CRITERIA FOR DISTINGUISHING PLEISTOCENE(?) ALLUVIAL TERRACE DEPOSITS FROM THE COKER FORMATION IN THE COTTONDALE, ALABAMA, AREA

by

CHARLES CARL WIELCHOWSKY

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in
the Department of Geology in
the Graduate School of the
University of Alabama

University, Alabama

1975

PREFACE

As part of the cooperative research program of the Geological Survey of Alabama with universities and colleges, the geology of the Cottondale, Alabama, $7\frac{1}{2}$-minute quadrangle was mapped by Dr. Stephen H. Stow and Dr. Travis H. Hughes of the Department of Geology and Geography, University of Alabama during the summer of 1971. The final geologic map along with various other studies in the area will be published in 1975 by the Survey as an environmental geologic atlas. During field mapping, great difficulty was encountered by Stow and Hughes in distinguishing between the Coker Formation and the alluvial terrace deposits that are exposed in the quadrangle area. This thesis, which fulfills part of the requirements for a Master of Science degree in geology, is a study of the aforementioned problem.

ACKNOWLEDGMENTS

The author would like to acknowledge the following individuals whose direct and indirect efforts made the completion of this manuscript possible: Dr. Stephen H. Stow and Dr. Travis H. Hughes, Department of Geology and Geography, University of Alabama, for the initial suggestion of this thesis topic, for freely given time in discussion of field and laboratory problems, for critical review of the manuscript, and for imparting their enthusiasm for geology to the writer; Dr. W. Gary Hooks, Department of Geology and Geography, University of Alabama, for discussion of laboratory procedures, critical review of the manuscript, and a demonstration of the value of careful field and laboratory work; Michael W. Szabo, Geological Survey of Alabama, for assistance in heavy mineral analysis and advice on various field problems; Thornton L. Neathery, Geological Survey of Alabama, for assistance in geochemical and X-ray analyses; Charles W. Copeland and Peter A. Boone, Geological Survey of Alabama, and John G. Newton, United States Geological Survey, for advice and constructive criticism in the field; Otis M. Clarke, Jr., Geological Survey of Alabama, for unpublished data on, and discussion of, clay minerals in the Cottondale area; Janyth S. Tolson, Geological Survey of Alabama, for critical review of the manuscript; Whitney Tell, Perry

Hubbard, Richard Katz, and John Clark, Department of Geology and Geography, University of Alabama, for assistance with various laboratory analyses; Rex Price, University of Alabama, for discussion of field and laboratory problems; Virginia Jacks, for drafting of figures; Philip Malone, for photographic work; and Rebecca Willmon, for what was perhaps the most tedious job of all, typing the manuscript.

The author also wishes to express his gratitude for the indirect aid given him by his family through their understanding, encouragement, and occasional prodding with special thanks to his wife, Linda R. Wielchowsky, and mother, Mary W. Wall.

Finally the author wishes to acknowledge the Creator of all natural systems for making them at least partially understandable to the minds of men.

CONTENTS

CONTENTS - continued

TABLES

ILLUSTRATIONS

ILLUSTRATIONS - continued

ILLUSTRATIONS - <u>continued</u>

ABSTRACT

Field, textural, mineralogical, and geochemical data were collected from the Coker Formation of Cretaceous age and the alluvial terrace deposits of Pleistocene(?) age in the Cottondale area to determine those criteria that could be used in the differentiation of these two units. It was found that no single criterion could be used with complete confidence, though a series of general criteria were developed.

The alluvial terrace deposits generally contain rounded and polished ironstone, rounded iron-cemented sandstone, and Pottsville Formation shale and sandstone clasts, whereas the Coker Formation contains few if any of these clasts. The occurrence of tripolitic chert, low kaolinite to illite X-ray peak intensity ratios, a heavy mineral assemblage dominated by opaques, zircon, and tourmaline, and a low mica content in the alluvial terrace deposits serves in a general way to distinguish them from the Coker Formation. Other less reliable criteria are presented as well as criteria that can be used only in a few localities.

The data collected indicate that the Coker Formation was derived from metamorphic, granitic, and sedimentary source terranes whereas the Pleistocene(?) alluvial terrace deposits were derived totally from a sedimentary source area which

included the Coker Formation. Textural and field data indicate rapid rates of deposition in a predominately marginal- to shallow-marine environment along an indented shoreline bordered by a coast of moderate relief. The existence of a marginal marine environment of deposition is supported by the presence of several diagnostic shallow-water marine minerals and a shallow-marine to brackish-water fauna. Thus the Coker Formation represents a mixed sedimentary environment whereas the Pleistocene(?) alluvial terrace deposits are totally fluvial in origin.

INTRODUCTION

Statement of Problem

Two lithostratigraphic units of formational rank are exposed in the vicinity of Cottondale, Alabama (Paulson and others, 1962; Stow and Hughes, in preparation). These two units consist of the indurated sandstone, siltstone, shale, conglomerate, coal, and underclay beds of the Pottsville Formation which is Pennsylvanian in age; and the lenticular sand, clay, and gravel beds of the Coker Formation of the Tuscaloosa Group which is Late Cretaceous in age. In addition, Holocene and Pleistocene(?) alluvial deposits that are lithologically similar to the Coker Formation underlie the flood plains and terraces of the Black Warrior River and its tributaries. These deposits overlie both the Pottsville and Coker Formations. These units were mapped by Stow and Hughes in 1971 (Stow and Hughes, in preparation) on the 7½-minute Cottondale quadrangle. This map represents the most recent and detailed geologic map in the Cottondale area.

Some difficulty has been encountered in distinguishing between the Pottsville and Coker Formations since certain deeply weathered Pottsville beds may be mistaken for the lowermost Coker clay and sand units (Naff, 1940; Paulson and others, 1962; Travis H. Hughes and Stephen H. Stow, 1974, oral communication). Generally, there are few problems encountered in differentiating Pleistocene(?) alluvial terrace deposits (hereinafter termed alluvial terrace deposits) from the Pottsville Formation. Great difficulty, however, has been experienced in distinguishing alluvial terrace deposits from the Coker Formation in the Cottondale area (Naff, 1940; Travis H. Hughes and Stephen H. Stow, 1974, oral communication). Similar problems were encountered to the east in the Montgomery area along the Alabama River (Szabo, 1972). This difficulty can be traced back as far as 1846 when Sir Charles Lyell mentioned ". . . great beds of gravel . . ." of Cretaceous age in the vicinity of Tuscaloosa (Lyell, 1849) that he felt were ". . . an ancient beach . . ." deposit, but which were in all probability alluvial terrace deposits (Smith, Johnson, and Langdon, 1894). Hilgard (1860) also called attention to the difficulty in distinguishing between "drift" or "orange soil" (alluvial terrace deposits in part) and certain Cretaceous units. This confusion has persisted to the present, for mapping of the Cottondale area by Conant and others (1945) and Paulson and others (1962); and of the $7\frac{1}{2}$-minute Cottondale quadrangle in 1971 by Stow and Hughes (in preparation) yields significantly different outcrop patterns for the alluvial terrace deposits.

Naff (1940) was the first to set up a series of formal criteria for distinguishing the alluvial terrace deposits from the Coker Formation in the Cottondale area, though Smith (1892) was probably the first to actually recognize that the alluvial terrace deposits were of a later age than Cretaceous, and to mention the difficulty in distinguishing between the two units (Smith, Johnson, and Langdon, 1894). Naff's (1940) studies were not sufficiently detailed or quantitative to yield valid criteria for differentiation; therefore, in the present study channel, soil, and clay samples were collected from alluvial terrace deposits and the Coker Formation for textural, mineralogical, and geochemical analyses to determine if quantitative physical criteria do exist for distinguishing between the aforementioned units. In addition, a careful investigation was carried out to determine those field criteria that could be used to distinguish between the units involved. This included the determination of the elevation of the alluvial terrace deposits, as well as the elevations of various contacts in the Cretaceous units. Also, stratigraphic relationships and megascopic lithology were examined. However, emphasis was placed on lithologic criteria for differentiation because the lenticular nature of the units involved and the lack of abundant fossil remains in most cases precluded the use of stratigraphic criteria other than lithology. No attempts were made to correlate or age date any of the alluvial terrace deposits in the Cottondale area, nor to relate their formation to the waxing and waning of Pleistocene glaciation, for this offered no means of establishing criteria for differentiation of the units and thus was beyond the scope of this thesis. The final conclusions presented in this thesis are based upon the aforementioned research by the author as well as upon the work of numerous previous investigators.

Location of Study Area and General Geologic Setting

Cottondale, a small municipality of west-central Alabama for which the study area is named, lies a few kilometers (km) east of the city of Tuscaloosa, which is located on the southern bank of the Black Warrior River in Tuscaloosa County, Alabama (fig. 1). The study area extends from near the eastern margin of the 7½-minute Cottondale quadrangle westward to the vicinity of Buhl, Alabama, with an approximate north-south width of 20 km. This includes all of the Cottondale, Tuscaloosa, and Coker 7½-minute quadrangles plus parts of the older 15-minute Cottondale, Samantha, and Searles quadrangles, an area encompassing approximately 740 square km (fig. 2). The most concentrated field work and sampling programs were carried out on the 7½-minute Cottondale quadrangle (hereinafter referred to as the Cottondale quadrangle) because this was the first quadrangle in the study area to be mapped at a large scale (1:24,000), and it is also the area where the major problem of differentiation was most recently encountered. In addition, criteria developed for use in this quadrangle possibly could be used in the mapping of subsequent quadrangles in the area. However, initial studies of the Cottondale quadrangle by the author quickly revealed that a larger part of the Cottondale area should be examined and

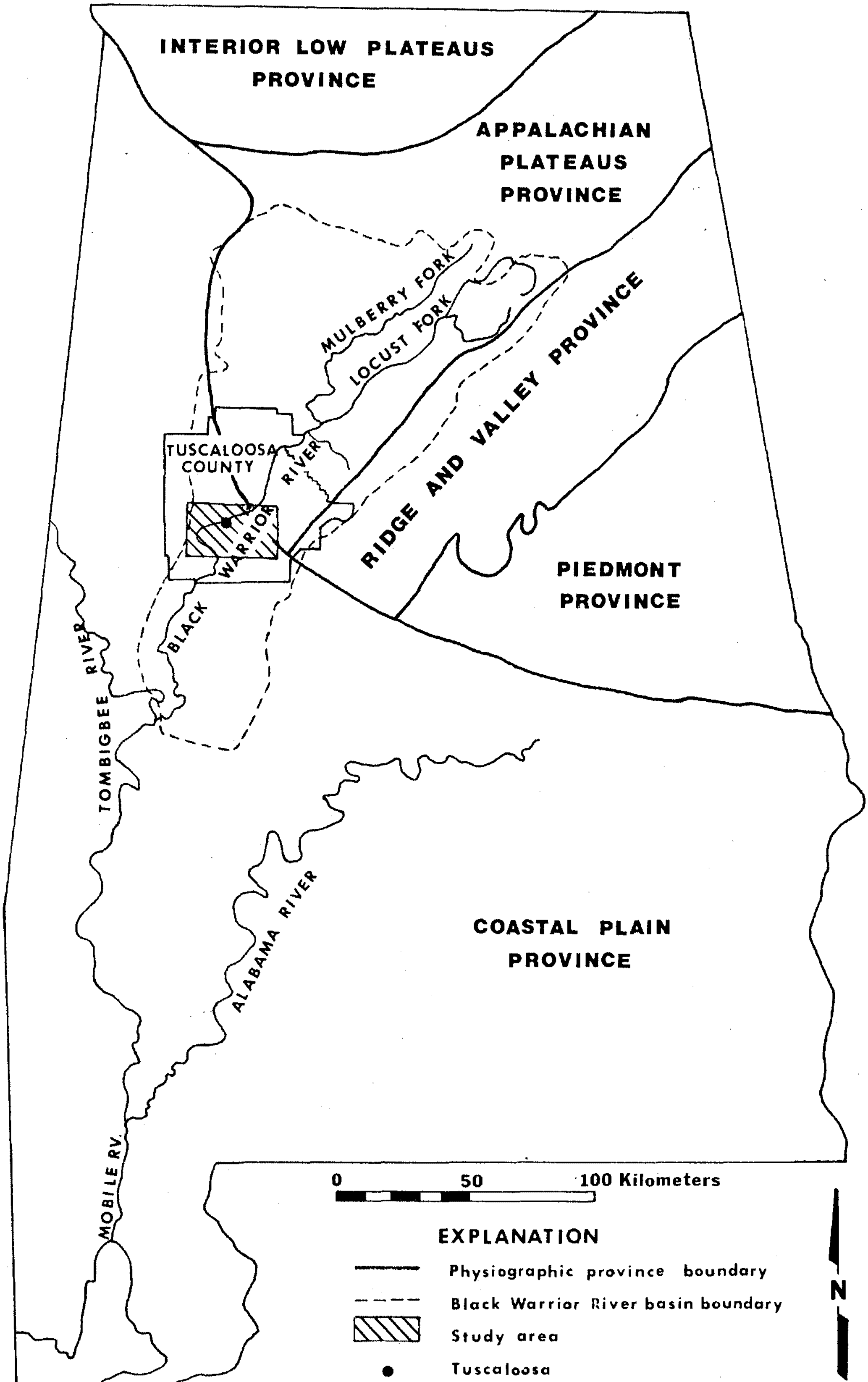


Figure 1. Map of Alabama with Black Warrior River basin, general physiography, and location of the study area.

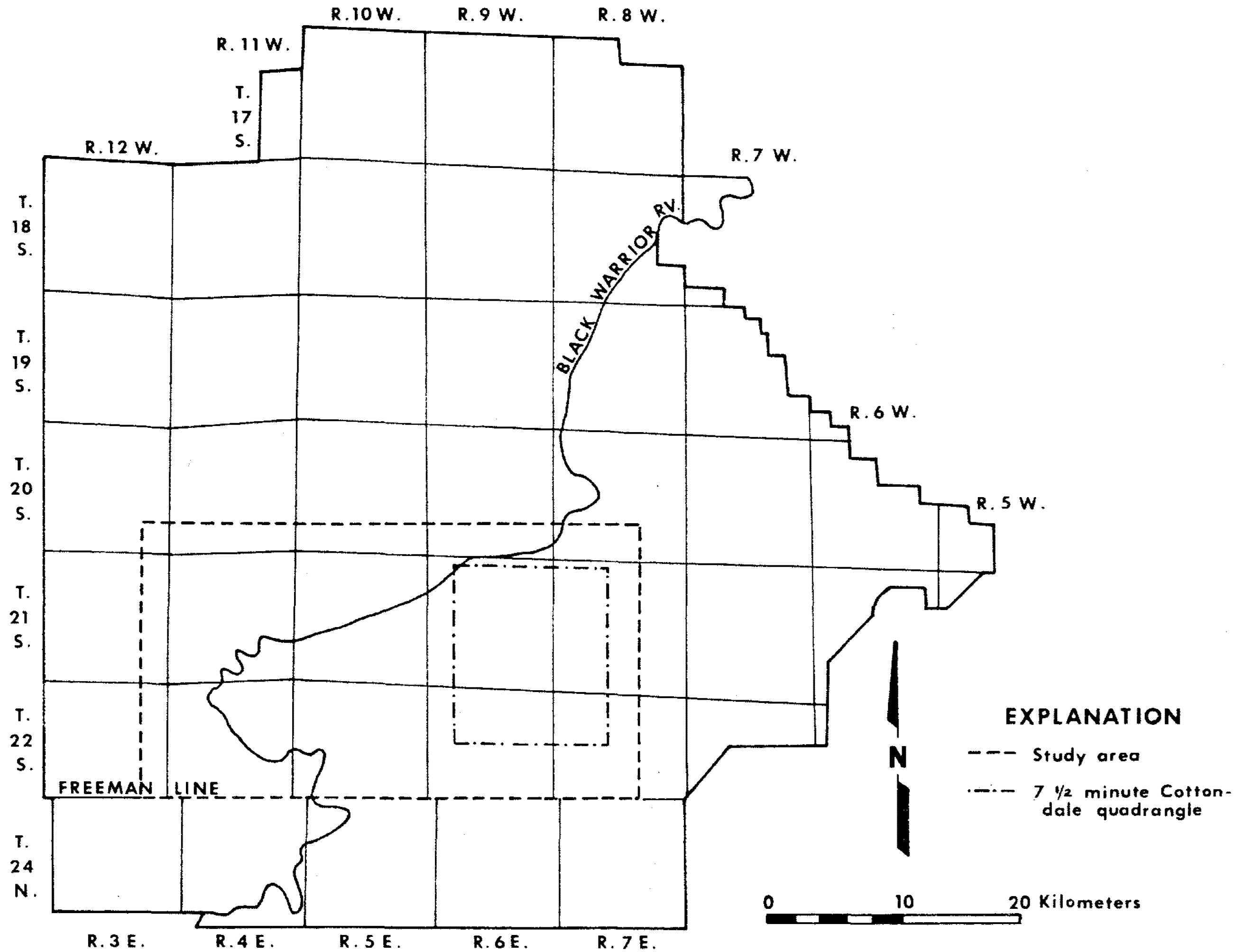


Figure 2. Map of Tuscaloosa County showing location of the study area and Cottondale quadrangle (see fig. 1 for location of Tuscaloosa County in Alabama).

sampled in order to gain a more complete understanding of the complex relationships between the alluvial terrace deposits and the underlying Coker Formation.

The study area selected lies entirely within the drainage basin of the Black Warrior River which encompasses a total area of approximately 16,250 square km (fig. 1). Above Tuscaloosa, the main channel is called the Black Warrior River and below Tuscaloosa, it is called the Warrior River until it becomes a tributary of the Tombigbee River at Demopolis, Marengo County, Alabama (Brown, 1968). To avoid possible confusion, the entire reach of the river and its basin will be called "Black Warrior" in this thesis. The Black Warrior River above Tuscaloosa has a drainage area of about 12,500 square km (Hains, 1973), and its drainage pattern is almost wholly dendritic.

The drainage basin of the Black Warrior River and its various tributaries above Tuscaloosa lies entirely within the outcrop area of the Paleozoic rocks of the Warrior basin and Sequatchie valley districts of the Cumberland Plateau section of the Appalachian Plateaus province, and in the Birmingham-Big Canoe Valley, Blount Mountain, and Murphree Valley districts of the southern section of the Ridge and Valley province of Alabama (figs. 1 and 3).

Detailed discussions of each district are given by Johnston (1930), and the stratigraphy of these regions is summarized by Thomas and Drahovzal (1973). Generally, the Cumberland Plateau section consists of a submaturely to

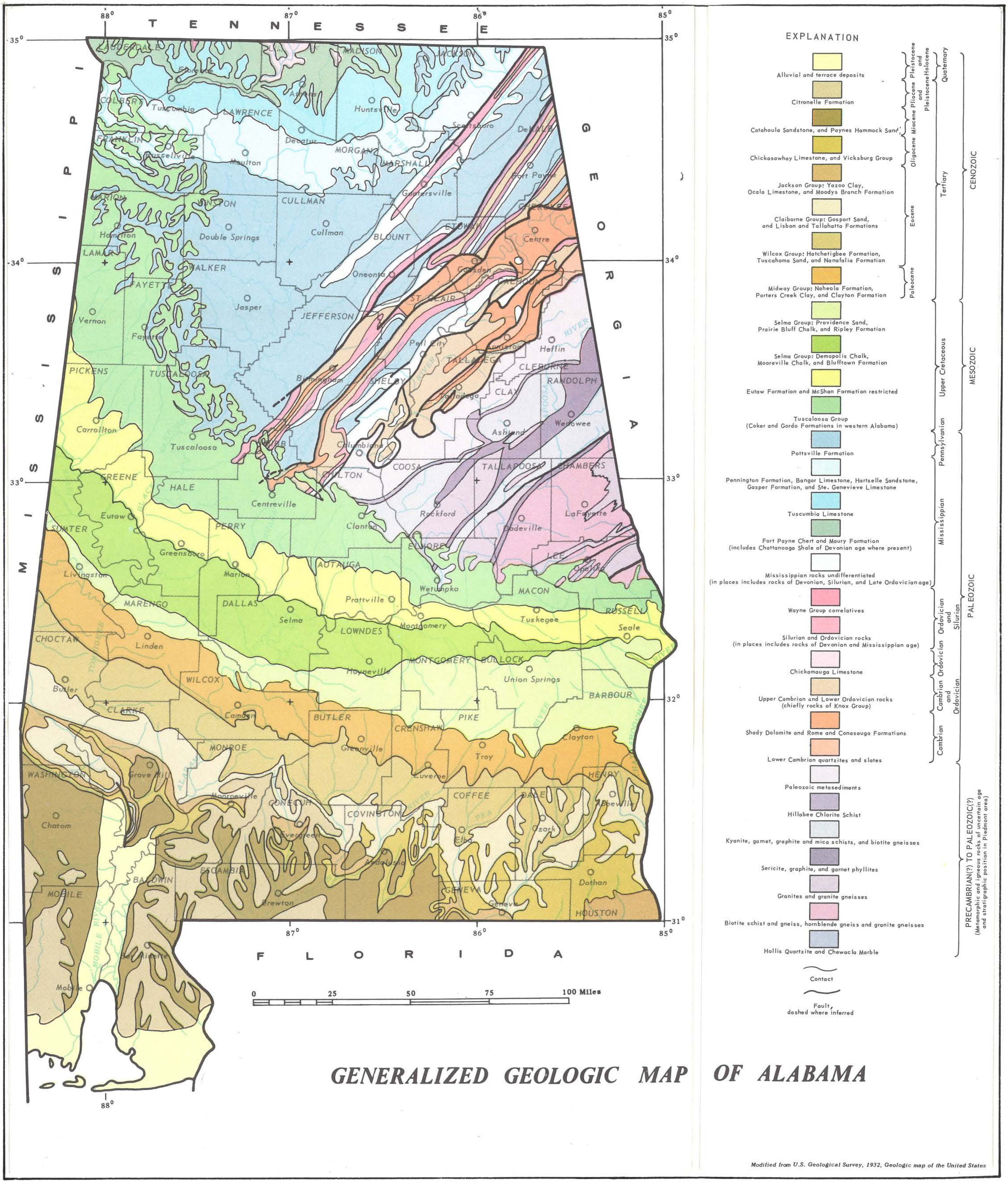


Figure 3. Generalized geologic map of Alabama (courtesy of the Geological Survey of Alabama).

maturely dissected plateau that is underlain by relatively horizontal Paleozoic sedimentary rocks (figs. 1 and 3). The southern section of the Ridge and Valley province consists of a series of roughly parallel ridges and valleys that strike northeast and are underlain by highly faulted and folded Paleozoic sedimentary rocks (figs. 1 and 3).

The Fall Line, which is the surficial expression of a major unconformity, marks the boundary between the Paleozoic rocks of the Cumberland Plateau section and the east-west striking Cretaceous sediments of the Fall Line Hills district of the East Gulf Coastal Plain section of the Coastal Plain province (Fenneman, 1938). In Alabama these sediments dip about 6 meters (m) per km south and southwest and occupy an arcuate belt that strikes east-west across the center of the state. In the western part of the state these sediments strike northwest. This belt is from 30 to 70 km wide (fig. 3). The Fall Line, which essentially bisects the Cottondale quadrangle from east to west, is a topographic break that was formed as a result of the varying resistance to erosion of the Paleozoic and Cretaceous rocks of the area (Thornbury, 1965; Copeland, 1968; Fairbridge, 1968). In addition, a significant change in the gradient of the Black Warrior River occurs at this line, and below it the Black Warrior River valley broadens significantly, changing from early maturity to old age (Naff, 1940).

The Fall Line Hills section, a dissected upland with a few flat ridges separated by valleys, ranges in elevation from 75 m to 210 m and is underlain by sand, clay, and gravel beds of Late Cretaceous age (figs. 1 and 3).

Soils of the study area and adjacent regions are classified as Ultisols (Red and Yellow Podzolic group) by the U. S. Department of Agriculture (Wilson, 1973). The climate of the study area is humid subtropical (Paulson and others, 1962). Vegetation consists mainly of mixed pines and hardwoods (Thomas, 1973).

Development of Stratigraphic Terminology and Previous Work

In order to logically trace the development of the stratigraphic terminology that led to the final definition of the Coker Formation, it will be necessary to discuss the Tuscaloosa Group, as defined by Drennen (1953a), in its entirety. Table 1 is an abbreviated guide to the development of this terminology. In addition, the selection of the term "alluvial terrace deposit" and the work that led to the delineation of these terrace deposits in the Cottondale area will be reviewed briefly.

Tuscaloosa Group

According to Paulson and others (1962), the sand, clay, and gravel beds of the Tuscaloosa Group were first described by Hilgard (1860), who included this unit in his Eutaw Group; however, Smith, Johnson, and Langdon (1894) point out that the existence of this unit was probably recognized as early as 1853 by Professor L. Harper, then State Geologist of

Smith & Johnson, 1887	Conant & Monroe, 1945	Drennen, 1953	Stow & Hughes, in preparation
Eutaw Formation	McShan Formation	McShan Formation	
unconformity	unconformity	unconformity	
Tuscaloosa Formation	Tuscaloosa Group — Gordo Formation	Tuscaloosa Group — Gordo Formation	Tuscaloosa Group — Not mapped by Stow and Hughes
	unconformity	unconformity	unconformity
Tuscaloosa Formation	Tuscaloosa Group — Coker Formation	Tuscaloosa Group — Coker Formation — Upper member	Tuscaloosa Group — Coker Formation — Upper member
	unconformity		locally unconformable
Tuscaloosa Formation	Tuscaloosa Group — Eoline Formation	Tuscaloosa Group — Coker Formation — Eoline member	Tuscaloosa Group — Coker Formation — Eoline member — Eoline member (clay)
Tuscaloosa Formation	Tuscaloosa Group — Cottondale Formation	Tuscaloosa Group — Coker Formation — Eoline member	Tuscaloosa Group — Coker Formation — Eoline member — Eoline member (sand)
unconformity	unconformity	unconformity	unconformity
Paleozoic rocks	Paleozoic rocks	Paleozoic rocks	Paleozoic rocks

Table 1. Development of Tuscaloosa Group stratigraphic nomenclature.

