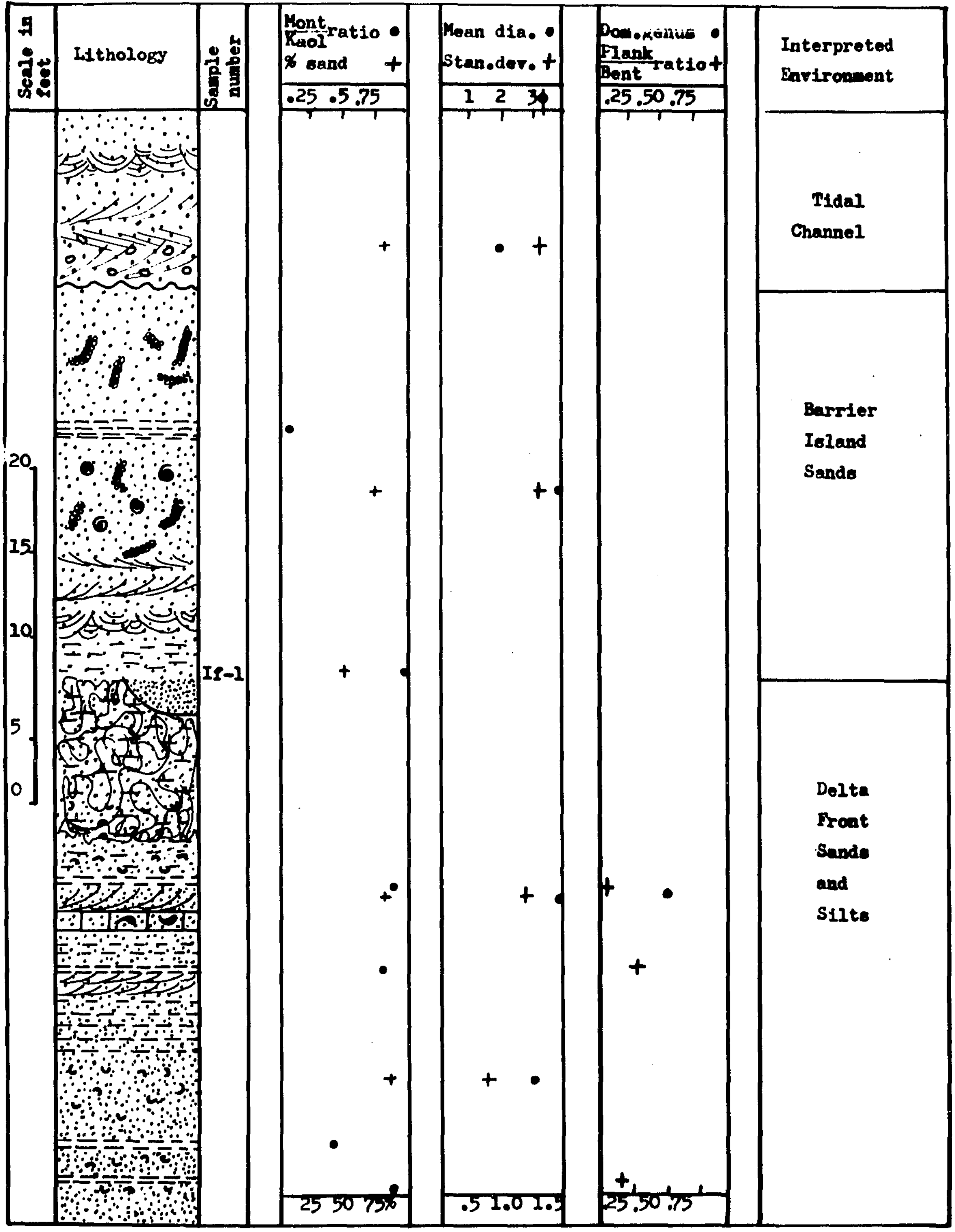


Figure 30 - Section If Series



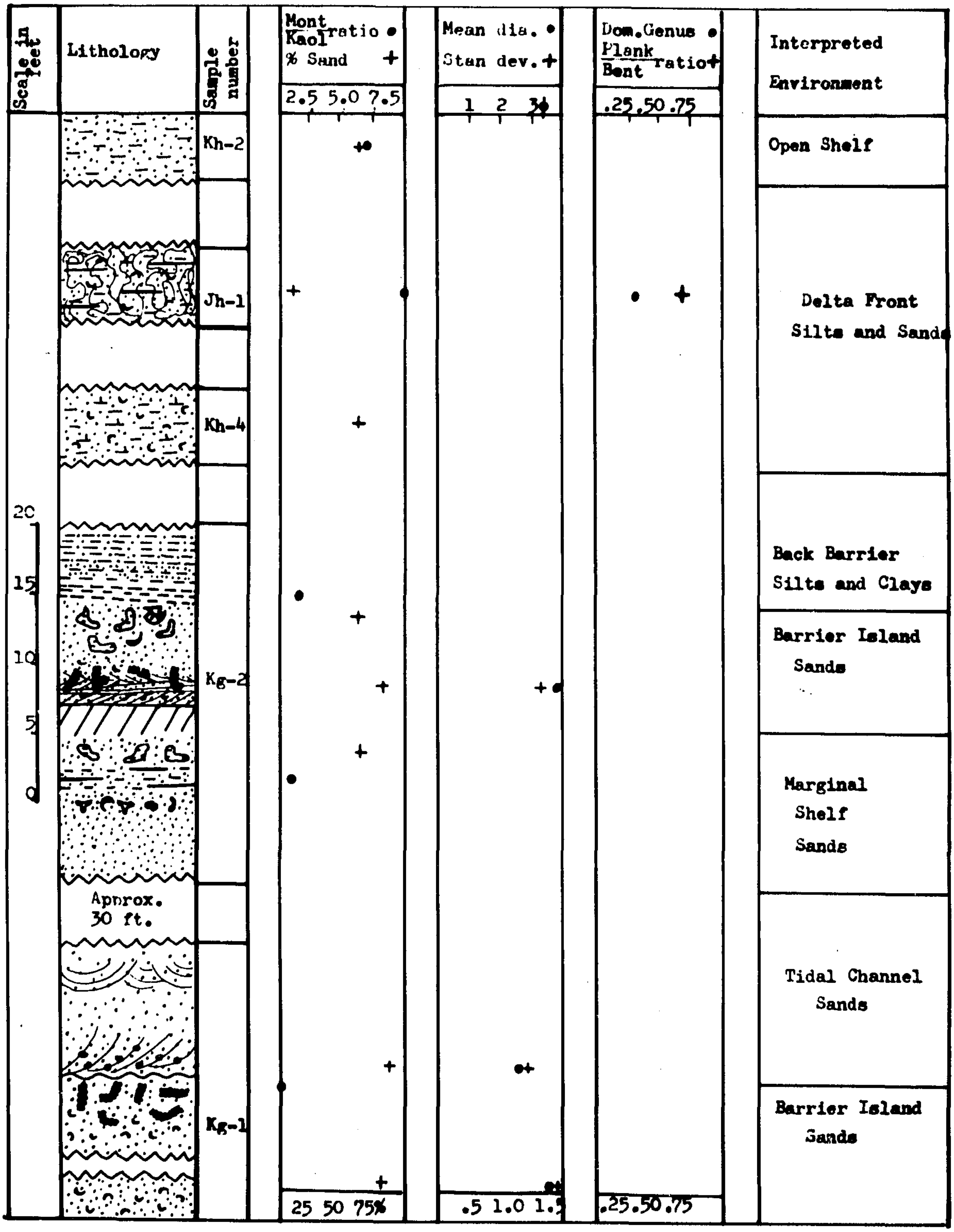


Figure 31 - Section Kg Series

Figure 32 - Section Lg Series

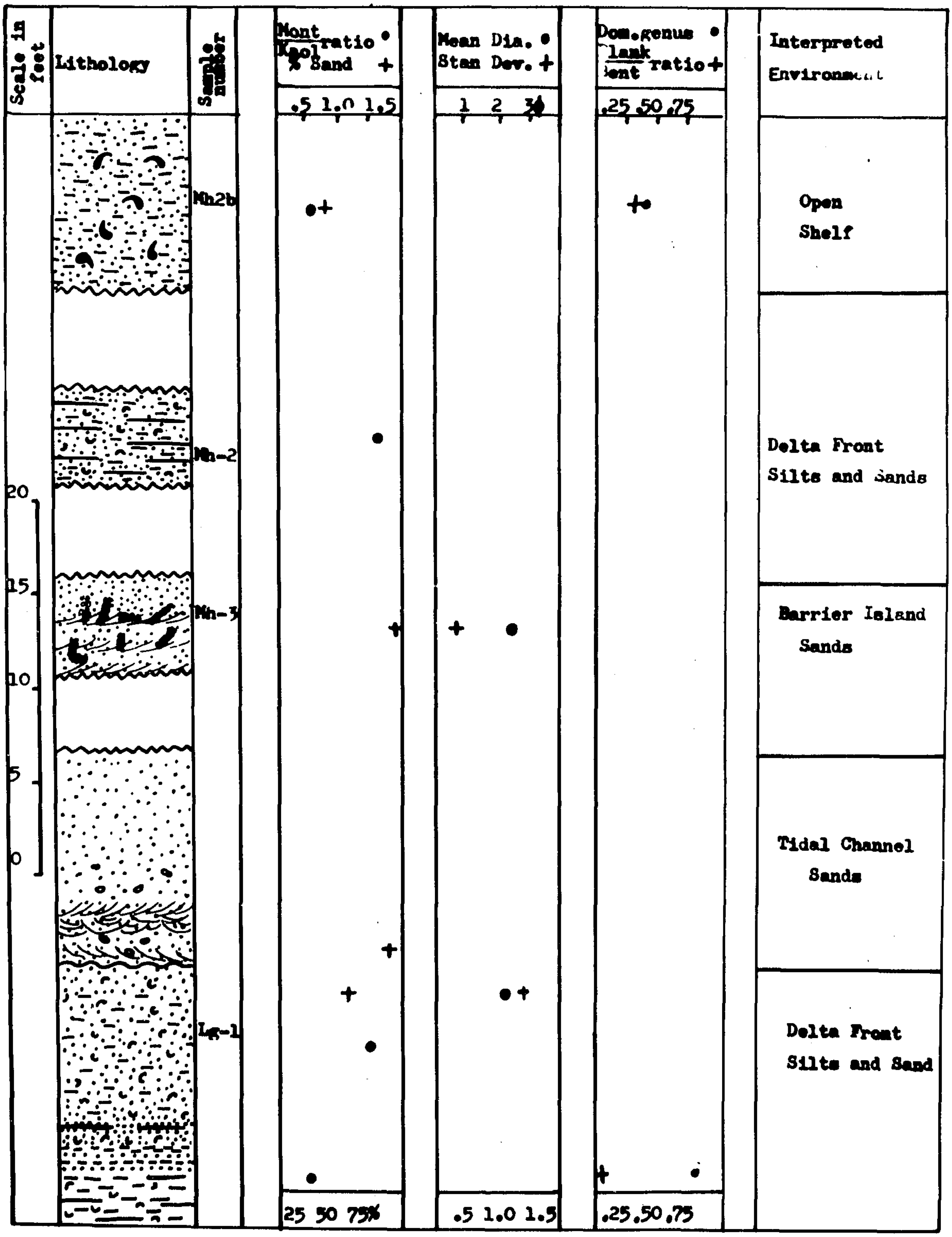


Figure 33 - Section Lh Series

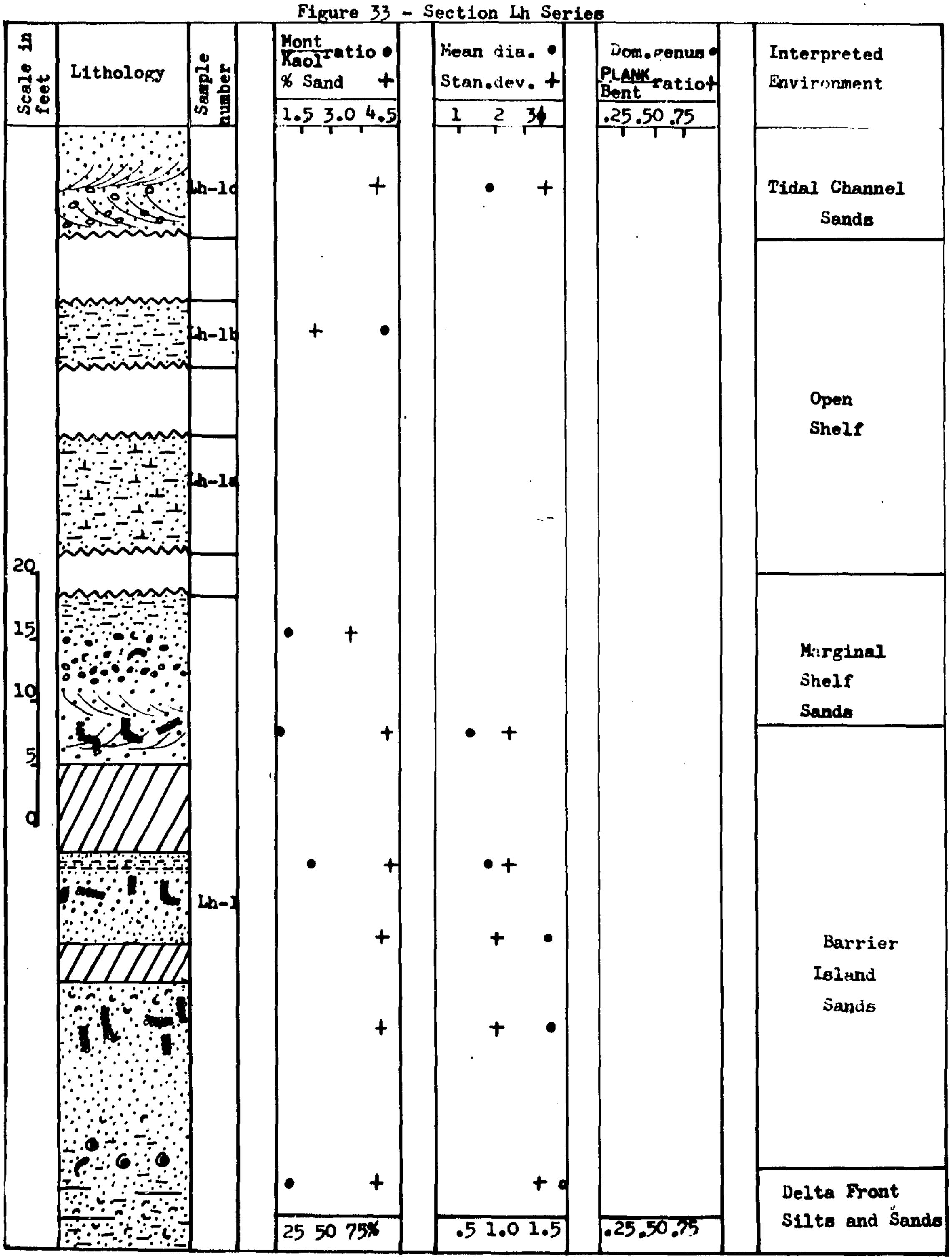


Figure 34 - Section Ng Series

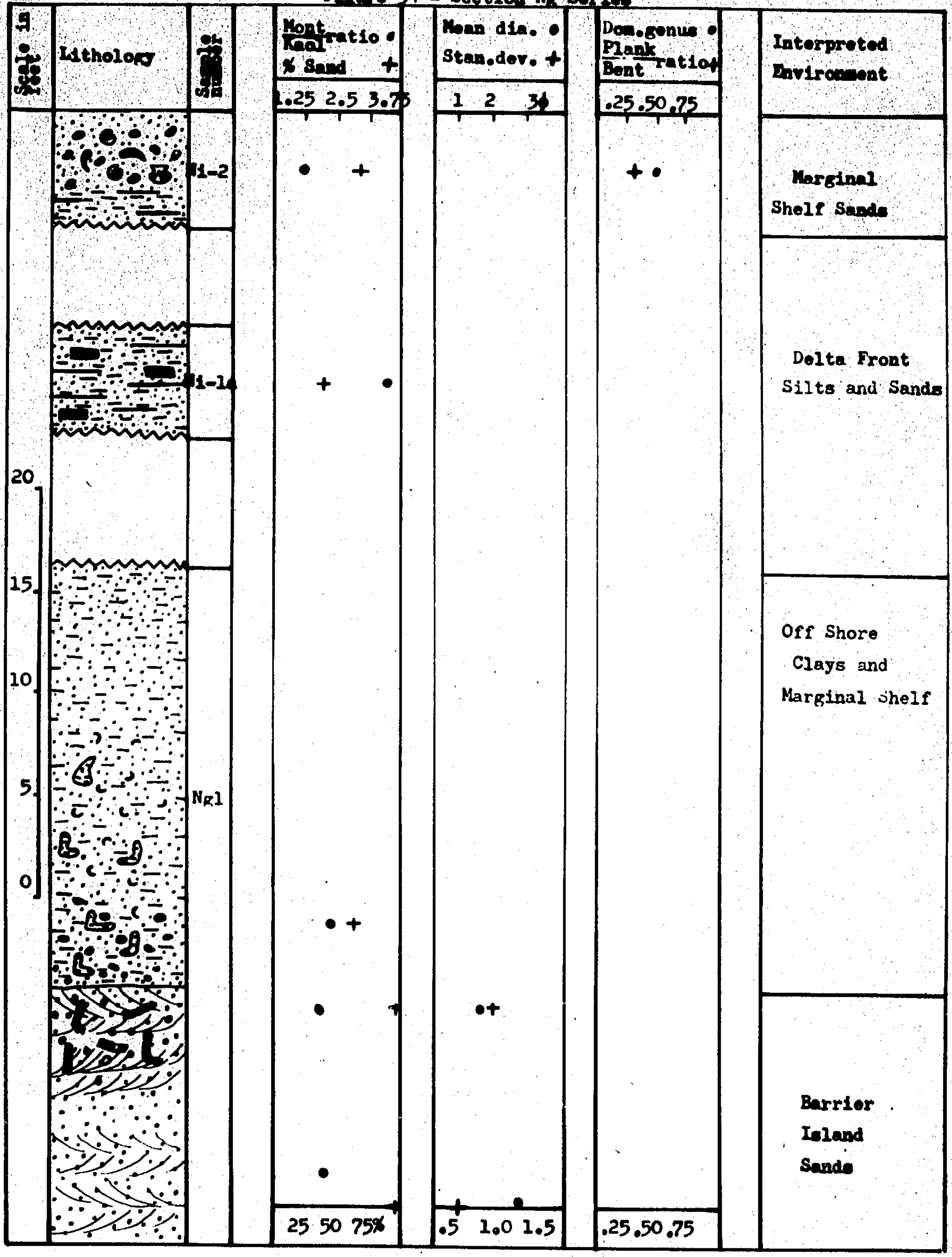


Figure 35 - Section Pe Series

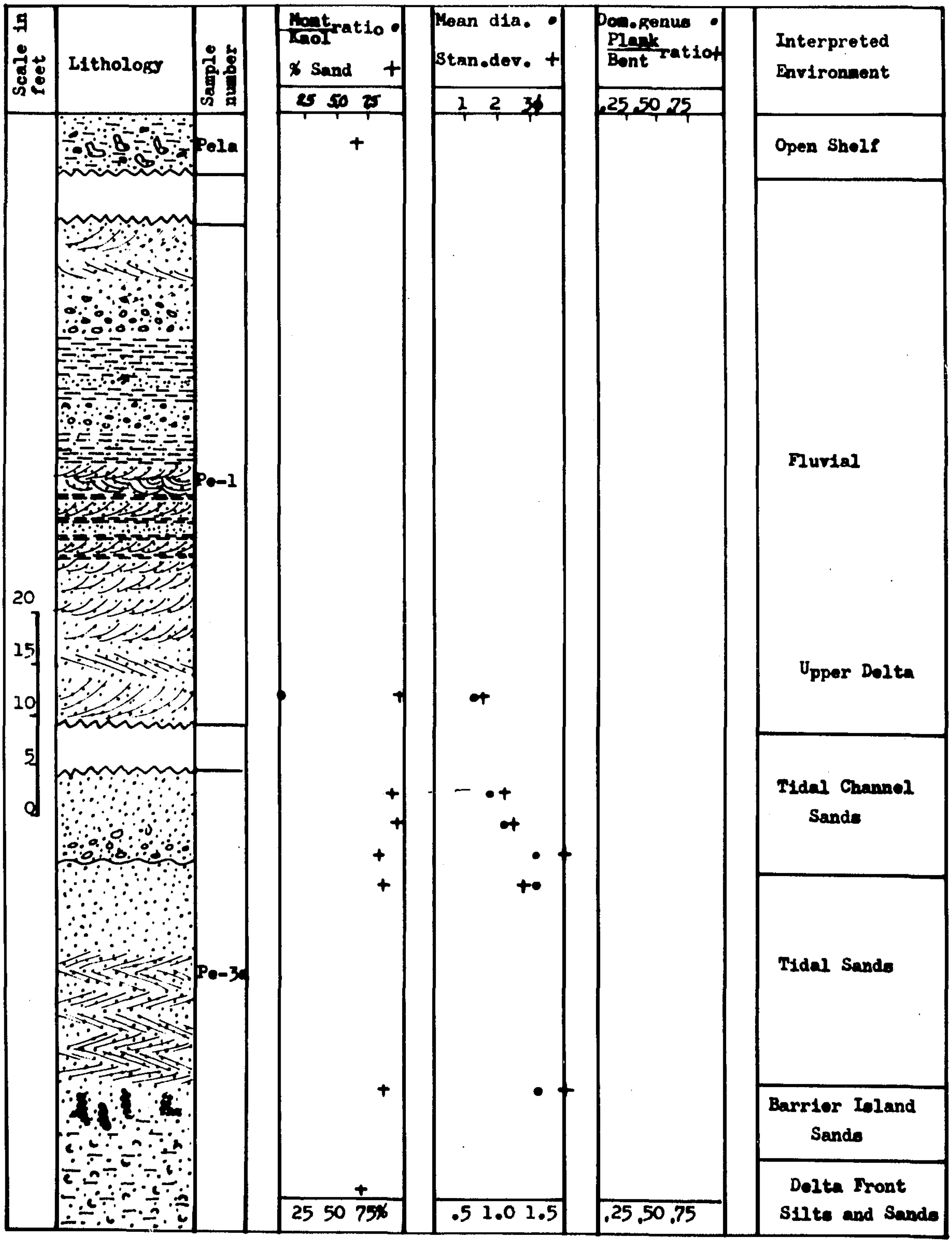
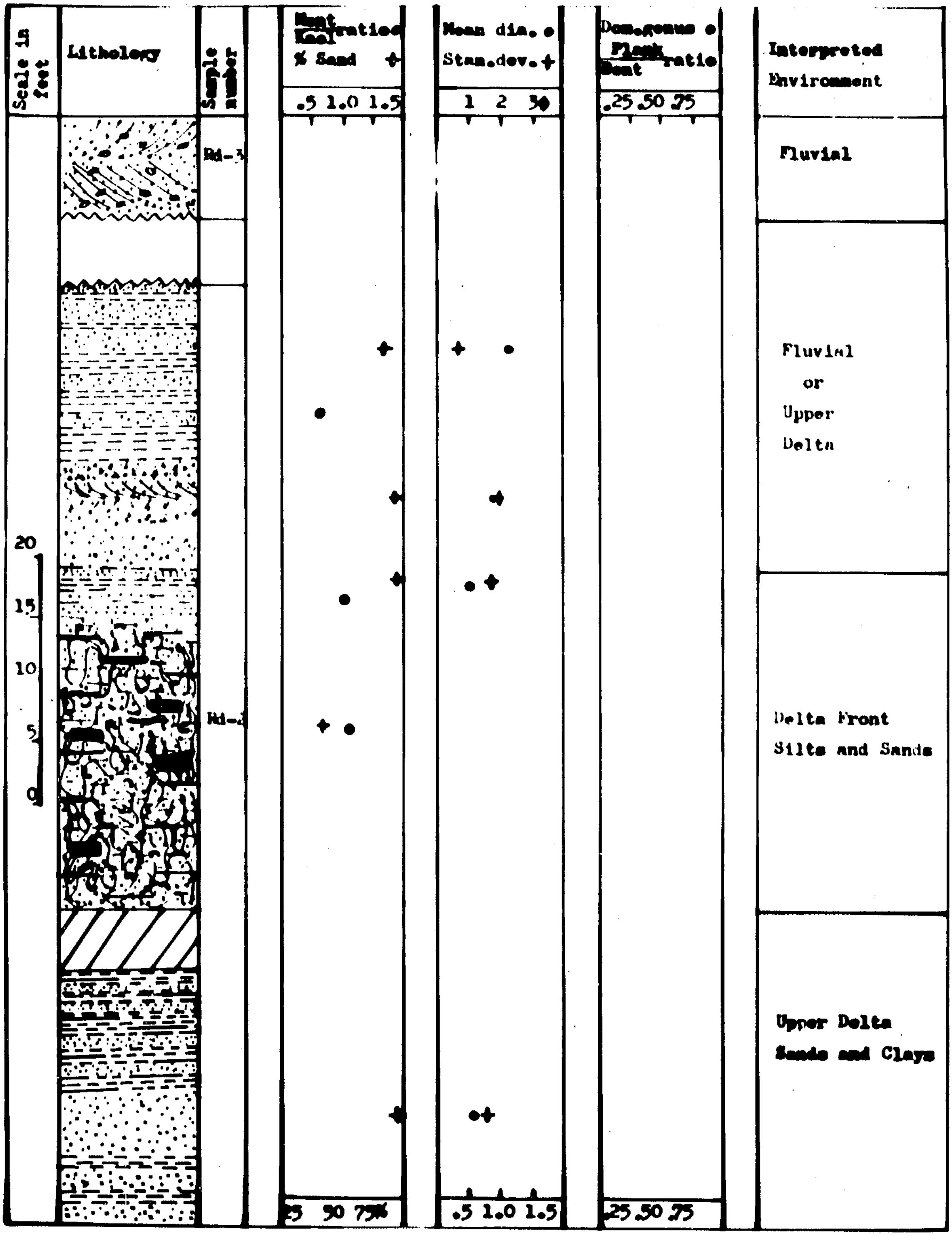


Figure 56 - Section Rd Series



tidal channel in origin. In section Kg (Fig. 31) the barrier island sand facies (Ophiomorpha facies) occurs at two distinctly different stratigraphic positions which suggest that barriers migrated into this area at least two different times. An unconformity exists between the lower Ophiomorpha facies and overlying medium to coarse cross-bedded sand which is interpreted as tidal channel.