Mississippi, and Professor Alexander Winchell. The Tuscaloosa Formation was first named and described as such by Smith and Johnson (1887) for exposures at Tuscaloosa, Tuscaloosa County, Alabama, and along the Tuscaloosa (Black Warrior) River at Steele's Bluff and White's Bluff, Hale County, Alabama. They included all the variegated sand, clay, and gravel units between the Paleozoic rocks and the Eutaw Formation in their new lithostratigraphic unit (table 1). According to Smith, Johnson, and Langdon (1894), the name Tuscaloosa Formation was first suggested by W. J. McGee.

The first regional scale map of Alabama that depicted the Tuscaloosa Formation was compiled at a scale of 1:500,000 in 1894 by Smith, McCalley, Langdon, Johnson, Squire, and Gibson. This map was later revised by Adams and others (1926). On the basis of field work begun in 1937, Monroe (1941) produced a revised 1:500,000 scale map of the outcropping Cretaceous units in central Alabama that included part of the Tuscaloosa Formation.

The Tuscaloosa retained formational rank until Watson Monroe recognized an apparent fourfold division of the unit during a reconnaissance near Tuscaloosa and Eutaw, Alabama, in the mid-1940's (Conant, 1967). Conant and Monroe (1945) and Monroe and others (1946) in their mapping of the area raised the rank of the Tuscaloosa Formation to the Tuscaloosa Group and subdivided the unit into four formations which were named, from oldest to youngest: the Cottondale, Eoline, Coker, and Gordo Formations (table 1). The contacts among all four units were considered to be unconformable with the exception of the contact between the Cottondale and Eoline Formations. The original mapping that led to the delineation of these units was done on the Tuscaloosa and Cottondale, Alabama, 15-minute quadrangles by Conant and others in 1945. In 1946 Eargle and others mapped the Aliceville, Mantua, and Eutaw, Alabama, 15-minute quadrangles, and in 1947 Conant and others mapped the McCrary, McShan, Gordo, Samantha, and Searles, Alabama and Mississippi 15-minute quadrangles using the fourfold division of the Tuscaloosa Group originally proposed by Conant and Monroe (1945).

Eight years later Drennen (1953a) proposed a new terminology now accepted by the U. S. Geological Survey and the Geological Survey of Alabama. He divided the Tuscaloosa Group into two formations, the Coker and Gordo, which were separated by an unconformity (table 1). The Coker Formation was then divided into two members, with the lower one being the Eoline member, which contained the Cottondale and Eoline Formations of Conant and Monroe (1945), and an unnamed upper member. This unnamed unit was given no formal lithostratigraphic name, and was equivalent to Conant and Monroe's (1945) Coker Formation. Drennen (1953a) dropped the term "Cottondale" because he felt that it was unsatisfactorily defined and could be traced for only 25 or 30 km from the type area.

In 1971 Stow and Hughes (in preparation) mapped the newly prepared (1969) Cottondale quadrangle and found it feasible to subdivide the Eoline member into what was essentially the Cottondale and Eoline Formations of Conant and Monroe (1945). Stow and Hughes (in preparation) distinguished between the two units by use of the informal lithostratigraphic terms "Eoline member (sand)" for the Cottondale Formation and "Eoline member (clay)" for the Eoline Formation. This subdivision was considered necessary because the lithologies associated with the two units differed greatly in their physical and engineering properties.

In addition to the previously mentioned investigations, a great volume of literature has been amassed on the paleontology and petrography of the Tuscaloosa Group of Alabama in outcrop (e.g., Langdon, 1891; Stephenson, 1914; Berry, 1917, 1919; Adams, 1930; Stephenson and Monroe, 1938; Eargle, 1947; Monroe, 1947; Drennen, 1950; Drennen, 1953b; Tanner, 1955; and Clarke, 1965), and in the subsurface (e.g., Monroe, 1955; Monroe and others, 1964 [The preceeding two references are particularly valuable in that they report on the results obtained from the drilling of four coreholes in the outcrop area in 1954 to obtain fresh samples and reliable thickness data. They contain lithologic and petrographic descriptions; electric logs; and descriptions of invertebrate fossils, a small microfauna, and a rich microflora.]; Applin and Applin, 1947; and Moore and Joiner, 1969). Guidebooks to the outcropping Tuscaloosa Group of Alabama have been published by Jones (1967), Copeland (1968, 1972), and Wielchowsky and Gilbert (1973).

Alluvial Terrace Deposits

"River terraces are topographic surfaces which mark former valley floor levels" (Thornbury, 1969). Therefore they are remnants of former or abandoned flood plains (Leopold and others, 1964), and may be classified as bedrock (strath) or alluvial terraces (Thornbury, 1969). The term "terrace" should only be used to refer to a geomorphic form rather than to the deposit that underlies that form, though commonly it is used to refer to the deposit itself (Leopold and others, 1964; Howard and others, 1968; Thornbury, 1969). Therefore, the term "alluvial deposit," "alluvial fill," "terrace alluvium," or the like should be used. The term "alluvial terrace deposit" was chosen for this study to represent the lithostratigraphic unit deposited by the Black Warrior River and its tributaries, probably during the Pleistocene Epoch.

Actually, "terrace" mapping results in the hybridization of geomorphology and stratigraphy (i.e., surface form is used as a mapping tool although there are certain problems associated with this approach as Johnson (1944) and Frye and Leonard (1954) have noted). Frye and Leonard (1954) have summed up this concept by stating that, ". . . the mapping of an alluvial terrace [deposit] is in fact the mapping of a lithologic stratigraphic unit. The mapping of a terrace . . . as a simple landform should be considered a problem of geomorphology and not included as a part of an areal geologic map."

The general stratigraphy of the Quaternary alluvial terrace deposits in the central Gulf Coast area has been recognized for approximately 50 years (Saucier and Fleetwood, 1970). Murray (1961) discusses various correlation and nomenclatural problems for the entire Atlantic and Gulf Coastal Plain sections. However in the Cottondale area, the first reference to these deposits was made by Lyell (1849), who thought them to be Cretaceous in age. Smith (1892) was the first to consider alluvial terrace deposits of the Cottondale area to be post-Cretaceous. In the Cottondale area, the alluvial terrace deposits of the Cottondale quadrangle have been mapped at a scale of 1:62,500 as "terrace deposits" by Conant and others (1945) who considered them to be Quaternary or Tertiary in age. Paulson and others (1962) also mapped "terrace deposits" at a scale of 1:62,500 and considered them to be Quaternary in age, while Stow and Hughes (in preparation) mapped "terrace" of Quaternary age at a scale of 1:24,000 (fig. 4). Significant discrepancies in outcrop pattern exist.

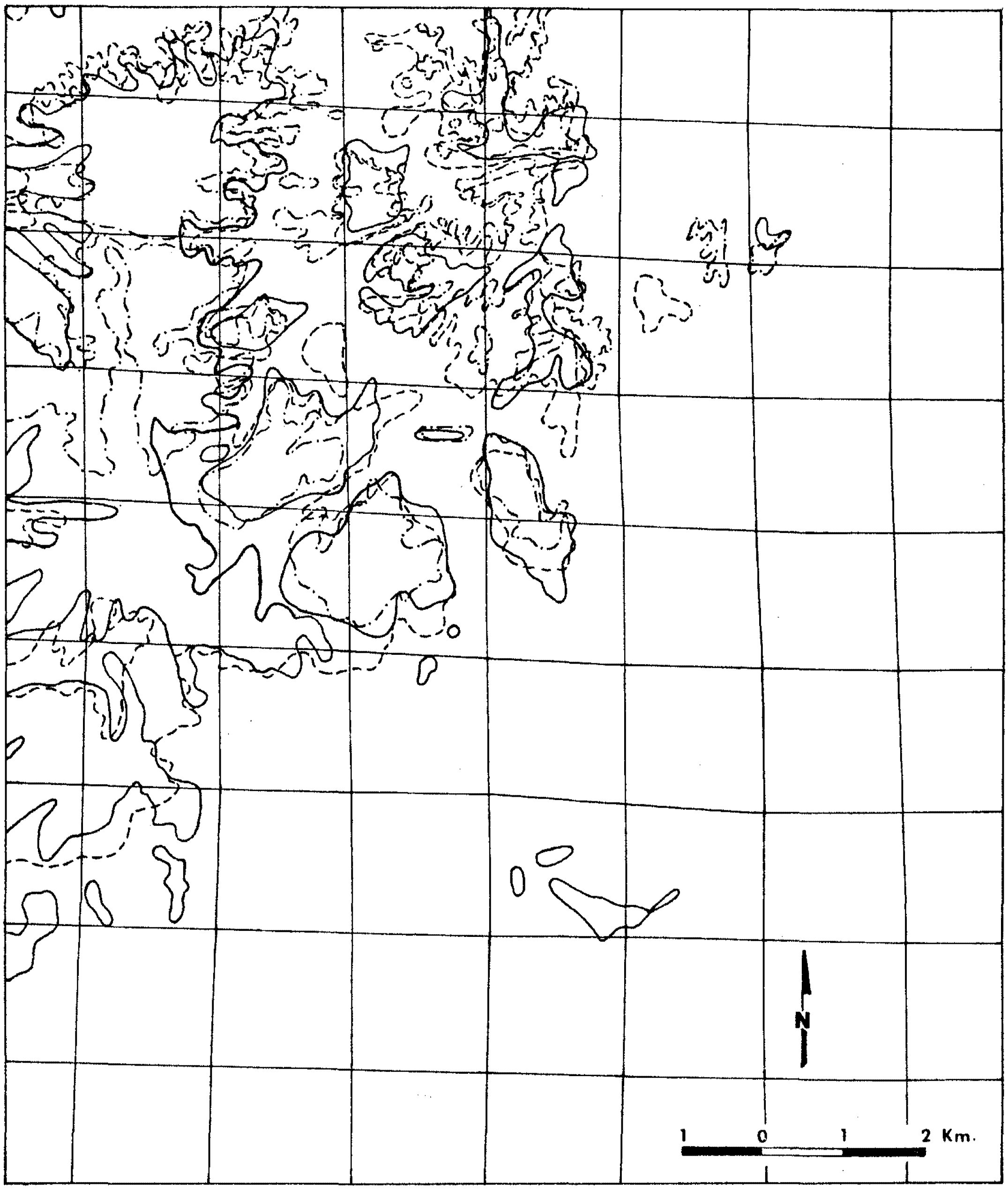


Figure 4. Map of 7½-minute Cottondale quadrangle with outcrop patterns of alluvial terrace deposits as mapped by previous workers (Conant and others, 1945 ——; Paulson and others, 1962 ----; Stow and Hughes, in preparation -·-·-).

METHODS

In order to determine those criteria that could be used to differentiate alluvial terrace deposits from the Coker Formation in the Cottondale area, both field and laboratory investigations were undertaken. Field work consisted of the identification and sampling of both the alluvial terrace deposits and the Coker Formation. No attempt was made to undertake detailed analyses of sedimentary structures, although sedimentary structures have been used to determine the agent or environment of deposition (e.g., Middleton, 1965; Selly, 1970; Rigby and Hamblin, 1972; Pettijohn and others, 1973). However, the environments of deposition of both units could have been similar; thus, the resulting sedimentary structures could be similar and of little use in discrimination.

Laboratory work consisted of textural, mineralogical (petrographic and X-ray), and geochemical analyses of channel and soil samples plus X-ray analysis of clay grab samples. No detailed analyses were done on the composition or morphology (i.e., surface texture and shape) of either the light or gravel fractions. No attempts were made to differentiate between quartz types though Monroe and others (1964) report on quartz types observed in core holes drilled in the outcrop area. This was because initial field and laboratory analyses indicated that the alluvial terrace deposits consisted to a great degree of reworked Coker Formation, but the reworking was not severe enough to radically change the surface texture or shape of the detritus involved. Intra-unit variation of data was so great that multivariant statistical analysis such as that undertaken by Kelly and Whetten (1969) was considered unfeasible.

Field Procedures

Outcrops of alluvial terrace deposits and the Coker Formation were identified in the field by use of previous maps (see fig. 4) and data (all previously referenced work on the alluvial terrace deposits and Coker Formation in the Cottondale area). Also, observations with an aneroid barometer-type altimeter and 1:24,000 topographic maps of the elevations of various terrace surfaces and contacts with each member of the Coker Formation were made. In addition, aerial photographs were used. General stratigraphic observations were made and recorded, and samples were collected. In order for an outcrop to be considered an alluvial terrace deposit and sampled as such, it had to meet the following criteria: 1) It must have been mapped by Conant and others (1945), Paulson and others (1962), and Stow and Hughes (in preparation), where applicable, as an alluvial terrace deposit, and 2) the present author must agree that it was an alluvial terrace deposit. Only one exception to these criteria was made in sample site selection. This was in the NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ section

16, T. 22 S., R. 9 W., Cottondale quadrangle. Here the author felt alluvial terrace deposits overlie the unnamed upper member of the Coker Formation; whereas, no other workers have mapped alluvial terrace deposits at this location. Figure 5 shows each sample location and Appendix 1 gives a detailed description of each sample locality and unit involved.

Channel samples, each restricted to a "sedimentation unit," as defined by Otto (1938), were collected from each lithostratigraphic unit in the outcrop area. An attempt was made to obtain samples that would be representative of the entire thickness of each unit. No complete vertical section of the Coker Formation at a single locality could be found; therefore, samples were obtained by moving up or down dip as necessary. Samples were collected from alluvial terrace deposits that ranged in elevation from 90 to 105 m. For channel sample collection, a vertical outcrop surface was scraped clean from top to bottom with an entrenching tool to a depth of about 0.3 m. Then approximately 2 kilograms (kg) of fresh sample were channeled from the back of the scraped area.

Soil samples for each unit were collected by the use of a posthole digger. A hole approximately 1 m deep was made and soil horizons were differentiated. Approximately 1 kg of sample was collected from the A horizon in the zone of maximum leaching (Hunt's [1972] A_2 zone).

Figure5. Map of study area showing sample localities.

Relatively fresh 1 kg grab samples of the clay units of each member were obtained by digging back approximately 0.3 m into the outcrop.

Rounded and polished ironstone and rounded iron-cemented sandstone clasts were collected from each terrace outcrop for analysis.

A total of 17 channel samples, 7 soil samples, and 10 clay samples was collected from the Coker Formation, and a total of 5 channel samples, 5 soil samples, and 1 clay sample was collected from the alluvial terrace deposits. In addition, 1 clay sample was collected from the present flood plain of the Black Warrior River and 3 clay samples were collected from the Pottsville Formation.

Laboratory Procedures

After collection, both channel, soil, and clay samples were allowed to air dry. Figure 6 shows the general flow chart for laboratory analysis of channel and soil samples. General procedures followed are outlined in Folk (1968), Royse (1970), and Carver (1971).

The channel and soil samples were split with the aid of a Tyler mechanical sample splitter. One half of the first split was hand sieved for selected samples with a 2 millimeter (mm) U. S. Standard Sieve. The 2<mm fraction was then coned and quartered to approximately 25 grams (gm). The sample was crushed with a Diamond mortar and pestle until approximately 95 percent of the 25 gm could pass

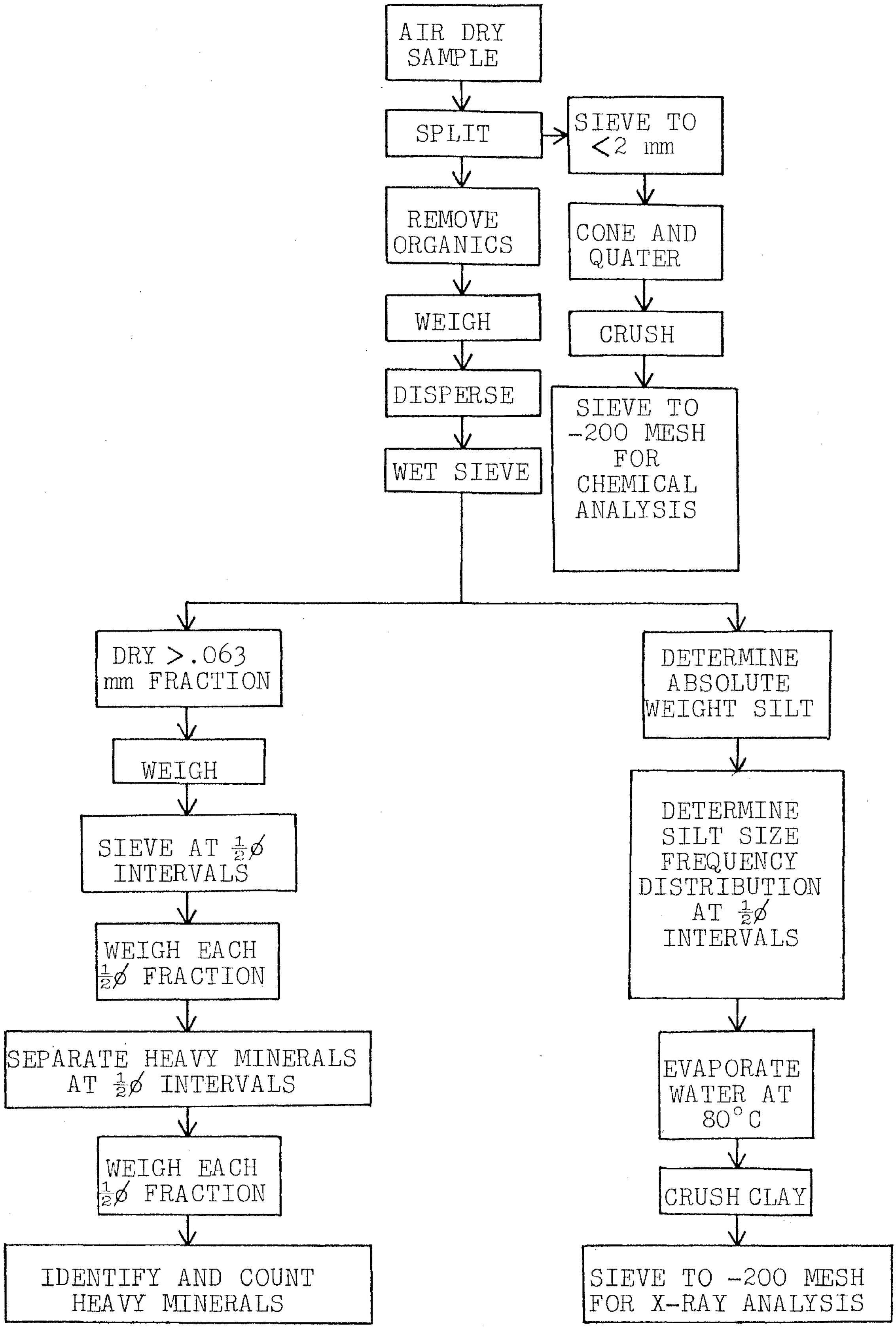


Figure 6. Laboratory analysis flow chart for channel and soil samples.

through a 200 mesh nylon screen. The bulk chemical composition of the sample was then determined. Aluminum (Al_2O_3), magnesium (MgO), calcium (CaO), manganese (MnO), titanium (TiO_2), potassium (K_2O), sodium (Na_2O), and total iron were determined by atomic absorption spectroscopy with a Model 303 Perkin-Elmer Atomic Absorption Spectrophotometer using a lithium metaborate ($LiBO_2$) fusion technique modified from Medlin, Suhr, and Bodkin (1969). Iron as FeO was determined by titrimetric methods. Silica as SiO_2 was determined by difference (i.e., percentages of all 8 elements were added together with the percent loss on ignition (LOI) and subtracted from 100 percent to determine the silica content). An additional discussion of the $LiBO_2$ fusion technique for the analysis of rocks high in silica can be found in the work of Graybeal (1971).

The alternate split was then coned and quartered to a weight of approximately 50 to 100 gm if the sample were predominately sand (Folk, 1968). If the sample contained a significant amount of gravel (detritus $>$2 mm in diameter), then approximately 1 kg was used (Folk, 1968). In this case, the total sample was weighed; the gravel removed and weighed; and then either sieved or hand measured, depending on the size, at $\frac{1}{2}$ phi (ϕ) intervals. The remaining sand, silt, and clay was weighed and split to a weight of 50 to 100 gm. After sieving, following the procedures outlined below, the $<$2 mm $\frac{1}{2}$ ϕ fractions were recalculated to the original sample weight by multiplying the weight of each $\frac{1}{2}$ ϕ fraction by the number of splits used to obtain the 50 to 100 gm <2 mm sample. When necessary, organics were removed from the <2 mm fraction by gentle heating in 30 percent hydrogen peroxide (Royse, 1970). Samples were then weighed, dispersed with sodium hexametaphosphate (Calgon), and wet sieved through a 0.063 mm U. S. Standard 8-inch (20.32 cm) screen. The >0.063 mm fraction was then dried, weighed, and sieved for 15 minutes (Folk, 1968) at $\frac{1}{2}$ ϕ intervals on a Tyler Ro-Tap machine. Weight percents and cumulative weight percents were then calculated for each $\frac{1}{2}$ ϕ interval.

The absolute weight of silt was determined by pipette analysis. Silt size frequency distributions were determined at $\frac{1}{2}$ ϕ intervals with a Coulter Counter (Model Z_B) according to a method described by C. E. Brett (1973, oral communication). Histograms and cumulative frequency curves were then constructed for each sample (Appendix 2). Folk and Ward's (1957) descriptive measures of sediment-size distributions were calculated. These included the median, mean, sorting, skewness, and kurtosis values for each sample (Appendix 2).

The water remaining in the <0.063 mm fraction was then evaporated at 80°C. The residue was gently crushed and sieved through a 200 mesh nylon screen onto a glass slide for routine X-ray analysis of clay minerals (Royse, 1970). Clay grab samples were gently crushed and sieved in the same manner (Royse's [1970] "dusted slide" technique for X-ray analysis of clays). These silt-clay samples were then X-rayed with a Philips X-ray diffractometer using $CuK\alpha$

radiation filtered through a lithium chloride, curved crystal monochromater. Scanning speed was 1 degree 2 θ per minute, time constant 4, 100 counts per second at 40 kilovolts and 20 milliamps. Clay minerals were identified by ASTM (American Society for Testing Materials) card comparison. In addition, standard diffractograms of the kaolinite, illite, and montmorillomite clay mineral groups were prepared with American Petroleum Institute Clay Mineral Standards (Project No. 49). Since illite and kaolinite were found to be the dominant clay minerals, the illite and kaolinite standards were mixed in the proportions 25:75, 50:50, and 75:25 to construct a semiquantitative working curve for kaolinite (7.15 Å peak) to illite (10.16 Å peak) peak intensity ratios. From this semiquantitative curve, it was determined which of the two minerals was most abundant. Though more accurate determinations can be made through comparing peak-area ratios, this was considered unnecessary due to the inherent difficulties and errors in even the most carefully executed quantitative X-ray analyses of clays (Pierce and Siegel, 1969; Carroll, 1970; Griffin, 1971). Kaolinite to illite peak-intensity ratios were computed for all samples. These data will be summarized and presented in a later section.

Heavy mineral grains were separated from the 0.500 to 0.354 mm (1.0 to 1.5 ø), 0.354 to 0.250 mm (1.5 to 2.0 ø), 0.250 to 0.177 mm (2.0 to 2.5 ø), 0.177 to 0.125 mm (2.5 to 3.0 ø), 0.125 to 0.088 mm (3.0 to 3.5 ø), and 0.088 to 0.063 mm (3.5 to 4.0 ø) fractions with tetrabromoethane (sp. gr.

2.96), identified, and counted. Briggs (1965) and Szabo (1972) found that heavy mineral grains were generally restricted to sizes of less than 0.500 mm in diameter. This was found to be true in this study. Hutton (1950) states that grains of less than 0.125 mm in diameter cannot be separated satisfactorily by standard separatory funnel methods (i.e., the more complex centrifuge techniques must be employed), whereas Szabo (1972) found that particles as small as 0.088 mm in diameter could be separated with standard separatory funnel techniques. Fairbank (1956) states that grains of less than 0.074 mm in diameter are too fine for satisfactory microscopic identification. However, in this study it was found that heavy minerals as small as 0.063 mm in diameter could be separated and identified. In a study by Bates and Bates (1960), open funnel, separatory funnel, and centrifuge techniques were all found to be of comparable recovery capability using artificially prepared heavy mineral samples. A slightly modified standard open-funnel technique such as that pictured in Griffiths (1967, p. 207) was used in this study.