In section Pe (Fig. 35) (Cusseta, Georgia) delta front silts and sands are followed by barrier island sands which are in turn overlain by tidal sand deposits. The interpretation of tidal sand deposits is based upon the presence of low angle cross-bedding alternating 180 degrees out of phase (northeast and southwest).

An unconformity which is associated with a channel deposit of very angular iron cemented sandstone block slabs and fragments overlies the tidal sands. There are at least two possible explanations for the presence of this seemingly anomolous deposit: (1) Tertiary terrace, (2) tidal channel. The proximity to the Chattahoochee River, which is a major drainage system for this area, favors the terrace interpretation. The absence of mica, which is so often used as a criterion for the terrace interpretation of these coarse cross-bedded deposits, is not reliable because the micas, due to their hydraulic nature, are more commonly found with the finer grained sediments which are associated with lower current energy levels.

The stratigraphic position of this coarse channel deposit, overlying and cutting through tidal sands, lends strong support to the tidal channel interpretation. The extreme coarseness of the deposit may lend support to the terrace interpretation, except that identical sediments have been observed on the Chandeleur Islands and in the deposits of the Appalachicola delta area.

Section Rd (Fig. 36) illustrates that the Cusseta Sand takes on a non-marine character (fluvial and upper delta) to the east.

Conclusions

From a study of vertical and composite sections it is illustrated that the Cusseta Sand changes facies from non-marine (fluvial and upper delta) in Georgia (sections Rd and Pe) to shallow open marine in Alabama (sections Cg, Dg, Eg, Fg). Sand which was transported by longshore drift in a westerly direction and deposited as barrier islands explains the presence of well sorted, clean, cross-bedded, nonfossiliferous (with the exception of *Ophiomorpha*) sand at different stratigraphic positions in a shallow, open marine sequence. The presence of an unconformity overlying this facies (associated with medium to coarse, cross-bedded sand) represents the tidal channel which destroyed the sub-aerial portion of the bar as the system migrated westward. The migration of the barrier bar facies from the lower part of the Cusseta Sand section in eastern Alabama to the upper portion of the section in the western extremity of Cusseta Sand suggests that this facies is transgressing time in a westerly direction.

CONCLUSIONS

The Cretaceous Cusseta Sand occurs in eastern Alabama and western Georgia, outcropping in a slightly arcuate pattern, paralleling the inner margin of the coastal province. Based upon faunal evidence, this sand is Campanian in age occurring entirely in the *Exogyra ponderosa* zone.

The general stratigraphic relationships show that this unit undergoes distinct lithologic changes from east to west. East of Flint River, Georgia, the Cusseta Sand is undifferentiated from the other formations of the Upper Cretaceous, because the entire section consists of coarse clastics, correlated with the Middendorf Formation of South Carolina. In Georgia, west of the Flint River, this sand has formational rank because it displays a lithology distinct from the overlying Ripley and underlying Blufftown. In Alabama, however, the Cusseta Sand is considered a basal member of the Ripley Formation, since it has a gradational boundary with the overlying Ripley. It has been determined, however, from this study, that the Cusseta Sand is not the basal transgressive sand representing the "advent of the Ripley Sea", but rather, the Cusseta is genetically related to the underlying Blufftown and Demopolis delta front silts and sands. The Cusseta Sand represents the final stage of the "coarsening upward" cycle of a deltaic sedimentary sequence.

Thickness distribution maps show a trough trending east-west through southern Georgia and southwest through Alabama, thickening to the southwest. A "depo-center" for Tuscaloosa time was located in south-central Georgia, and migrated southwestward through time to the present location of the Appalachicola delta.

Subsurface data from well logs and lithologic descriptions illustrate that the clastic character of the Cusseta Sand and underlying Blufftown and Demopolis Formations change facies to chalk (Ripley facies) in a down dip direction to the south and southwest. However, in the eastern-most portion of this area of study, the clastic nature of the outcropping sediments persists for a considerable distance to the southeast.

The average cross-bedding direction is 185 degrees azimuth, with considerable dispersion in the southeast and southwest quadrants. A mode trending West-Northwest is present in the Chattahoochee River area, suggesting long-shore drift in this direction. In several localities of the Chattahoochee River area, cross-bedding was observed which alternated 180° out of phase, suggesting tidal influence.

Measurements of median diameter of largest grains demonstrates a slight reduction in grain size to the southwest, in Georgia, and then a distinct reduction in grain size westward into Alabama to Montgomery County.

Heavy mineral analyses show no distinct regional variation in the Cusseta Sand and no difference between the assemblages of the overlying Ripley Formation and underlying Blufftown Formation. However, at least three provinces can be differentiated in the Upper Cretaceous outcrop belt for synchronous units of the Cusseta Sand - kyanite-zircon for the McNairy Formation of Tennessee, epidote for the Ripley Formation of Mississippi, zircon-tourmaline-staurolite for the Cusseta Sand of Alabama and Georgia, staurolite for the Middendorf Formation of central and eastern Georgia.

Intensive post-deposition, sub-aerial weathering has altered the heavy mineral assemblage to a point that garnet and hornblende have been destroyed and the surfaces of epidote and staurolite have been altered. The assemblage in order of relative abundance is composed dominantly of tourmaline, rutile, zircon, staurolite, kyanite, epidote, sillimanite, hornblende, titanite, and monazite. Opaques were present mainly in the form of leucoxene and ilmenite. From observations made on heavy mineral fractions from fresh outcrops, it is considered that garnet was an important constituent of this assemblage before destruction by post-depositional, sub-aerial weathering. The large part of this assemblage characterizes a metamorphic source with minor contributions from acid igenous and sedimentary rocks. Counts made on the tourmaline show that approximately 95 percent are angular and that the samples displaying lowest percentages are in the western area of the outcrop belt. This suggests that a sedimentary source was more prominent to the west.

In the study of the light mineralogy, post-depositional, sub-aerial weathering was considered an important factor in the alteration of the feldspar content. Study of a weathering profile illustrated a reduction from 12 percent fresh angular feldspar in the unweathered portion of the section, to 2 percent of weathered feldspar at the top of the sampled section. Where fresh samples could be obtained for analysis, an average of 82 percent quartz, 10 percent feldspar, and 8 percent muscovite was found to be the dominant light mineral constituents.

Using Folk's classification, the rock is classified as a subgraywacke or subarkose. The quartz was found to be 98 percent angular which suggests that it is first cycle. Observations made on the degree of elongation demonstrated that the average for quartz was approximately 68 percent which suggests a metamorphic source. The presence of fresh angular feldspar made up predominantly of microcline and orthoclase strongly suggests a primary igneous or metamorphic source.

Textural analysis of the Cusseta Sand demonstrated that this sand is moderately to poorly sorted in most areas and ranges in grain size from fine to coarse. Only two samples were found to be well sorted, and this was in the down dip areas of the Chattahoochee River. A general reduction in mean grain size takes place in going from east to west.

The clay minerals present are montmorillonite, kaolinite and minor amounts of illite. Through use of these mineral assemblages the Blufftown Formation and Cusseta Sand could be separated into distinct facies. The Blufftown clays are composed of a somewhat equal mixture of montmorillonite and kaolinite. The entire Cusseta of western Georgia and the lower Cusseta of the Chattahoochee River area contain a clay assemblage where kaolinite predominates. In the middle and upper Cusseta of the eastern Alabama and Chattahoochee River area, and in the lower Cusseta of central Alabama, the clay mineral assemblage is characterized by montmorillonite. This demonstrates that a definite trend exists for the Cusseta Sand which shows a reduction in kaolinite and an increase in montmorillonite in a westerly direction. The kaolinite is considered definitely to be detrital in origin with minor contributions from sub-aerial post-depositional weathering of feldspar in the outcrop. The presence of the montmorillonite in the western portion of the outcrop could possibly be explained by mixing of source materials resulting from the influence of a detrital source from the northwest (McNairy delta). A volcanic origin for the montmorillonite is very doubtful since the montmorillonitic clays are so thick and so persistent through Upper Cretaceous and Teriary time. The most logical explanation is that different weathering conditions in the source area to the north formed montmorillonitic clays. Subsequent erosion and segregation determined the ultimate depositional loci.

The Cusseta Sand occurs as three major facies which are deltaic in origin (Fig. 37). On a regional scale they are: (1) fluviatile and upper delta in the up-dip area of western Georgia, (2) delta front and inner neritic in the Chattahoochee River area, (3) prodelta and outer neritic generally west of Barbour and Russell Counties, Alabama. The source area for these sediments is in the Appalachian Mountains and Piedmont Plateau to the north and northeast. The general direction of major transport of sediment is down the paleoslope to the south. The strandline in Georgia was generally east-west. Longshore currents transported sand to the west-north-west where it was deposited as barrier bars and marginal shelf sand. In a westerly direction, the barrier sands continue to appear higher in the section until in Montgomery County, Alabama, (the distal margin of the Cusseta Sand) barrier bar sands appear at the top of the Cusseta Sand.

The absence of a restricted littoral environment in the Cusseta Sand of Alabama is attributed to destruction by the transgressive phase of the

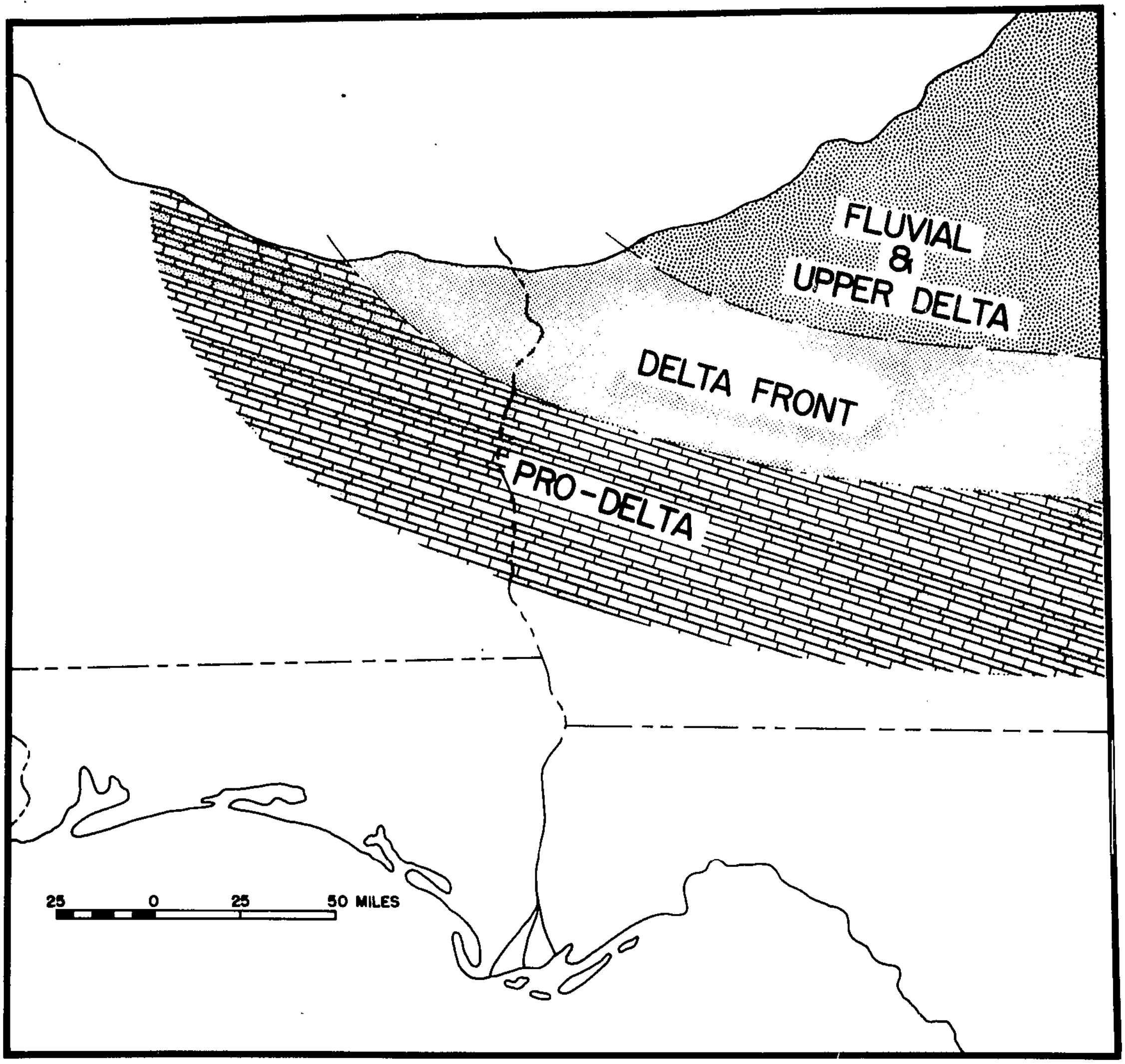


Figure 37 - Paleogeographic reconstruction of the regional facies of the Cusseta sand

Ripley Formation. Later, uptilting resulting from southward migration and down warping of the thick wedge of sediments, followed by truncation, would serve to further obliterate any shoreward facies of the Cusseta Sand. The deposition of the Cusseta sands and clays of Alabama took place in a shallow inner neritic and outer neritic environment where the depth of water ranged in depth between less than 10 feet and not greater than 100 feet.

The regional environmental setting for formations synchronous and diachronous with the Cusseta Sand are: (1) the Middendorf Formation, representing the fluvial environment, (2) the Blufftown Formation, representing the delta front silts and sands, (3) and the Demopolis Formation, representing the pro-delta, open shelf.

An investigation into the usefulness of X-ray analysis of heavy mineral assemblages demonstrates that it can be applied semi-quantitatively, and that regional differences in heavy mineral suites can be determined. It may prove to be a desirable method from an economic standpoint in that it reduces considerably the time-consuming optical work.

IDENTIFICATION OF HEAVY MINERAL ASSEMBLAGES BY X-RAY DIFFRACTION

One of the problems a sedimentary petrologist encounters during the examination of a suite of outcrop or well samples is the large numbers of samples that are necessary for meaningful heavy mineral studies. It is not uncommon to be faced with the petrographic analysis of 200 to 500 heavy mineral samples which represent scores of hours at the microscope.

With this problem in mind, this work on X-Ray diffraction analysis techniques was carried out in an effort to develop a method which might reduce considerably the time involved in making heavy mineral analysis for provenance studies.

The objectives of this investigation are to characterize or "diffraction finger print" an assemblage of minerals of a sample: to characterize a large number of samples and group them according to their diffraction "finger prints": and then to select representative samples from the diffraction "character groups" for detailed petrographic analysis. It is not, however, the objective of this technique to initially identify all of the heavy minerals in a suite, or even to initially identify any of the minerals. This is still best accomplished by conventional petrographic techniques, where the minerals and their varieties can be well identified.

X-ray diffraction methods have been utilized by many workers to determine the presence and percentage of rock components, however, to the author's knowledge its use for identification of heavy mineral assemblages has yet to be published. Tatlock (1966) has used X-ray methods extensively for rapid modal analysis, Black (1953) made use of the X-ray technique for analysis of bauxite samples and Schmalz (1958) employed the X-ray method for identifying the common minerals in sediments from the Peru-Chile trench.

For this study the analyses and techniques were developed using two suites of samples. One set of samples represents beach sands extending from Beaufort, North Carolina to Port Isabel in southern Texas. The other suite is composed of Upper Cretaceous sands of the Atlantic and Gulf Coastal Plains from Fayetteville, North Carolina to the northern part of the Mississippi Embayment in Illinois.

There are a number of problems involved both in non-provenance caused variability of heavy mineral assemblages and in the preparation of the minerals for diffraction irradiation. The techniques which we are developing attempt to minimize the effects of these variables, so that reproducible and meaningful diffraction groups may be obtained.

One of the most important variables in heavy mineral analysis is that of mineral composition. This is really what we are looking for and we want the other variables to exert little or no effect upon this variable.

Two of the trouble makers are size sorting and hydraulic sorting of heavy minerals, caused by density and size differences of the different minerals.

Figure 37 shows the effects of several size groupings on the mineralogy and diffraction pattern of one sample. These pattern differences can be easily discerned. The fine size, .044 mm to .500 mm is dominated by the zircon and rutile peacjs, because these two minerals

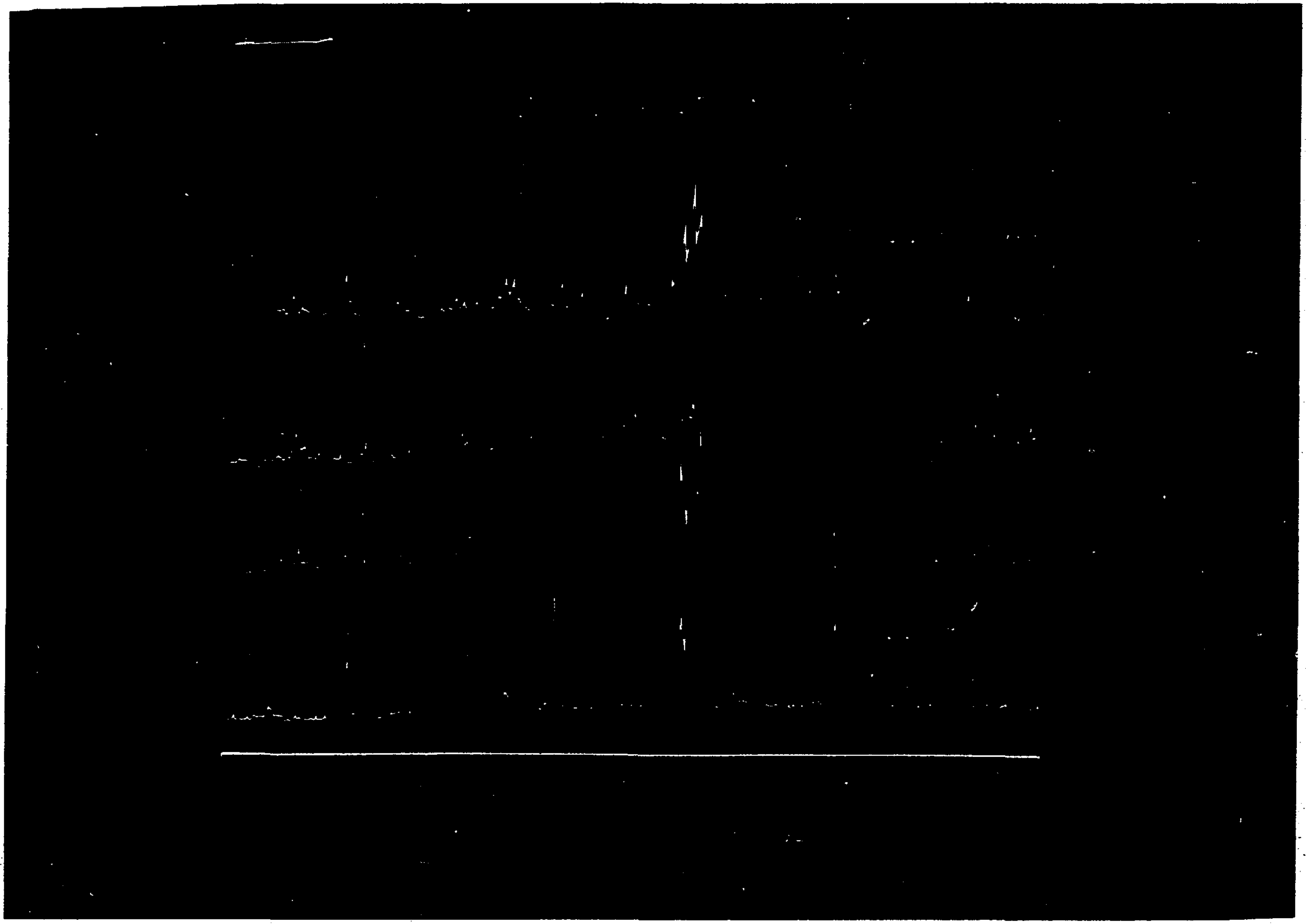


Figure 38 - Effects of size fraction on X-ray diffraction patterns of heavy mineral assemblages

are dominantly of that size. The coarse size .250 mm to .500 mm is dominated by the kyanite peak which occurs mostly in that size fraction. This problem of size sorting can be minimized by taking Van Andel's advice and analyzing the broad size range of the sample. In this study the .063 mm to .25 mm fraction was used.

The most common problem associated with X-ray diffraction of an assemblage of minerals is the mass absorption which produces background caused by the flourescence of iron, manganese, cobalt, nickel, etc., or any mineral rich in any one of these constituents. Iron, however, is the most important element whose flourescence under copper irradiation causes conspicuous differences in background.

These minerals, oxides, or compounds with undesirable, high mass-absorption coefficients must be removed or reduced sufficiently to resolve the diffraction peaks. By boiling in concentrated HCl for 2 minutes the manganese oxide, iron oxide and limonite can be removed. Using the Franz magnetic separator at a current setting of .45 amps and side and front slopes of 20° and 27° respectively, magnetite, ilmenite, garnet, chromite and most hornblendes are removed. This still leaves titanium oxide which occurs frequently as a strong constituent in the heavy mineral assemblages of the Upper Cretaceous in the form of rutile and leucoxene.

The most important components of the heavy mineral assemblage irradiated after the above preparation are as follows:

Rutile - TiO_2 may contain up to 16% FeO

Tourmaline - in this assemblage the Dravite -----to----
$(H_8Na_2Mg_6B_6Al_{12}Si_{12}O_{62})$

Schorlite series is the dominant $(H_8Na_2Fe_6B_6Al_{12}Si_{12}O_{62})$ type and of these Dravite (dark yellowish brown) is the most common.

Zircon - $ZrSiO_4$ may contain some Fe_2O_3, ThO_2, U_2O_3. As a result of the radioactive effects of the thorium and uranium zircon gradually alters to a metamict mineral (amorphous state). If Th and U are present high background results from radiation. If zircon has become metamict, poor diffraction patterns will result.

Staurolite - $HFe_2AlgO_8Si_4O_{16}$ where Mg, Mn, Co, Ni may proxy in part for Fe.

Kyanite - Al_2OSiO_4 a little Fe''' is commonly present.

Sillimanite - a polymorphic form of Al_2OSiO_4

Epidote - probably dominantly Clinozoisite $(Ca_2Al_3(OH)Si_3O_{12})$ colorless or pale yellow (iron poor).