The apparatus used in this study is pictured in figure 7. Two 0.5-inch [1.27 centimeter (cm)] by 1 foot (0.3 m) by 8 feet (2.4 m) plywood planks were obtained. Seven 6-inch (15.24 cm) diameter equally-spaced and centered holes were cut in the planks. The planks were then mounted between concrete blocks. An electric vibrating motor, such as that used to polish sections for ore microscopy, was placed in

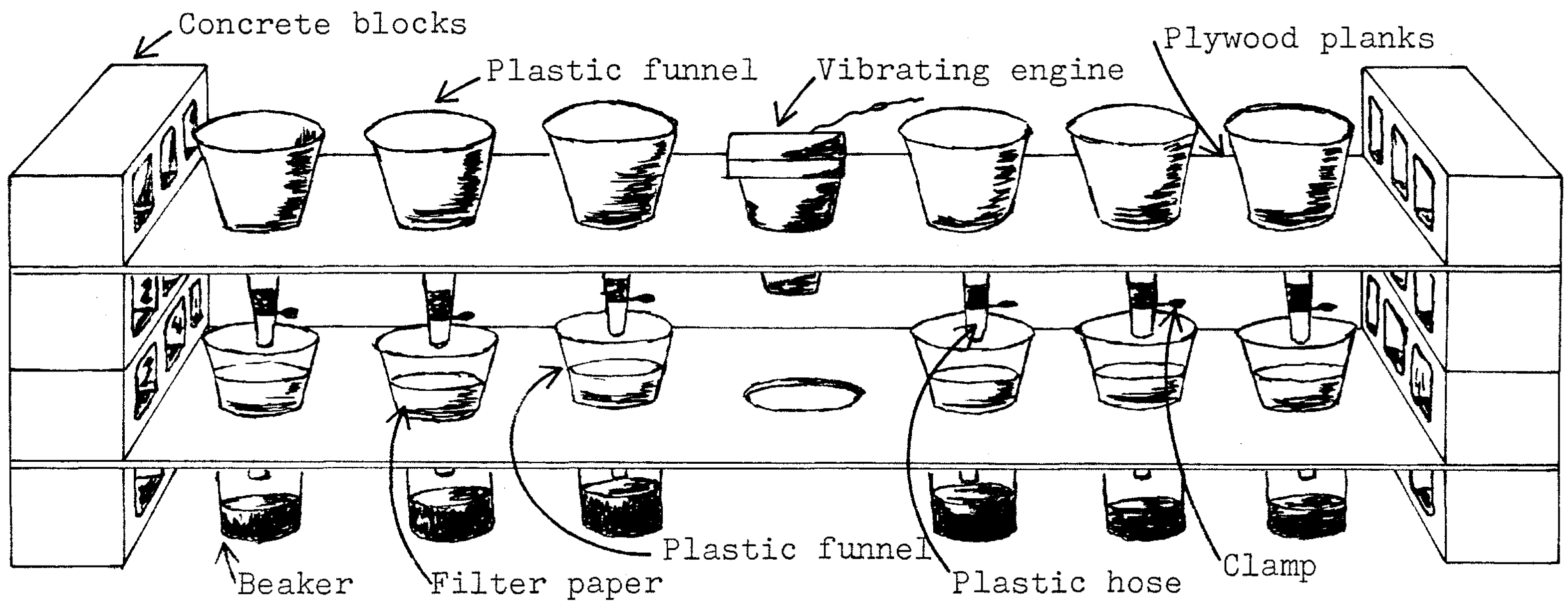


Figure 7. General diagram of apparatus used for separation of heavy minerals.

one of the upper holes. The vibration of the motor with simultaneous stirring yielded almost complete recovery (>95 percent) of heavy minerals (6 samples at a time) from 1 to 4 ϕ at $\frac{1}{2}$ ϕ intervals in 45 minutes. After separation from the light minerals, the heavy minerals were washed with acetone, dried, and weighed. Magnetite and other magnetic minerals were removed from each sample, weighed or counted, combined by lithostratigraphic unit, and X-rayed.

The remaining heavy mineral grains were identified using petrographic and binocular microscopes. The use of X-ray diffraction was found to be necessary to identify some species. Although Pryor and Hester (1969) found that units could be correlated (and hence differentiated) by the X-raying of the entire heavy mineral fraction of certain Cretaceous sands, this procedure was not attempted because of the lack of significant variation among the various heavy mineral suites.

Each heavy mineral sample was mounted on a glass slide in an immersion oil having an index of refraction of 1.70 and covered with a glass cover slip. The grains were then counted with a petrographic microscope using a mechanical stage. The line method which has been described by Ramesam (1966) and reviewed by Galehouse (1969) was employed to determine number frequencies. To make certain that no grain was counted twice, the distance between each horizontal traverse was greater than the long dimension of the largest grain on the slide. When more heavy minerals were contained in a sample than could be mounted on a single slide, a representative fraction was obtained with a needle dipped in index oil as described by Fairbank (1956).

Assuming a binomial distribution of heavy mineral grains in each sample, Hubert (1971) has shown that it is best to count between 200 and 300 grains. To count more than 200 to 300 grains is probably a waste of time because the 95 percent confidence limits of the population mean do not close significantly about the fixed, real population mean, even when as many as 1,000 grains are counted. A total of 204 slides were prepared, of which 177 contained more than 200 grains. Only those slides containing more than 200 grains were considered because of the above statistical considerations. The number of grains counted ranged from 207 to 1,219, and averaged 497 per slide. A total of 87,944 grains were identified and counted.

Assuming a spherical shape for grains, the grain counts were converted to weight percents for each sample by using weight of heavy mineral grains in each size grade and selected specific gravities for each mineral species. This technique with slight modifications has been used or described by Rittenhouse (1944), Berman (1953), Young (1966), Hunter (1967), and Szabo (1972). Young (1966) has shown that the use of number frequency (grain count), weight of heavy minerals in each size grade, and selected specific gravities of each mineral species yields the lowest percent relative deviation when compared with other methods to determine the weight percent of each mineral species in a sample.

Finally, samples of rounded and polished ironstone and rounded iron-cemented sandstone clasts collected from various alluvial terrace deposits were X-rayed and major mineral constituents were qualitatively determined.

FIELD DESCRIPTIONS AND RELATIONSHIPS OF LITHOSTRATIGRAPHIC UNITS

This section includes a description of the gross lithologies of, and stratigraphic relationships among, the various units that crop out in the study area. Data are presented on thicknesses; sedimentary structures; gravel morphology, color, composition, and bedding characteristics; color of weathered and fresh outcrops; general bedding characteristics; and sand size, morphology, and composition as observed in hand specimen. In addition, brief descriptions are given of the flora and fauna associated with the Cretaceous units. Though the units within the Coker Formation of the Tuscaloosa Group are highly lenticular and variable, a general column modified from the work of Conant and others (1945) is presented in figure 8.

The Tuscaloosa Group in the Cottondale area varies in thickness from 125 to 245 m (Conant and others, 1945) and consists of two units of formational rank, the Coker and Gordo Formations. Cross sections in the study area have been constructed by Conant and others (1945) and Stow and Hughes (in preparation). In addition, Conant and others (1945) have drawn contours indicating elevations of the various units on the 15-minute Tuscaloosa and Cottondale quadrangles.

SYSTEM	GROUP	FORMATION	MEMBER	SYMBOL	EXPOSED THICKNESS IN METERS	DESCRIPTION
QUATERNARY(?)	Alluvial terrace deposits			Qt	<1 to 17	Gravel, red, fine- to coarse-grained sand, and mottled red and white clay lenses.
CRETACEOUS	TUSCALOOSA	Coker	Upper member	Ku	45 to 66	Crossbedded, fine- to coarse-grained, micaceous sand and gravel lenses; laminated gray and massive red to tan to gray clay lenses.
			Eoline member (clay)	Kec	15 to 38	Laminated gray clay and glauconitic, fine-grained, crossbedded sand lenses.
			Eoline member (sand)	Kes	9 to 23	Crossbedded fine- to coarse-grained sand, silt, and gravel lenses; laminated and massive clay lenses.
PALEOZOIC		Pottsville		Cpv	60	Crossbedded sandstone, conglomerate, siltstone, shale, coal, and underclay beds.

Figure 8. Generalized columnar section of the rocks exposed in the Cottondale area exclusive of the Gordo Formation [modified from Conant and others, 1945 (not to scale)].

Coker Formation

In the study area the Coker Formation, which consists of varicolored, unconsolidated, lenticular beds of sand, gravel, and clay, is the lowermost formation of the Tuscaloosa Group. The formation is overlain unconformably by the Gordo Formation of Late Cretaceous age and is underlain by the Pottsville Formation of Pennsylvanian age. In Tuscaloosa County the Coker Formation dips southwest from 5.5 to 6.5 m per km (Paulson and others, 1962), and varies in thickness from about 75 m in the Cottondale quadrangle to 150 m in the southwestern corner of the county. The unit can be divided into the Eoline member and an upper member that has no formal lithostratigraphic name (Drennen, 1953a).

Eoline Member

The Eoline member of the Coker Formation lies unconformably on the Pottsville Formation. In places the contact between these two units is hard to define because of the deep weathering of the Pottsville which, when unweathered, consists of massive, commonly crossbedded, strongly cemented, jointed sandstone units that are interbedded with shale, siltstone, coal, and underclay beds. For example, in figure 9 the Pottsville Formation grades from a thin-bedded indurated siltstone at the base of the cut to a weathered siltstone just below the contact with the Eoline member. The contact is placed at the first occurrence of typical Eoline member gravel. In other localities the contact between the

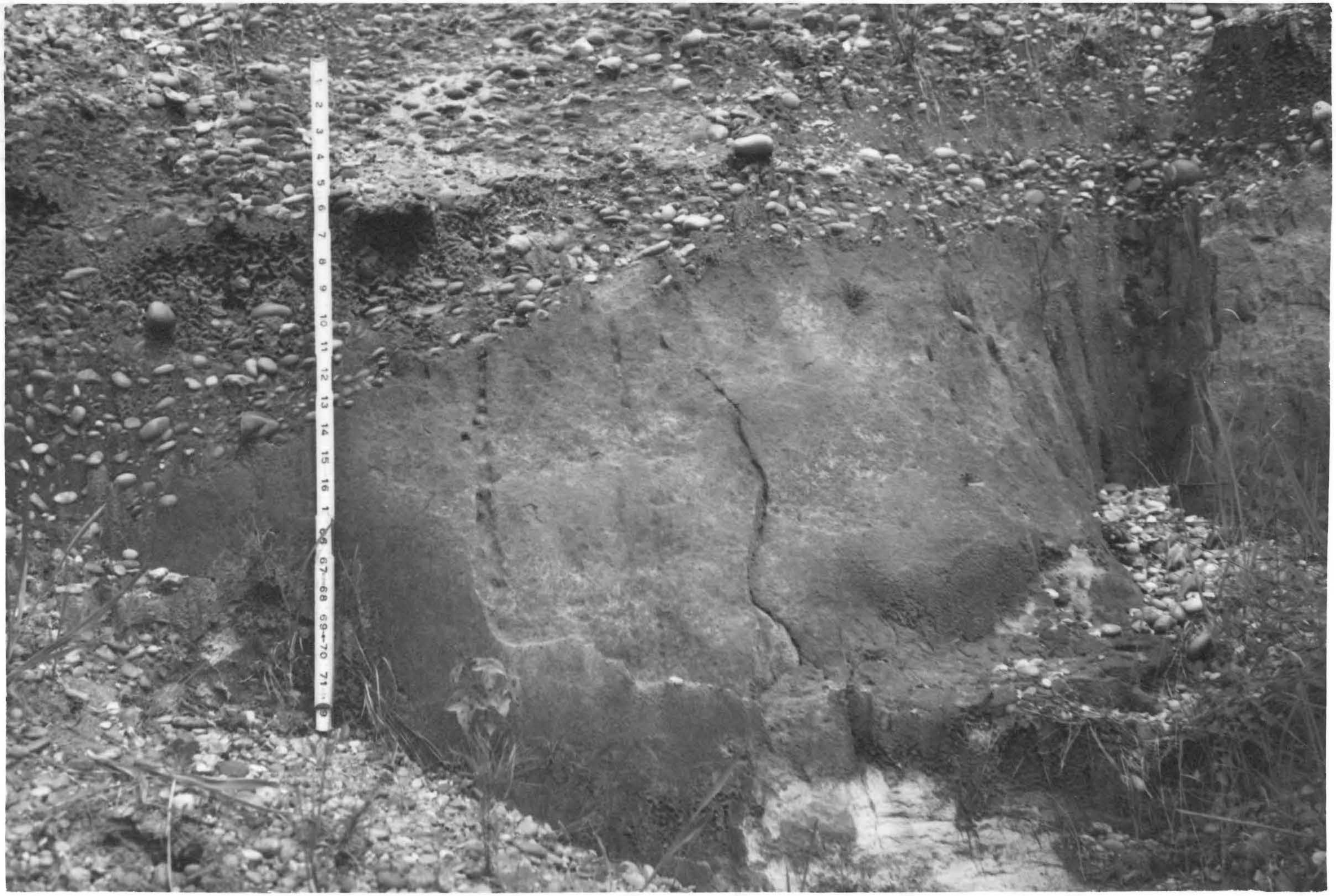


Figure 9. Contact between the weathered Pottsville Formation and Eoline member, SW$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle (scale is .6 m).

Pottsville Formation and Eoline member is sharp and distinctive (fig. 10). The Eoline member is overlain conformably, with local exceptions, by the unnamed upper member of the Coker Formation. In the study area the upper erosional surface of the Pottsville Formation may show considerable relief, and in several localities the deeply weathered shale and sandstone beds of the unit may be confused with units of the Coker Formation. For example, deeply weathered clay units of the Pottsville Formation (fig. 11) that crop out near Canyon Lake in the Cottondale quadrangle greatly resemble clay units that have been mapped in the past as Eoline (fig. 12). In figure 13 weathered, jointed claystone and siltstone beds of the Pottsville Formation lie at the same elevation of, and only a few meters from, the clay units pictured in figure 12. Generally, the clay units of the Pottsville Formation are a lighter color than those of the lower part of the Eoline member (fig. 14). At the location for figure 14, filled joints of the weathered Pottsville are terminated by the non-jointed clay units of the Eoline member.

Stow and Hughes (in preparation), in their mapping of the Cottondale quadrangle, informally divided the Eoline member into a lower sand, gravel, and massive clay unit which they designated the Eoline member (sand); and an upper laminated clay and fine-grained glauconitic sand unit designated the Eoline member (clay). These two units correspond, respectively, to the Cottondale and Eoline Formations of Conant and Monroe (1945). The terminology of Stow and Hughes (in preparation) will be used in this discussion.

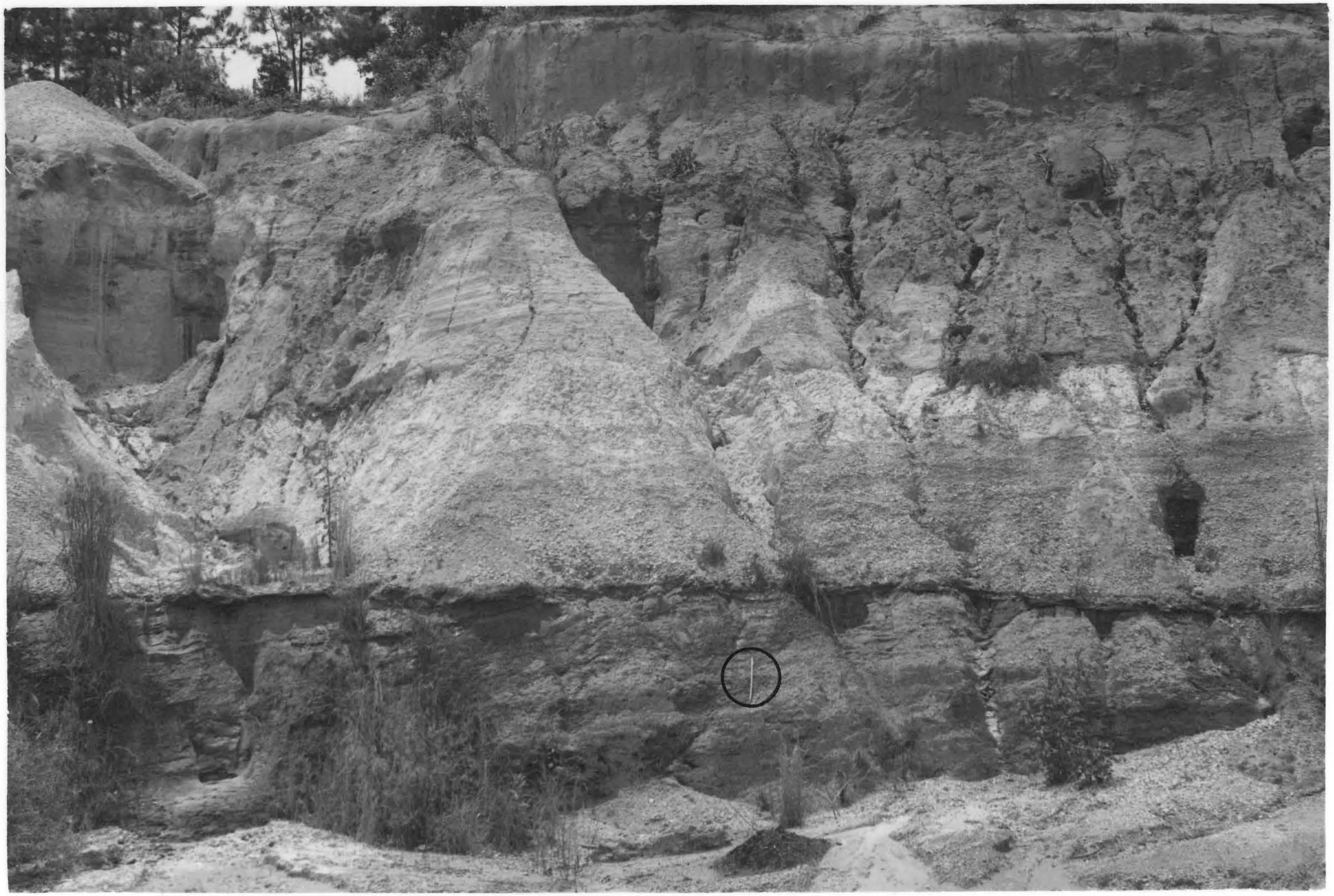


Figure 10. Contact between the unweathered Pottsville Formation and a sequence of gravel, clay, and gravel beds of the Eoline member, SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 27, T. 20 S., R. 8 W., Searles quadrangle (scale is .6 m and is circled).

Figure 11. Clay unit of the Pottsville Formation interbedded with weathered sandstone and siltstone, SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 30, T. 21 S., R. 8 W., Cottondale quadrangle (scale is .6 m).

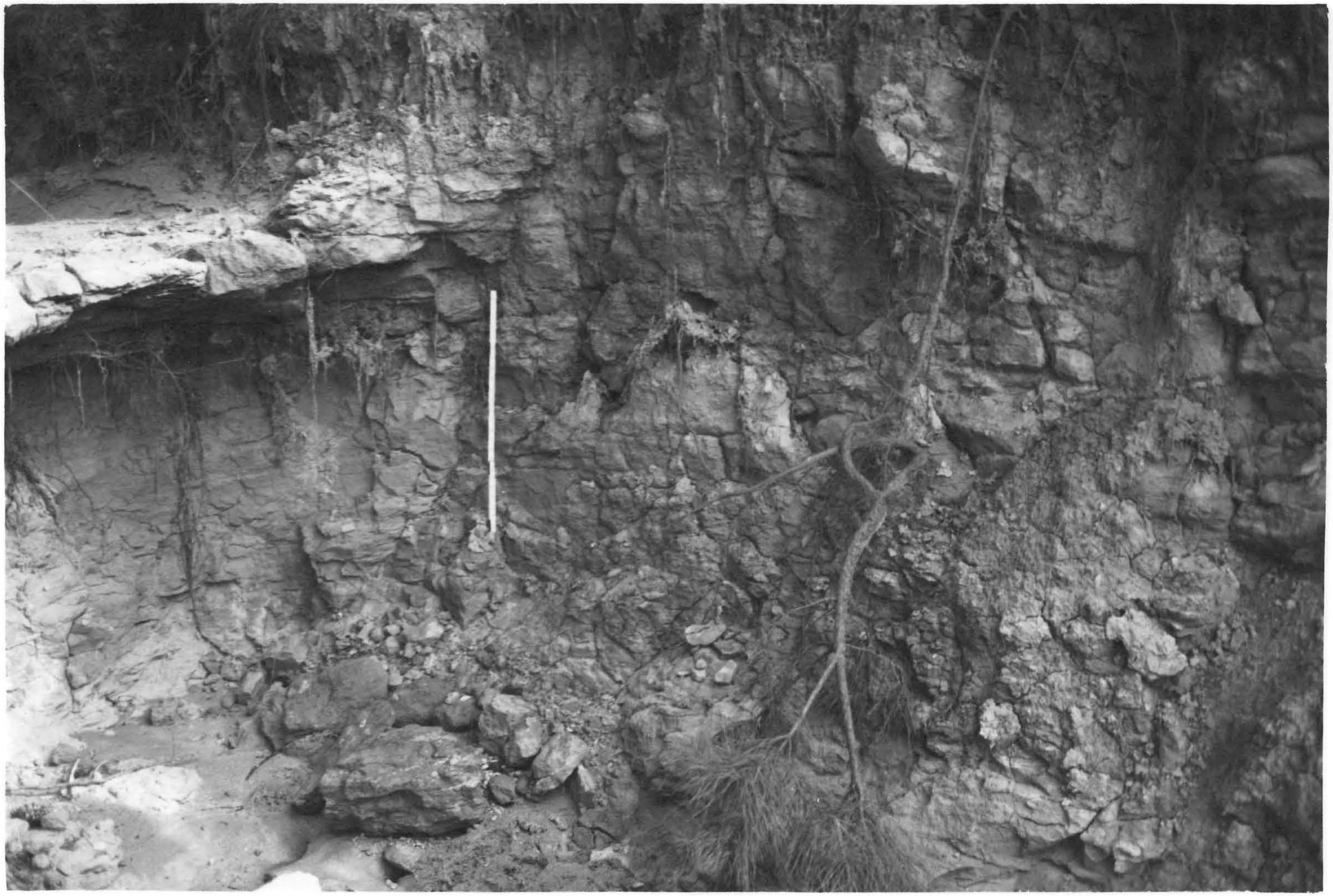


Figure 12. Probable weathered clay beds of the Pottsville Formation, NW$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

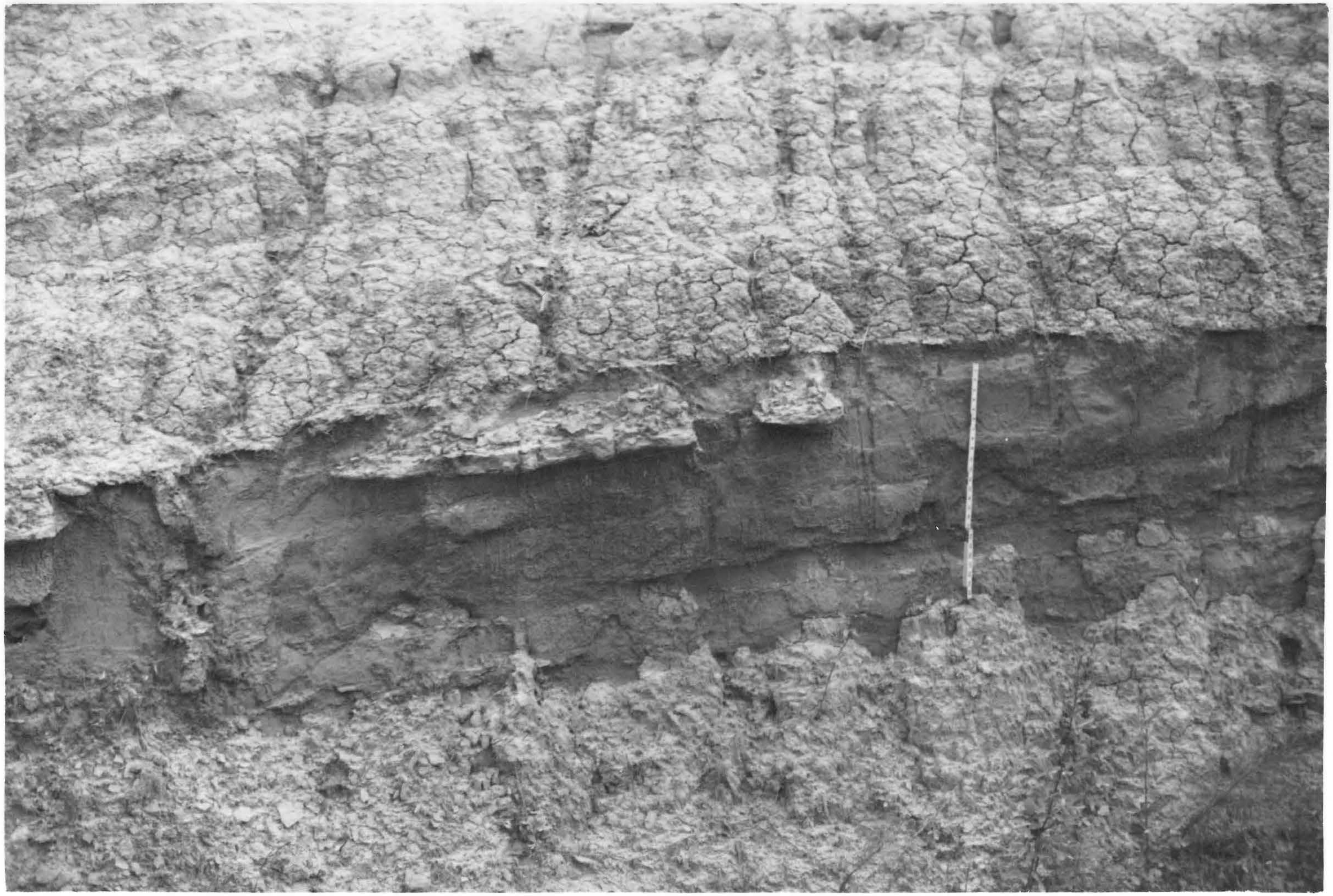


Figure 13. Weathered clay- and siltstone of the Pottsville Formation, NW$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

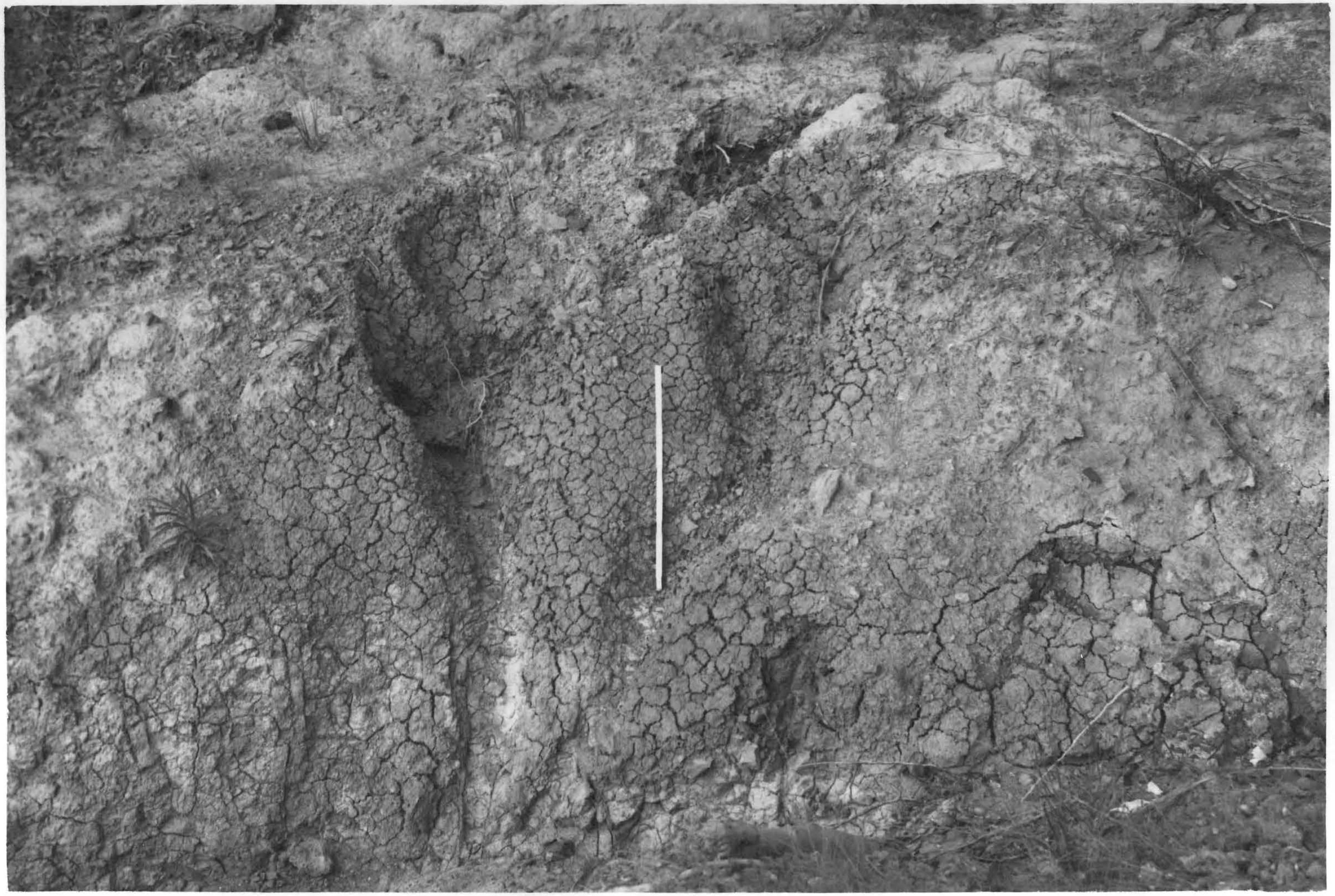


Figure 14. Contact between clay beds of the Pottsville Formation and clay beds of the Eoline member, $NE\frac{1}{4}NE\frac{1}{4}NW\frac{1}{4}$ sec. 1, T. 22 S., R. 8 W., Cottondale quadrangle (base of .6 m scale is placed at contact).