For the most part the above assemblage is iron-poor consisting of iron-poor oxides and aluminum rich nesosilicates. For this reason the X-ray diffraction method is quite effective for qualitative and some quantitative work for minerals in abundance of greater than 20 percent.

After mineral identification and counts were made by petrographic means, individual X-ray patterns were made of the more important minerals of the heavy mineral suite. These were used as a set of standards for identification of the minerals in the X-ray patterns of heavy mineral suites.

In preparing the mineral separations for diffraction analysis, they are ground in a mortar and pestle and then mounted on glass slides. Only a few thousand grains are needed for this analysis. However, several problems of reproducibility are encountered during these steps (Fig. 38). This illustration shows the differences encountered with various grinding sizes from one sample. Many peaks are missing or subdued in the coarse and medium grinds. The most reproducible results by far came from the fine grind to a uniform size of less than 37 microns. This uniformity can be achieved with practice or with an automatic grinder such as the Pitchford Grinder. A particle size ranging from 5-15 microns was found by Alexander, Klug and Kummer (1948) to provide the best reproducibility of peak heights. Tatlock, who used a particle size less than 40 microns found that peak intensity is largely subdued by extinction if particles are greater than 30-40 microns. The samples used in this study were ground by agate mortar and pestle to a particle size less than 37 microns number 400 mesh. The next problem is encountered in the mounting of the ground material. Since many of the mineral grains have well developed cleavage there is a tendency for them to preferentially orient themselves when mounted on a glass slide, or when packed in a sample holder. In order to produce the desired random orientation in the mount, several mounting media were tried - water, acetone and Duco Cement.

The degree of reproducibility is shown for 3 scans with a thick water slurry and a Duco Cement slurry in figure 39. Overall reproducibility was best achieved with Duco Cement, which is viscous and hardens rapidly, leaving the fine mineral particles in positions of random

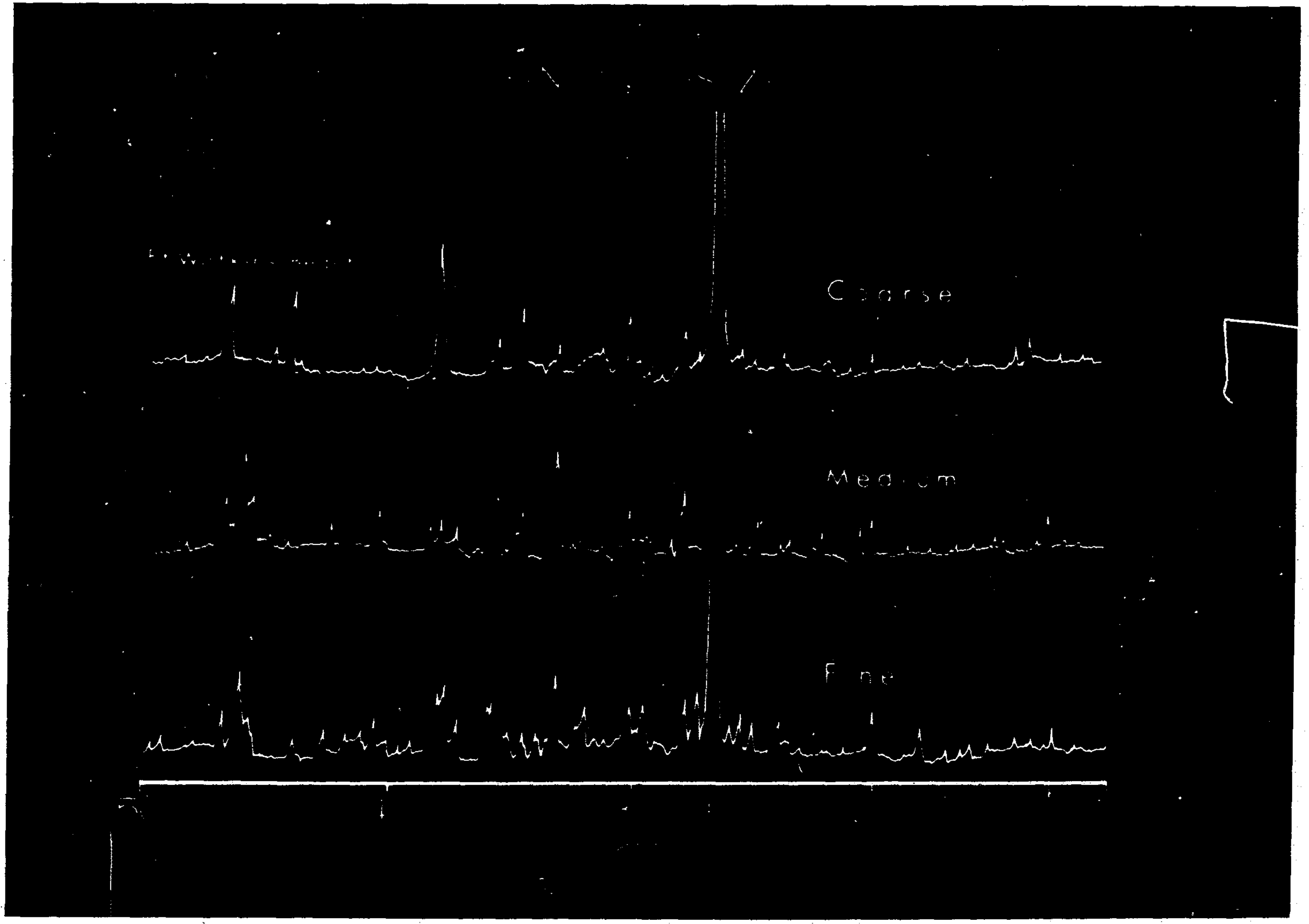


Figure 39 - Effect of grinding size on X-ray diffraction patterns of heavy mineral assemblages

orientation. The mounted samples are then irradiated at a scan rate of 2° 2θ per minute in the range of 10° 2θ-to 50° 2θ.

With these disruptive variables minimized, reproducible diffraction patterns can be produced, that have distinctive appearances or character for given mineral suites.

To test the optical method agains the X-ray method a simple experiment was run using the Keownville, Mississippi sample. A percentage count by optical methods was carried out for this heavy mineral assemblage after which a duplicate assemblage was fabricated from the University mineral collection. Diffraction patterns were then run on both of these samples (Fig. 40). The similarity of the two patterns is striking and the presence of the dominant characteristic mineral peaks is apparent.

For the first regional study, several dozen beach samples from the Atlantic and Gulf Coasts were analyzed using these techniques (Fig. 41). By looking at the overall character of the traces, certain patterns can be grouped together into identities.

The south Texas and north Texas samples stand out as two separate identities. The North Carolina samples are distinctively different. The east Gulf Coast samples are a distinctive group of patterns, which can be divided into two sub-groups. This grouping is done strictly on appearance of the diffraction traces, without specific mineral identification.

Figure 42 is a selection of X-ray diffraction traces of Cretaceous heavy mineral samples from North Carolina, around the coastal plain to southern Illinois. A rapid examination of these traces shows at least

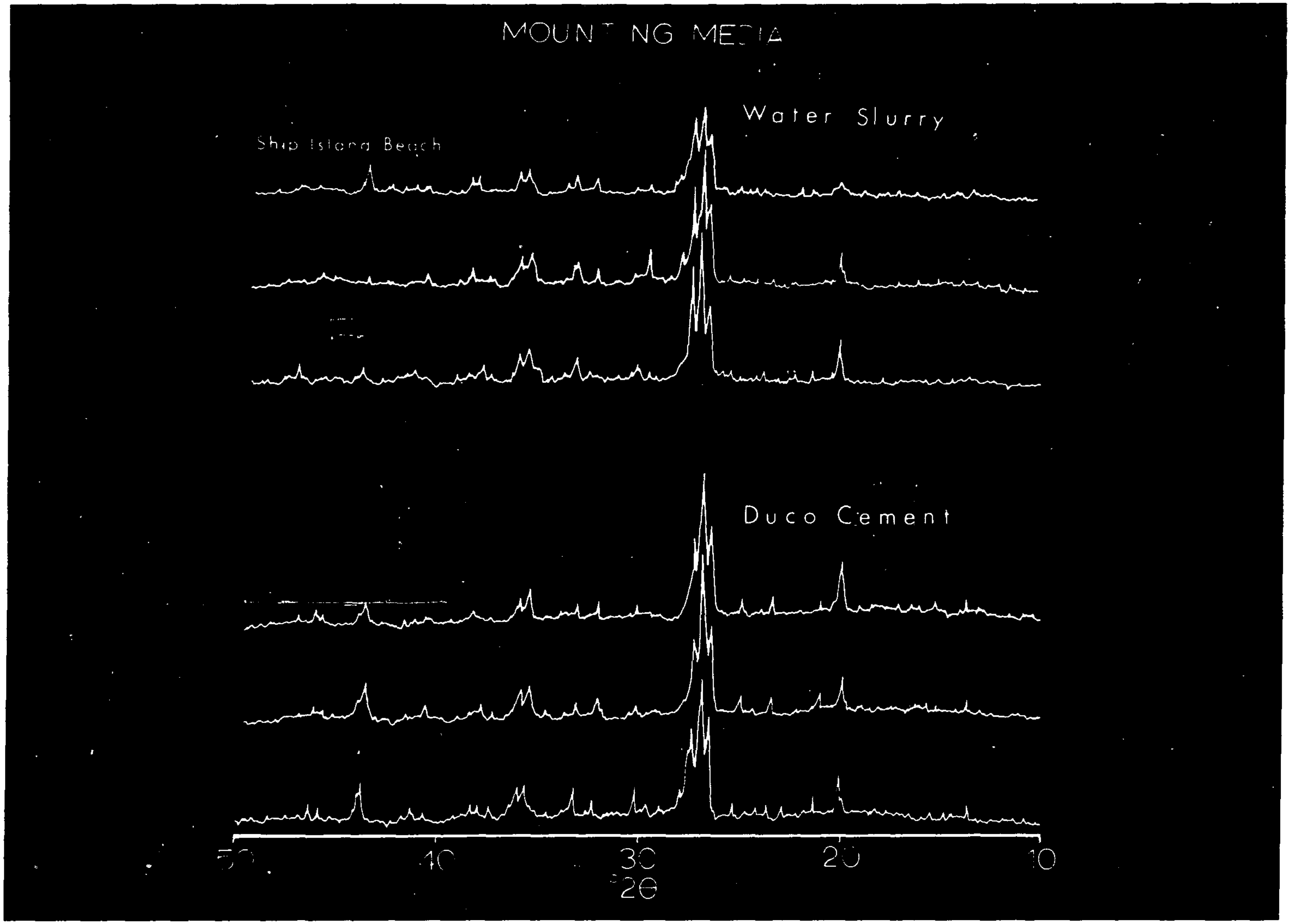


Figure 40 - Degree of reproducibility with various mounting media

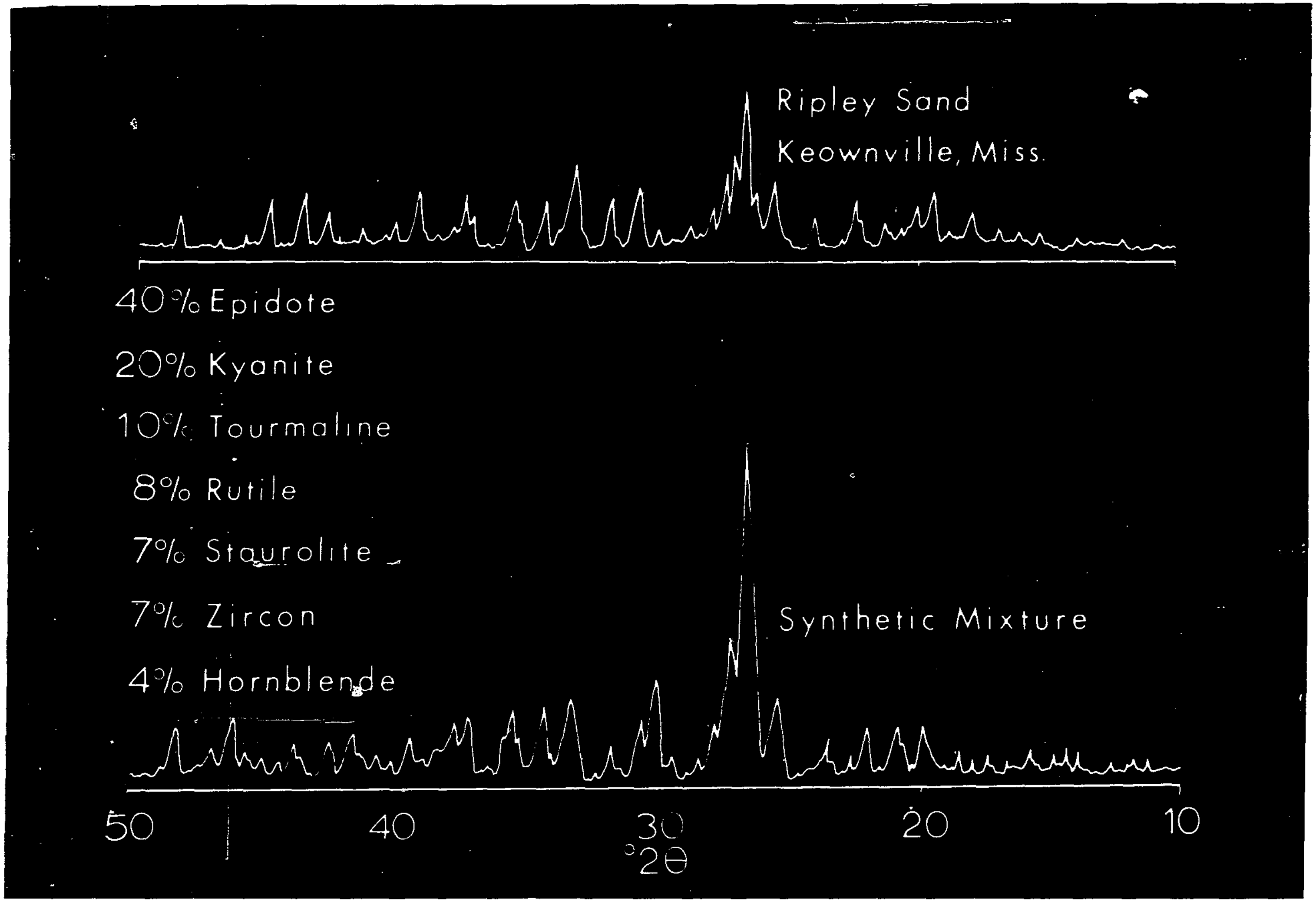


Figure 41 - Diffraction patterns of Keownville, Mississippi heavy mineral assemblages; natural and synthetic

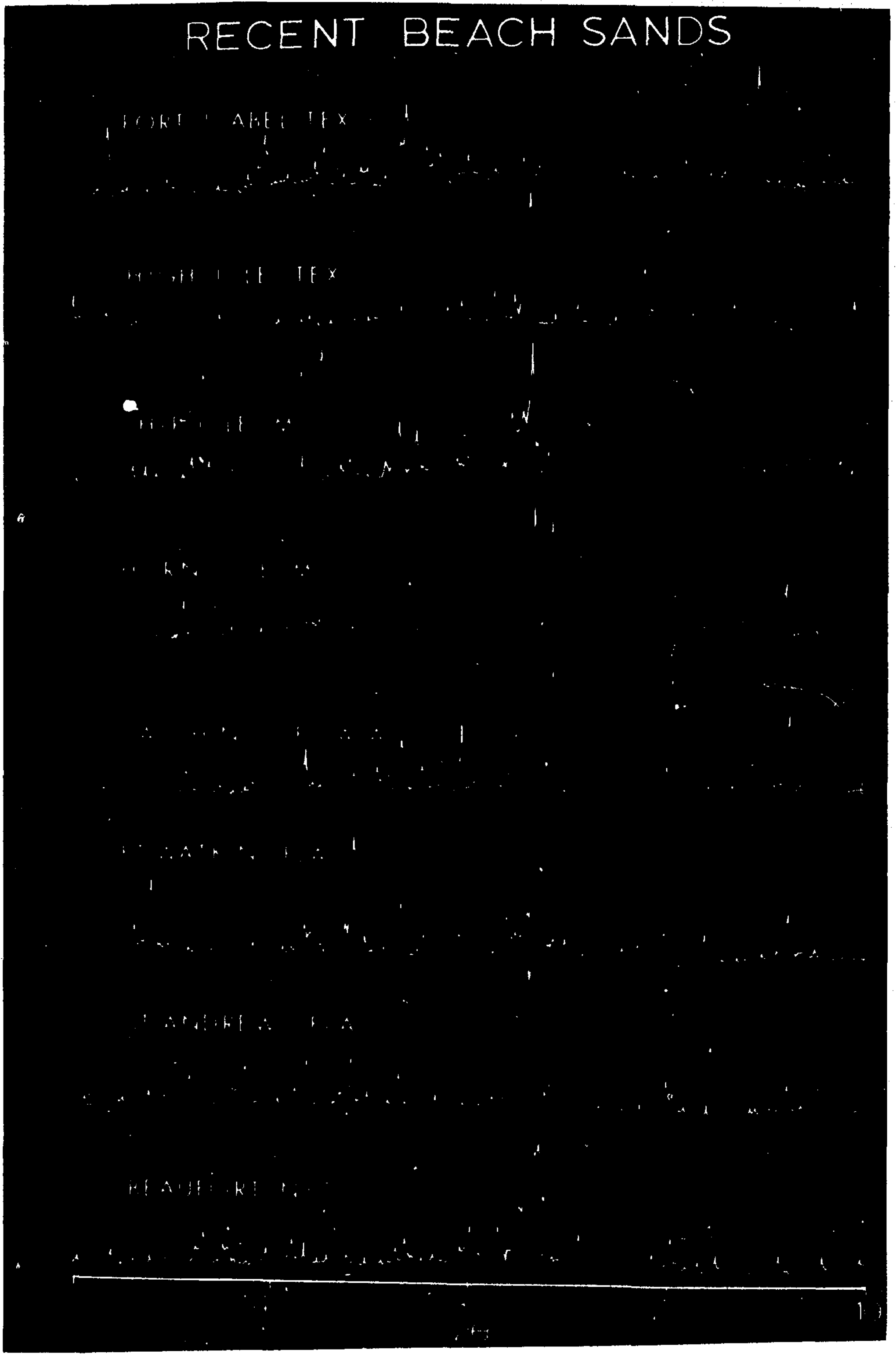


Figure 42 - X-ray diffraction patterns of Recent heavy mineral assemblages from Atlantic Gulf Coasts

6 distinctive "Diffraction Finger Print" groups.

A regional map of the area (Fig. 43) demonstrates that the Upper Cretaceous heavy mineral assemblages can be separated into 6 provinces - A, B, C, D, E, and F. For the beach sands Number I is a staurolite-garnet-hornblende association. Number II is a kyanite-staurolite association. Number III is a hornblende-zircon association and Number IV is a hornblende-augite association.

This use of grouping established by X-ray diffraction trace character for some Recent beach samples and Cretaceous samples shows positive results, when the effects of problematic variables are minimized.

Large numbers of samples from outcrop belts and from well cores can be routinely treated to extract the heavy minerals. They can then be prepared for diffraction analysis, and routinely scanned with X-ray diffraction equipment, all of which can be carried out by technicians. The diffraction patterns can be recorded either by the normal pen recorder or the data can be digitally stored on punch cards or tape.

Scanning the diffraction patterns by eye can rapidly sort them into groups of identities - or a sorting program for the punched cards or magnetic tapes can be devised.

It is concluded that X-ray analysis of heavy mineral assemblages is a reliable, rapid method of obtaining qualitative and semi-quantitative information, which may be computerized for further analysis. The results can then be supplemented by petrographic analysis where detailed quantitative results are necessary. The preparation of the samples is important so that the variations observed are not the results of sample

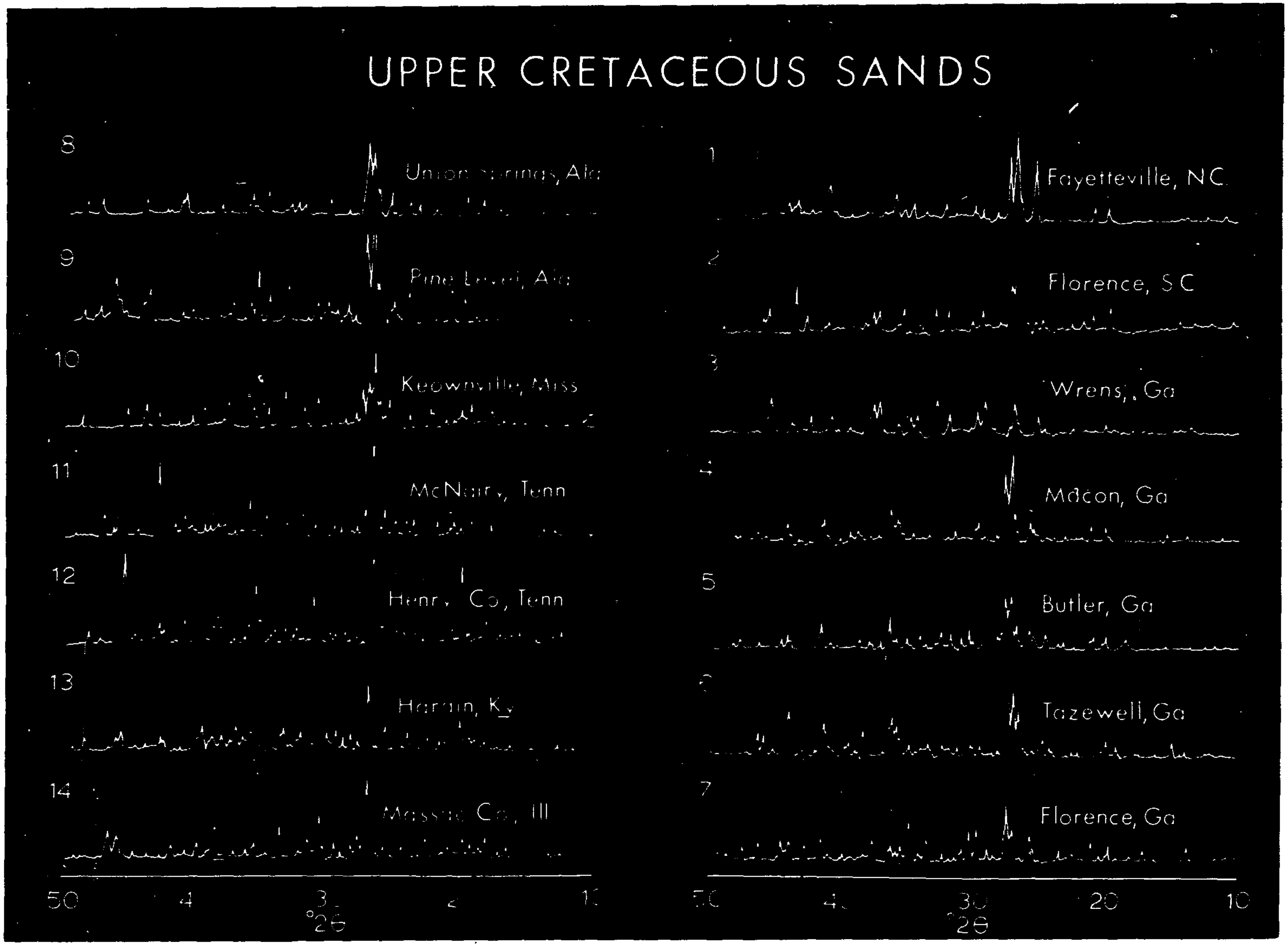


Figure 43 - X-ray diffraction patterns of Upper Cretaceous heavy mineral assemblages from North Carolina to southern Illinois

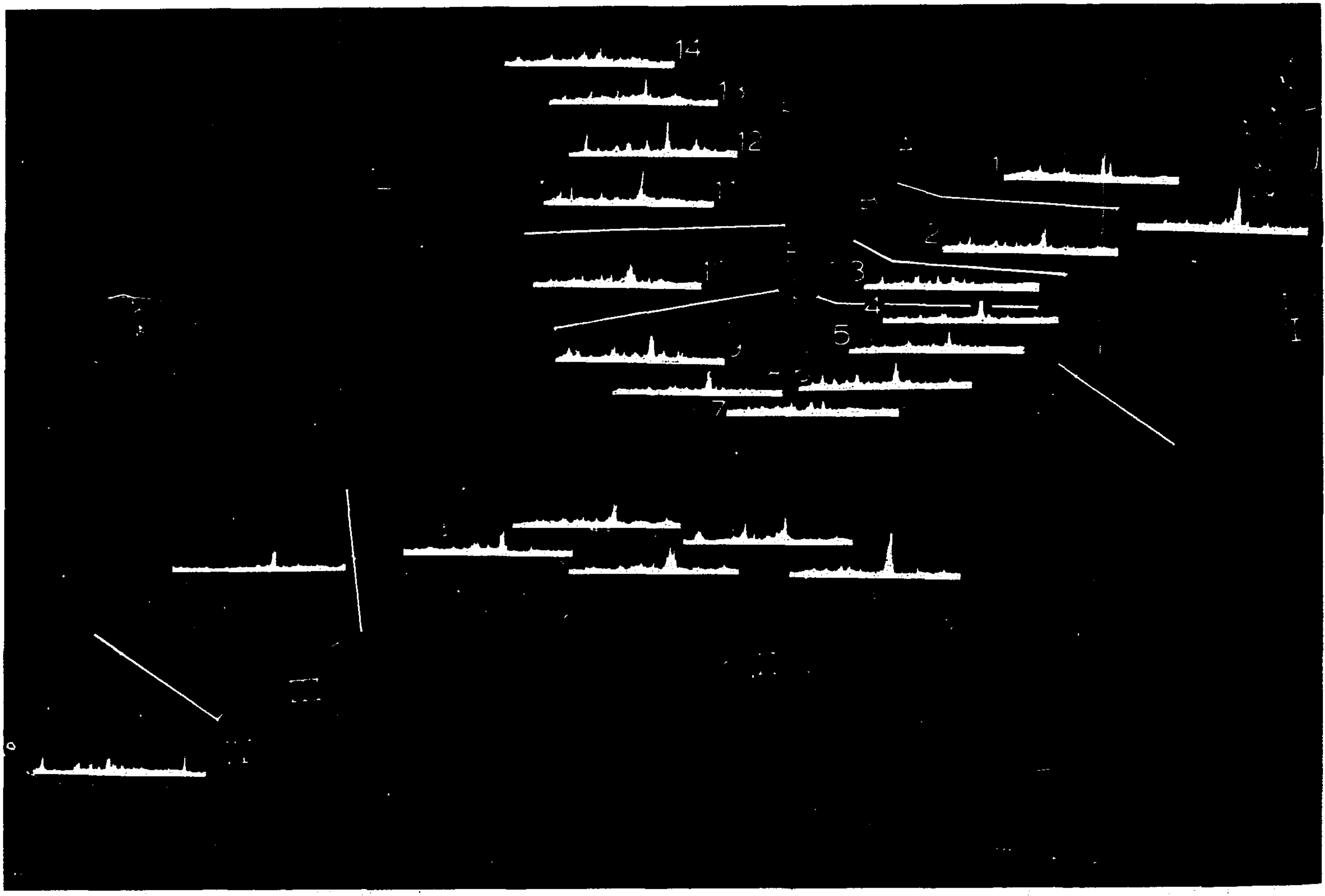


Figure 44 - Map demonstrating zonation of heavy mineral associations utilizing X-ray diffraction technique

selection or preparation.

The problems encountered which strongly affect the reproducibility and reliability of this technique can be greatly reduced or overcome by avoiding size-hydraulic sorting, using proper grinding techniques, obtaining randomly oriented samples and reducing flourescence resulting from mass absorption. This X-ray method is desirable from an economic standpoint in that it reduces considerably the time-consuming optical work, thus large numbers of heavy mineral analyses for provenance studies and correlation can be obtained in a relatively short time.

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APPENDIX I

APPENDIX I

OUTCROP LOCATIONS

(See Plate I in Pocket)

Number	Description of Location
	Blufftown
Gg-4a	Stream Cut, Conecuh Falls, in Union Springs, N of Peachburg Rd., SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 35, T 14 N, R 23 E, Bullock Co., Ala.
If-1	Road cut, approx. 3 mi. ENE of Peachburg, 1 mi. S of Suspension, E $\frac{1}{2}$, SW $\frac{1}{4}$, Sec. 19, T 14 N, R 25 E, Bullock Co., Ala.
If-2	Road cut, 0.2 mi. E of S.R. 26, 18 mi. W of Enon, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 27, T 14 N, R 25 E, Bullock Co., Ala.
Kg-1	Road cut, 0.5 N of Spring Hill, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 28, T 13 N, R 27 E, Barbour Co., Ala.
Lg-1	Road cut, 0.2 mi. S of Glenville on U.S. 431, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 12, T 13 N, R 28 E, Russell Co., Ala.
Lh-1	Gully and roadside ditch, 1 mi. N of Hawkinsville, 0.4 mi. S of Middle Fork Cowikee Co., SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 4, T 12 N, R 28 E, Barbour Co., Ala.
Of-3	Creek cut, under bridge between Julia and road no. S 641, on Hannahatchee Creek, Stewart Co., Ga.
Pe-3a	Road cut, S side of Cusseta, 100' E of U.S. 27 on S.R. Spur 55, Chattahoochee Co., Ga.
Rc-1a	Road cut, just S of Parkers Mill Cr., S.R. 352, Marion Co., Ga.

Number	Description of Location
Rc-2a	Road cut on S.R. 352, approx. 4.6 mi. (st. line) NW of Jct. with S.R. 41, 4 mi. E of Chattahoochee Co. line, Marion Co., Ga.
Rd-2	Road cut, 2.8 mi. NNE of S.R. 137 on S.R. 355, 1 mi. E of Chattahoochee Co. line, approx. 9 mi. NW of Buena Vista, Marion Co., Ga.

Demopolis

Number	Description of Location
Cg-2	Road cut, NE of Ramer, 1.3 mi. N S.R. 94, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 30, T 13 N, R 19 E, Montgomery Co., Ala.
Dg 1-1 - 14	Road cut, 2 mi. N of Pine Level, on U.S. 231, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 17, T 13 N, R 20 E, Montgomery Co., Ala.
Eg-1	Road cut, 1 mi S of Hecton, (1 mi. S U.S. 82), NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 24, T 13 N, R 21 E, Bullock Co., Ala.
Fg-5	Road side ditch, 0.5 mi. S of Bruceville, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 21, T 13 N, R 22 E, Bullock Co., Ala.
Gf-2	Road side ditch, 1.8 mi. N of Union Springs, on U.S. 29, NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 26, T 14 N, R 23 E, Bullock Co., Ala.

Cusseta

Number	Description of Location
Cg-1	Road side ditch, 1.5 mi. SW of Davis Crossroads, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 7, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1a	Road cut, 1.7 mi. SW of Davis Crossroads, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 7, T 13 N, R 19 E, Montgomery Co., Ala.

Number	Description of Location
Cg-1b	Road side ditch, 1.9 mi. SW of Davis Crossroads, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 7, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1c	Road side ditch, 2.8 mi. SW of Davis Crossroads, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 18, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1d	Road cut, 3.1 mi. SSW of Davis Crossroads, SW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 18, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1e	Road cut, 3.3 mi., SSW of Davis Crossroads, NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 18, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1f	Road cut, 3.7 mi. SSW of Davis Crossroads, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 17, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1g	Road side ditch, NE of Ramer, 2.2 mi. N S.R. 94, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 20, T 13 N, R 19 E, Montgomery Co., Ala.
Cg-1h	Road cut, NE of Ramer, 1.8 mi. N S.R. 94, SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 29, T 13 N, R 19 E, Montgomery Co., Ala.
Dg-1 15 - 31	Road cuts, extending from 2 mi. N of Pine Level to 1.4 mi. N. of Pine Level, on U.S. 231, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 17, E $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 20, T 13 N, R 20 E, Montgomery Co., Ala.
Eg-1a	Road cut, 1.7 mi. S of U.S. 82, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 24, T 13 N, R 21 E, Bullock Co., Ala.
Eg-2	Road cuts, extending from 2 mi. S of U.S. 82 to 2.5 mi. S of U.S. 82, W $\frac{1}{2}$, NE $\frac{1}{4}$, Sec. 25, T 13 N, R 21 E, Bullock Co., Ala.
Fg-1	Road cut, 1.5 mi. S of Bruceville, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 28, T 13 N, R 22 E, Bullock Co., Ala.
Fg-2	Road cut, 1.8 mi. S of Bruceville, SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 28, T 13 N, R 22 E, Bullock Co., Ala.

Number	Description of Location
Fg-2a	Road cut, 2 mi. S of Bruceville, NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 33, T 13 N, R 22 E, Bullock Co., Ala.
Fg-3	Road cut, 0.7 mi. N of Hooks Cross Roads, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 33, T 13 N, R 22 E, Bullock Co., Ala.
Fg-4	Road cut, 0.5 mi. N of Hooks Cross Roads, SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 33, T 13 N, R 22 E, Bullock Co., Ala.
Fg-6	Borrow Pit, 0.1 mi. N of Hooks Cross Roads, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 4, T 12 N, R 22 E, Bullock Co., Ala.
Gf-1	Road cut, N edge of Union Springs, on U.S. 29, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 35, T 14 N, R 23 E, Bullock Co., Ala.
GG-1	Road side ditch, 0.8 mi. N of Aberfoil, SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 25, T 13 N, R 23 E, Bullock Co., Ala.
Gg-2	Road side ditch, 1.0 mi. N of jct. S.R. 239 on U.S. 29, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 24, T 13 N, R 23 E, Bullock Co., Ala.
Gg-3	Road cut, 2.8 mi. (St. Line) SSE of Union Springs, on U.S. 29, NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 13, T 13 N, R 23 E, Bullock Co., Ala.
Gg-4	Road cut, west edge of Union Springs on U.S. 82, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 3, T 13 N, R 23 E, Bullock Co., Ala.
Hg-1	Road cut and road side ditch, 0.6 mi. SW of Three Notch, SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 24, T 13 N, R 24 E, Bullock Co., Ala.
Hg-1a	Road cut, 1.5 mi. SW of Three Notch, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 24, T 13 N, R 24 E, Bullock Co., Ala.
If-1	Road cut, approx. 3 mi. ENE of Peachburg, 1 mi. S of Suspension, E $\frac{1}{2}$, SW $\frac{1}{4}$, Sec. 19, T 14 N, R 25 E, Bullock Co., Ala.

Number	Description of Location
If-2	Road cut, 0.3 mi. N of Enon, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 35, T 14 N, R 25 E, Bullock Co., Ala.
If-2a	Road cut, 0.2 mi. E of S.R. 26, 1.8 mi. W of Enon, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 27, T 14 N, R 25 E, Bullock Co., Ala.
Ig-1	Road cut, 1.3 mi. E of Midway, on U.S. 82, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 26, T 13 N, R 25 E, Bullock Co., Ala.
Ih-1	Road cut 1.2 mi. (st. line) NE of Pine Grove, on blacktop co. road to Midway, NE $\frac{1}{4}$, SW $\frac{1}{4}$, T 12 N, R 25 E, Bullock Co., Ala.
Jh-1	Stream cut, between Comer and U.S. 82, just E of bridge, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 12, T 12 N, R 26 E, Barbour Co., Ala.
Kg-1	Road cut, 0.5 mi. N of Spring Hill, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 28, T 13 N, R 27 E, Barbour Co., Ala.
Kg-2	Road cut, approx. 3 mi. (st. line) NE of Comer, 1.5 mi. SW of Spring Hill, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 33, T 12 N, R 27 E, Barbour Co., Ala.
Kh-1	Creek cut, under bridge of U.S. 82, 0.5 mi. N of Batesville, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 22, T 12 N, R 27 E, Barbour Co., Ala.
Kh-2	Road cut, approx. 1 mi. (st. line) S of Comer, NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 19, T 12 N, R 27 E, Barbour Co., Ala.
Kh-3	Road cut, 0.3 mi. SW of Batesville, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 22, T 12 N, R 27 E, Barbour Co., Ala.
Kh-3a	Roadside ditch, 0.6 mi. SW of Batesville, SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 22, T 12 N, R 27 E, Barbour Co., Ala.

Number	Description of Location
Kh-4	Roadside ditch, 1.5 mi. (st. line) NE of Comer, SW ¼, SW ¼, Sec. 5, T 12 N, R 27 E, Barbour Co., Ala.
Lg-1	Road cut, 0.2 mi. S of Glenville on U.S. 431, SE ¼, SE ¼, Sec. 12, T 13 N, R 28 E, Russell Co., Ala.
Lg-2	Road cut, 0.6 mi. E of U.S. 231, 1.3 mi. (st. line) N of Glenville, SE ¼, NE ¼, Sec. 1, T 13 N, R 28 E, Russell Co., Ala.
Lg-3	Road cut, approx. 0.8 mi. N of Glenville, on U.S. 231, SE ¼, SW ¼, Sec. 1, T 13 N, R 28 E, Russell Co., Ala.
Lg-4	Roadside ditch, 1.8 mi. due W of North Fork Cowikee Creek, 0.6 mi. SE of Mt. Gilead Church, SW ¼, NE ¼, Sec. 28, T 13 N, R 28 E, Barbour Co., Ala.
Lh-1	Exposures starting in gully 30 ft. W of unimproved co. road, continuing in road ditch and ending at road cut, 1 mi. N of Hawkinsville, 0.4 mi. S of Middle Fork Cowikee Creek, SW ¼, SE ¼, Sec. 4, T 12 N, R 28 E, Barbour Co., Ala.
Lh-1a	Roadside ditch, 0.5 mi. N of Hawkinsville, SW ¼, NE ¼, Sec. 9, T 12 N, R 28 E, Barbour Co., Ala.
Lh-1b	Roadside ditch, 0.3 mi. N of Hawkinsville, NW ¼, SE ¼, Sec. 9, T 12 N, R 28 E, Barbour Co., Ala.
Lh-1c	Road cut, 0.2 mi. N of Hawkinsville, SW¼, SE ¼, Sec. 9, T 12 N, R. 28 E, Barbour Co., Ala.
Mh-1	Road cut, 0.2 mi. N of N. Fork Cowikee Creek on Co. Road 97, SE ¼, SW ¼, Sec. 6, T 12 N, R 29 E, Barbour Co., Ala.

Number	Description of Location
Mh-2	Roadside ditch, approx. 3.5 mi. N of U.S. 431 on Co. Road 97, NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 32, T 12 N, R 29 E, Barbour Co., Ala.
Mh-3	Road ditch, 0.25 mi. S of Russell-Barbour Co. line on S.R. 97, NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 6, T 12 N, R 29 E, Barbour Co., Ala.
Ng-1	Borrow pit, 1.3 mi. ESE of Florence, N of road no. 655, Stewart Co., Ga.
Ng-2	Deep arroyo, 1.5 mi. (st. line) ENE of Florence, 100 ft. N of unimproved co. road, 0.6 mi. N of road no. S-655, Stewart Co., Ga.
Ng-3	Arroyo, just N of unimproved co. road, 2.5 mi. (st. line) ENE of Florence, 0.25 mi. N of Grass Creek, Stewart Co., Ga.
Nh-1a	Roadside ditch, 2.25 mi. N of Quitman Co. line, 2 mi. E of Ala. line, 0.2 mi. S of "Old" Coffintown site, Stewart Co., Ga.
Ni-1	Creek cut bank, 0.6 mi. E road no. S-651, just S of Bustahatchee Cr., S of unimproved co. road, Quitman Co., Ga.
Of-1	Arroyo, just N of unimproved co. road, 3.1 mi. (st. line) NW of Julia, Stewart Co., Ga.
Of-2	Roadside ditch, 2.4 mi. W of Julia, N of Hannahotchee Cr., 4 mi. E of Omaha, Stewart Co., Ga.
Og-1	Road cut, 2.5 mi. (st. line) WSW of Julia and 4 mi. E of Omaha on road no. S-641, Stewart Co., Ga.
Og-2	Road cut, 3 mi. (st. line) W of U.S. 27 on Omaha Rd., no. S-641, Stewart Co., Ga.

Number	Description of Location
Pe-1	Arroyo, 200 ft. N of unimproved co. road, 0.4 mi. E of U.S. 27, 0.75 mi. N of Stewart Co. line, Chattahoochee Co., Ga.
Pe-1a	Road cut, 1.25 mi. (st. line) N of Stewart Co. line on U.S. 27, Chattahoochee Co., Ga.
Pe-2	Road cut, 3.0 mi. (st. line) S of Cusseta on U.S. 27, Chattahoochee Co., Ga.
Pe-3	Road cut, just S of Cusseta, 0.3 mi. W of S.R. 280 on Spur 55, Chattahoochee Co., Ga.
Pe-3a	Road cut, S side of Cusseta, 100 ft. E of U.S. 27 on S.R. Spur 55, Chattahoochee Co., Ga.
Pe-3b	Road cut, Cusseta sand type locality, 0.2 mi. S of Cusseta Courthouse on U.S. 27, Chattahoochee Co., Ga.
Pf-2	Arroyo, 50 ft. W of U.S. 27, 1.25 mi. NE of Louvale, Stewart Co., Ga.
Pf-3	Road cut, 0.3 mi. S of Louvale, on U.S. 27, Stewart Co., Ga.
Pg-1	Road cut, 2.25 mi. (st. line) W of U.S. 27 on Omaha Rd. (S-641), Stewart Co., Ga.
Pg-2	Road cut, 2 mi. S of Louvale on U.S. 27, 300 ft. S. of road no. S-641, Stewart Co., Ga.
Qd-1	Road cut, on S.R. 137, 2 mi. W of Marion Co. line, Chattahoochee Co., Ga.
Qe-1	Road cut, 3.9 mi. (st. line) E of Cusseta Courthouse, 100 ft. S of S.R. 26 on co. road, Chattahoochee Co., Ga.

Number	Description of Location
Qe-2	Sand pit, 3.2 mi. (st. line) E of Cusseta Courthouse on S.R. 137, Chattahoochee Co., Ga.
Qe-3	Road cut, 6.75 mi. (st. line) SE of Cusseta Courthouse on paved secondary road paralleling U.S. 280, 4.25 mi. N of Stewart Co. line, Chattahoochee Co., Ga.
Qe-4	Road cut, 7.75 mi. (st. line) SE of Cusseta Courthouse on unimproved country road paralleling U.S. 280, 3.8 mi. N of Stewart Co. line, Chattahoochee Co., Ga.
Rc-1	Arroyo, 100 ft. E of S.R. 352, on unimproved co. road, 8.75 mi. (st. line) NW of Buena Vista, .25 mi. S of Parkers Mill Cr., Marion Co., Ga.
Rc-2	Road cut, on S.R. 352 approx. 4.5 mi. (st. line) NW of jct. with S.R. 41, 4 mi. E of Chattahoochee Co. line, Marion Co., Ga.
Rd-1	Road cut, on S.R. 137, 4 mi. (st. line) WNW of Buena Vista, 6.75 mi. W of jct. S.R. 41, Marion Co., Ga.
Rd-2	Road cut, 2.8 mi. NNE of S.R. 137 on S.R. 355, 1 mi. E of Chattahoochee Co. line, approx. 9 mi. NW of Buena Vista, Marion Co., Ga.
Rd-3	Road gully, 1 mi. S of Heards Lakes, 0.5 W of Poplar Spring Ch., 2.2 mi. E of Chattahoochee Co. line, 1.4 mi. (st. line) NE of jct with S.R. 137, Marion Co., Ga.
Sc-1	Arroyo, E of S.R. 41, approx. 11 mi. N of Buena Vista, 1 mi. S of S.R. 267, Marion Co., Ga.

Number	Description of Location
Sd-1	Road cut, 4.5 mi. N of Buena Vista on S.R. 41, Marion Co., Ga.
Tb-1	Arroyo, just N of S.R. 90, 0.5 mi. E of Mauk, Taylor Co., Ga.
Tc-1	Roadside ditch, E side of S.R. 137, just S of S.R. 90 jct., N side of Charing, Taylor Co., Ga.
Td-1	Road cut, 0.7 mi. SW of Tazewell on S.R. 137, Marion Co., Ga.
Ub-1	Kaolin pits, S side of S.R. 137, approx. 3 mi. SW of Butler, Taylor Co., Ga.
Uc-1	Road cut, 5.5 mi. (st. line) SW of Butler, 1 mi. S of VFW Club, 1.75 mi. (st. line) SW of Lt. Col. Brewer Cem., just S of Whitewater Cr. on unimproved co. road, Taylor Co., Ga.
Va-1	Sand pit, 2.5 mi. N of Butler, approx. .25 mi. W of U.S. 19, Taylor Co., Ga.
Wb-1	Gully, 50 ft. S of S.R. 96, 2.75 mi. W of Reynolds, Taylor Co., Ga.
Wb-2	Roadside ditch, 2.5 mi. (st. line) WNW of Reynolds, approx. 0.5 mi. N of S.R. 96 on unimproved co. road, Taylor Co., Ga.
Wb-3	Road cut, 1.25 mi. (st. line) SW of Reynolds on road no. S-1506, 2.25 mi. N of Petterville, Taylor Co., Ga.
Xa-1	Road cut, 3.0 mi. N of S.R. 96, on unimproved co. road no. S-1713, 1.5 mi. (st. line) SW of Hebron, Crawford Co., Ga.
Xa-2	Sand pit, 1.9 mi. (st. line) NNW of Hebron, 1.25 SE of Gaillard, 1 mi. SW of S.R. 7, Crawford Co., Ga.
Xa-3	Sand and gravel pit, 0.25 mi. W of Gaillard on co. road no. S-1435, Crawford Co., Ga.

Number	Description of Location
Xa-4	Road cut, 0.5 mi. S of Gaillard on co. road no. S-1435, Crawford Co., Ga.

Ripley

Number	Description of Location
Dg-1a	Road cut, 0.5 mi. NNW of Pine Level, U.S. 231, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 29, T 13 N, R 20 E, Montgomery Co., Ala.
Hg-2	Road ditch, 0.2 mi. E of U.S. 29 on S.R. 239, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 30, T 13 N, R 24 E, Bullock Co., Ala.
Hh-1	Road cut, 0.8 mi. N of Pine Grove, on blacktop co. road to Midway, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 1, T 12 N, R 24 E, Bullock Co., Ala.
Kh-36	Road cut, 0.9 mi. SW of Batesville, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 27, T 12 N, R 27 E, Barbour Co., Ala.
Mh-2a	Roadside ditch, approx. 3.8 mi. N of U.S. 431 on co. road 97, SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 32, T 12 N, R 29 E, Barbour Co., Ala.
Mh-2b	Road cut, approx. 3.2 mi. N of U.S. 431 on co. road 97, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 32, T 12 N, R 29 E, Barbour Co., Ala.
Nh-1	Road cut, 2.0 mi. N of Quitman Co. line, 2 mi. E of Ala. line, 0.4 mi. S of "Old" Coffintown site, Stewart Co., Ga.
Ni-2	Road cut, 0.1 mi. S of Bustahatchee Cr. on co. road no. S-641, 0.6 mi. S of Stewart Co. line, Quiteman Co., Ga.
Ni-2a	Road cut, approx. 3 mi. (st. line) NE of Georgetown, 1.5 mi. S of Soapstone Cr., on co. road no. S-641, Quitman Co., Ga.