The Eoline member (sand) consists of beds of white to light-gray to tan, fine- to coarse-grained, angular to subangular, crossbedded, micaceous, quartzose sand that generally weathers to a light- to medium- to dark-red or yellow. Some of the sand beds are fairly feldspathic. Interbedded with these sand units are balls and laminae of dark-gray to purple clay that weather to white or tan (fig. 15). Some ironstone ledges may be found in the Eoline member (sand). These consist of thin beds of iron-cemented gravel, sand, and clay particles (see p. 145 and 147 for a more thorough explanation). The thickness of the sand units varies from 9 to approximately 23 m. Generally at the base of the sand units a 3 m thick bed of gravel and coarse sand occurs. The gravel consists of polished, rounded, white, gray, tan, red, or purple quartz and quartzite pebbles of various shapes with some spheroidal to roller shaped chert pebbles (figs. 16 and 17). Quartz pebbles predominate and red and purple discs are highly characteristic of this unit. This chert gravel has been derived from the Carboniferous, and Cambrian and Ordovician chert of the Ridge and Valley province of Alabama for it contains fossils that are distinctive of the Fort Payne Chert of Carboniferous age and pisolitic and "zebra" cherts that are characteristic of the Knox Group of Cambrian and Ordovician age (James A. Drahovzal and Peter A. Boone, 1974, oral communication). Monroe and others (1946) report the presence of a few Pottsville pebbles in this lowermost gravel; however, the author was unable to find a single

Figure 15. Fine-grained micaceous crossbedded sand unit of the Eoline member (sand), SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

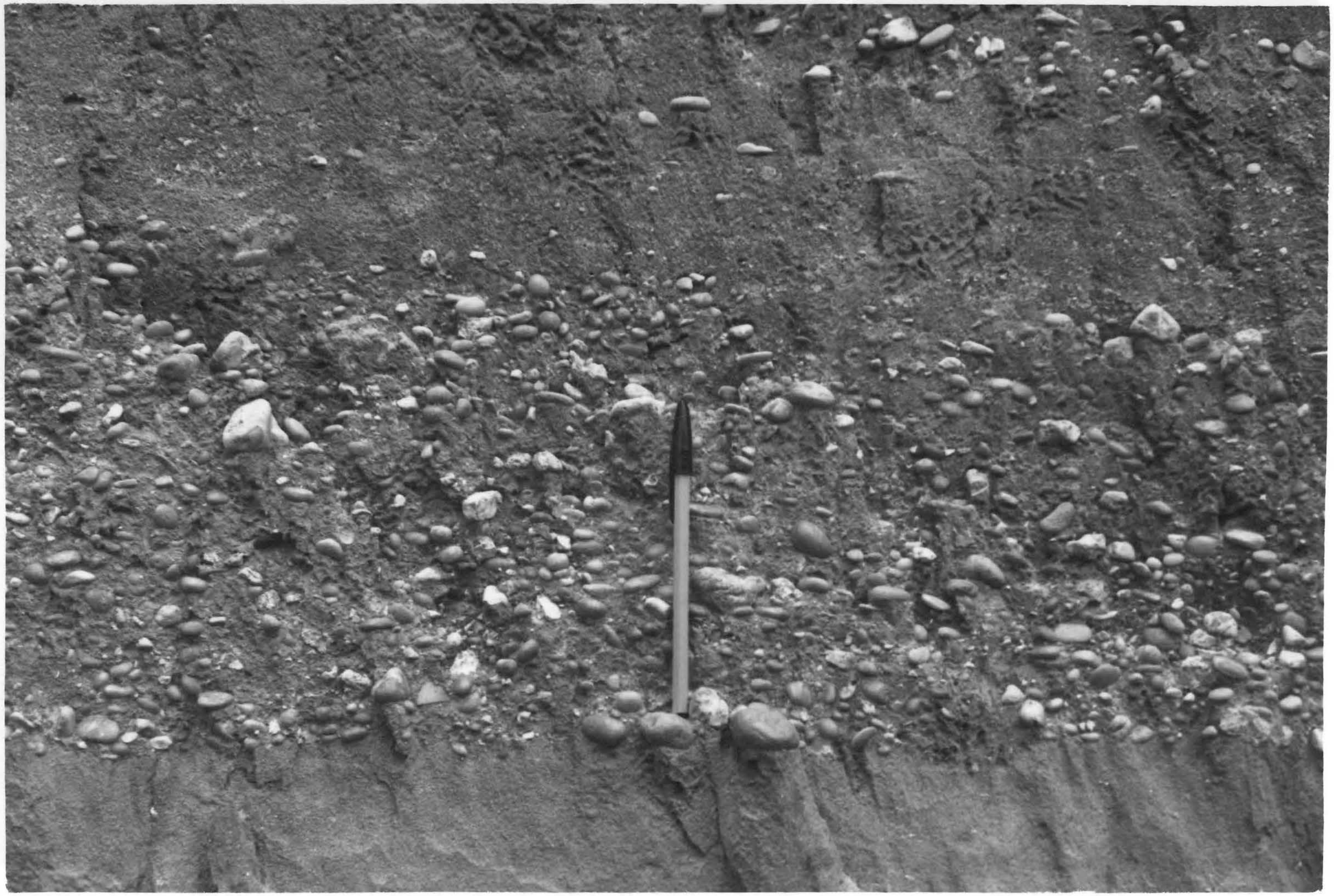


Figure 16. Basal gravel bed of the Eoline member (sand), NW$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle.

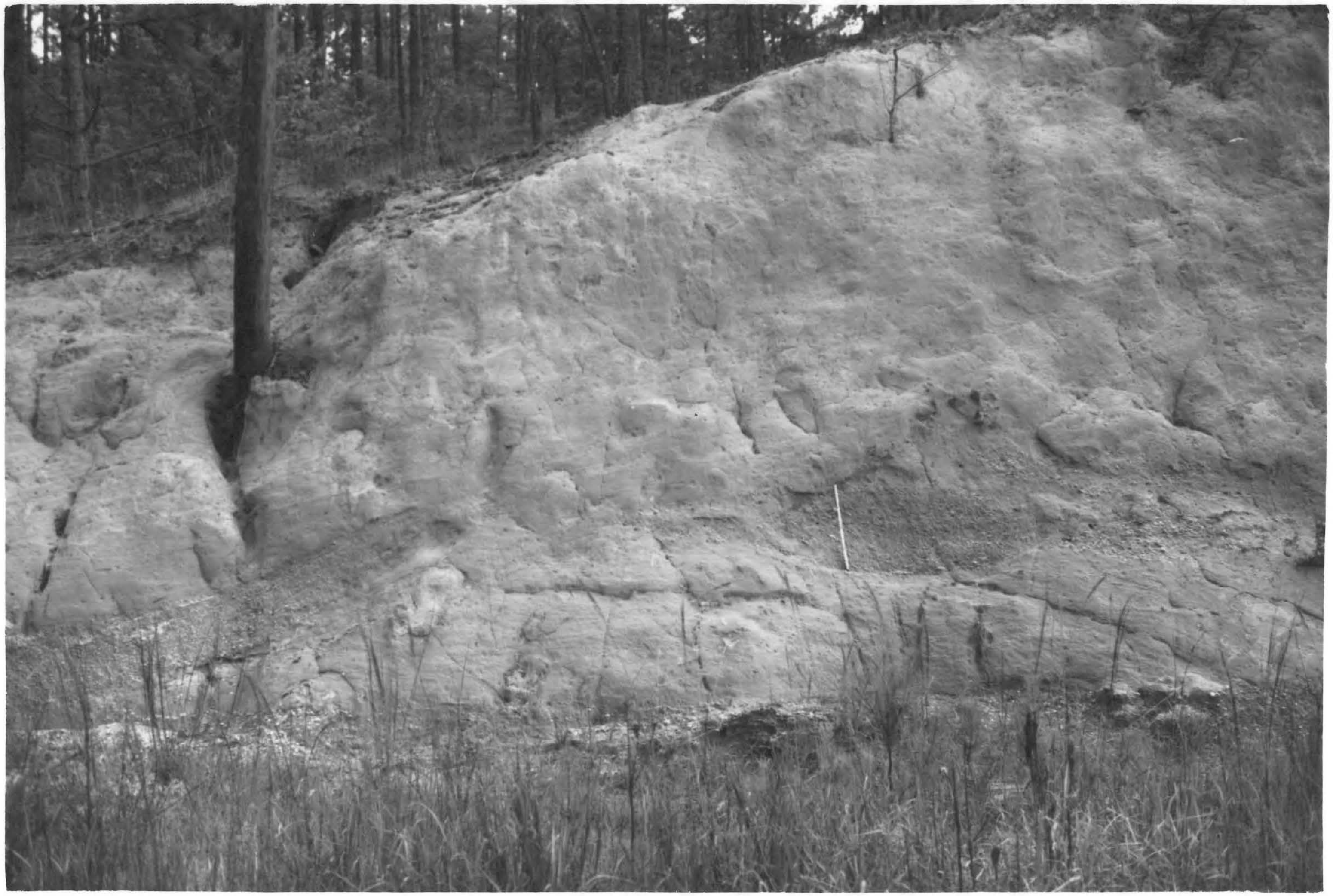


Figure 17. Channel gravel bed of the Eoline member (sand), NW$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

Pottsville rock fragment in the Eoline member (sand) during the field work phase of this thesis. These pebbles may be present, but are extremely rare except in the very lowermost part of the unit. Average quartz and chert pebble length is about 2.5 cm, but some pebbles range up to 7.5 cm in length. In addition, the gravel can occur in thin lenses throughout the Eoline member (sand) section and has been observed just below the contact with the Eoline member (clay)(fig. 18). At a locality north of Northport, Alabama, the long axes of most pebbles in the basal unit are oriented parallel to bedding planes within a matrix of manganite crystals (Naff, 1940). Naff (1940) also observed that the larger pebbles tend to be much more well-rounded than the smaller ones. In addition, phosphate nodules have been found up to 10 cm long in parts of the Eoline member (sand). Much of the Eoline member (sand) section appears to represent a sequence that fines upwards.

A light- to dark-gray to purple massive to laminated, lensatic, and in places carbonaceous and lignitic, illitic clay that contains some leaf imprints and siderite nodules sporadically overlies (fig. 19), or occurs in place of the sand and gravel units. This clay generally weathers white or tan and contains some kaolinite. When the clay unit overlies the sand units, it rarely exceeds 2.5 m in thickness, but when it replaces the sand units it may be as thick as 18 m (fig. 20). The Eoline member (sand) generally grades upward into the Eoline member (clay)(fig. 21), but it may be

Figure 18. Gravel unit of the Eoline member (sand) just below the contact with the Eoline member (clay), $S\frac{1}{2}NW\frac{1}{4}SE\frac{1}{4}$ sec. 27, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m and is circled).

Figure 19. Lense of massive gray clay (Cl) overlying crossbedded sand and gravel beds (SG) of the Eoline member (sand), NW$\frac{1}{4}$NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 30, T. 21 S., R. 8 W., Cottondale quadrangle (scale is .6 m).

Figure 20. Carbonaceous clay unit of the Eoline member (sand) near where Berry (1919) probably collected plant fossils, NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

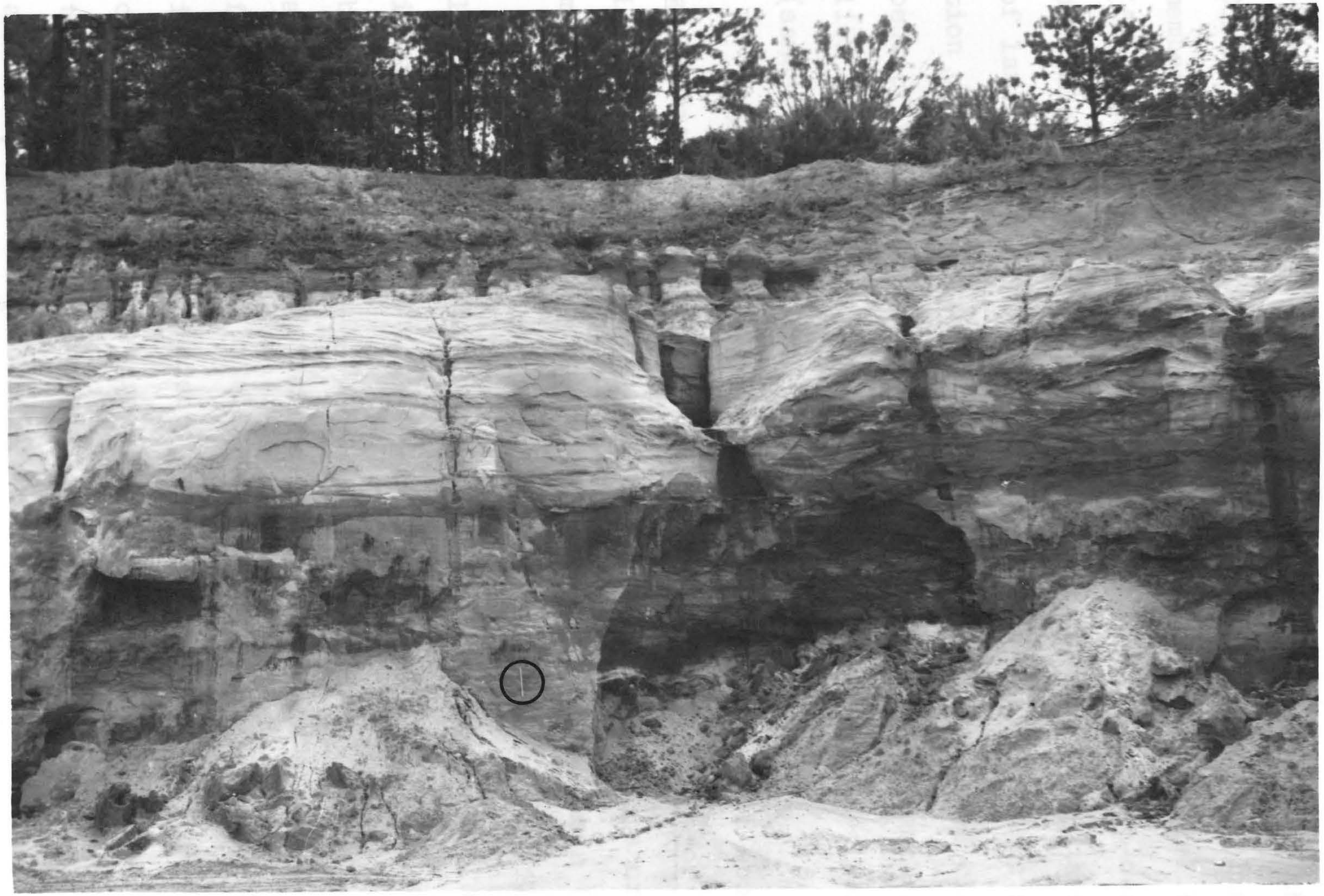


Figure 21. Conformable contact between the Eoline member (sand) and Eoline member (clay), SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle (scale is .6 m and is circled).

locally unconformable (figs. 22, 23, and 24) or complexly interbedded. To the right side of figure 25 a simple unconformable contact between the sand and gravel units of the Eoline member (sand) and the laminated clay of the Eoline member (clay) is marked by a thin iron-cemented gravel bed (fig. 24). However, to the left (fig. 25), the iron-cemented bed thickens into a 0.3 m gravel lens that separates a wedge of laminated clay and sand below, in the stratigraphic position of the Eoline member (sand), from the laminated clay beds of the Eoline member (clay) above. This sequence overlies the typical sand and gravel units of the Eoline member (sand).

Drennen (1953a) has reported the occurrence of sporadic glauconite and borings that resemble _Halymenites major_ Lesquereux (_Ophiomorpha_) indicating a possible nearshore marine origin for the major part of the Eoline member (sand).

The Eoline member (clay) in outcrop consists of illitic, laminated, greenish to purple to gray clay units that are interbedded with fine, light-gray to purple to white cross-bedded glauconitic sand units (fig. 26). Kaolinite is also a minor constituent of these clays. The glauconite is difficult to recognize in all but the freshest exposures due to its small size and tendency to weather from a characteristic olive-green to a pale-green, light-yellow, or white; however, the glauconite can commonly be recognized by its capsular and botryoidal shape.

Figure 22. Unconformable contact with relief between laminated micaceous clay and sand units of the Eoline member (sand) and laminated clay and sand beds of the Eoline member (clay), SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 35, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

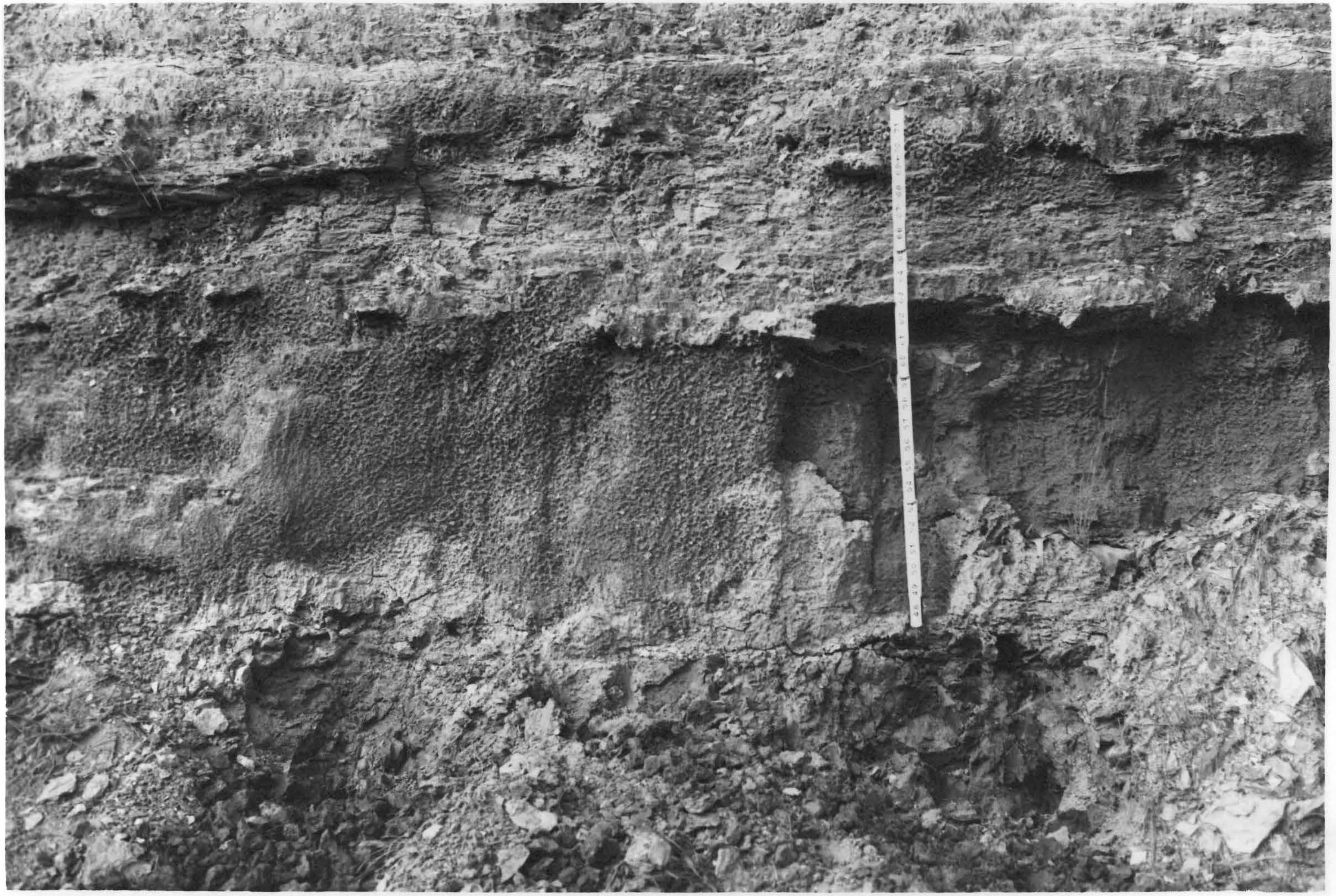


Figure 23. Unconformable contact between massive carbonaceous clay unit of the Eoline member (sand) and laminated clay and sand units of the Eoline member (clay), NE$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, T. 22 S., R. 8 W., Cottondale quadrangle (base of .6 m scale is at contact).

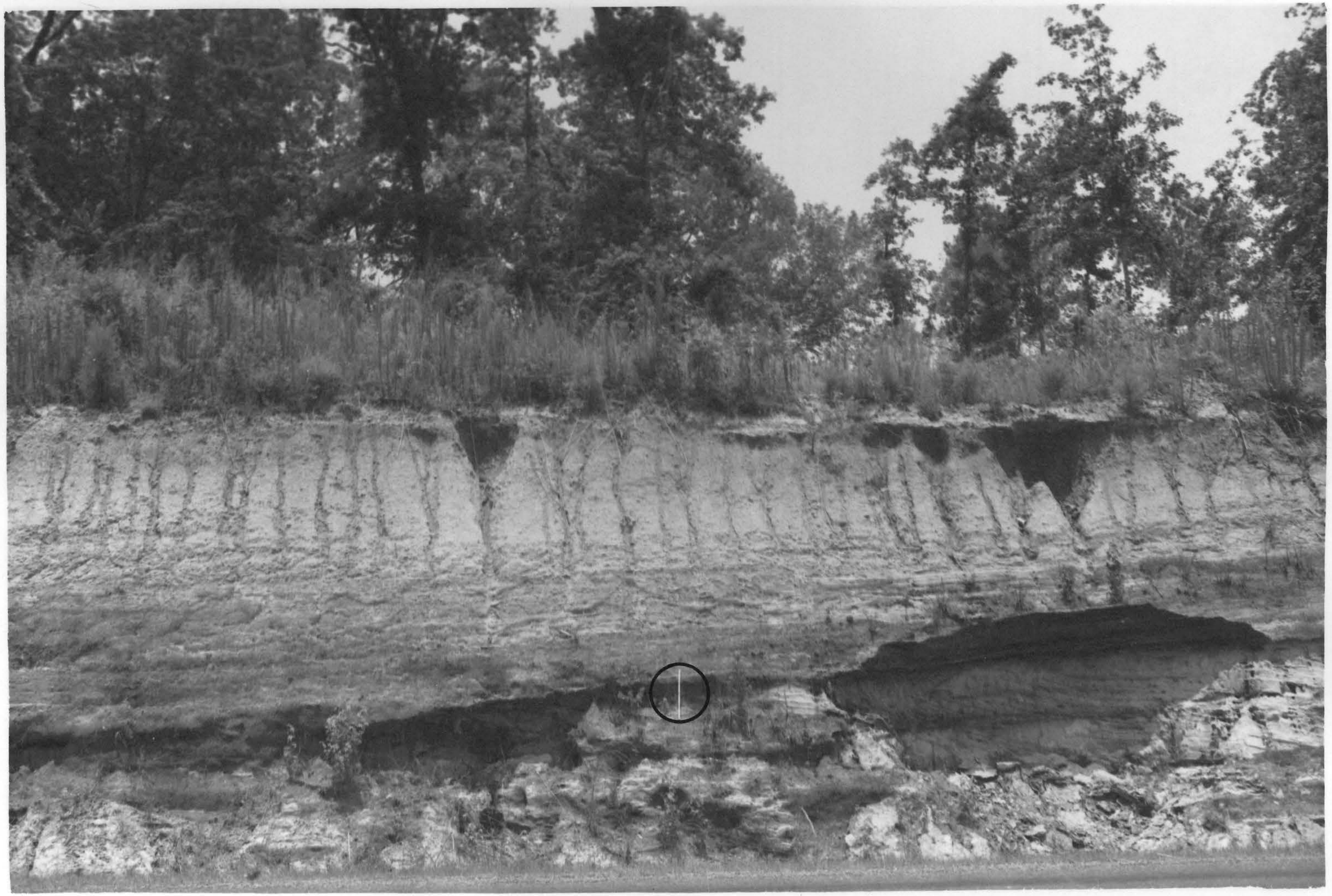


Figure 24. Unconformable contact between sand and gravel beds of the Eoline member (sand) and the laminated clay and sand beds of the Eoline member (clay). An iron-cemented gravel layer marks the contact, NE$\frac{1}{4}$NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 16, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m and is circled).

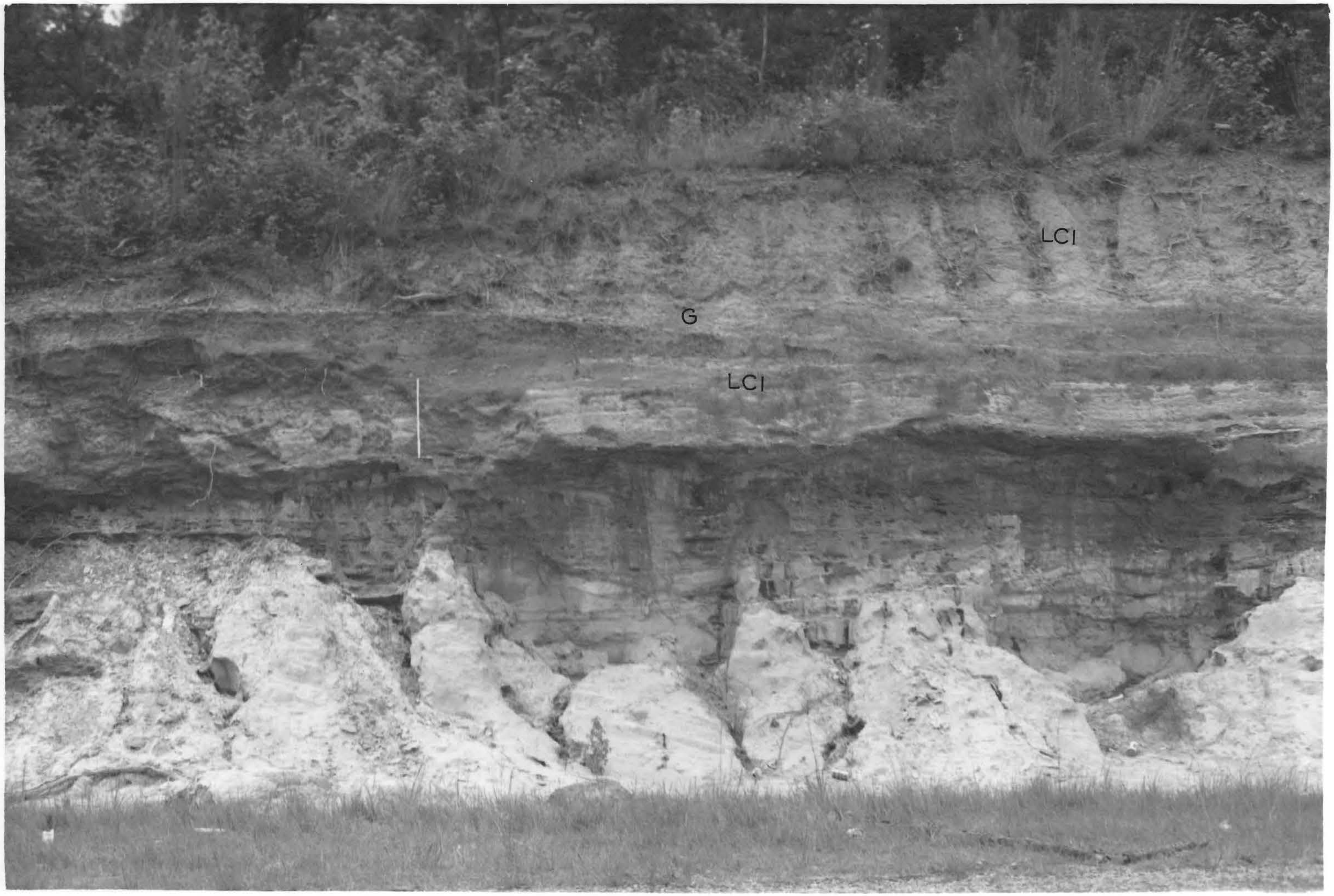


Figure 25. Complexly interbedded Eoline member (sand) and Eoline member (clay), NE$\frac{1}{4}$NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 16, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m; G = gravel, LCl = laminated clay).

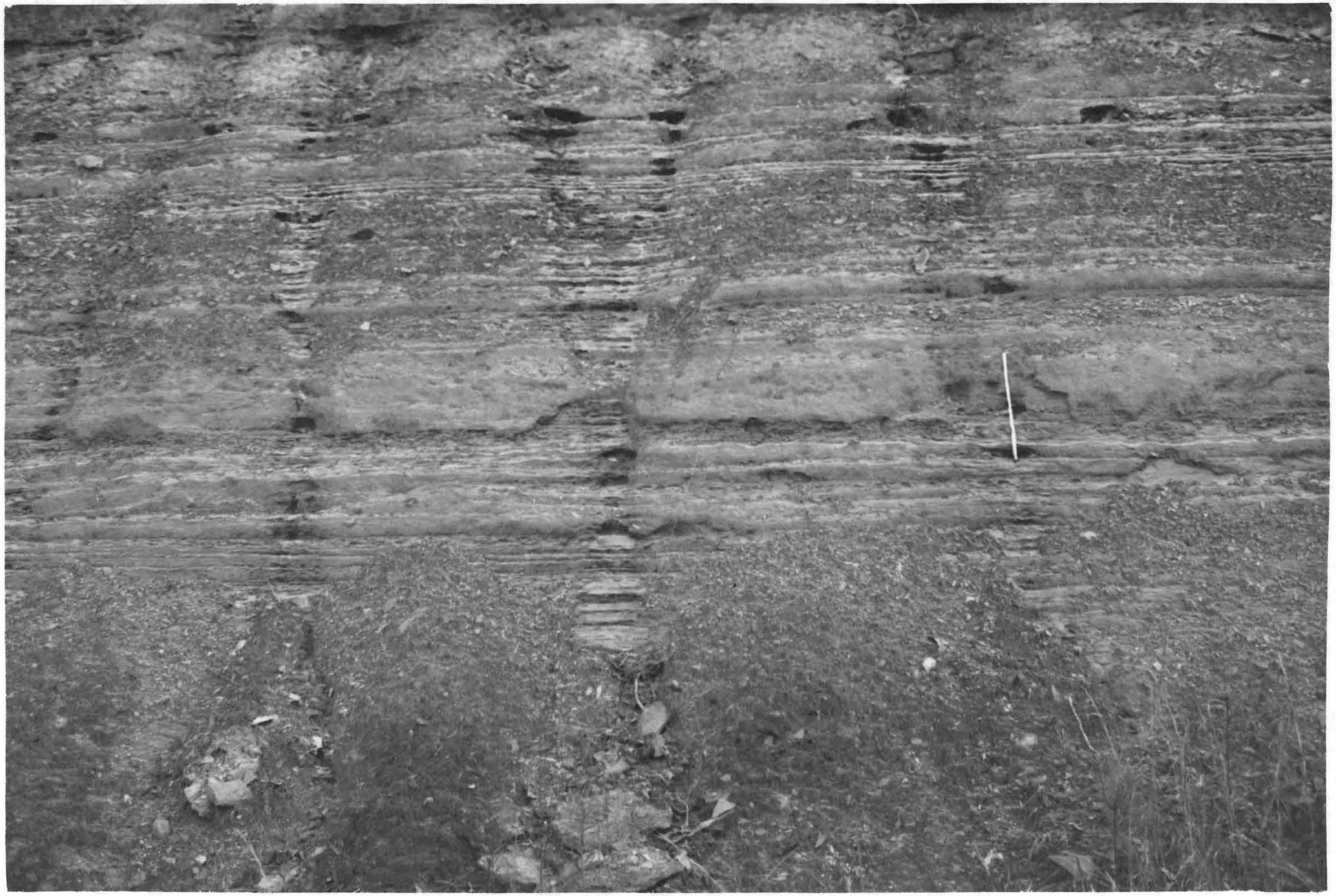


Figure 26. Laminated clay and fine-grained sand units of the Eoline member (clay), NW$\frac{1}{4}$SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

In some areas Eoline member (clay) lithologies become predominately crossbedded, fine- to medium-grained micaceous sand with abundant laminated clay lenses. This sand may weather yellow or rusty-red. Characteristically, however, the Eoline member (clay) can be recognized by the alternation of thin-bedded clay, silt, and rippled and crossbedded fine sand lenses. In some places the thinly-bedded sand and clay units take on a "rolled-up" appearance as if they have been disturbed (fig. 27). Monroe and others (1946) explain these features by submarine slippage along bedding planes. In other places post-depositional slumping has occurred (figs. 28 and 29). The clay units are too lenticular to be traced very far and are characterized by rapid thickness changes with some lenses being over 30 m thick. The maximum outcrop thickness of the Eoline member (clay) is about 38 m, though locally it is much thinner due to channel incision by the unnamed upper member. Extreme dips of as much as 40° have been noted in the laminated clay lenses and may represent foreset beds or structural disturbance. Ironstone ledges are very common in the Eoline member (clay).

In a few places where the basal contact of the Eoline member (clay) with the Eoline member (sand) is unconformable, a bed of 0.6 cm pebbles occur (fig. 25). Because laminated clay occurs in both the Eoline member (sand) and Eoline member (clay) some difficulty was encountered in the differentiation of these two units.

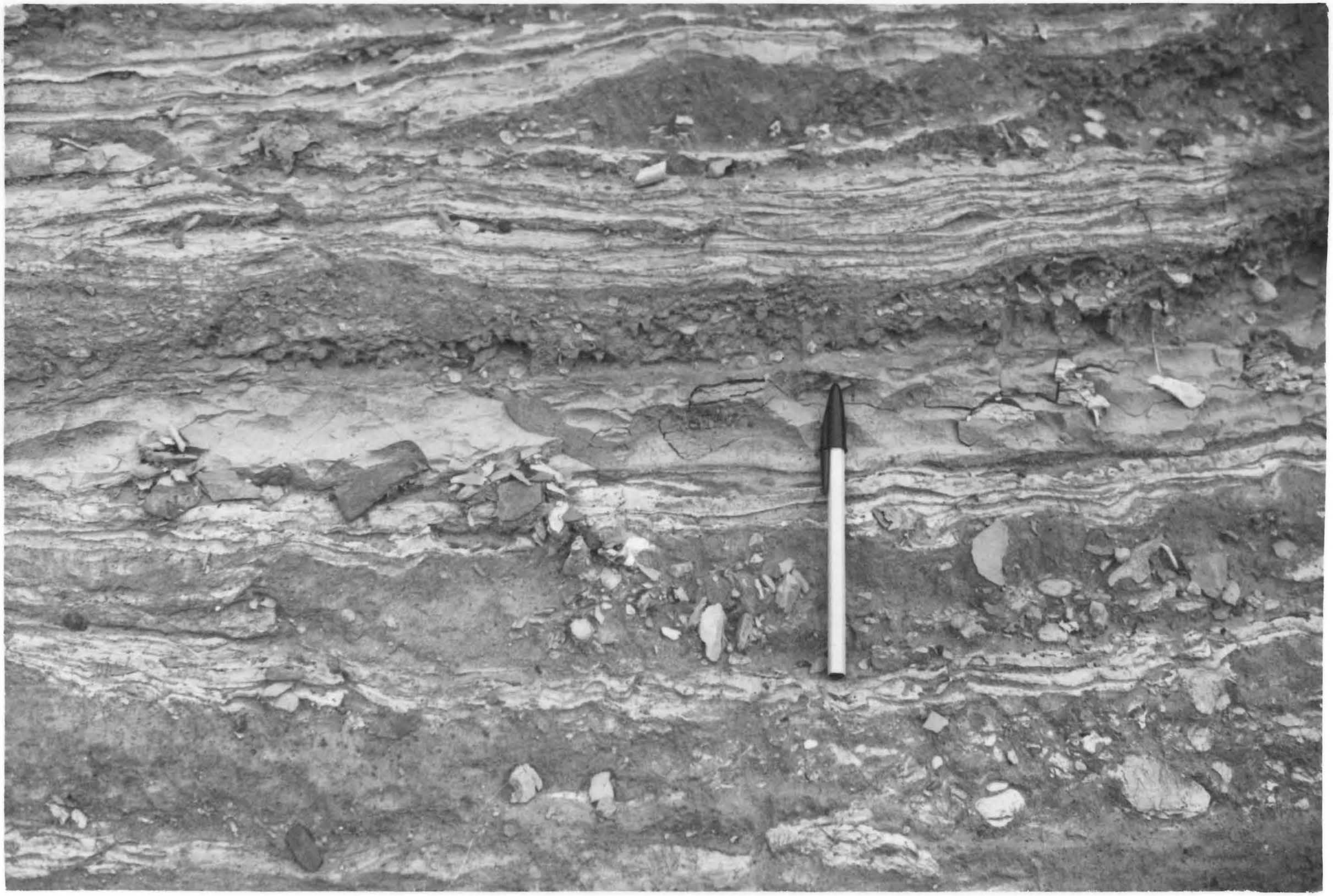


Figure 27. "Rolled-up" and rippled appearance of the Eoline member (clay), NW$\frac{1}{4}$SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle.

Figure 28. Post-depositional slumping along the contact between the Eoline member (clay) and the Eoline member (sand), SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 35, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

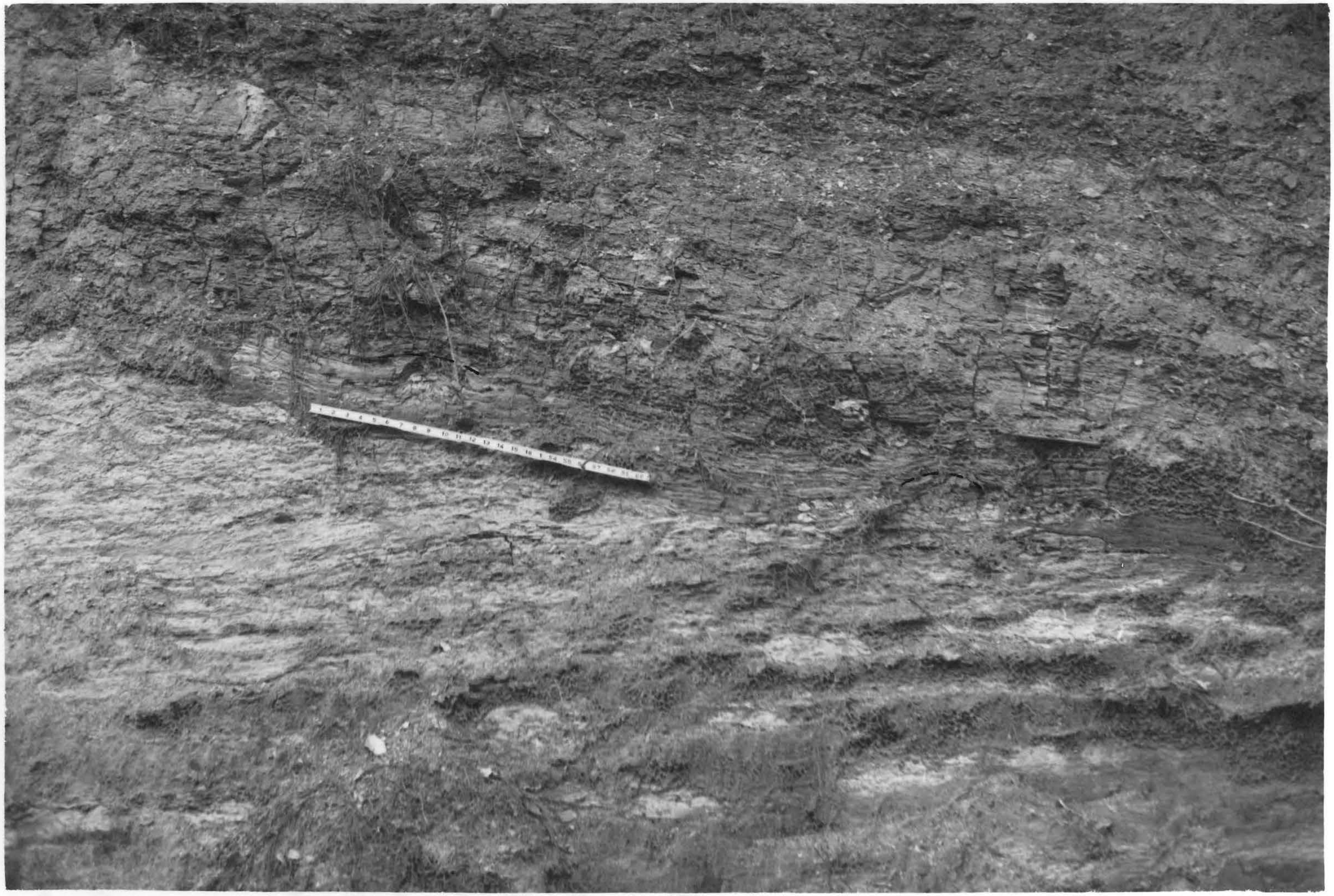


Figure 29. Drag folds in the Eoline member (clay) caused by post-depositional slumping, SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 35, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

In general, the lower half of the Eoline member (clay) is sandy while the upper half contains more clay. At some exposures this clay contains carbonized leaves, lignitized wood, scattered amber, pyrite, and concretions of marcasite and massive siderite. The siderite locally becomes so abundant that it appears as a conglomeratic bed several inches thick (Monroe and others, 1946).

The Eoline member (clay) is overlain both conformably (Drennen, 1953a) and unconformably (figs. 30 and 31) by the unnamed upper member of the Coker Formation that, in places, has scoured channels that extend as much as 12 m into the underlying unit (Monroe and others, 1946). However, relief on this unconformable surface is usually no more than 6 m.

Stephenson and Monroe (1938) report borings of *Halymenites major* Lesquereux (*Ophiomorpha*) in the upper Eoline member (clay) as well as obscure prints of mollusks. Also, Stephenson has recognized remains of *Ostrea* sp., *Brachidontes* sp., *Glycymeris*(?), and *Corbicula* sp. collected from two 0.9 m beds of silty clay near the top of the unit (Drennen, 1953a). This fauna along with the presence of glauconite suggests a definite marine depositional environment for the Eoline member (clay).

Upper Member

Lithologically, the unnamed upper member of the Coker Formation is highly variable, but consists predominantely of extremely clean, highly crossbedded, fine- to coarse-grained

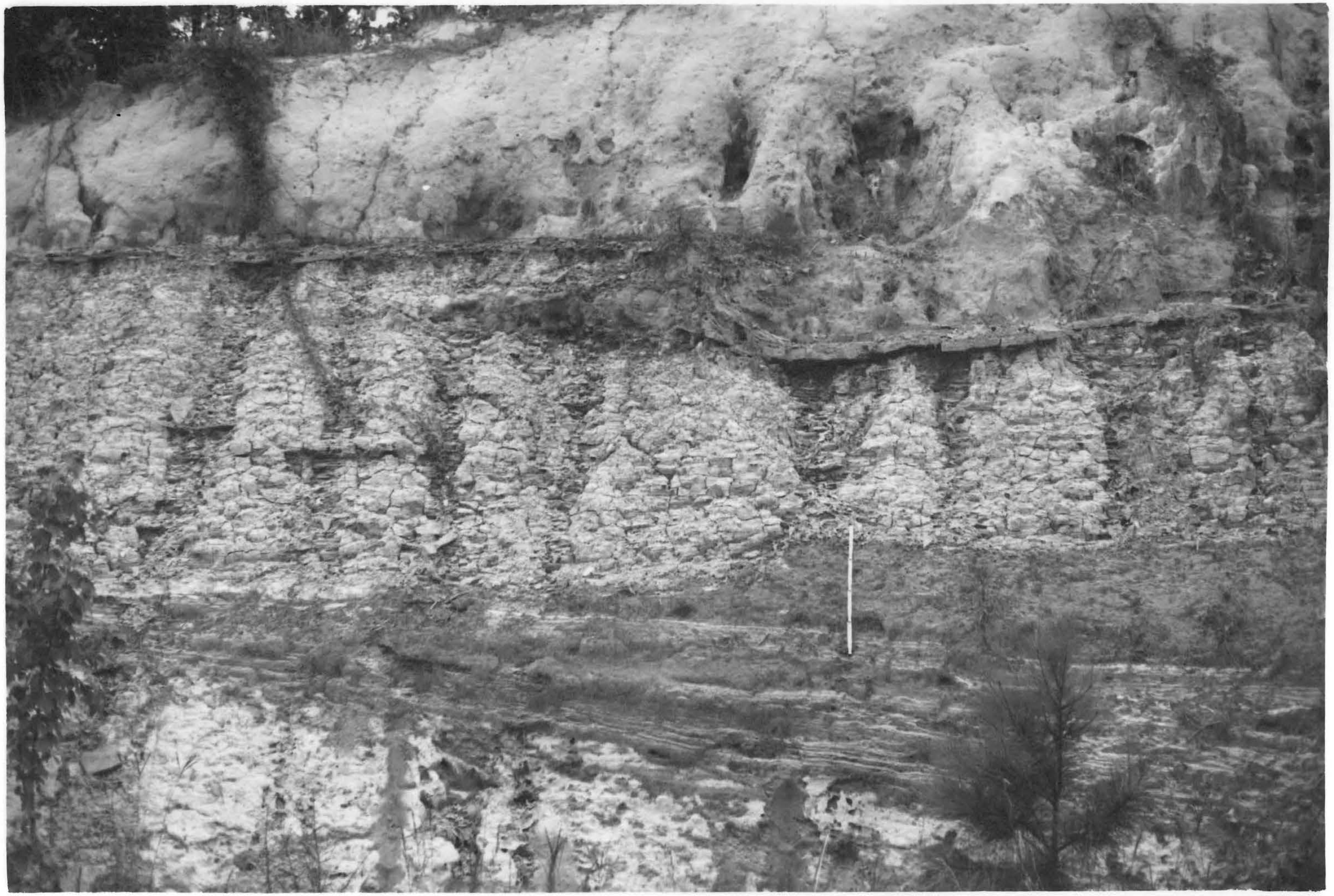


Figure 30. Unconformable contact of the laminated sand and clay units of the Eoline member (clay) with the sand units of the unnamed upper member marked by an ironstone ledge, SW$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

Figure 31. Unconformable contact of the laminated clay beds of the Eoline member (clay) with chert-rich gravel and sand beds of the unnamed upper member. At this locality the Eoline member (clay) contains abundant marcasite concretions, NW$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 10, T. 21 S., R. 11 W., Coker quadrangle (scale is .6 m and is circled).

(characteristically fine-grained), extremely micaceous, white to tan to light-gray sand units that may weather to a fairly deep red color (fig. 32). A few grains of glauconite have been reported in some of the sand units (Drennen, 1953a). Gravel lenses that contain rounded to angular polished quartz pebbles and abundant chert pebbles are common. In some beds these pebbles vary in size from 2 to 7 cm in length, but most pebble beds contain much smaller clasts and resemble the chert gravel units of the overlying Gordo Formation. Generally the beds containing the smaller pebbles consist of very angular abundant chert clasts (fig. 33), whereas the beds containing the larger pebbles consist of a mixture of fairly well-rounded quartz and chert pebbles. The chert pebbles in the unnamed upper member are less abundant than the quartz pebbles; however chert pebbles in the unnamed upper member are more abundant than the chert pebbles in the Eoline member (sand). The beds with the larger pebbles also contain a few clasts that resemble the quartz pebbles of the Eoline member (sand)(fig. 34).