APPENDIX II

APPENDIX II

CONTROL WELL LOCATIONS

(See Plate I in Pocket)

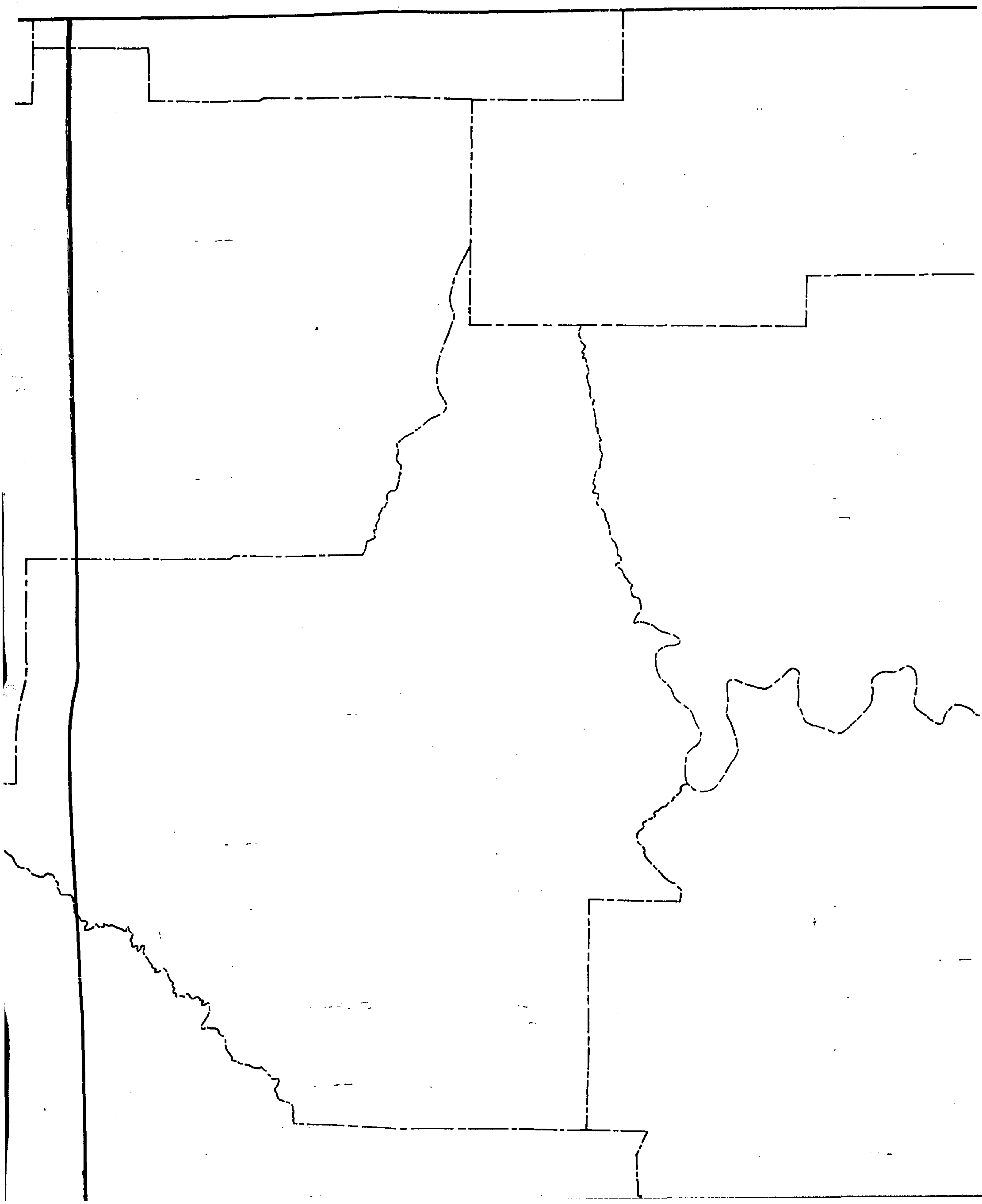
Number	Description of Location
	Alabama
GGS 308	512' N of SW corner, NE/4 of NE/4 of S 36, T 7 N, R 13 E, Butler Co., Ala.
GGS 412	T 6 N, R 20 E, Coffee Co., Ala.
GGS 542	T 5 N, R 21 E, Coffee Co., Ala.
GGS 17	1310' N/S line and 1900' W/E line SE/4 of S 10, T 2 N, R 14 E, Covington Co., Ala.
GGS 183	SW/4 of NW/4 of S 20, T 5 N, R 15 E, Covington Co., Ala.
GGS 309	660' S and 660' E of NW cor. of NE/4 of S 27, 6 N R 14 E, Covington Co., Ala.
GGS 381	660'S and 660' W of NE/cor. of SW/4 of SW/4 of S 23, T 5 N, R 18 E, Covington, Co., Ala.
GGS 452	660' S/N line and 660' E/W line SW/4 of SW/4 of S 25 T 3 N, R 16 E, Covington Co., Ala.
GGS 492	660' S/N line and 660' W/E line NE/4 of NE/4 of S 7 T 5 N, R 17 E, Covington, Ala.
GGS 204	330' S/N line and 330' W/E line NE/4 of S 19 T 6 N, R 10 E, Conecuh Co., Ala.
GGS 350	1980' W/E line and 660' N/S line of SW/4 SE/4 S 12 T 6 N, R 11 E, Conecuh Co., Ala.

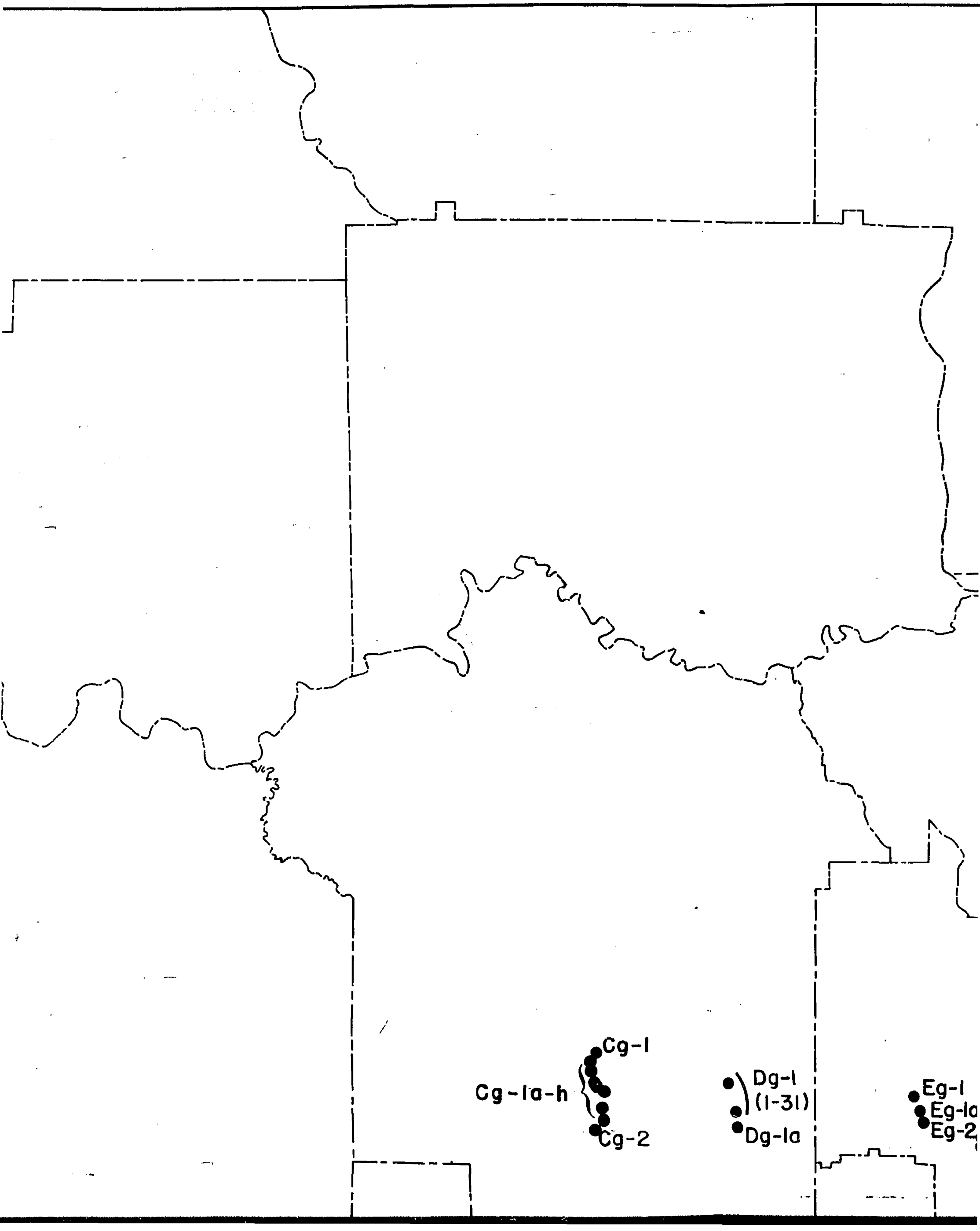
Number	Description of Location
GGS 469	Center of SW/r of SW/4 of S 22, T 5 N, R 11 E, Conecuh Co., Ala.
GGS 560	760' S/N line and 660' W/E line NE/4 of SE/4 of S 9, T 4 N, R 10 E, Conecuh Co., Ala.
GGS 145	N/½ of NW/4 of S 26, T 18 N, R 16 E, Crenshaw Co., Ala.
GGS 560	667' S/N line and 660' W/E line SW/4 of NW/4 of S 30, T 8 N, R 19 E, Crenshaw Co., Ala.
GGS 58	4782' S/N line and 3464' W/E line cen. SE/4 SW/4 of S 15, T 1 N, R 10 E, Escambia Co., Ala.
GGS 168	NE/4 of SW/4 S 18, T 2 N, R 12 E, Escambia Co., Ala.
GGS 352	660' E/W line and 660' N/S line cen. SW/4 SW/4 of S 30, T 1 N, R 9 E, Escambia Co., Ala.
GGS 396	735' S/N line and 585' W/E line SW/4 of NW/4 of S 8, T 3 N, R 9 E, Escambia Co., Ala.
GGS 398	T 3 N, R 13 E, Escambia Co., Ala.
GGS 436	660' S/N line and 660' W/E line NE/4 of NE/4 of S 20, T 2 N, R 8 E, Escambia Co., Ala.
GGS 475	660' W/E line and 660' N/S line cen. SE/4 of SE/4 S 19, T 2 N, R 11 E, Escambia Co., Ala.
GGS 525	660' S & W of cen. of NE/4 of SW/4 of S 21, T 3 N, R 10 E, Escambia Co., Ala.
GGS 541	660' S/N line and 530' W/E line of SE/4 of NW/4 of S 21, T 1 N, R 12 E, Escambia Co., Ala.
GGS 1168	Cen. SW/4 SE/4 of S 17, T 3 N, R 8 E, Escambia Co., Ala.

Number	Description of Location
GGS 169	660' S/N line and 660' W/E line SW/4 of SE/4 of S 27, T 1 N, R 19 E, Geneva Co., Ala.
GGS 439	Center of NW/4 of NW/4 of S 17, T 2 N, R 25 E, Geneva Co., Ala.
GGS 514	NW/4 of SW/4 of S 16, T 1 N, R 21 E, Geneva Co., Ala.
GGS 615	SE/4 of SE/4 of S 13, T 1 N, R 24 E, Geneva Co., Ala.
GGS 186	783' S/N line and 660' W/E line NE/4 of NE/4 of S 20, T 7 N 11 W, Houston Co., Ala.
GGS 238	660' S/N line and 1920' W/E line NW/cor. NW/4 of S 10, T 2 N, R 29 E, Houston Co., Ala.
GGS 426	Center of NW/4 of SW/4 of S 18, T 3 N, R 26 E, Houston Co., Ala.
437	SE/4 of NW/4, Sec. 14, T 9 N, R 9 E, Monroe Co., Ala.
449	NW/4 of NW/4, Sec. 3, T 7 N, R 8 E, Monroe Co., Ala.
GGS 450	660' S/N line and 660' W/E line cen. NW/4 NE/4, S 18, T 9 N, R 11 E, Monroe Co., Ala.
GGS 668	Center of SW/4 of SW/4 Sec. 15, T 9 N, R 8 E, Monroe Co., Ala.
GGS 118	NE/4 of NW/4 of S 26, T 8 N, R 20 E, Pike Co., Ala.
GGS 184	660' E of NW/ corner of SE/4 of SW/4 of S 14, T 9 N, R 19 E, Pike Co., Ala.

Number	Description of Location
	Georgia
GGS 107	1650' N and 660' E of SW corner of Land Lot 71, 7th Land District, Atkinson Co., Ga.
GGS 7	8 mi. S of Macon, at Avondale, Bibb Co., Ga.
GGS 357	SW Macon, 1.5 mi. E of Hgwy 11, Bibb Co., Ga.
GGS 184	2780' S, 1570' W of NE cor. of Land Lot 454, 12th Land District, Brooks Co., Ga.
GGS 192	200' N of S line and 200' E of W line of Land Lot 328, 4th Land District, Calhoun Co., Ga.
GGS 170	760' W of E line, 210' N of S line, Land Lot 270, 8th Land District, Colquitt Co., Ga.
GGS 168	Center of NE quarter of Land Lot 260, 21st Land District, Decatur Co., Ga.
619	9 mi. ESE of Vienna, 811' N and 1003' E of Land Lot 163, 6th Land District, Dooly Co., Ga.
GGS 121	6 mi. NW of Saffold, Land Lot 406, 26th Land District, Early Co., Ga.
GGS 189	660' S 666' E of NW cor. of Land Lot 146, 12th Land District, Echols Co., Ga.
GGS 194	SE cor. of Land Lot 266, 14th Land District, Houston Co., Ga.
476	4 mi. SE of Buena Vista, ½ mi. W of Hgwy 26, Land Lot 207, Land District 31, Marion Co., Ga.

Number	Description of Location
GGS 331	12' N and 6' W of SW footing of water tower, ½ block N of Courthouse, W side of Hgwy 55, in Morgan, Calhoun Co., Ga.
GGS 109	5.5 mi. E of Pelham, Land Lot 133, 10th Land District, Mitchell Co., Ga.
472	4 mi. S of Pulaski-Bleckley Co. line, E side of US 26, Land Lot 306, 21st Land District, Pulaski Co., Ga.
552	In Cuthbert, Randolph Co., Ga.
GGS 187	660' from S line and 660' from E line of Land Lot 82, 27th Land District, Seminole Co., Ga.
GGS 451	2.5 mi. N of Lumpkin on Hgwy 27, Stewart Co., Ga.
GGS 442	4 mi. SW of Americus, Land Lot 210, Land District 17, Sumter Co., Ga.
GGS 375	588' from SW line, 410' from SE line of Land Lot 260, 7th Land District, Telfair Co., Ga.
GGS 416	NE part of Co., 1.75 mi. SE of Liberty Church, which is 0.75 mi. E of Myerick's Pond, Twiggs Co., Ga.
GGS 441	In Irwinton, Wilkinson Co., Ga.

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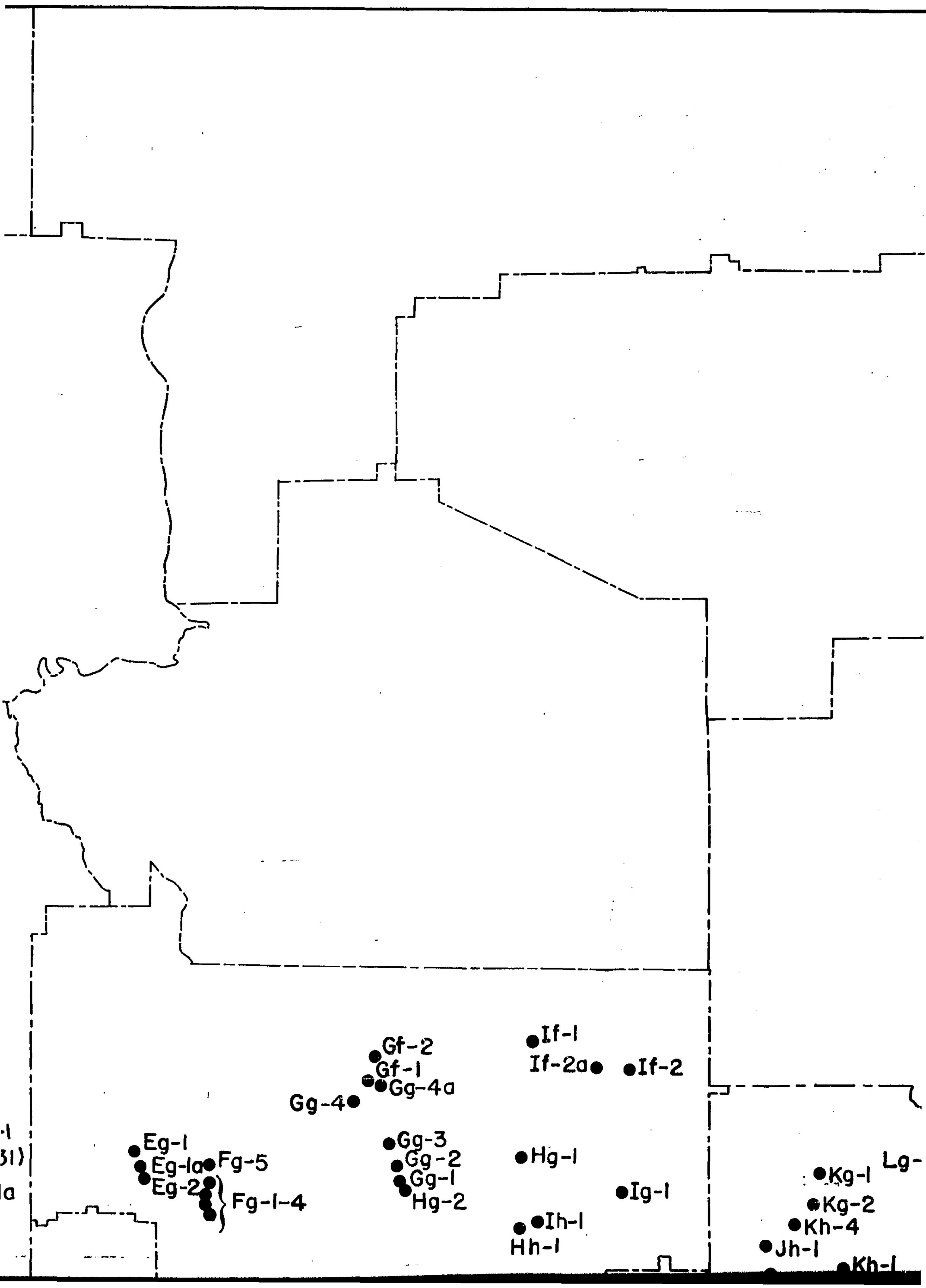
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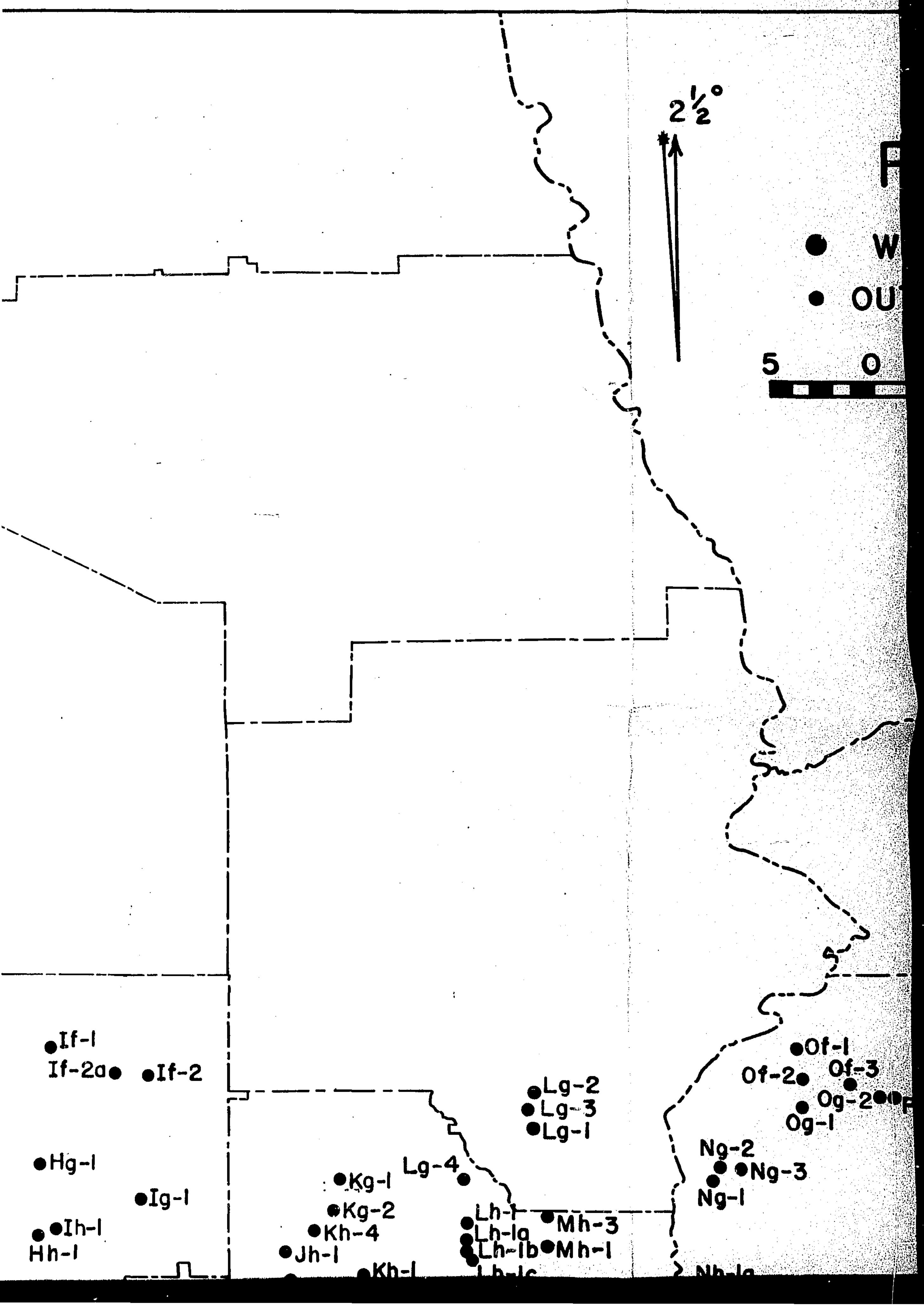
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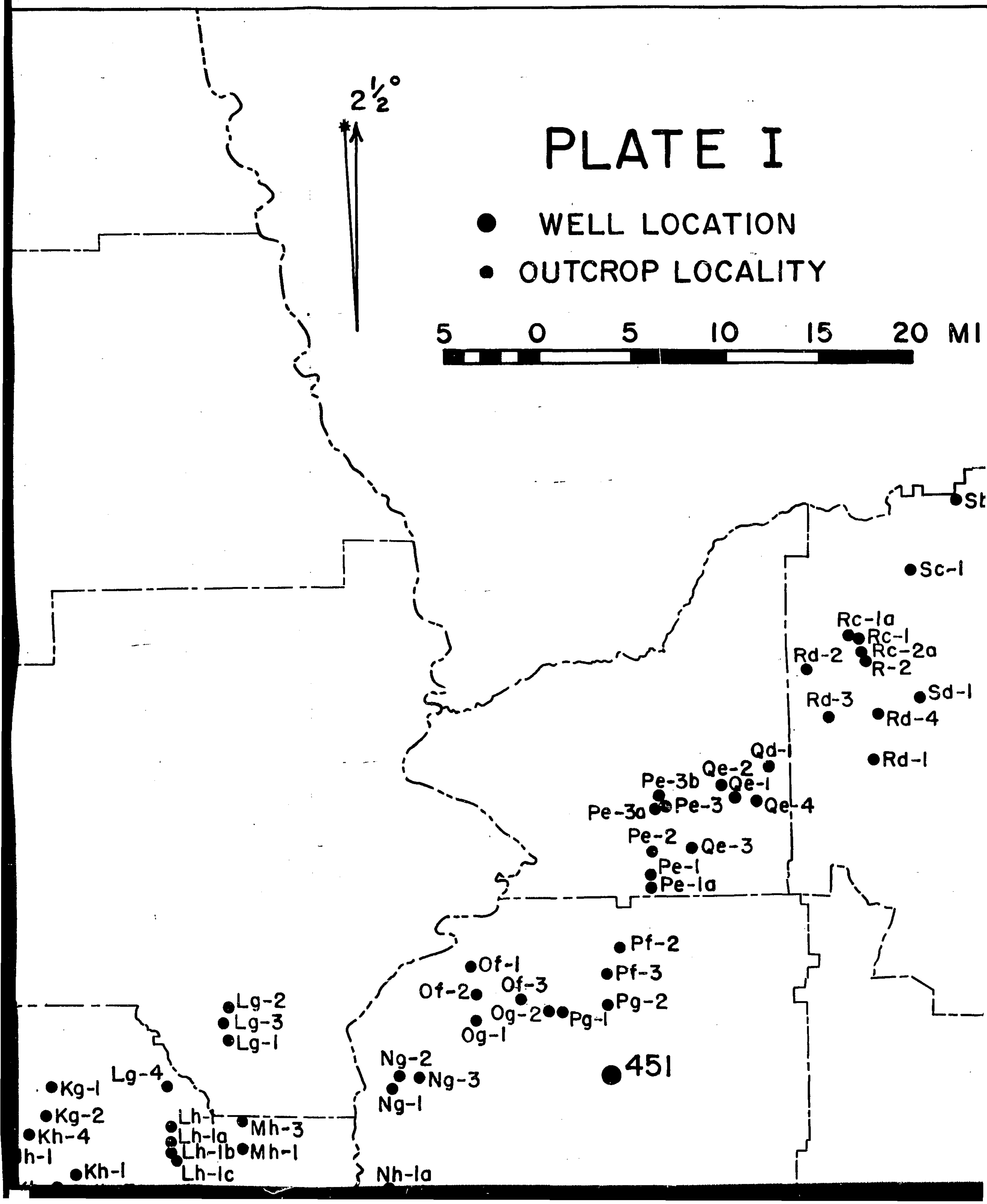