Rounded clay balls (fig. 35) and laminated clay breccia (fig. 36) also occur in the crossbedded sand of the upper member. In places, masses of unrounded iron-cemented sandstone, ironstone ledges, and spherulitic limonite (weathered from siderite) occur. In addition, thinly laminated clay lenses that resemble the laminated clay lenses of the Eoline member are interbedded with the sand (fig. 37). This sand unit may be as much as 23 m thick. Near the middle of this section selenite

Figure 32. Fine-grained, crossbedded, micaceous sand at the type section of the unnamed upper member, SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21, T. 21 S., R. 11 W., Coker quadrangle (scale is .6 m).

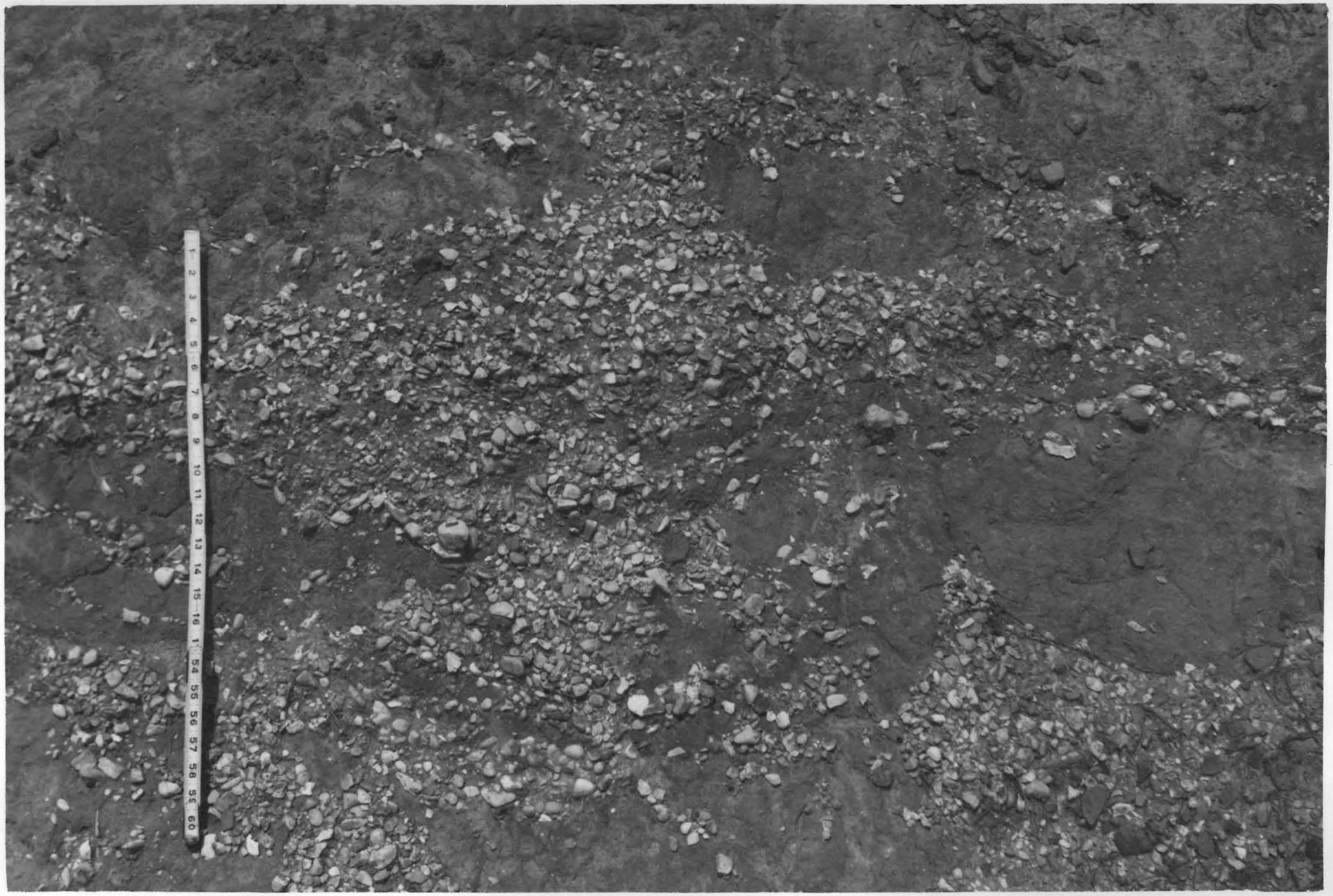


Figure 33. Angular chert gravel bed of the unnamed upper member, NW$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 11, T. 21 S., R. 11 W., Coker quadrangle (scale is .6 m).

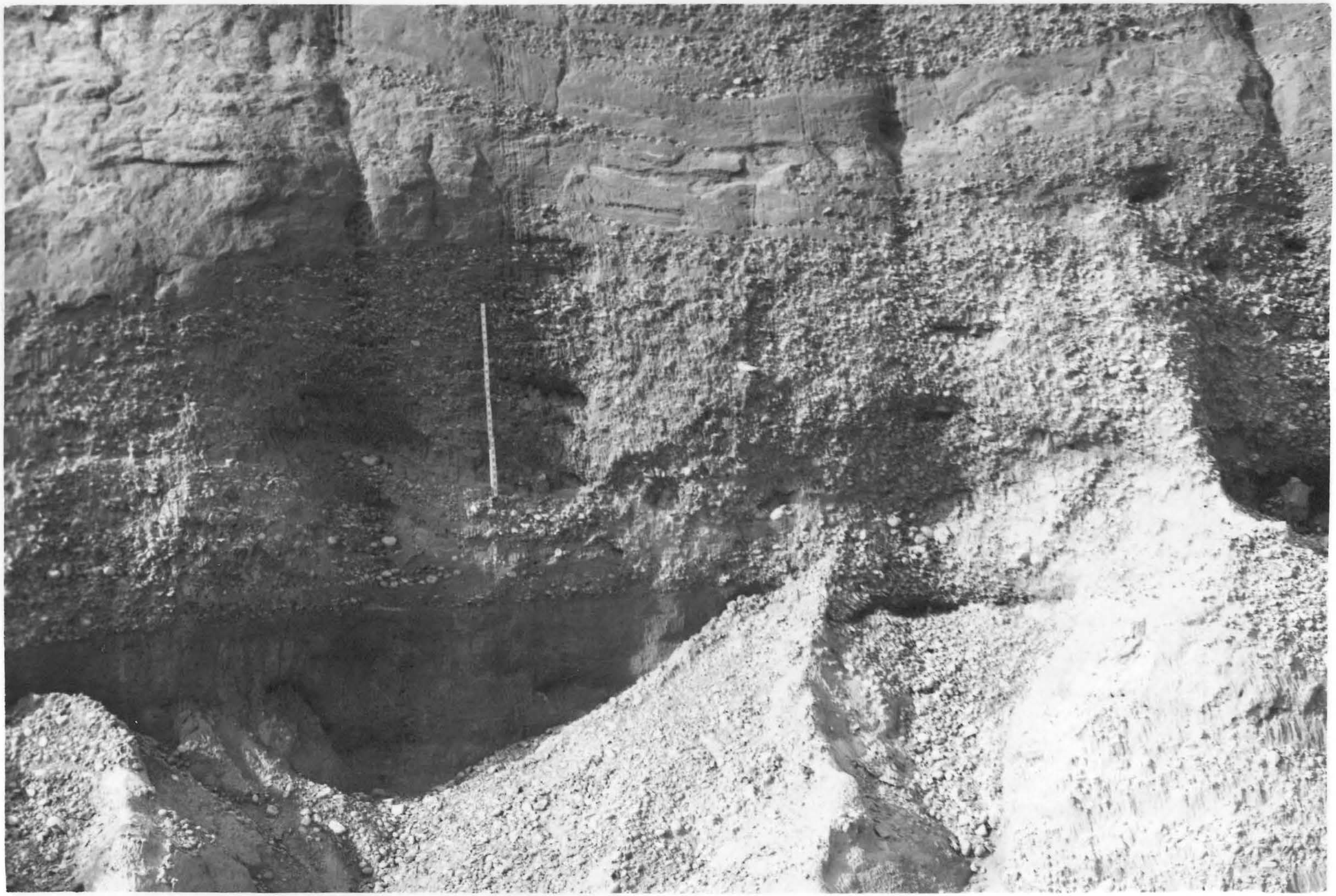


Figure 34. Beds of chert ($>$20%) and quartz pebbles of the unnamed upper member, NW$\frac{1}{4}$SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 7, T. 22 S., R. 9 W., Tuscaloosa quadrangle (scale is .6 m).

Figure 35. Fine-grained, highly crossbedded and micaceous sand beds of the unnamed upper member containing rounded clay clasts, NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 22 S., R. 9 W., Cottondale quadrangle (scale is .6 m).

Figure 36. Fine-grained, crossbedded, micaceous sand unit at the type section of the unnamed upper member containing laminated clay breccia (one is circled), SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21, T. 21 S., R. 11 W., Coker quadrangle (scale is .6 m).

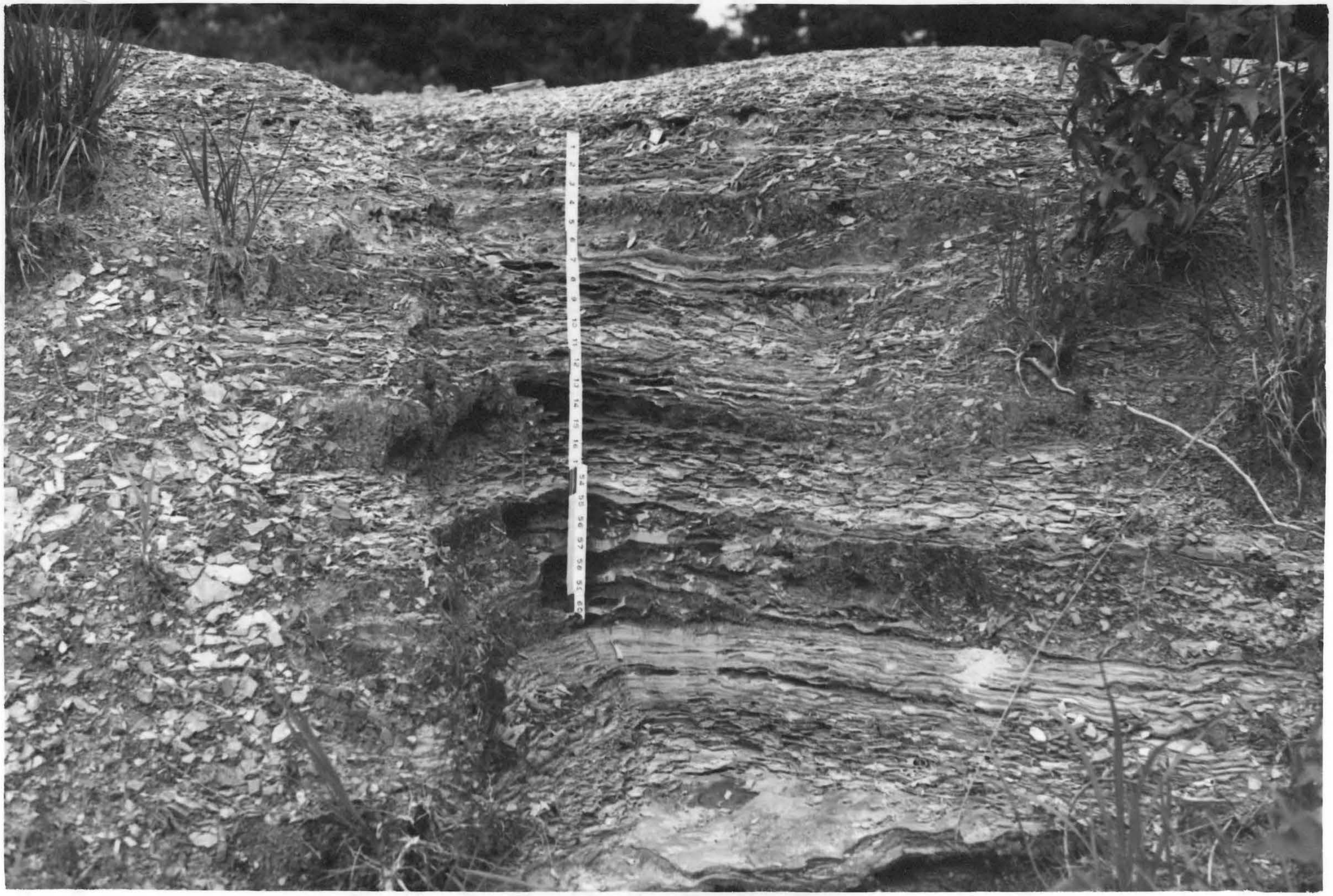


Figure 37. Laminated clay lenses of the unnamed upper member that strongly resemble the clay lenses of the Eoline member (clay), NE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 4, T. 21 S., R. 11 W., Coker quadrangle (scale is .6 m).

crystals have been reported in a light-gray clay unit (Monroe and others, 1946).

Locally, the lower 6 m of the member consist of massive gray clay containing nodular siderite. Also a 0.6 m thick bed of bentonite has been reported near the base of this member (Monroe and others, 1946). Red-mottled grayish to white, purple, maroon, and yellow, silty, illitic clay is common near the top of the unnamed upper member (fig. 38). Many of these clays are micaceous and contain some kaolinite. The total thickness of the entire unnamed upper member may be as great as 66 m.

As previously mentioned, the basal contact with the Eoline member may be conformable or locally unconformable (fig. 30). Either the lower sand or clay unit of the upper member may be present at its base. The upper contact of the unnamed upper member with the Gordo Formation is unconformable and is generally marked by an ironstone ledge (fig. 39).

Apparent marine borings resembling Halymenites have been found in the unnamed upper member, which along with the sporadic occurrence of glauconite, suggest a marine origin for this unit (Drennen, 1953a).

Pleistocene(?) and Holocene Alluvial Deposits

Alluvial terrace deposits overlie the older units in the Cottondale area, and alluvial deposits underlie the flood plains of the Black Warrior River and its major tributaries. The alluvial terrace deposits consist of lenticular

Figure 38. Massive purple, yellow, and gray clay lenses of the unnamed upper member, NW$\frac{1}{4}$SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 31, T. 20 S., R. 11 W., Samantha quadrangle (scale is .6 m and is circled).

Figure 39. Unconformable contact between the unnamed upper member and the Gordo Formation marked by an ironstone ledge, SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 31, T. 20 S., R. 11 W., Samantha quadrangle (scale is .6 m and is circled).

deep red to brown to yellow, and, when extremely fresh, tan to white crossbedded fine- to coarse-grained fairly nonmicaceous sand (fig. 40) and gravel units interbedded with massive clay lenses (fig. 41) that are generally mottled red to tan or white. Alluvial terrace deposits usually weather to a deep reddish-brown or gray. When a complete sequence can be observed, the deposits grade upward from a basal gravel and coarse sand to medium sand to silt or clay.

Alluvial terrace gravel units are distinctive in that the quartz clasts are generally frosted, pitted, and iron-stained and the chert is usually friable and tripolitic. Rounded and polished ironstone, rounded, iron-cemented sandstone, and fairly abundant pebbles of Pottsville sandstone and shale occur in these gravel deposits (fig. 42). The quartz pebbles consist both of vein and metamorphic varieties. Some banded agate, silicified wood, and oolitic, siliceous pebbles have also been observed. John W. Reynolds (1968, written communication) has reported pebbles of rhyolite and limestone in these gravel beds. These clasts were not observed by the author *in situ*, but were studied from the collections made by John W. Reynolds. Generally, in the Cottondale area, alluvial terrace deposit pebbles are larger in size than the majority of those in the Eoline or unnamed upper member of the Coker Formation. In addition, in some localities alluvial terrace deposit pebbles are not bedded in the same manner as the Coker Formation pebbles which usually are not well imbricated. Alluvial terrace gravels are, in

Figure 40. Sand beds of the alluvial terrace deposits, NE$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle (scale is .6 m).

Figure 41. Interbedded sand, clay, and gravel beds of the alluvial terrace deposits, NW$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 22, T. 21 S., R. 10 W., Tuscaloosa quadrangle (scale is .6 m and is circled).

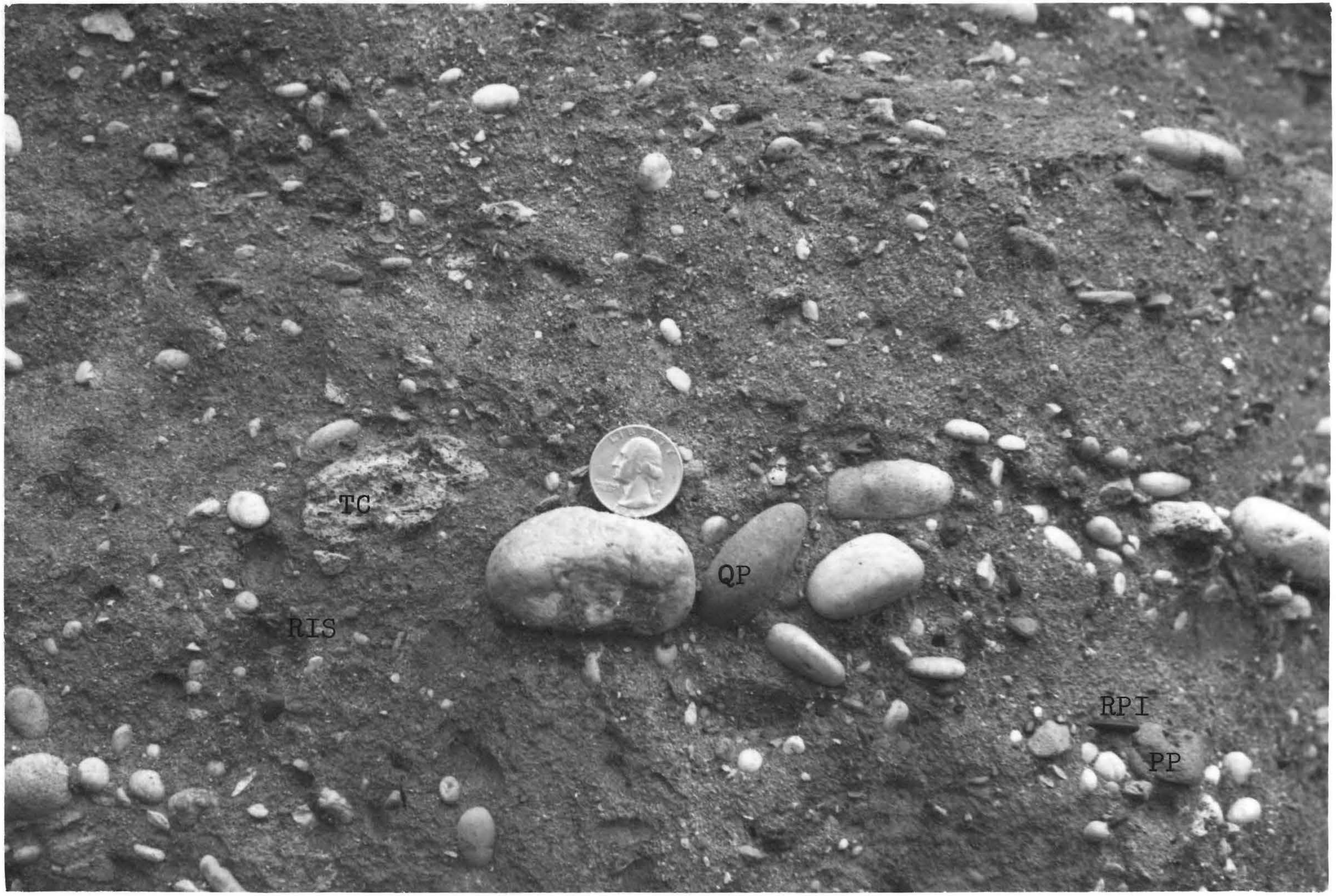


Figure 42. Tripolitic chert (TC), rounded and polished ironstone (RPI), rounded iron-cemented sandstone (RIS), frosted, ironstained quartz pebbles (QP), and Pottsville pebbles (PP) of the alluvial terrace deposits, SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle.

some places, imbricated and massively crossbedded (fig. 43), and in other places take on a chaotic appearance that may result from "colluvial" movement. Some Coker Formation pebbles are also bedded in this chaotic manner. Locally, pebbles that are characteristic of the Eoline member are found in the alluvial terrace deposits, indicating that these deposits were derived in part from reworked Eoline. John W. Reynolds (1968, written communication) reports that chert comprises 90 percent of the alluvial terrace gravels; Naff (1940) reports that the gravel consists predominately of quartz; Paulson and others (1962) report that near the Black Warrior River the gravel units are chiefly quartz; and Stow and Hughes (in preparation) report that the gravel units contain both quartz and chert. Careful field observation has revealed that gravel composition in the alluvial terrace deposits varies from predominately quartz to predominately chert from outcrop to outcrop, probably because of variations in source.

According to Miller and Causey (1958) alluvial terrace deposts are found as high as 30 to 90 m above the Black Warrior River flood plain; however no alluvial terrace deposits were observed above the 105 m elevation in the study area. Generally, the alluvial terrace deposits form a relatively flat topographic surface that may be identified in the field, on aerial photographs, or on topographic maps; however, in many places these surfaces have been severely dissected. Below Tuscaloosa, the Black Warrior River has migrated to the west and has thus cut away any alluvial terrace deposits that

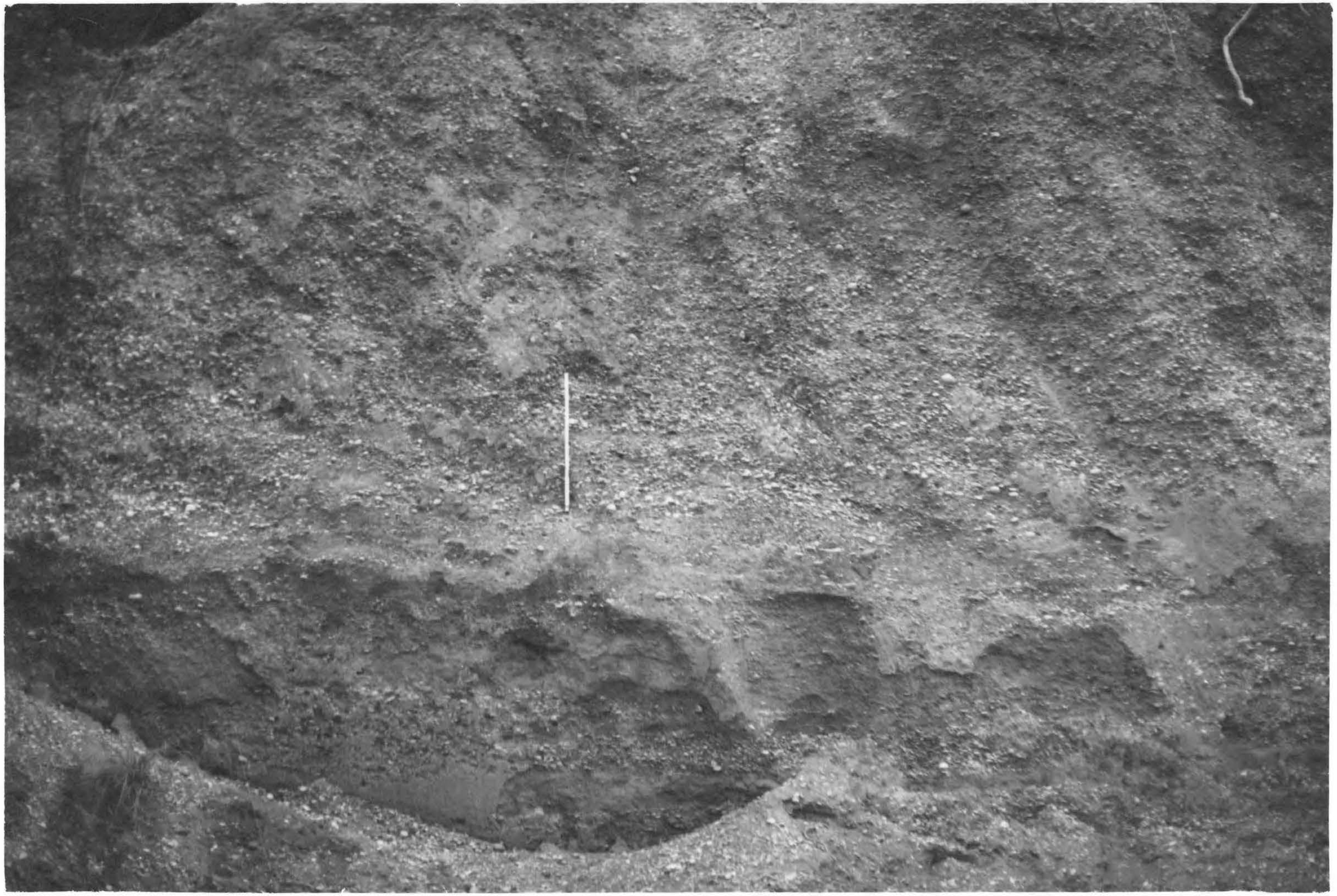


Figure 43. Typical gravel-rich massively crossbedded alluvial terrace deposit, SW¼SE¼NW¼ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle (scale is .6 m).

may have existed on that side of the flood plain (Monroe, 1941). Thicknesses vary from less than 1 m to a maximum of 17 m (Miller, 1958).

The alluvial terrace deposits unconformably overlie the Pottsville Formation (fig. 44), and the Eoline member (sand) (fig. 45), Eoline member (clay)(fig. 46), and the unnamed upper member of the Coker Formation (figs. 47 and 48). The age of the alluvial terrace deposits has been previously discussed (p. 18).

Alluvium as thick as 24 m (Paulson and others, 1962) consisting of lenticular beds of sand, silt, carbonaceous clay, and gravel are found in the present Black Warrior River flood plain. The sand units are generally tan to white and the gravel beds contain the rounded and polished ironstone, rounded iron-cemented sandstone, and Pottsville pebbles that are characteristic of the alluvial terrace deposits. Also, clasts of coal have been found in the alluvium of the Black Warrior River.