PLATE I

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● WELL LOCATION
● OUTCROP LOCALITY
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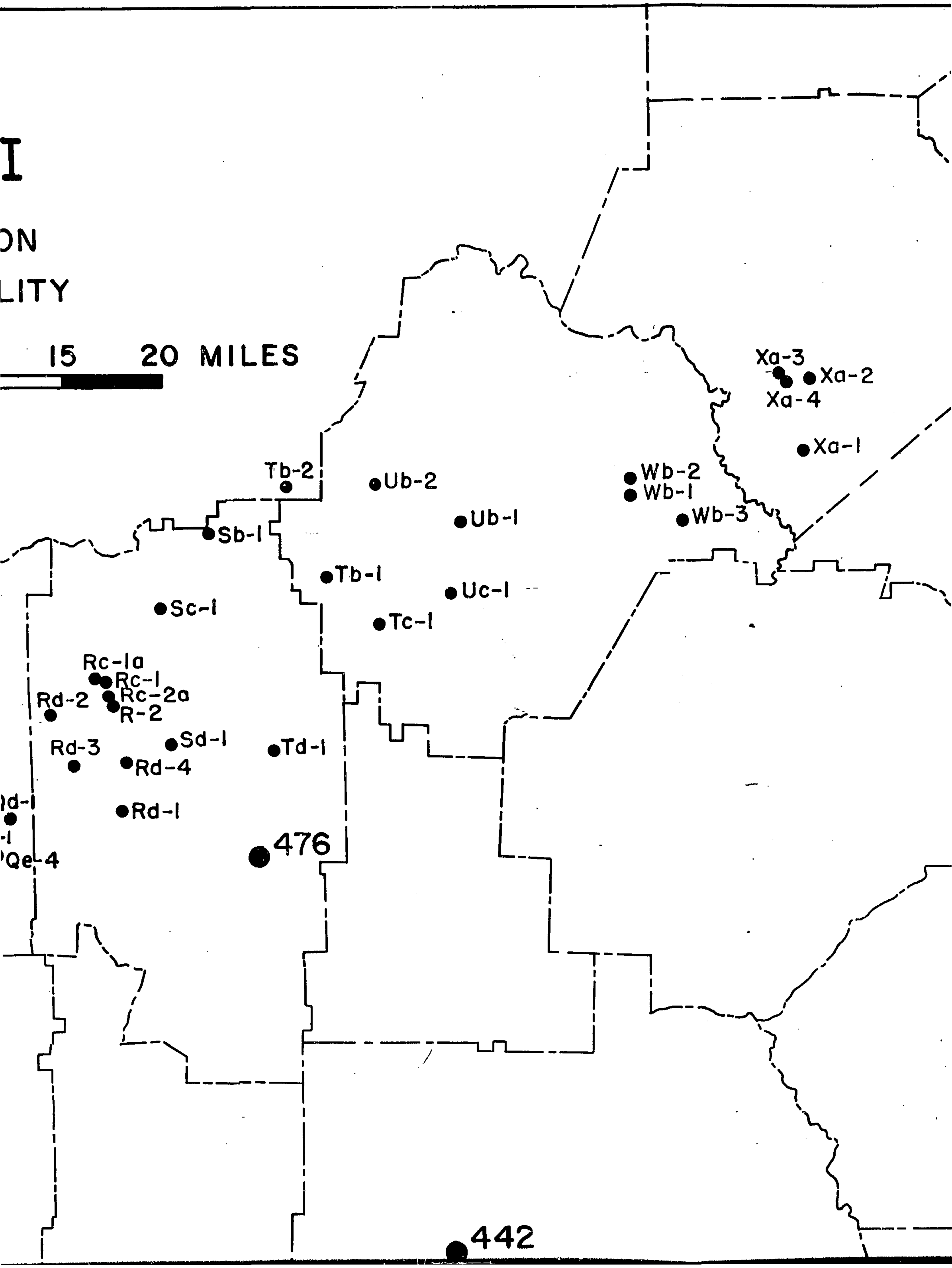
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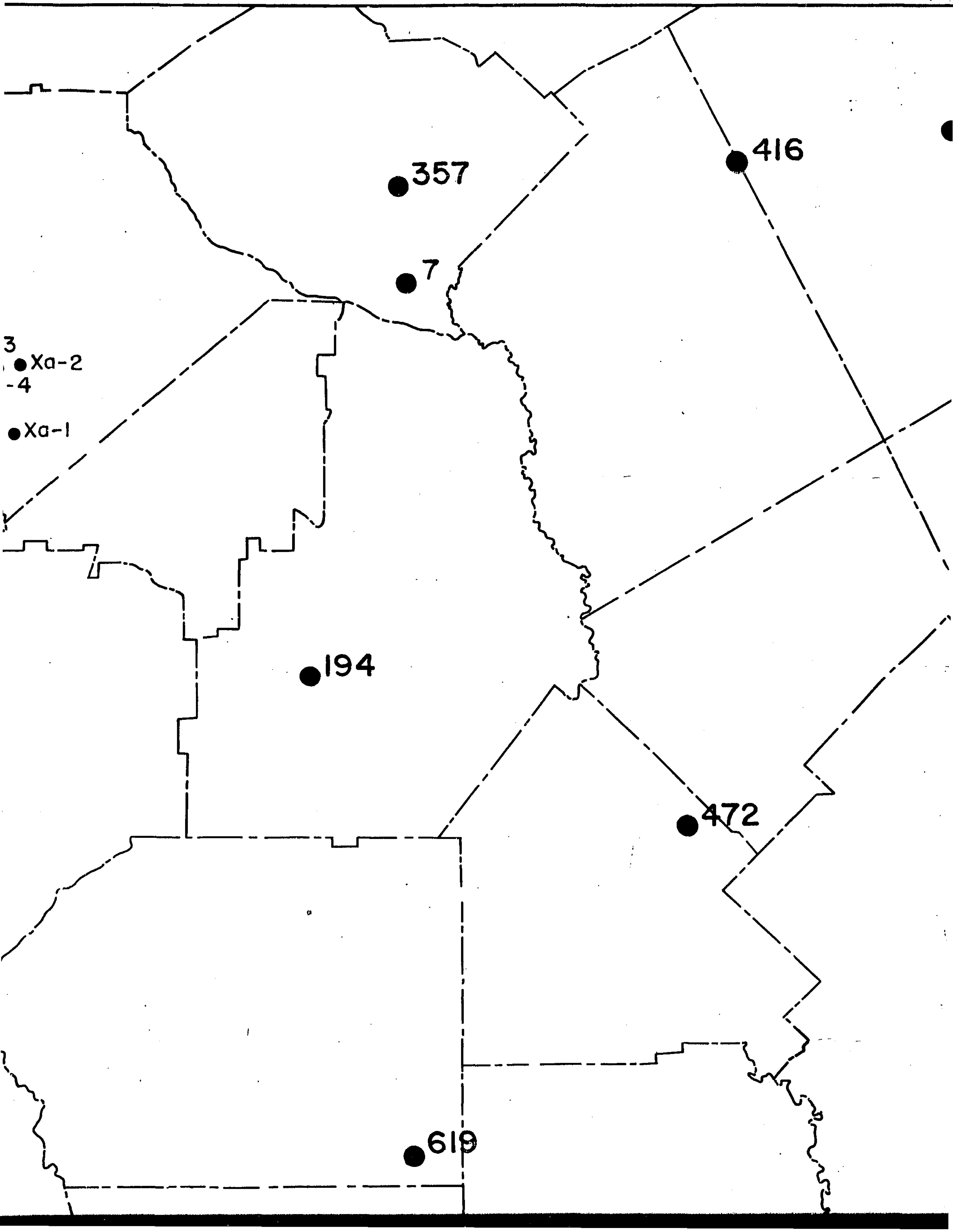
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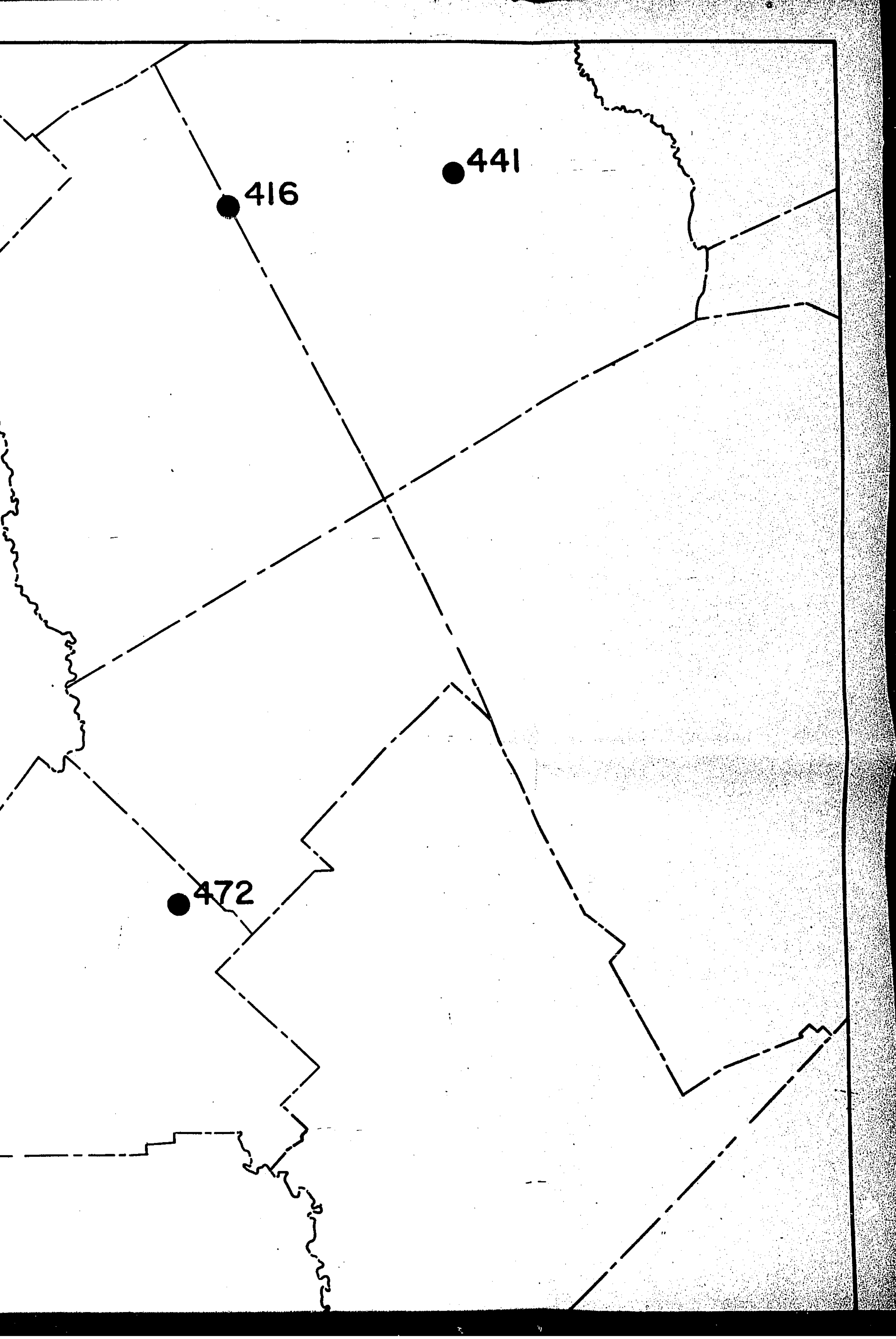
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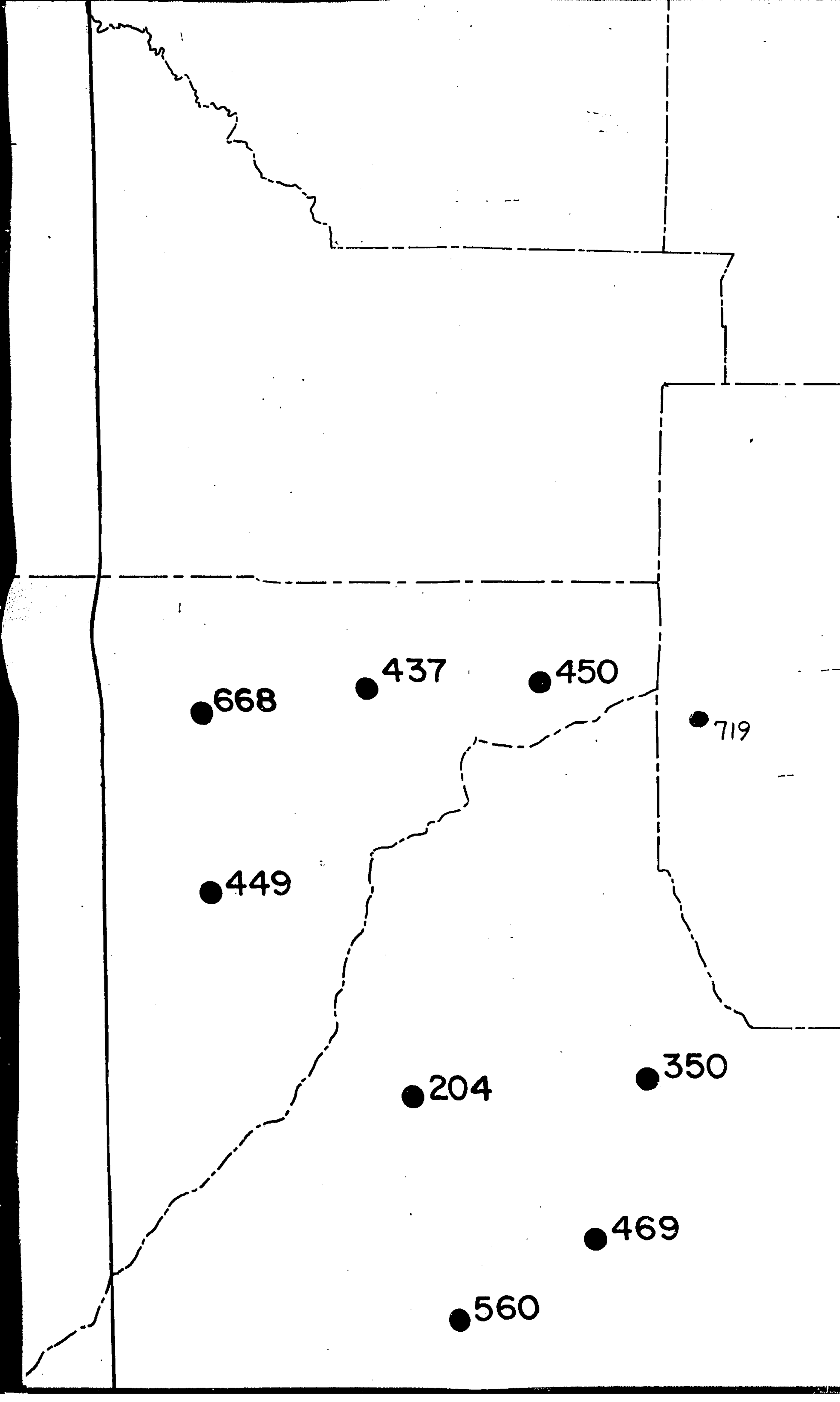
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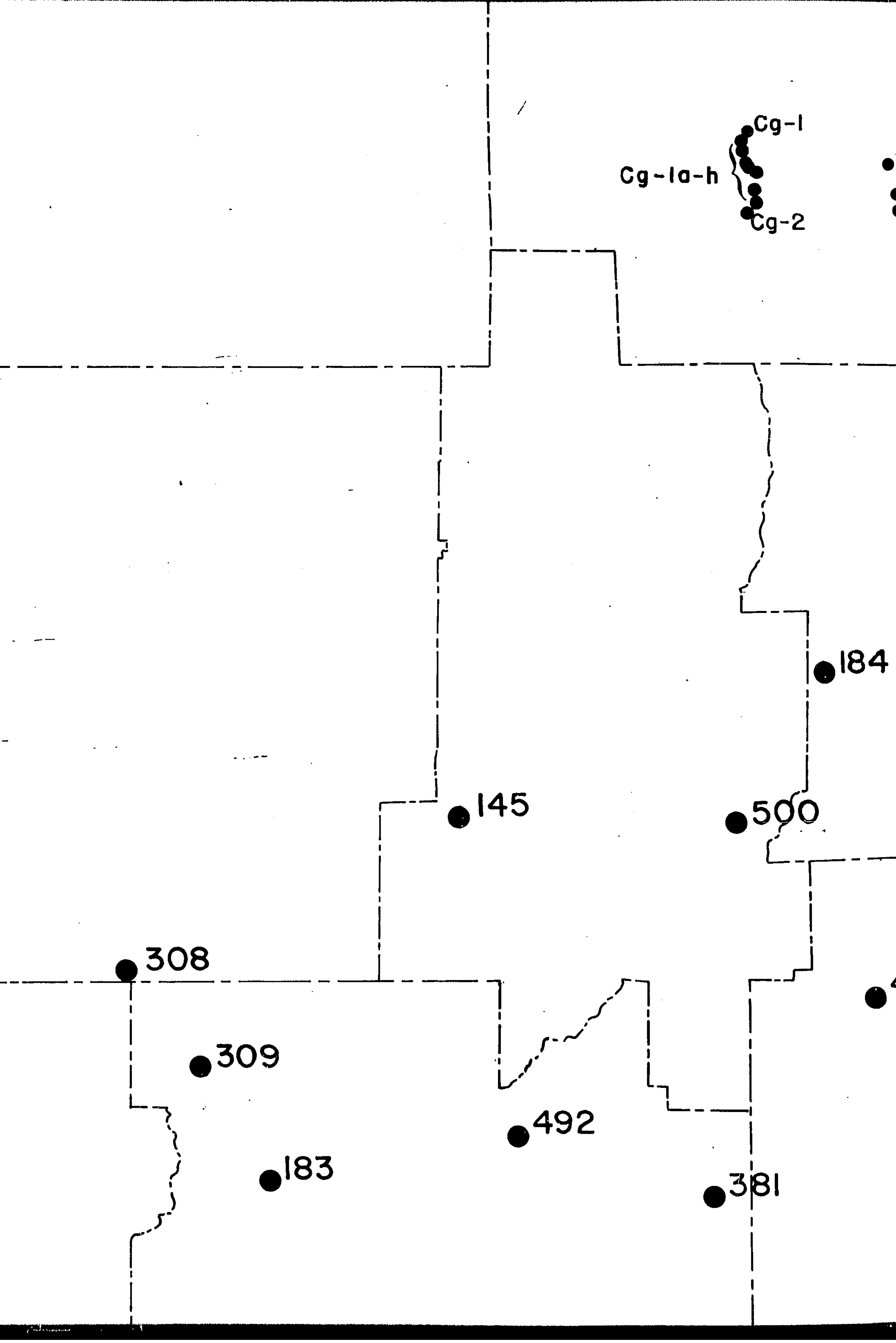
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Cg-2
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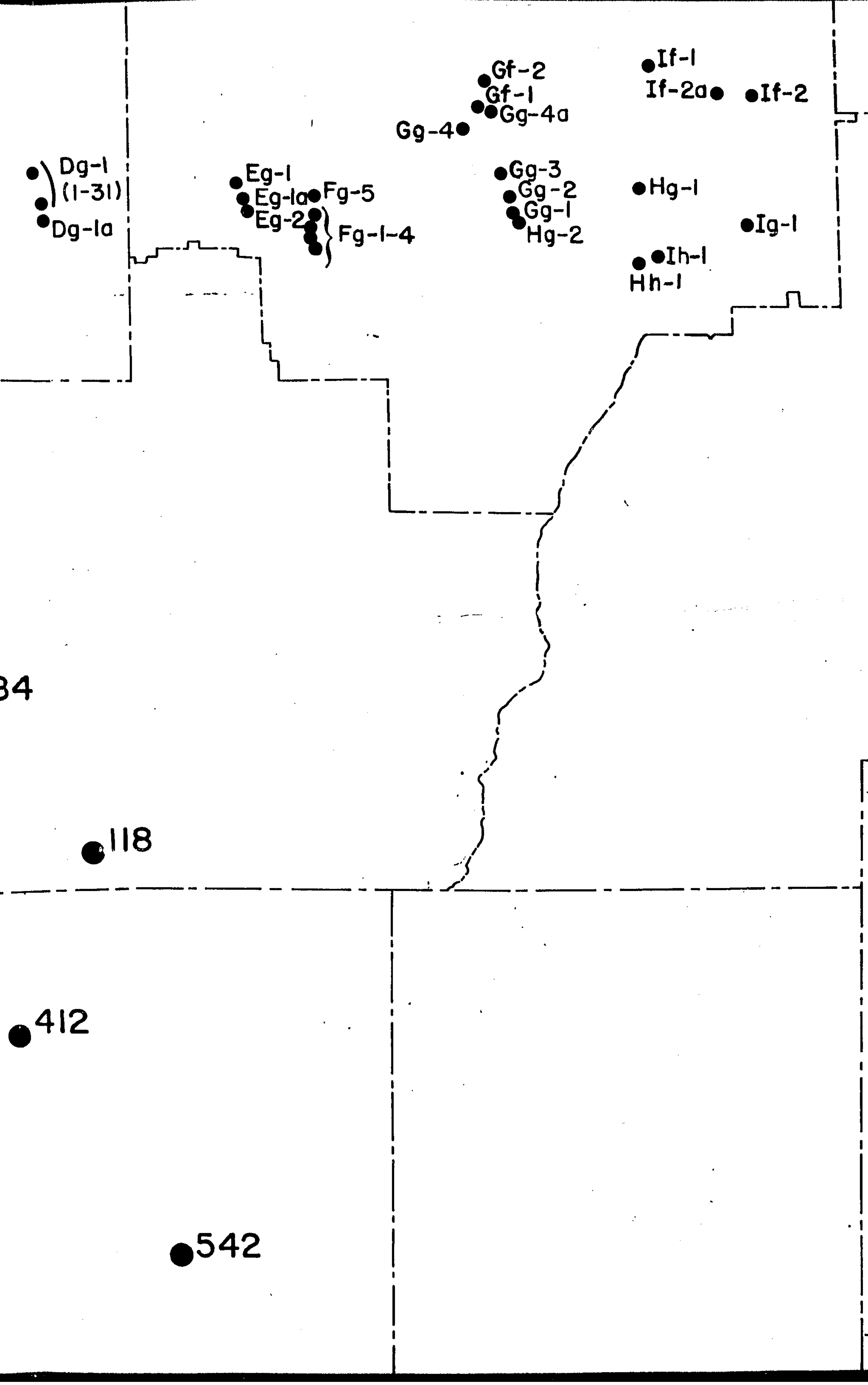
If-1
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Gf-1
If-2a
If-2
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Gg-4
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(1-31)
Dg-1a
Eg-1
Eg-1a
Eg-2
Fg-5
Fg-1-4
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Gg-2
Gg-1
Hg-2
Hg-1
Ig-1
Ih-1
Hh-1
34
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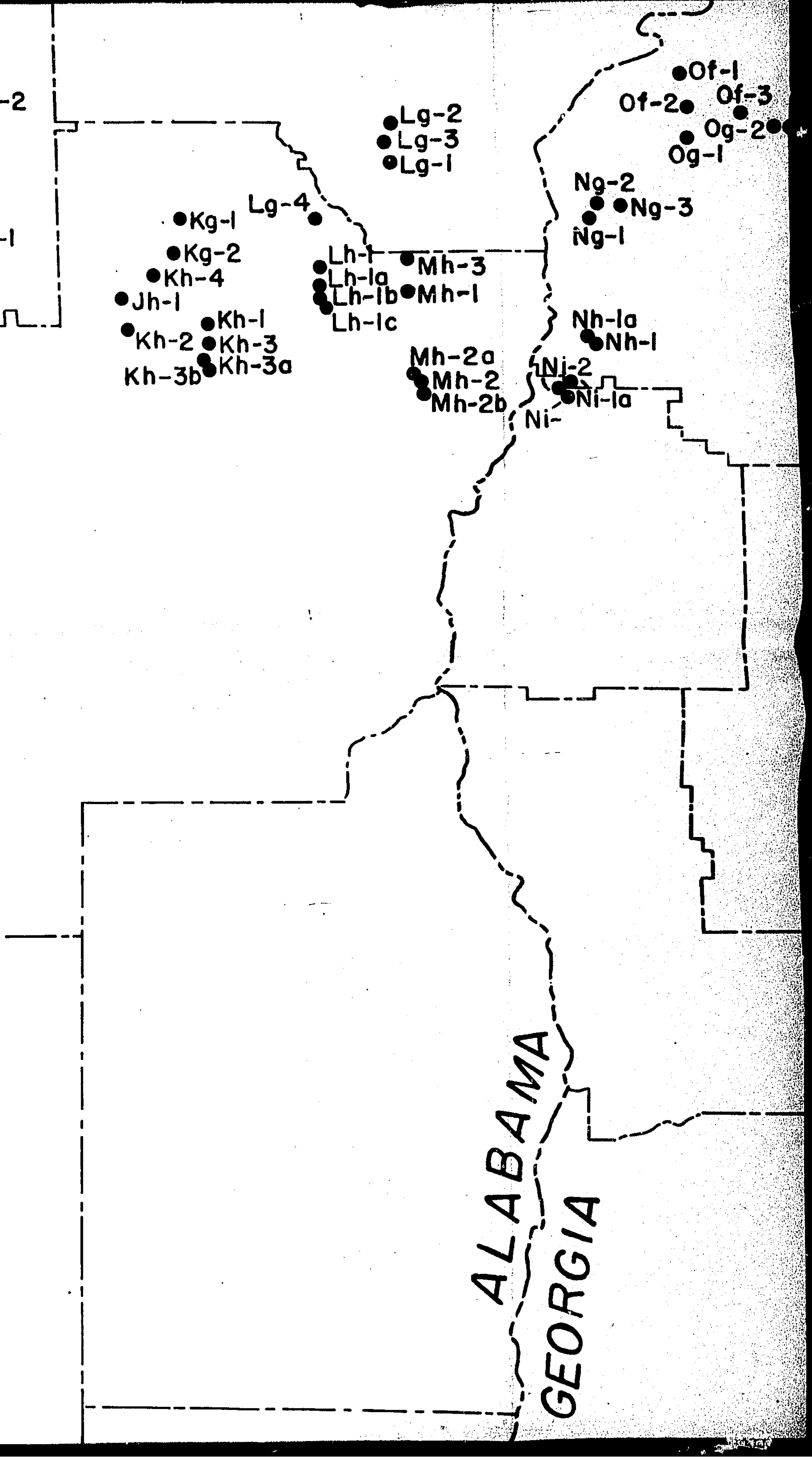
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Of-2
Of-3
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Og-1
Lg-2
Lg-3
Lg-1
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Ng-2
Ng-3
Ng-1
Kg-1
Kg-2
Kh-4
Jh-1
Lh-1
Lh-1a
Lh-1b
Lh-1c
Mh-3
Mh-1
Kh-1
Kh-2
Kh-3
Kh-3a
Kh-3b
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Mh-2
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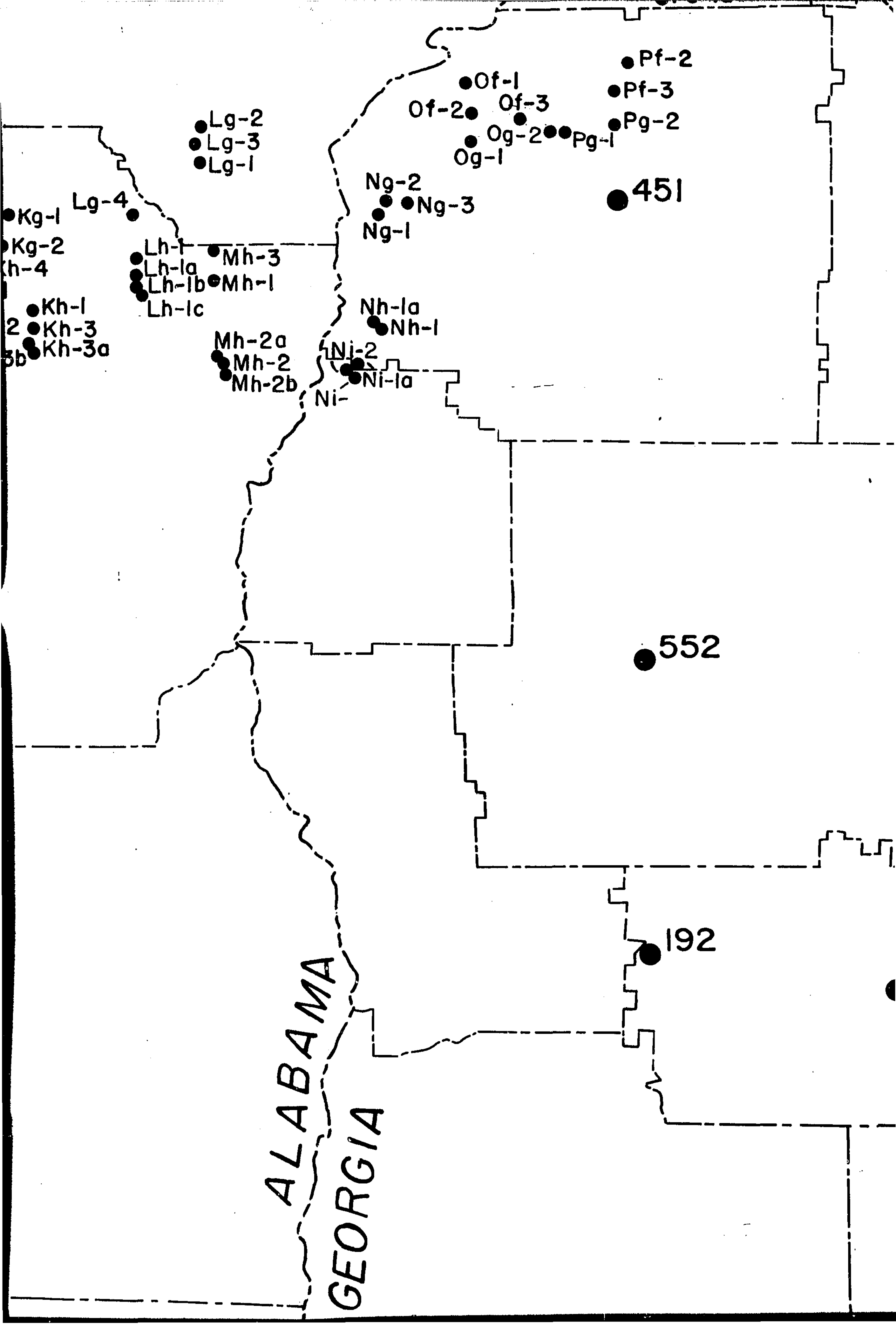
Ni-2
Ni-1a
Ni-
ALABAMA
GEORGIA


Pf-2
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Pf-3
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Of-3
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Pg-2
Og-2
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Lg-3
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Ng-2
451
Lg-4
Ng-3
Kg-1
Ng-1
Kg-2
Lh-1
Mh-3
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Lh-1a
Lh-1b
Mh-1
Lh-1c
Kh-1
Nh-1a
Nh-1
2
Kh-3
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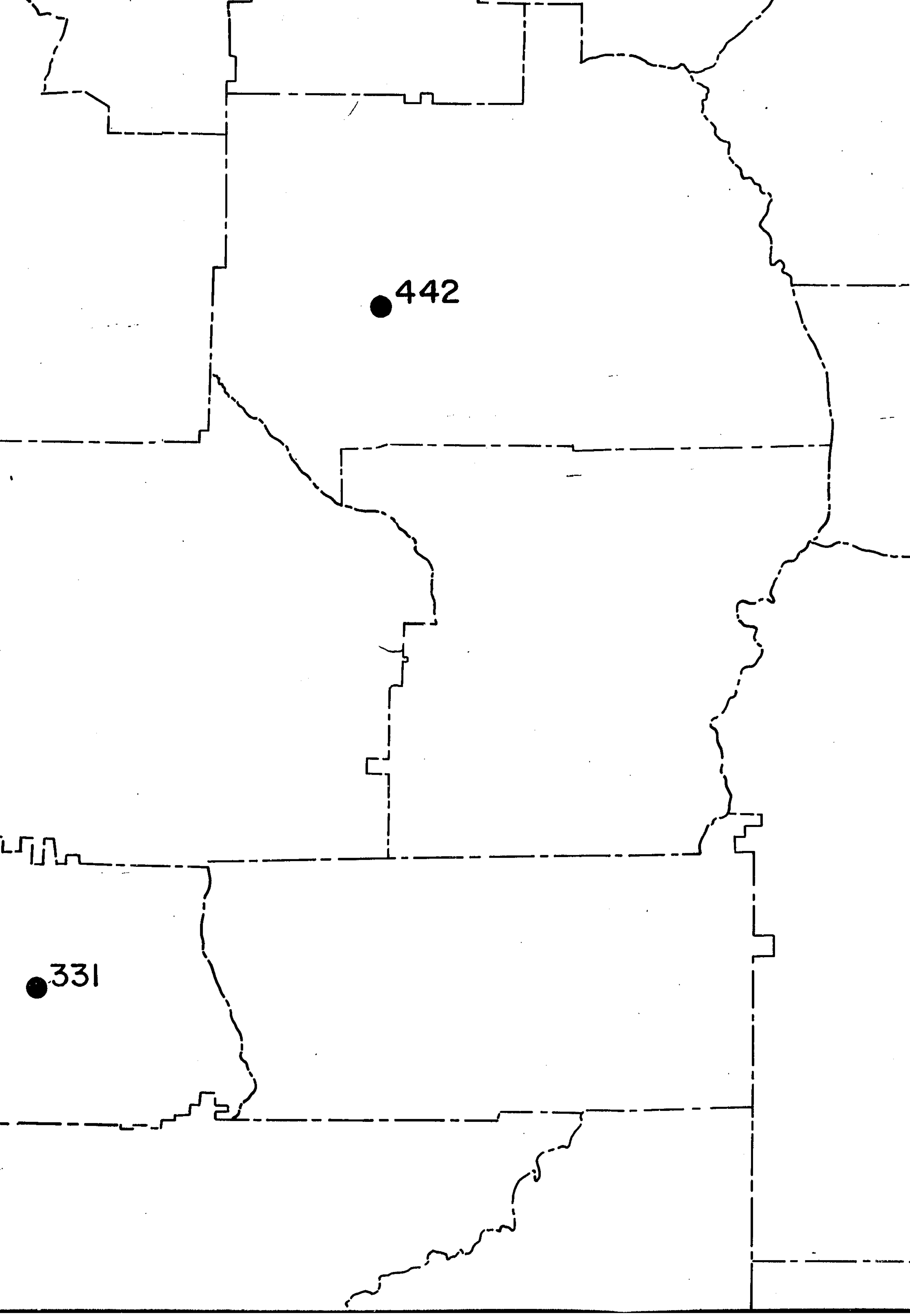
Ni-
552
192
ALABAMA
GEORGIA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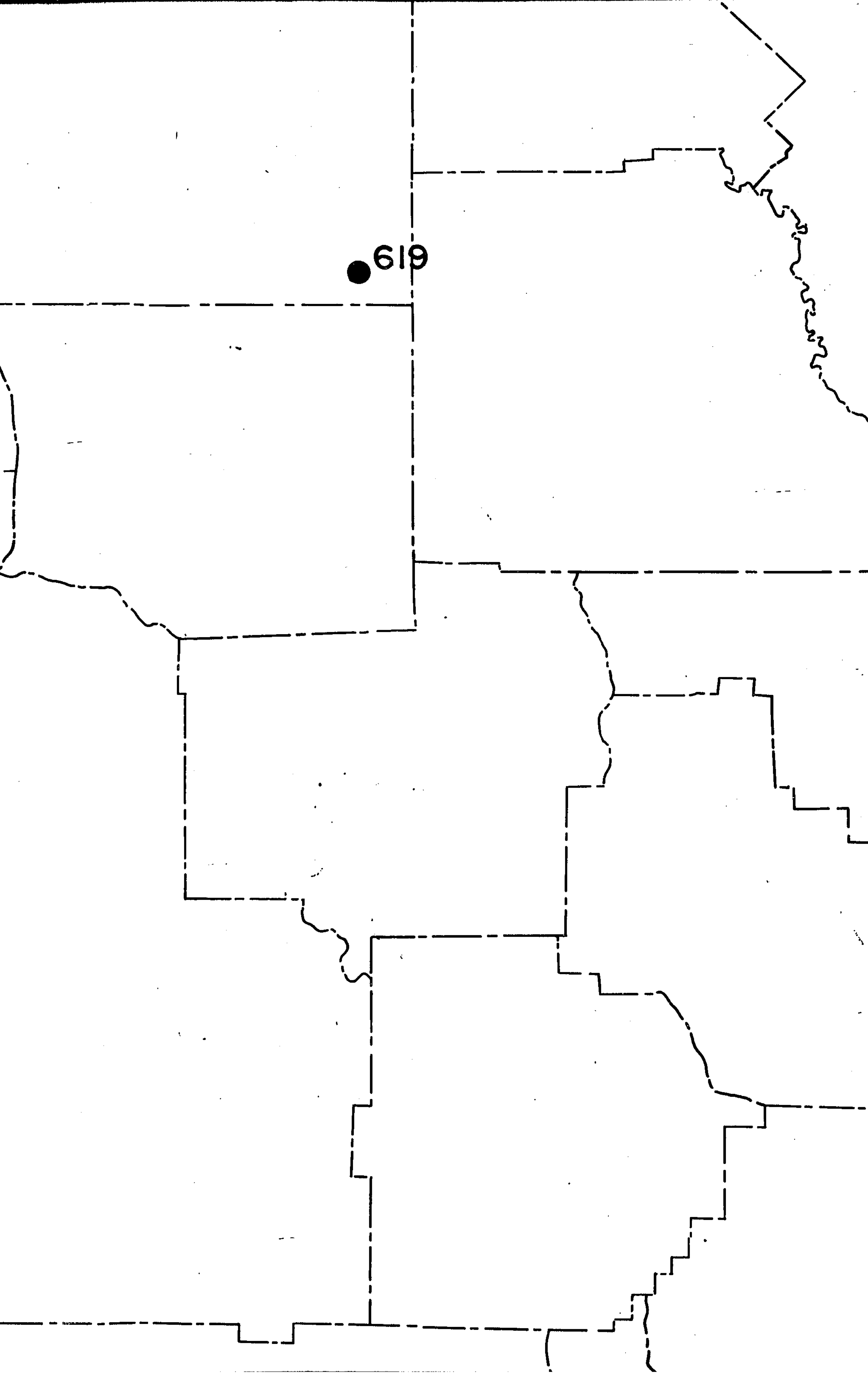
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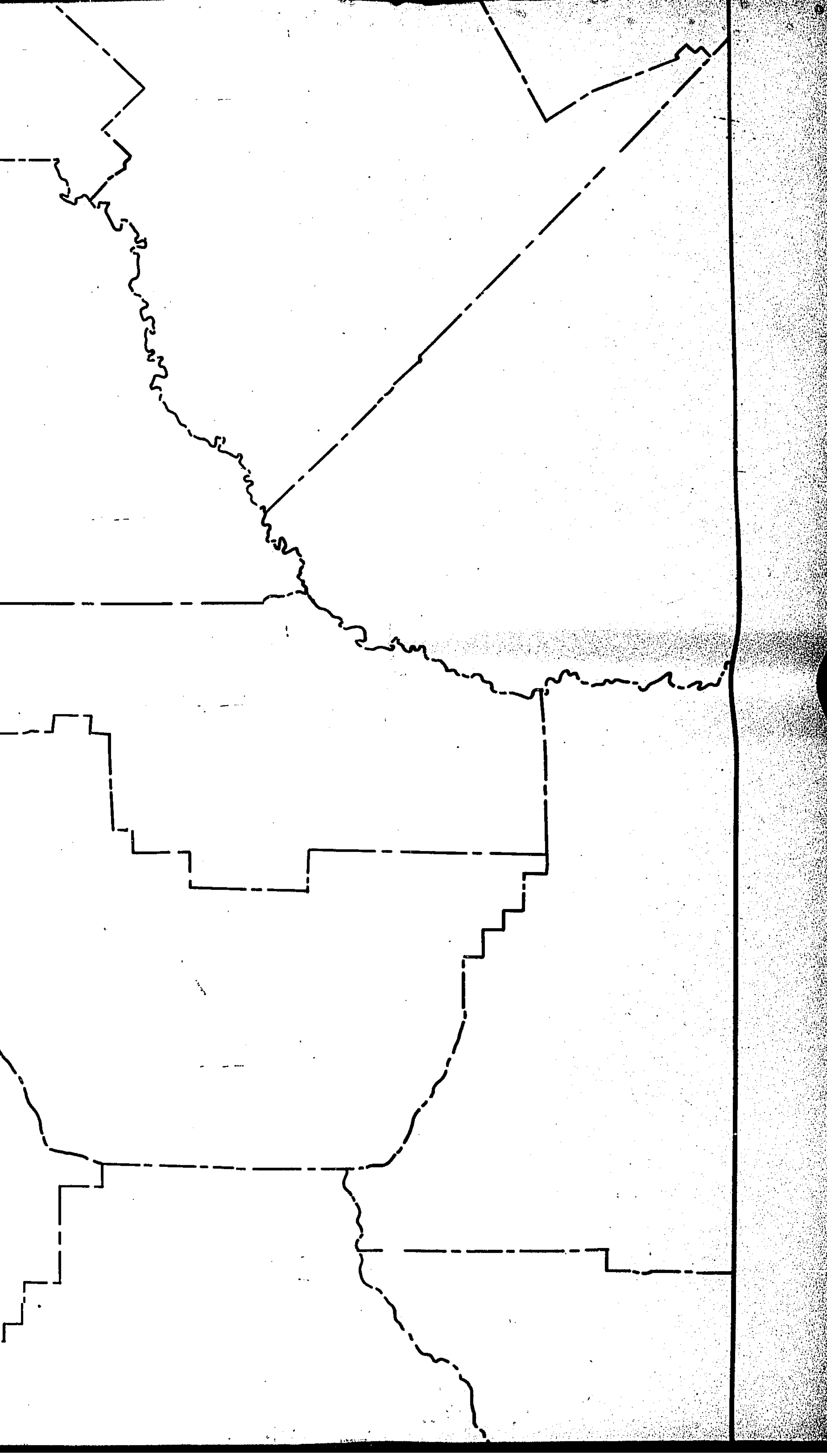