Figure 44. Gravel and sand beds of the alluvial terrace deposits overlying the Pottsville Formation, SW$\frac{1}{4}$NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 14, T. 21 S., R. 14 W., Tuscaloosa quadrangle (scale is .6 m and is circled).

Figure 45. Gravel and sand beds of the alluvial terrace deposits overlying the Eoline member (sand), NE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 24, T. 21 S., R. 10 W., Tuscaloosa quadrangle (scale is .6 m and is circled).

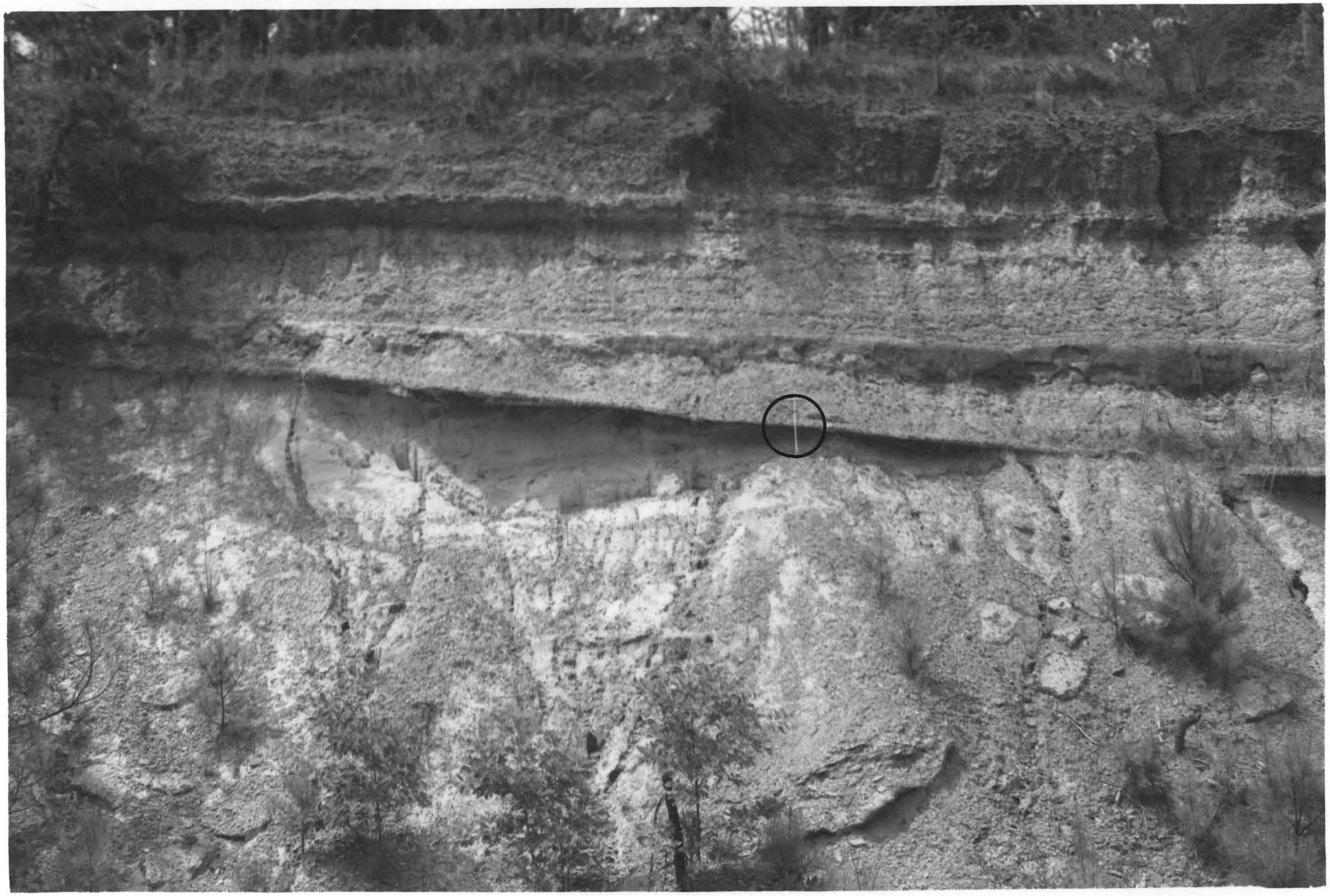


Figure 46. Alluvial terrace deposits overlying the Eoline member (clay) which in turn overlies the Eoline member (sand), NW$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 17, T. 21 S., R. 9 W., Cottondale quadrangle (scale is .6 m and is circled).

Figure 47. Probable alluvial terrace deposits overlying the fine-grained sand units of the unnamed upper member, NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 22 S., R. 9 W., Cottondale quadrangle (scale is .6 m and is circled).

Figure 48. Alluvial terrace deposits overlying the unnamed upper member, SE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 26, T. 22 S., R. 10 W., Tuscaloosa quadrangle. Slumping has obscured the contact (scale is .6 m and its base is placed at the contact).

PRESENTATION OF LABORATORY DATA

Textural, mineralogical, and geochemical analyses are presented in this section. Mineralogical analyses include data on the heavy and clay minerals present in each channel and soil sample, as well as X-ray diffraction data on "pure" clay samples. In addition, qualitative X-ray analyses are presented for the rounded and polished ironstone and rounded iron-cemented sandstone clasts collected from the alluvial terrace deposits. The detailed interpretation and discussion of these data will be deferred to later sections.

Textural Analyses

Cumulative frequency curves, histograms, and Folk and Ward (1957) descriptive measures of the size frequency distribution for each channel and soil sample are presented in Appendix 2. Table 2 summarizes these data by presenting means, standard deviations, and ranges of values for the Eoline member (sand), unnamed upper member, and alluvial terrace deposits. The Eoline member (clay), due to its distinctive lithologies that serve to differentiate it from the alluvial terrace deposits, was not sampled extensively, and is thus not included in table 2. The verbal scale suggested by Folk and Ward (1957) will be used in the following discussion.

	Eoline member (sand) channel samples (CSKes)			Unnamed upper member channel samples (CSKu)			Alluvial terrace deposit channel samples (CSQt)		
	$\bar{x}$	s	R	$\bar{x}$	s	R	$\bar{x}$	s	R
Md ($\emptyset$)	.61	1.76	-2.30 to 2.50	2.80	.55	2.24 to 3.33	.90	1.09	- .58 to 2.45
Mn ($\emptyset$)	1.19	2.28	-1.72 to 4.13	3.41	.88	2.60 to 4.85	.91	1.88	- .49 to 4.08
σ_I ($\emptyset$)	2.52	1.44	.44 to 5.04	2.38	1.33	1.29 to 4.61	3.00	.73	1.95 to 3.73
Sk_I	.46	.23	.01 to .80	.64	.30	.09 to .78	.22	.38	- .10 to .86
K_G	2.55	1.78	.59 to 5.08	2.20	1.26	.76 to 3.35	2.23	1.82	.93 to 5.10

	Eoline member (sand) soil samples (SSKes)	Unnamed upper member soil samples (SSKu)	Alluvial terrace deposit soil samples (SSQt)
	$\bar{x}$	$\bar{x}$	$\bar{x}$
Md ($\emptyset$)	2.58	3.95	2.61
Mn ($\emptyset$)	3.42	4.16	2.97
σ_I ($\emptyset$)	2.85	1.83	3.24
Sk_I	.44	.07	.25
K_G	.98	2.06	2.31

Table 2. Summary of channel and soil sample textural data ($\bar{x}$ = mean; s = standard deviation; R = range; Folk and Ward (1957) Md = median, Mn = mean, σ_I = sorting, Sk_I = skewness, K_G = kurtosis).

From table 2 it can be seen that the channel samples selected from each unit are generally very poorly sorted, though the alluvial terrace deposit samples are more poorly sorted than the samples collected from the Cretaceous units. In addition, the mean values for skewness of samples obtained from the two Cretaceous units show that these deposits are very positively skewed; whereas, those from the alluvial terrace deposits are only positively skewed. Mean channel sample values indicate that all three units' cumulative frequency curves are leptokurtic. Standard deviations and ranges were so great that further statistical analyses of these data were of little use.

Only the means of the Folk and Ward (1957) size distribution parameters were calculated for the soil samples from each unit because of the small number of samples collected. Eoline member (sand) and alluvial terrace deposit soil samples are generally very poorly sorted, the alluvial terrace deposit samples being the most poorly sorted, whereas the unnamed upper member samples are poorly sorted. The mean skewness values from samples of each unit indicate that the Eoline member (sand) soils are generally very positively skewed; the unnamed upper member is nearly symmetrical; and the alluvial terrace deposits are positively skewed. Mean soil sample values for kurtosis show that the Eoline member (sand) is mesokurtic; whereas, the unnamed upper member and the alluvial terrace deposits are very leptokurtic. The alluvial terrace deposit soil samples seem to be generally the most leptokurtic. The sample mean and median particle sizes for the soils of each unit are generally smaller than those for the channel samples.

Mineralogical Analyses

A detailed description of the light fraction of the Cretaceous units in the subsurface of the Cottondale area can be found in Monroe and others (1964). This includes a description of the composition, texture, and morphology of the light fraction, as well as identification of quartz types. Qualitative examination of the alluvial terrace deposits in outcrop yielded results similar to those of Monroe and others (1964). Data on the heavy minerals; clay minerals; and rounded and polished ironstone, and rounded iron-cemented sandstone clasts of the alluvial terrace deposits and the Cretaceous units in outcrop of the Cottondale area will be presented in the following sections.

Heavy Minerals

The average heavy mineral content for the samples collected from each unit is summarized in table 3. Both opaque and nonopaque minerals were identified. The heavies are similar to Goldstein's (1942) East Gulf Province assemblage. Tables 4 through 9 show the heavy mineral content of each channel and soil sample while Appendix 3 lists the heavy mineral content for each sample at $\frac{1}{2}$ ϕ intervals. Confidence limits (t tests) were run on the means of the heavy mineral

Mineral Species	CSKes			CSKec[1]			CSKu		
	$\bar{x}$ (%)	s (%)	R (%)	$\bar{x}$ (%)	s (%)	R (%)	$\bar{x}$ (%)	s (%)	R (%)
Ilmenite	27.29	11.33	2.78 to 47.20	39.81	-	-	34.90	14.76	16.72 to 47.15
Magnetic minerals	.48	.58	.04 to 2.10	.44	-	-	.73	.47	.22 to 1.38
Other opaques	38.58	20.90	20.28 to 93.48	37.43	-	-	38.41	13.22	25.43 to 55.69
Garnet	.07	.14	0 to .40	0	-	-	.08	.14	0 to .30
Kyanite	9.03	5.76	1.26 to 17.58	2.12	-	-	5.95	3.03	2.88 to 9.98
Rutile	.71	.54	0 to 1.71	1.10	-	-	.78	.83	0 to 1.88
Staurolite	9.55	5.38	1.08 to 18.53	5.12	-	-	7.03	3.05	4.15 to 11.26
Tourmaline	8.79	3.98	.98 to 13.62	7.67	-	-	7.48	1.79	4.53 to 9.30
Zircon	3.89	3.37	.24 to 12.32	6.29	-	-	4.32	1.88	2.16 to 7.11
Others	.38	.47	0 to 1.31	0	-	-	.33	.66	0 to 1.51
Weight % Total Sample	.31	.18	.10 to .78	.49	-	-	.51	.05	.47 to .61

[1]Only 1 sample collected.

Table 3. Mean heavy mineral content ($\bar{x}$), standard deviation (s), and range (R) of each unit. CSKes = Eoline member (sand) channel samples; CSKec = Eoline member (clay) channel sample; CSKu = unnamed upper member channel samples.

Mineral Species	CSQt			SSKes			SSKec[1]		
	$\bar{x}$ (%)	s (%)	R (%)	$\bar{x}$ (%)	s (%)	R (%)	$\bar{x}$ (%)	s (%)	R (%)
Ilmenite	10.13	5.22	3.98 to 16.74	33.62	3.46	30.03 to 36.60	5.18	–	–
Magnetic minerals	1.50	1.79	.08 to 16.74	4.26	3.09	.95 to 8.42	12.50	–	–
Other opaques	79.97	7.47	71.66 to 91.79	32.58	9.46	22.70 to 41.74	78.23	–	–
Garnet	.14	.30	.04 to .35	.13	.16	0 to .34	.77	–	–
Kyanite	1.60	1.05	.67 to 3.20	4.33	1.50	2.15 to 5.35	.48	–	–
Rutile	.42	.46	0 to 1.08	1.33	.39	1.04 to 1.87	.17	–	–
Staurolite	1.40	1.22	.34 to 3.44	6.80	2.12	3.69 to 8.42	1.03	–	–
Tourmaline	2.16	1.43	.87 to 4.36	9.47	3.03	6.52 to 13.62	1.09	–	–
Zircon	2.65	2.73	.11 to 4.82	7.40	2.75	3.78 to 10.47	.53	–	–
Others	.02	.05	0 to .11	.11	.08	0 to .19	.05	–	–
Weight % Total Sample	.51	.25	.19 to .81	.28	.08	.21 to .41	.59	–	–

[1]Only 1 sample collected.

Table 3. Continued (CSQt = alluvial terrace deposit channel samples; SSKes = Eoline member (sand) soil samples; SSKec = Eoline member (sand) soil sample).

Mineral Species	SSKu[2]			SSQt		
	$\bar{x}$ (%)	s (%)	R (%)	$\bar{x}$ (%)	s (%)	R (%)
Ilmenite	19.86	–	–	21.40	9.99	9.71 to 36.87
Magnetic minerals	3.25	–	–	7.16	5.62	.70 to 15.06
Other opaques	56.02	–	–	41.92	18.24	16.64 to 64.07
Garnet	.08	–	–	.49	.36	0 to 1.01
Kyanite	3.67	–	–	4.61	2.31	1.97 to 7.41
Rutile	1.35	–	–	1.72	.95	.76 to 2.99
Staurolite	5.81	–	–	7.05	3.49	3.69 to 11.68
Tourmaline	5.56	–	–	5.10	1.76	3.01 to 6.78
Zircon	4.28	–	–	10.52	4.80	5.44 to 15.51
Others	.12	–	–	.04	.07	0 to .19
Weight % Total Sample	.46	–	–	.29	.12	.16 to .47

[2] Only 2 samples collected.

Table 3. Continued (SSKu = unnamed upper member soil samples; SSQt = alluvial terrace deposit soil samples).

Mineral Species	Sample Number											
	CSKes											CSKec
	1	2	3	4	5	6	7	8	9	10	11	1
Ilmenite	22.30	23.68	33.37	31.26	30.49	23.44	2.76	47.20	37.11	28.65	19.92	39.81
Magnetic minerals	.20	.08	.43	.37	.40	.42	.06	2.10	.82	.40	.04	.44
Other opaques	30.36	30.36	26.24	23.09	27.05	56.09	93.45	20.28	33.86	44.81	38.78	37.43
Garnet	0	.40	0	0	0	0	.10	.21	0	.08	.02	0
Kyanite	15.18	6.63	4.02	17.58	14.88	5.41	1.26	3.94	7.33	7.03	16.08	2.12
Rutile	0	.29	.11	.93	.71	.95	.02	1.71	1.09	.97	1.02	1.10
Staurolite	18.53	7.77	15.57	14.17	10.23	5.18	1.08	4.79	5.98	7.88	13.92	5.12
Tourmaline	11.18	13.62	13.24	9.38	13.44	4.95	.98	6.13	7.65	6.95	9.21	7.67
Zircon	1.45	3.03	6.61	2.78	2.68	3.55	.24	12.32	5.85	3.22	1.02	6.29
Others	1.25	.35	.42	.47	.06	tr	0	1.31	.33	0	.02	0

Table 4. Heavy mineral content of Eoline member channel samples.

Mineral Species	Sample Number				
	CSKu				
	1	2	3	4	5
Ilmenite	16.72	47.15	45.67	21.00	43.96
Magnetic minerals	.22	1.38	.32	.94	.78
Other opaques	49.22	31.55	30.17	55.69	25.43
Garnet	0	.30	0	.11	0
Kyanite	9.98	3.20	5.86	7.83	2.88
Rutile	0	.55	1.88	1.40	.08
Staurolite	11.26	4.15	6.15	4.56	9.04
Tourmaline	7.51	8.31	7.77	4.53	9.30
Zircon	5.06	3.30	2.16	3.96	7.11
Others	0	.12	0	0	1.51

Table 5. Heavy mineral content of unnamed upper member channel samples.

Mineral Species	Sample Number				
	CSQt				
	1	2	3	4	5
Ilmenite	13.38	10.53	6.05	3.98	16.74
Magnetic minerals	.51	.44	.08	2.08	4.39
Other opaques	71.66	80.69	79.46	91.79	76.25
Garnet	.10	.35	.14	.04	.09
Kyanite	3.20	2.09	1.21	.67	.83
Rutile	.70	.31	1.08	.03	0
Staurolite	3.44	1.04	1.50	.34	.68
Tourmaline	2.12	2.54	4.36	.91	.87
Zircon	4.82	2.02	6.13	.11	.18
Others	.11	0	0	.01	0

Table 6. Heavy mineral content of alluvial terrace deposit channel samples.

Mineral Species	Sample Number				
	SSKes				SSKec
	1	2	3	4	1
Ilmenite	31.21	36.60	30.03	36.50	5.18
Magnetic minerals	4.08	.98	3.54	8.42	12.50
Other opaques	41.74	22.70	39.52	26.35	78.23
Garnet	0	0	.34	.18	.77
Kyanite	2.15	5.35	4.53	5.28	.48
Rutile	1.04	1.87	1.05	1.34	.17
Staurolite	3.69	8.42	7.45	7.64	1.03
Tourmaline	8.18	13.62	9.54	6.52	1.09
Zircon	7.73	10.47	3.78	7.63	.53
Others	.09	0	.19	.14	.05

Table 7. Heavy mineral content of Eoline member soil samples.

Mineral Species	Sample Number SSKu 1	2
Ilmenite	13.03	26.69
Magnetic minerals	3.41	3.09
Other opaques	60.47	51.56
Garnet	.16	0
Kyanite	4.51	2.83
Rutile	1.79	.91
Staurolite	6.96	4.65
Tourmaline	5.01	6.10
Zircon	4.52	4.03
Others	.10	.13

Table 8. Heavy mineral content of unnamed upper member soil samples.

Mineral Species	Sample Number				
	SSQt				
	1	2	3	4	5
Ilmenite	36.87	19.63	23.39	17.42	9.71
Magnetic minerals	5.74	15.06	3.99	.70	10.31
Other opaques	16.64	41.11	34.09	53.69	64.07
Garnet	0	.51	.41	1.01	.51
Kyanite	7.41	5.29	5.87	1.97	2.49
Rutile	2.99	.76	1.96	2.10	.78
Staurolite	11.68	6.34	9.52	4.00	3.69
Tourmaline	6.78	5.66	6.46	3.60	3.01
Zircon	11.88	5.47	14.28	15.51	5.44
Others	0	.19	0	0	0

Table 9. Heavy mineral content of alluvial terrace deposit soil samples.

content of each unit. Overlap of these limits occurred even at the 80 percent level; however, certain trends can be noted.

For example, in the channel samples, the mean order of abundance of heavies is generally: opaques (ilmenite + magnetic minerals + other opaques), staurolite, kyanite, tourmaline, and zircon for the Eoline member (sand); opaques, tourmaline, staurolite, kyanite, and zircon for the unnamed upper member; and opaques, zircon, tourmaline, kyanite, and staurolite for the alluvial terrace deposits. All alluvial terrace deposit channel samples contain garnet, whereas about one half of the Cretaceous deposit channel samples contain garnet. In addition, the alluvial terrace deposit samples contain more garnet than the Cretaceous deposits. Magnetic minerals plus other opaques tend to be more abundant in the alluvial terrace deposit channel samples than in the Cretaceous deposit samples, whereas ilmenite tends to be more abundant in the Cretaceous deposit samples. Generally, alluvial terrace deposit samples contain the greatest abundance of total opaque heavy minerals. Trends in the soil samples are less obvious.

Opaques

Opaque heavy minerals were separated into three categories:

Ilmenite.--Ilmenite occurs as black to bluish-gray, rounded to subangular grains, many of which are partially coated with, or altered to leucoxene, as defined by Lynd (1960), limonite, goethite, hematite, and possibly rutile. According to Temple (1966), grains of ilmenite that alter to rutile should be called pseudorutile. These grains were counted as rutile when complete alteration had taken place (see p. 104). If the grain appeared to be >50 percent unaltered, it was counted as ilmenite.

Magnetite (magnetic fraction).--Magnetite occurs as rounded to subangular, equant to elongate, black grains that in some samples have been altered in part to hematite, geothite, or limonite. Some grains exhibit octahedral parting.

The magnetic fractions of each unit were combined and X-rayed with the following results: The alluvial terrace deposits and unnamed upper member samples contained, as major constituents, magnitite, goethite, and hematite with minor amounts of rutile, ilmenite, quartz, muscovite, and clay. The Eoline member (clay) contained, as major constituents, magnetite, goethite, and hematite with minor amounts of rutile, quartz, muscovite, and clay. The Eoline member (sand) contained major amounts of magnetite and ilmenite with minor amounts of hematite and goethite, and trace amounts of quartz and muscovite. The presence of maghemite was suspected in each sample, though the peaks were not definitive.

Other Opaques.--These include discrete rounded to subangular grains of leucoxene, goethite, limonite, and hematite. Leucoxene occurs as gray-white to white, rounded to subangular, porous grains completely altered from ilmenite or rutile, and as coatings on rutile, ilmenite, and magnetite. If the grain appeared to be >50 percent altered, it was counted as "other opaques." Goethite, ilmonite, and hematite occur as alterations of ilmenite and magnetite and as discrete yellow, orange, reddish, or brown grains.

Nonopaques

The nonopaque heavy minerals consist predominately of garnet, kyanite, rutile, staurolite, tourmaline, and zircon. Minor amounts of monazite, sillimanite, andalusite, gahnite, biotite, muscovite, and possible sphene and cassiterite also are present. These minor nonopaques and grains that could not be identified are included under the heading "others."

Many of the heavy mineral species show signs of a multicyclic origin and more than one source area (i.e., presence of angular and rounded, or euhedral and rounded grains of the same species). A description of the major nonopaque heavy minerals follows.

Garnet.--Garnet occurs as red to green to clear, rounded to angular, grooved and pitted, equant grains that showed distinct conchoidal fracture and generally contained abundant inclusions of opaque minerals. Some of the garnets were partially altered. The most abundant variety was red (probably almandite) garnet.

Kyanite.--Kyanite occurs as clear to very pale blue, prismatic, elongate grains that contained abundant dark and clear inclusions and distinctive cleavage. A few grains were subrounded. Some of the elongate grains were slightly curved and highly cross-fractured.

Rutile.--Detrital rutile occurs as deep red to deep yellow and, at times almost opaque, subrounded to subangular grains. A few deep reddish-brown grains were noted and it is suspected that these grains may represent pseudorutile altered from ilmenite (Temple, 1966). Szabo (1972) and Rosen (1969) report the occurrence of pseudorutile in the Alabama River alluvial terrace deposits and the Citronelle Formation, respectively. Pseudorutile grains were too few in number to significantly affect the total rutile percent reported.

Staurolite.--Staurolite occurs as yellow- to reddish-brown to straw yellow, angular to subrounded, pleochroic grains with abundant black inclusions. Some grains have very ragged edges.

Tourmaline.--Tourmaline occurs as black, blue, green, clear, gray, brown, yellow, and reddish-brown, highly pleochroic, elongate to equant, rounded to subangular to euhedral grains. Terminations and striations were observed on a few grains. Dark and clear inclusions were common.

Zircon.--Zircon occurs as well-rounded to rounded to slightly euhedral, pink and clear, elongate to equant grains, some of which contained clear and dark inclusions.

Clay Minerals

The predominant clay mineral present in most channel, soil, and clay samples was illite with minor amounts of kaolinite. Minor amounts of vermiculite, montmorillonite, chlorite, and glauconite were identified in some samples. Table 10 presents data on kaolinite/illite (K/I) peak intensity ratios and table 11 summarizes clay minerals present with descriptions of kaolinite and illite peaks. In general, peak intensity K/I ratios of the alluvial terrace deposits are much lower than those of the Cretaceous deposits. Also, the peaks of both illite and kaolinite in the alluvial terrace deposits are relatively low and diffuse compared to those of the Cretaceous deposits. Confidence limits (t tests) on the means of the clay for each unit were run. Due to the small number of samples and relatively large standard deviations, overlaps of these limits occurred even at the 80 percent level. Too few soil and clay grab samples were collected for statistical analysis.

Rounded and Polished Ironstone and Rounded Iron-cemented Sandstone Clasts

Major amounts of goethite and quartz, minor amounts of kaolinite, illite, vermiculite, and hematite with possible magnetite and maghemite were identified by routine X-ray analysis of rounded and polished ironstone clasts collected from various alluvial terrace deposits.