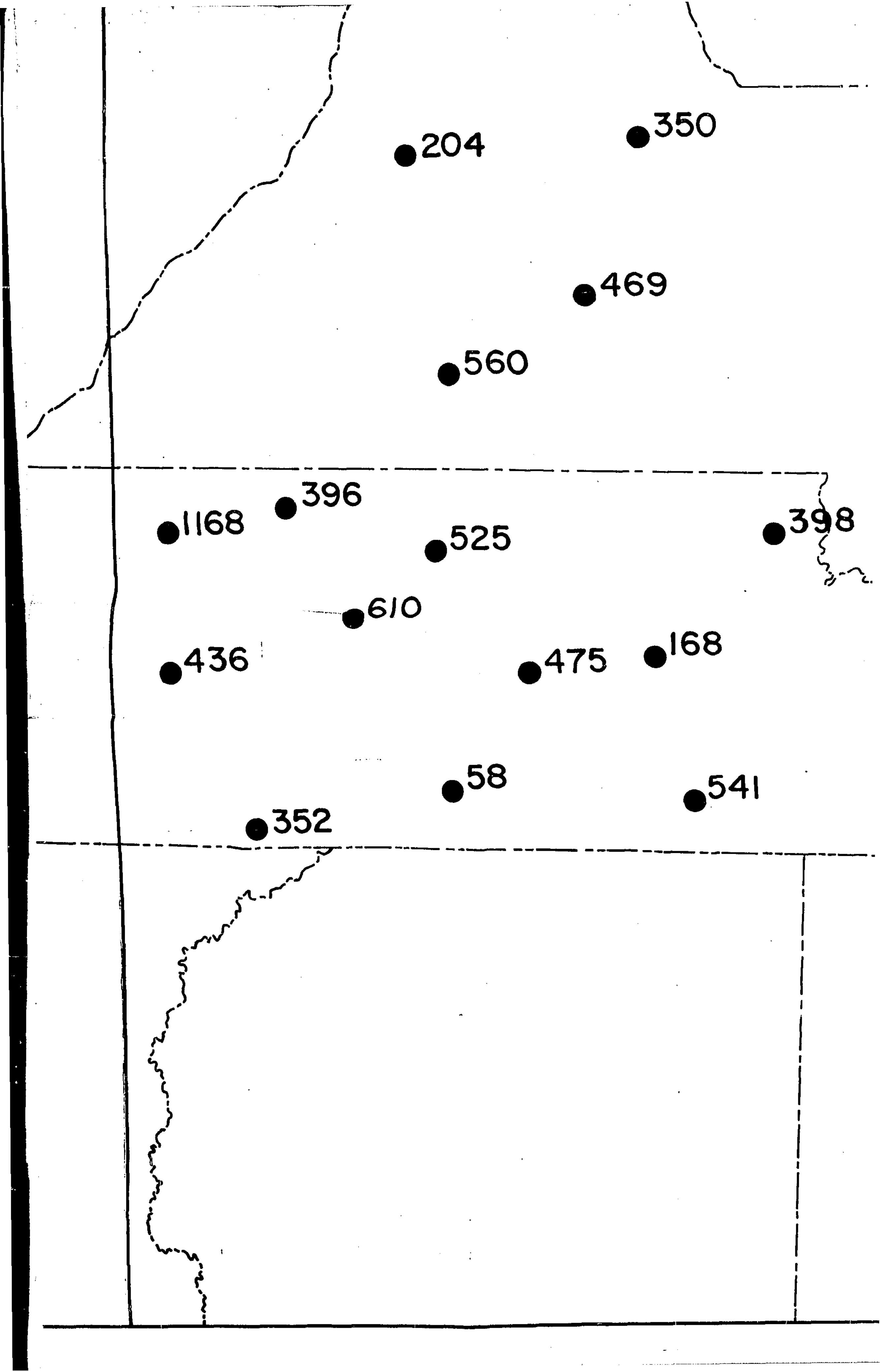
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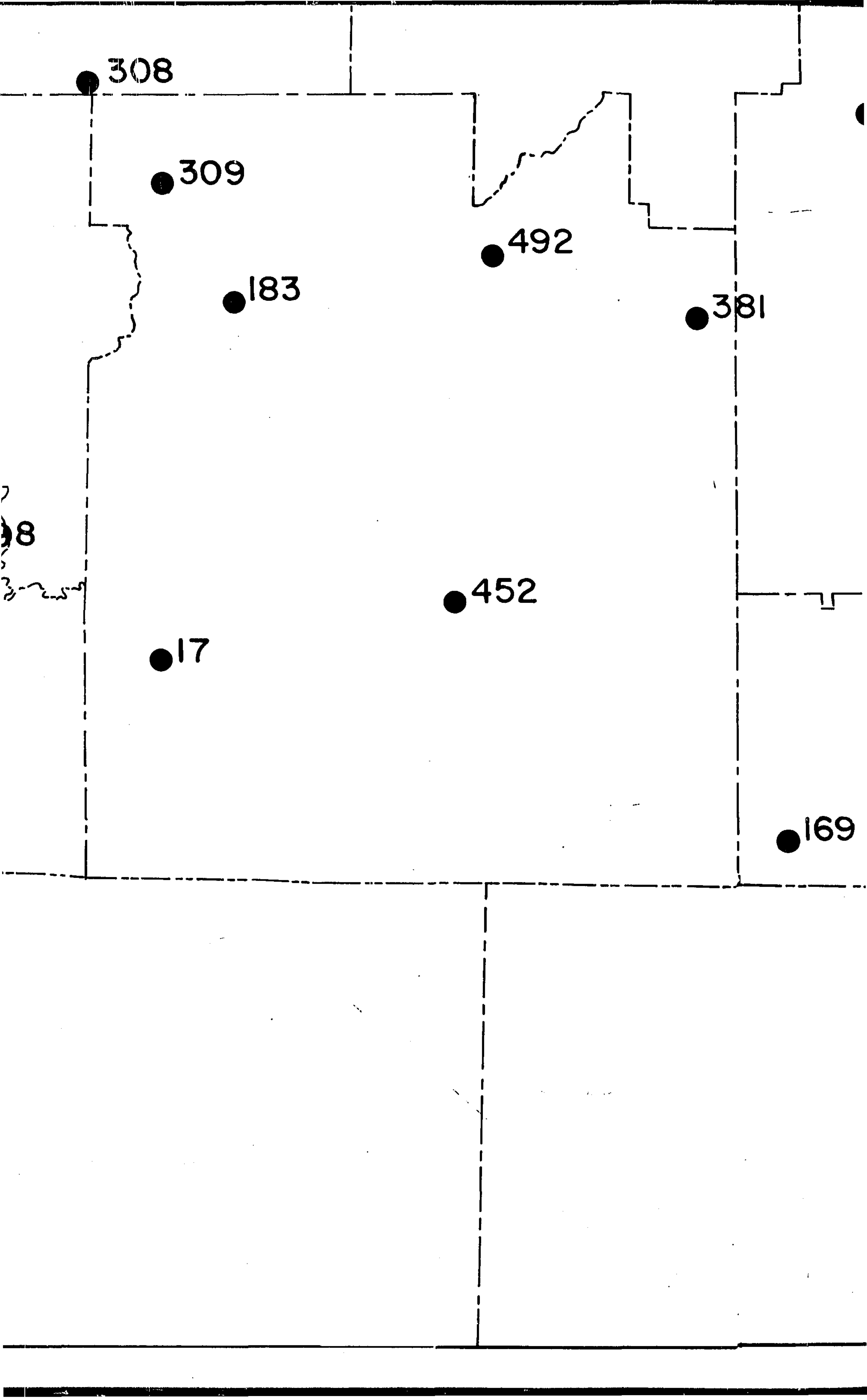
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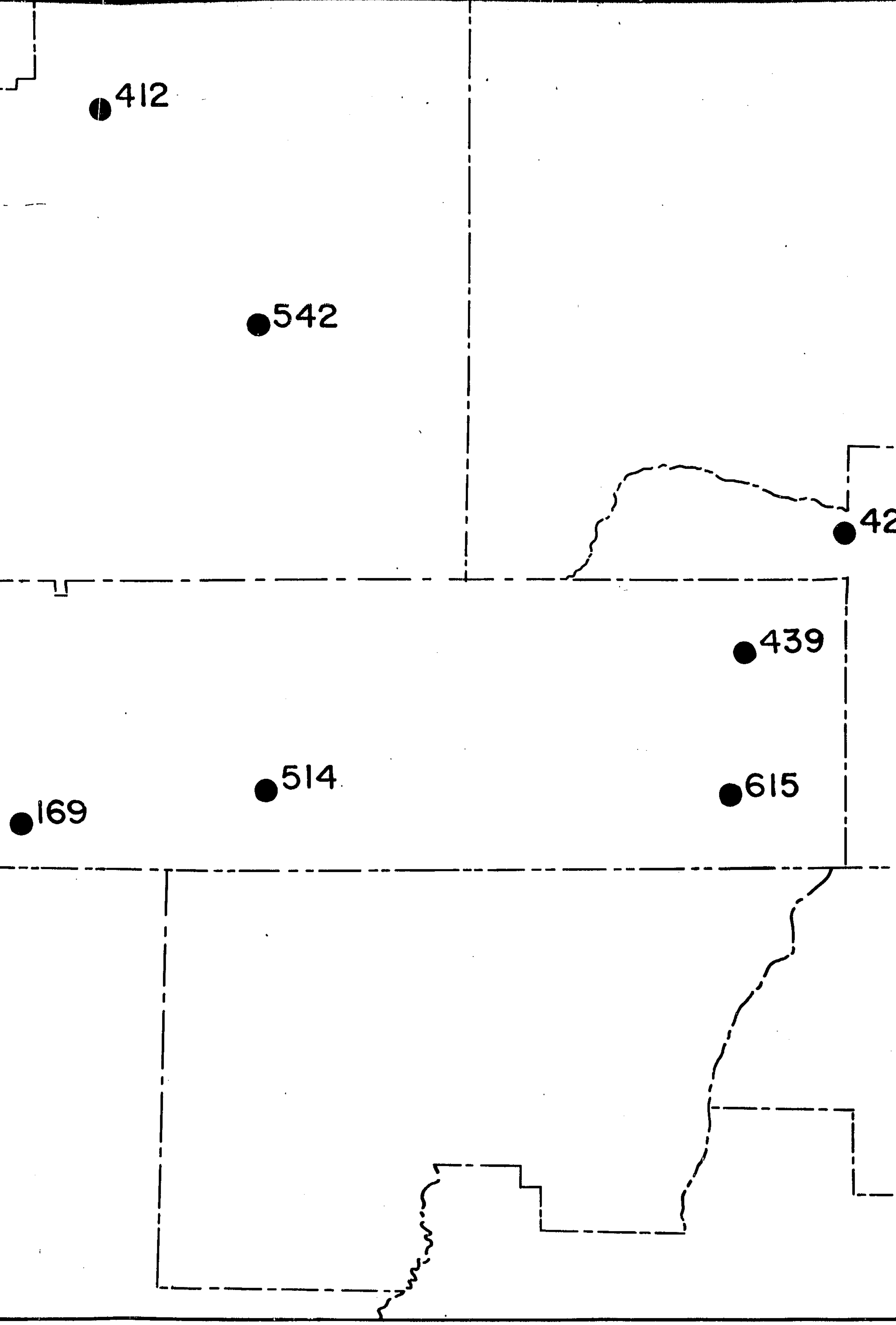
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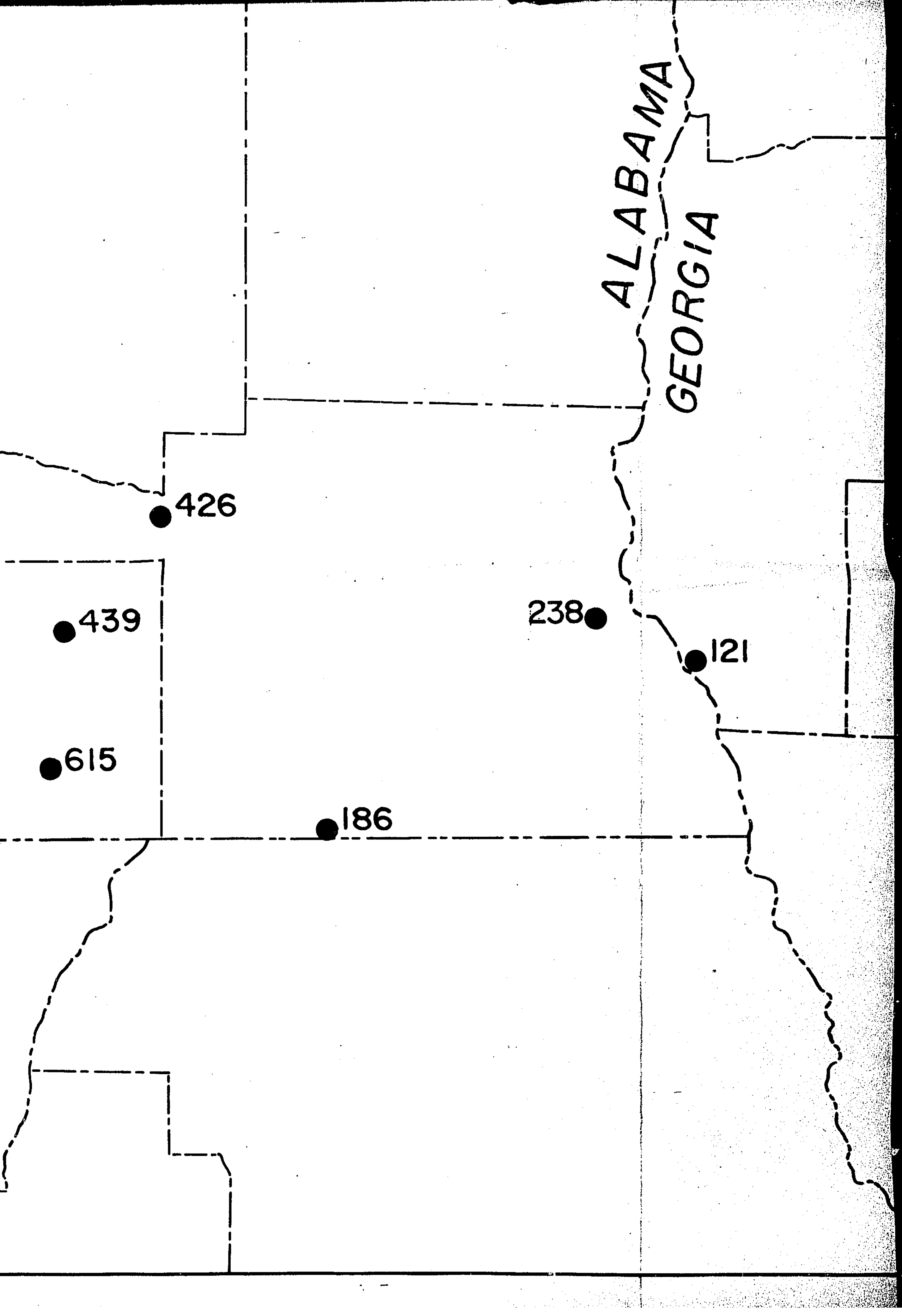
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GEORGIA
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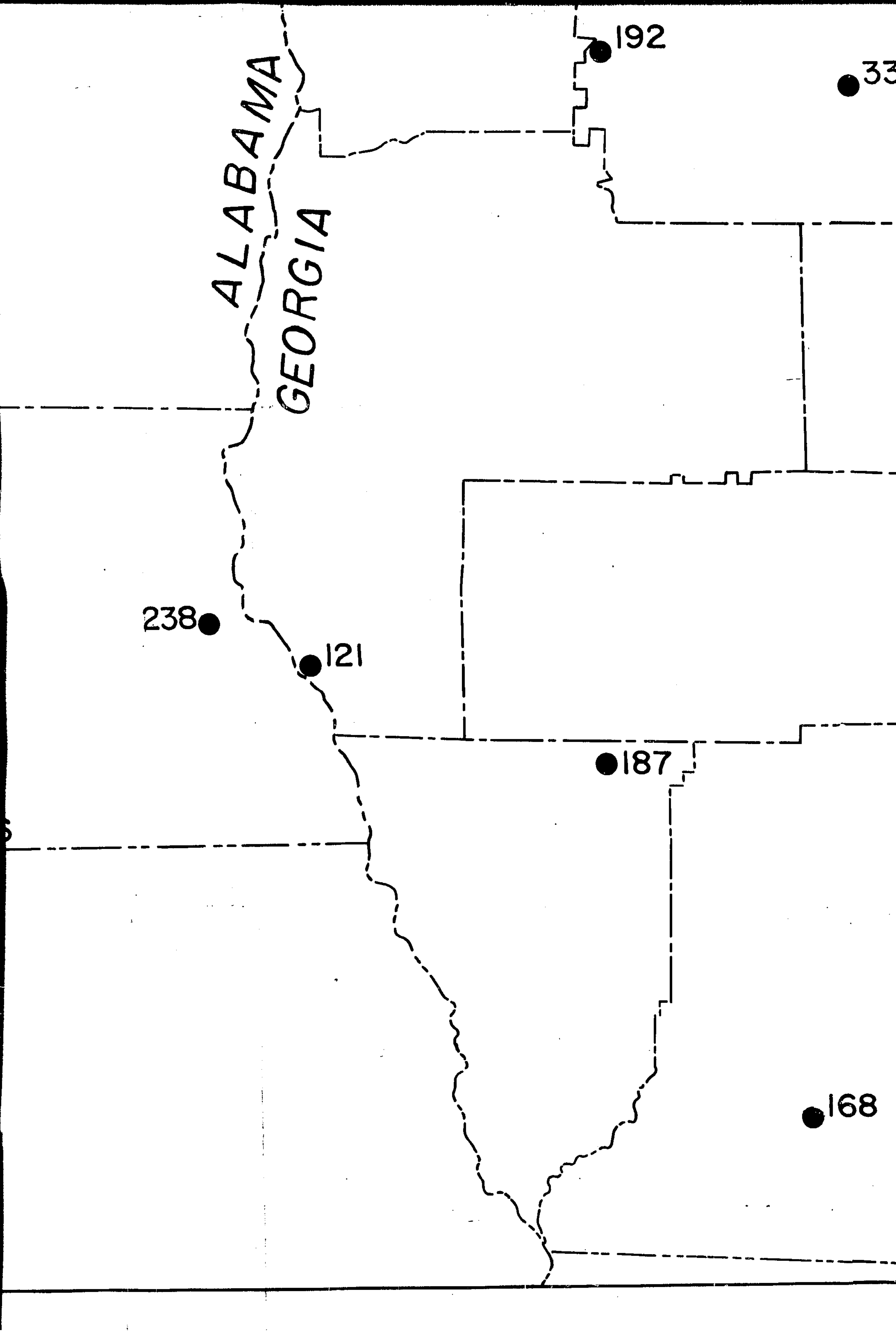
ALABAMA
GEORGIA
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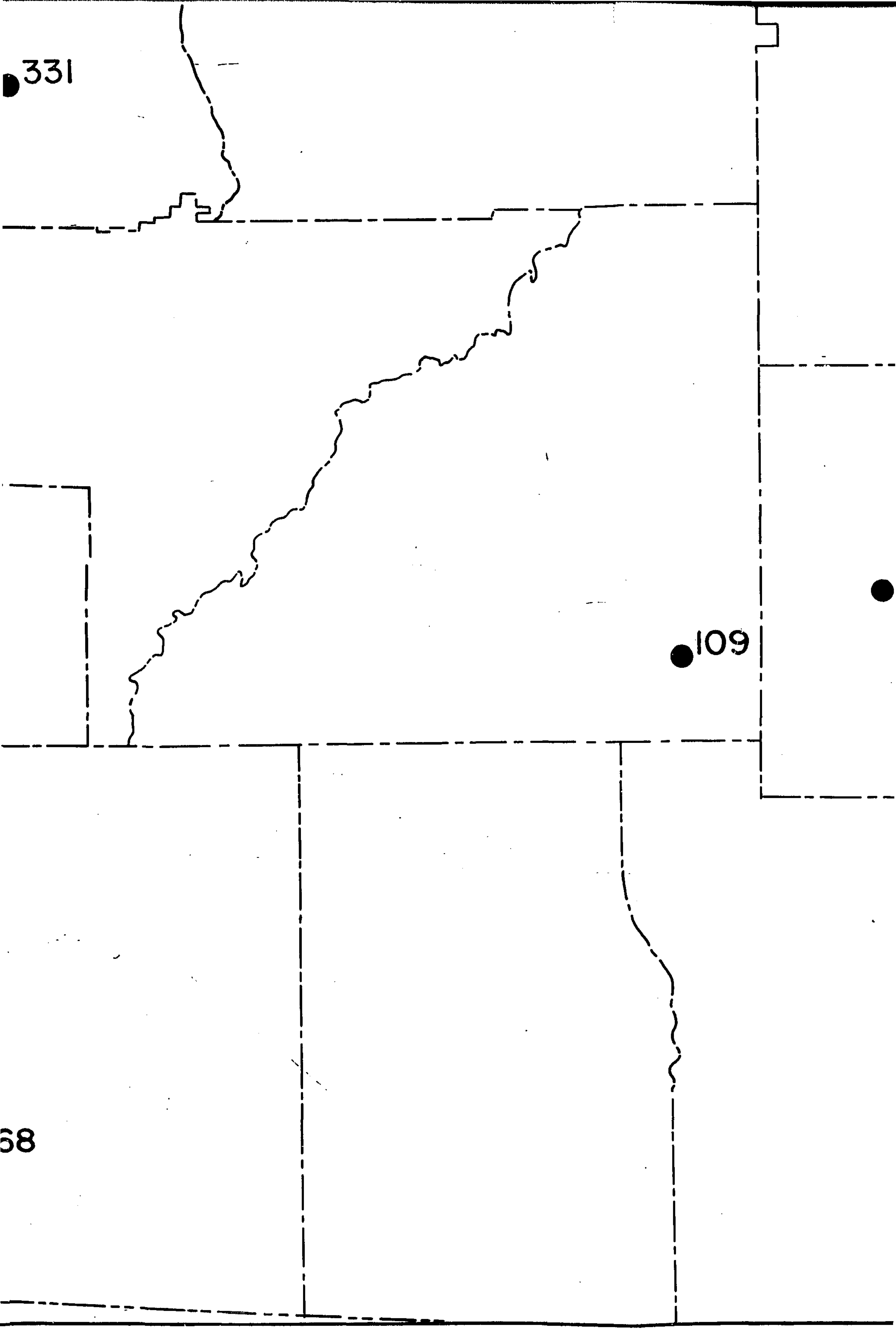
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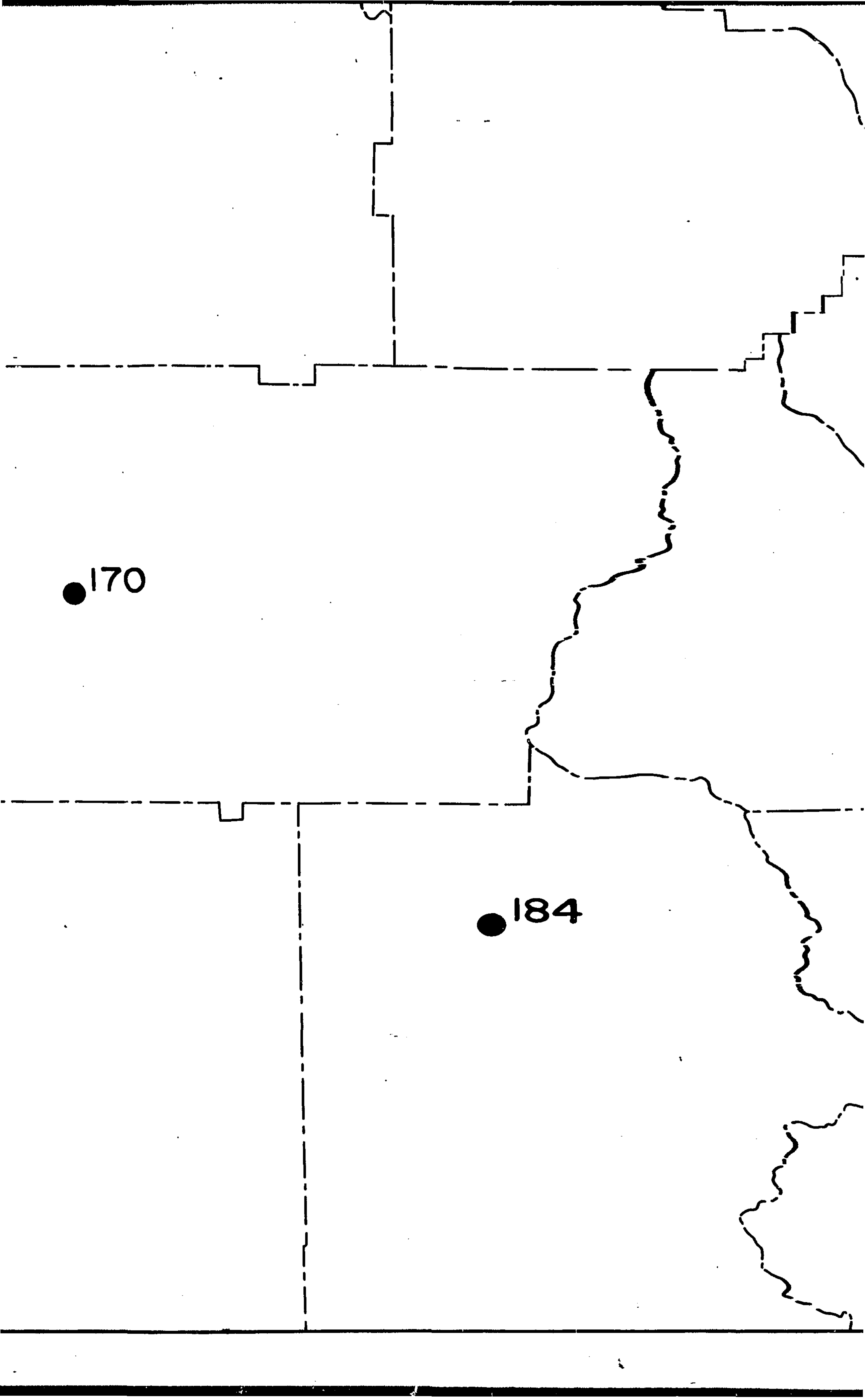
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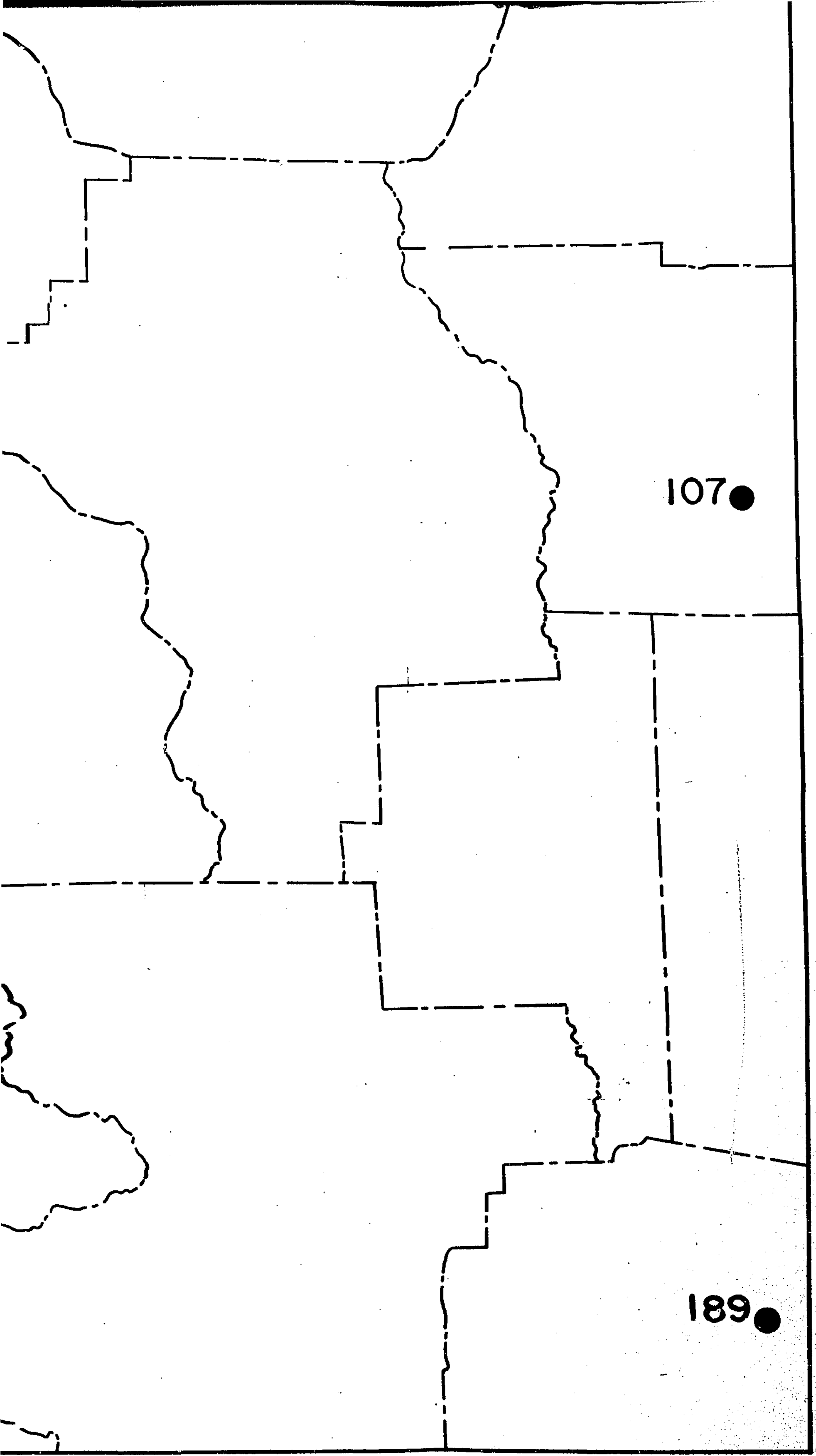
107
189