Kes Sample No.	Kes K/I ratio	Kec Sample No.	Kec K/I ratio	Ku Sample No.	Ku K/I ratio	Qt Sample No.	Qt K/I ratio	Cpv Sample No.	Cpv K/I ratio	Qal Sample No.	Qal K/I ratio
CS 1	3.00	CS 1	3.82	CS 1	3.82	CS 1	1.24	–	–	–	–
2	2.89			2	1.54	2	–				
3	2.07			3	1.61	3	1.18				
4	3.11			4	1.72	4	1.06				
5	3.50			5	1.41	5	.66				
6	3.39										
7	3.10										
8	1.43										
9	2.47										
10	1.61										
11	2.42										
$\bar{x}$	2.64		–		1.90		1.04		–		–
s	.70		–		1.09		.26		–		–
R	3.50 to 1.43		–		1.12 to 3.82		.66 to 1.24		–		–
SS 1	.54	SS 1	1.00	SS 1	2.77	SS 1	–	–	–	–	–
2	–			2	–	2	1.34				
3	.84					3	–				
4	–					4	1.0				
						5	–				
$\bar{x}$	.69		–		–		1.22		–		–

Table 10. Summary of kaolinite to illite (K/I) peak intensity ratios for channel (CS), soil (SS), and clay (Cl) samples (Eoline member (sand) = Kes, Eoline member (clay) = Kec, unnamed upper member = Ku, alluvial terrace deposits = Qt, Pottsville Formation = Cpv, flood-plain alluvium = Qal).

Kes Sample No.	K/I ratio	Kec Sample No.	K/I ratio	Ku Sample No.	K/I ratio	Qt Sample No.	K/I ratio	Cpv Sample No.	K/I ratio	Qal Sample No.	K/I ratio
Cl 1	1.79	Cl 1	1.02	Cl 1	2.20	Cl 1	1.33	Cl 1	1.10	Cl 1	1.52
2	1.56	2	1.08	2	1.05			2	1.50		
3	2.83			3	.90			3	.30		
4	2.66										
5	1.75										
$\bar{x}$	2.12		1.05		1.38		-		.97		-

Table 10. Continued

Sample Number	Description of Peaks				
	Kaolinite (7.15Å)	Illite (10.16Å)	Vermiculite (14.2Å)	Montmorillonite (15.4Å)	Others
CSKes- 1	sharp	sharp	-	-	-
2	sharp	sharp	-	-	-
3	sharp	sharp	-	-	-
4	sharp	very sharp	-	-	-
5	sharp	very sharp	-	-	-
6	sharp	sharp	-	-	-
7	sharp	sharp	-	-	-
8	sharp	sharp	-	-	-
9	sharp	sharp	-	-	-
10	sharp	sharp	-	-	-
11	sharp	sharp	-	-	glauconite
CSKec- 1	extremely sharp	extremely sharp	-	-	-
CSKu- 1	sharp	sharp	-	-	-
2	sharp	sharp	-	-	-
3	very sharp	very sharp	-	-	-
4	sharp	sharp	-	-	-
5	sharp	sharp	-	-	-
CSQt- 1	diffuse	diffuse	-	-	-
2	very diffuse	very diffuse	-	-	-
3	diffuse	diffuse	-	-	-
4	diffuse	diffuse	-	-	-
5	diffuse	diffuse	-	-	-

Table 11. Summary of clay minerals present in each sample with a qualitative description of kaolinite, illite, vermiculite, and montmorillonite peaks (see table 10 for explanation of sample numbers).

Sample Number	Description of Peaks				
	Kaolinite (7.15Å)	Illite (10.16Å)	Vermiculite (14.2Å)	Montmorillonite (15.4Å)	Others
SSKes- 1	diffuse	sharp	-	-	-
2	very diffuse	very diffuse	-	-	-
3	diffuse	diffuse	low, sharp	-	-
4	-	-	-	-	-
SSKec- 1	fairly sharp	fairly sharp (doubled)	-	-	-
SSKu- 1	sharp	sharp	-	-	-
2	-	-	-	-	-
SSQt- 1	-	-	low, diffuse	-	-
2	very diffuse	very diffuse	-	-	-
3	-	-	-	-	-
4	fairly sharp	fairly sharp	-	-	-
5	-	diffuse	-	-	-
ClKes- 1	fairly sharp	fairly sharp	-	-	-
2	fairly sharp	fairly sharp	-	-	-
3	sharp	sharp	-	-	-
4	sharp	sharp	-	-	-
5	sharp	sharp	low, fairly sharp	-	-
ClKec- 1	sharp	sharp	-	-	-
2	sharp	sharp	-	-	-
ClKu- 1	fairly sharp	fairly sharp	-	-	-

Table 11. Continued

Sample Number	Description of Peaks				
	Kaolinite (7.15Å)	Illite (10.16Å)	Vermiculite (14.2Å)	Montmorillonite (15.4Å)	Others
ClKu- 2	fairly sharp	fairly sharp	–	fairly sharp	–
3	diffuse	fairly sharp	–	–	–
ClQt- 1	sharp	sharp	low, sharp	low, sharp	chlorite
ClCpv- 1	sharp	sharp	low, diffuse	–	–
2	diffuse	fairly sharp	–	–	–
3	fairly sharp	sharp	sharp	–	–
ClQal- 1	diffuse	diffuse	diffuse	diffuse	chlorite

Table 11. Continued

Major amounts of goethite, hematite, and quartz were identified by X-ray analysis of rounded iron-cemented sandstone collected from alluvial terrace deposits. The compositions of angular iron-cemented sandstone in various Cretaceous units were similar to those of the alluvial terrace deposits.

Geochemical Analyses

Table 12 summarizes the geochemical analyses carried out on channel, soil, and clay samples selected to be representative of the Pottsville and Coker Formations and the alluvial terrace deposits. Unfortunately, with the possible exception of the Eoline member (sand), too few samples were analyzed for the units to draw any valid statistical conclusions. Generally, however, the alluvial terrace deposit channel samples tend to be higher in total iron than the Cretaceous samples. Soil samples tend to be lower in total iron than channel samples; whereas, clay samples seem to fall between the two extremes.

Sample Number	Al_2O_3	SiO_2	MgO	CaO	Fe_2O_3	FeO	TiO_2	K_2O	Na_2O	MnO	Loss on Ignition (LOI)
CSKes- 3	13.3	75.8	0.23	0.23	2.58	0.26	0.96	3.18	0.26	0.06	3.22
5	12.6	78.9	0.23	0.24	1.75	0.24	0.70	0.52	0.08	0.05	4.68
6	14.2	72.8	0.26	0.23	4.83	0.21	0.76	0.54	0.09	0.06	6.02
7	12.7	68.3	0.28	0.23	10.50	0.23	0.64	0.39	0.09	0.05	6.56
8	18.1	62.7	0.35	0.26	7.18	0.29	2.53	0.76	0.11	0.08	7.62
10	20.9	60.3	0.38	0.22	5.59	0.26	2.41	0.84	0.12	0.05	8.98
11	3.9	91.2	0.08	0.21	1.49	0.09	0.83	0.92	0.09	0.05	1.18
$\bar{x}$	13.7	72.9	.26	.23	4.85	.23	1.26	1.02	.12	.06	5.47
CSKec- 1	11.8	76.6	0.33	0.21	2.82	0.16	1.92	3.07	0.22	0.05	2.86
CSKu- 1	17.9	71.7	0.22	0.24	1.33	0.12	1.40	0.84	0.12	0.06	6.10
2	18.2	66.2	0.42	0.25	3.76	0.45	2.43	1.15	0.12	0.07	6.98
$\bar{x}$	18.0	68.9	0.32	0.25	2.55	0.29	1.92	1.00	0.12	0.07	6.54
CSQt- 2	13.9	67.4	0.34	0.23	9.76	0.40	0.65	0.49	0.07	0.07	6.73
3	16.4	65.6	0.39	0.07	7.25	0.21	1.17	0.91	0.09	0.05	7.92
$\bar{x}$	15.1	66.5	0.37	0.15	8.51	.31	.91	.70	.08	.06	7.33
SSKes- 1	7.7	83.4	0.23	0.09	2.20	0.28	1.46	1.13	0.15	0.06	3.33
SSQt- 1	5.9	85.9	0.23	0.15	1.48	0.27	1.71	0.78	0.19	0.09	3.33
3	6.5	84.3	0.23	0.11	1.65	0.36	1.62	0.68	0.16	0.09	4.28
$\bar{x}$	6.2	85.1	0.23	0.13	1.57	0.32	1.67	0.73	0.18	0.09	2.81

Table 12. Geochemical analyses of selected channel (CS), soil (SS), and clay (Cl) samples (see table 10 for explanation of sample numbers).

Sample Number	Al_2O_3	SiO_2	MgO	CaO	Fe_2O_3	FeO	TiO_2	K_2O	Na_2O	MnO	Loss on Ignition (LOI)
ClKes- 3	17.8	66.5	0.35	0.07	5.43	0.11	1.56	0.99	0.14	0.06	6.97
ClKec- 2	15.3	67.5	0.72	0.12	6.17	0.10	1.41	1.75	0.16	0.10	6.54
ClKu- 2	14.5	74.5	0.51	0.08	2.20	0.11	1.34	1.46	0.14	0.05	5.08
ClCpv- 1	15.0	70.3	0.82	0.12	3.87	0.23	1.68	1.72	0.18	0.06	6.00

Table 12. <u>Continued</u>

INTERPRETATION OF DATA

An interpretation of each set of data (i.e., field, textural, mineralogical, and geochemical) will be presented in this section. Only those data that bear directly on the differentiation of alluvial terrace deposits from the Coker Formation will be discussed, with the exception of an explanation of the mineralogical and geochemical differences between channel and soil samples. In addition, the Coker Formation and alluvial terrace deposits will be classified texturally, mineralogically, and geochemically.

Field

Those megascopic field data that tend to distinguish the alluvial terrace deposits from the Coker Formation will now be discussed.

Generally, alluvial terrace deposits are deeper red in color than the Coker Formation due to a greater iron content in the alluvial terrace deposits (i.e., the remobilized, oxidized iron in the alluvial terrace deposits has not yet been leached and/or eluviated out). This iron was probably derived from the upland soils of the Black Warrior drainage basin as brown ferric oxide. In some places more than one half of the total iron concentrated in a sediment is found in the clay fraction (Van Houten, 1972). Carroll (1958) has noted that detrital hematite and limonite are carried mainly as colloids or adsorbed coatings on fine-grained materials. In an oxidizing environment, brown amorphous and hydrated ferric oxide pigments in the muddy alluvium dehydrate to red hematite, while magnitite and ilmenite are eventually oxidized to hematite, thus imparting a red color to the beds (Van Houten, 1968, 1972). Walker (1974) has found that interstitial water in moist tropical climates occurs in the Eh-pH stability field of hematite. This might be extrapolated to humid subtropical climates. Thus, conditions would be favorable for the oxidation of various iron minerals. Oxidation of glauconite and siderite with time would yield the same results (i.e., red coloration). It should be noted that Bryan (1963) reports hematite, limonite, and glauconite in the Pottsville Formation, which is a probable detrital source for some of the alluvial terrace deposits.

Alluvial terrace deposits underlie geomorphic terrace surfaces that are usually fairly flat and regular and occur at predictable elevations ($<$105 m). For example, the community of Cottondale in sections 26 and 27, T. 21 S., R. 9 W., Cottondale quadrangle is built on such a surface. All flat geomorphic surfaces, however, are not underlain by alluvial terrace deposits. Unfortunately, because most terraces are highly dissected in the study area, and terrace surfaces, as geomorphic forms, are not completely flat to begin with (Johnson, 1944), this criterion based on topographic expression can be used only in a few instances.

Alluvial terrace deposits contain Pottsville sandstone and shale pebbles that range in abundance from one or two pebbles in an outcrop up to an estimated 2 to 3 percent of the pebbles exposed in an outcrop, whereas the units of the Coker Formation contain few, if any, Pottsville clasts. Either the Pottsville Formation pebbles were included in the Coker Formation and were subsequently destroyed by intrastratal solution, or they were never deposited with the Coker beds. No evidence was found to indicate that intrastratal solution destroyed the pebbles. That is, no voids or relict Pottsville pebbles were found, and the heavy minerals assemblages indicate a lack of significant intrastratal solution (see p. 130). The following are possibilities that would explain why Pottsville pebbles were never deposited with the Coker Formation: 1) the agent of deposition for the lower part of the Coker Formation was energetic enough in the Cottondale area to destroy any rock fragments derived from the Pottsville, 2) the agent of deposition was not energetic enough to rework the Pottsville, 3) the Coker was deposited so rapidly on top of the Pottsville in the Cottondale area that no, or very few Pottsville clasts were reworked and deposited in the Coker Formation. Rapid and extended alluvial transport outside the Cottondale area would destroy the Pottsville clasts derived from the northern area of outcrop, or 4) the major part of the lower Coker was derived from Pottsville soil zones where the clasts had already been broken down by chemical weathering.

When the alluvial terrace deposits were laid down, they included Pottsville clasts due to either a short distance of transport, or to the fact that the Pottsville soil zones were much thinner and bedrock was exposed. From the presence of these clasts it can also be surmised that the Pottsville Formation was, in part, a source area for the alluvial terrace deposits.

Alluvial terrace deposits usually contain friable, tripolitic chert pebbles, whereas, the chert pebbles of the Coker Formation are generally dense, compact, and non-tripolitic. This may be due to either a difference in provenance, and, thus a difference in chert type, or to a difference in weathering. That is, the silica in the chert of the alluvial terrace deposits was more easily leached due to its recent exposure to possible "lateritic" weathering near the land surface (i.e., in the soil zone). The Coker Formation chert was perhaps protected by depth of burial or impermeable clay units. When Coker Formation chert gravel is found in the soil zone, it too is tripolitic due to "lateritic" weathering. An outcrop of the unnamed upper member in section 33, T. 21 S., R. 9 W., Cottondale quadrangle north of highway U. S. 11 contains highly tripolitic chert.

Alluvial terrace deposits generally contain quartz pebbles that are frosted, pitted, dull, iron-stained, and larger than the polished quartz pebbles of the Coker Formation, except where alluvial terrace deposit gravel has been derived from the Cretaceous units (e.g., center of section 12, T. 21

S., R. 9 W., Tuscaloosa quadrangle). The frosting is probably caused by chemical etching in the zone of "lateritic" weathering, while the pitting may be caused by the percussion of one pebble against another or chemical etching. Pebbles that are dull (i.e., neither frosted nor polished) are common in fluvial deposits (Folk, 1968). Dullness of detrital grains is caused by small angular irregularities on the surface of the grain and indicates a lack of abrasive action. Leaching and eluviation of iron in the upper soil profile, with subsequent precipitation and illuviation in the lower soil profile probably caused the iron-staining of the alluvial terrace deposit pebbles. The fact that the alluvial terrace deposits have pebbles that in some cases are larger in size than the Coker pebbles is probably related to the transportation medium and/or source area.

Alluvial terrace deposit gravel is generally more rounded than that of the Coker Formation. Again this may be due to source area and/or environment of deposition (transportation medium). Brock (1974), however, shows that coarse sediment morphometry is generally a poor tool for environmental discrimination. As Clifton (1973) points out, pebble roundness and shape depend on a variety of factors that include, transportational history, depositional process, composition, and initial shape of the pebbles.

The difference in bedding characteristics of the gravel as previously mentioned (p. 76 and 80) may be of limited value in differentiation of alluvial terrace deposits from the Coker

Formation. This difference probably is due to environment of deposition. A discussion of wave-worked versus alluvial gravel has been given by Clifton (1973). He notes that wave-worked pebbles tend to be better separated into discrete beds than those of alluvial deposits. Many outcrops of the Cretaceous units exhibit the characteristic of having pebbles separated into discrete beds; however, a few Cretaceous outcrops do not exhibit this characteristic. This is probably due to the fact that all the Cretaceous gravels were not wave-worked, but may have been emplaced by littoral currents or streams. Also, possible Ostler lenses (Martini and Ostler, 1973) that may indicate fluvial gravels have been observed in a few alluvial terrace deposits.

The rounded and polished ironstone and rounded iron-cemented sandstone that is almost always present in the alluvial terrace deposits, and is generally absent in the Coker Formation probably results from the fluvial reworking of the ironstone and iron-cemented sandstone ledges that were formed in the Cretaceous deposits after the regression of the sea exposed these units to subaerial weathering. The suggestion by Drennen (1953a) that the Coker Formation is chiefly marine in origin would explain the general lack of such clasts in the Cretaceous units. Some of the rounded and polished ironstone clasts may be altered siderite. Riccio and others (1972) have used this criteria to distinguish the Citronelle Formation from the underlying Miocene units in the Mobile County area. The Citronelle is fluvial in origin and the

Miocene is marine. Maxwell (1971) reports secondary occurrence of ironstone ledges and broken, angular ironstone in the Alabama River alluvial terrace deposits.

The alluvial terrace deposits are relatively nonmicaceous, whereas, most of the Cretaceous deposits are highly micaceous (see p. 44, 59, 66, and 76). This may result from a difference in source area, or from the winnowing out of the mica by the Black Warrior River.

Certain of the laminated clay and fine-grained sand units of the Coker Formation are easily distinguished from the alluvial terrace deposits because no laminated clays have been observed thus far in the alluvial terrace deposits, and the sand of much of the Cretaceous units is generally much finer-grained than that of the alluvial terrace deposits (see Appendix 2). This would result chiefly from different environments of deposition and different source areas.

No glauconite has yet been found in any alluvial terrace deposit which would serve to distinguish these deposits from the greater part of the Eoline member (clay) and a few intervals in the other units of the Coker Formation. Recent reworking and exposure to "lateritic" weathering would explain the absence of glauconite in the alluvial terrace deposits. Because the Pottsville (Bryan, 1963) and Coker (Drennen, 1953a) Formations contain glauconite and are source areas for the alluvial terrace deposits, a few grains might be expected to be found in the more recent deposits.

No siderite or marcasite nodules have been found thus far in the alluvial terrace deposits. Thus, presence of these nodules might be used as possible negative evidence to preclude any units' containing them as being an alluvial terrace deposit.

Presence of marine fossils in the Coker Formation can serve to distinguish the Coker from the alluvial terrace deposits. However, fossils are rare in the sand and gravel beds of the Coker Formation.

Of all the previously listed field criteria, the most reliable was found to be the ubiquitous nature of the rounded and polished ironstone and rounded iron-cemented sandstone clasts in the alluvial terrace deposits, and the almost total absence of these fragments in the Coker Formation.

Textural

Though much work has been done in distinguishing environments and process of deposition on the basis of grain-size interpretation [e.g., use of binary plots of various parameters such as skewness, kurtosis, sorting, mean and median values by Passega (1957, 1964), Mason and Folk (1958), and Friedman (1961, 1967); discriminant function analysis by Sahu (1964); factor analysis by Klovan (1966); and subpopulation differentiation from cumulative frequency curves by Visher (1969)], application of these techniques proved of little value in differentiating alluvial terrace deposits from Cretaceous deposits. Virtually all binary plots possible were constructed with no evident trends. Omar and others (1974) found this to be true of the Nubia Sandstone of Egypt.

For example, as was previously mentioned for channel samples (see table 2), the alluvial terrace deposit samples are less positively skewed (thus more negatively skewed in a relative sense) than are the Cretaceous deposit samples, some of which are definitely marine in origin. This is contrary to the findings of Friedman (1961, 1967) for fluvial versus beach environments. Possibly winnowing of the fines to produce more negative skewness did not occur in the Cretaceous deposits because much of the Coker samples was deposited rapidly below wave base and therefore would not be subject to subsequent winnowing by wave action. This is supported by the poor mean sorting of the Cretaceous deposits (table 2) and the findings of Passega (1957) who states that tidal-flat sediments and sediments deposited by bottom marine (tractive) currents plot in a manner similar to river deposits on a Passega (1957) CM diagram (i.e., the depositional agents consist of essentially unidirectional currents). Possibly, unidirectional, low-velocity submarine currents were prevalent. These currents would have a finite upper limit to the size of particle that may be transported. Thus, positive skewness would result. Alternative explanations are: 1) the bivariant plots applied were too simple for effective environmental differentiation as suggested by Solohub and Klovan (1970); 2) the environment and processes of deposition were similar because skewness values are very similar (e.g., much of the Coker Formation sampled may be fluvial rather than marine in origin in the Cottondale area); 3) too few samples were analyzed for statistical validity; or 4) sampling or other operator errors were made.

Generally, the alluvial terrace deposit samples are slightly less well sorted than the Cretaceous deposit samples (see table 2), which probably reflects either a difference in environment of deposition or of source area. However, plotting sorting values against other parameters yielded no discernible trends.

A Passega (1957, 1964) CM plot was constructed (fig. 49) and from this diagram general trends can be recognized. The Cretaceous deposits fit quite well within a beach environment "envelope" while the alluvial terrace deposits fall within the bed load and graded suspension categories of Passega (1957). As was previously mentioned, it is interesting to note that tidal-flat sediments and sediments deposited by bottom marine (tractive) currents also plot in a manner similar to river deposits (Passega, 1957). The absence of a uniform suspension category for the alluvial terrace deposits results from the fact that the samples collected probably excluded flood-plain and backswamp deposits because mostly gravel and basal sand units were sampled. This also would account, in part, for the less positive mean skewness for the alluvial terrace deposits. Another possible explanation would be that the source area did not contain a significant amount of material that was available for uniform suspension transportation.

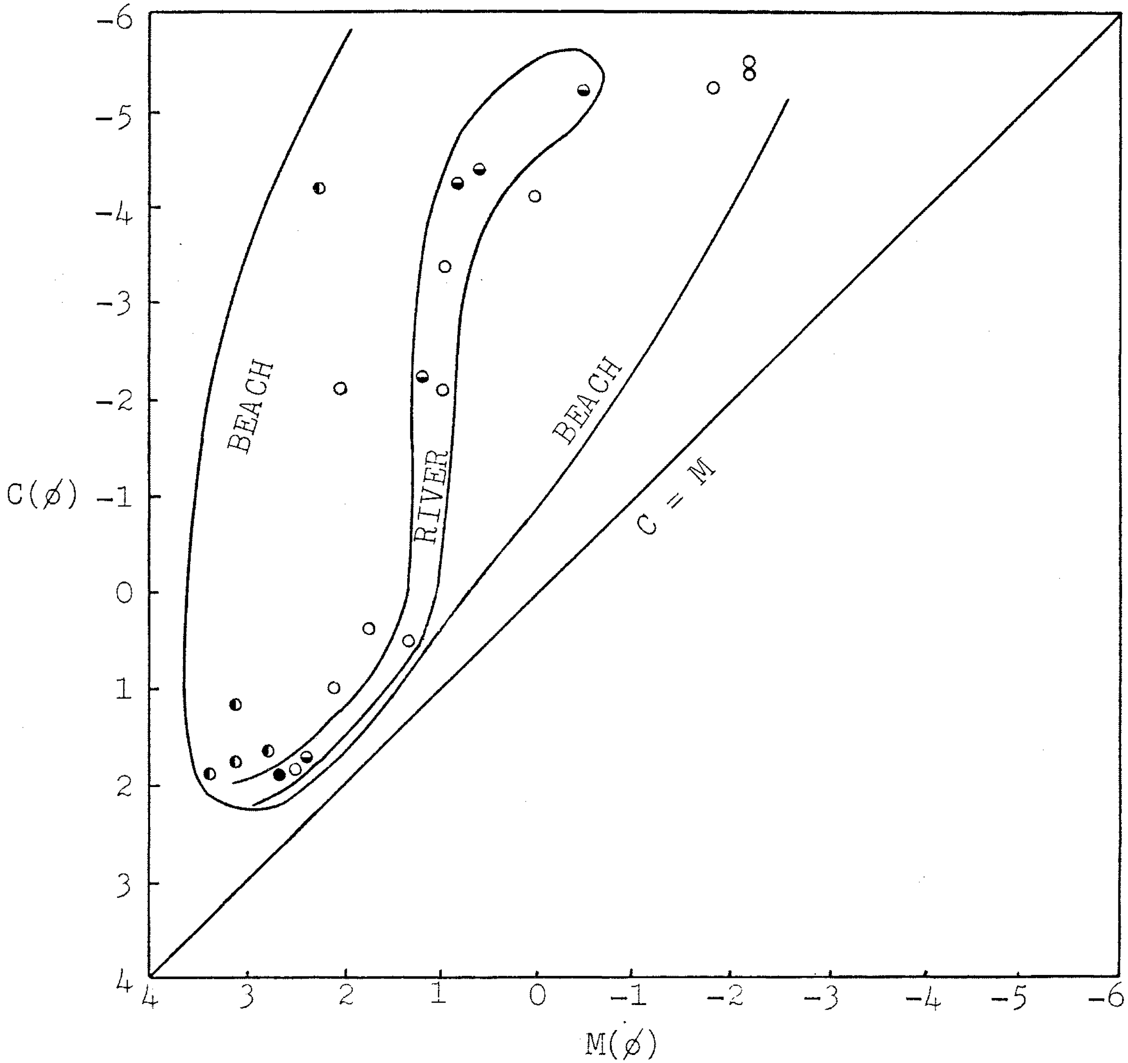


Figure 49. Passega CM plot for all channel samples (Eoline member (sand) = ○ , Eoline member (clay) = ● , unnamed upper member = ◐ , alluvial terrace deposits = ◒ , coarsest one percentile = C, median diameter = M).

Application of Visher's (1969) subpopulation technique was generally as unproductive as the various binary plots, though these cumulative frequency curves are presented in Appendix 2. This is partially due to the fact that Visher (1969) used only sand samples (i.e., he excluded deposits containing gravel). In addition, Visher's (1969) technique is extremely qualitative and does not take into account the mixing of many subpopulations. It is evident, however, from the curves that in some channel samples, as many as 5 log normal populations are present. The Eoline member (sand) samples seem to conform to those cumulative frequency curves that fall within the general "marine" and "deltaic distributary" categories, as does the one Eoline member (clay) sample, and the unnamed upper member samples. All but one of the alluvial terrace deposit samples have at least 4 log normal subpopulations, and most of the samples resemble "deltaic distributary" and not river cumulative frequency plots. This is probably due to the inclusion of gravel in the cumulative frequency plots.

Folk (1951, 1954) considers three properties necessary to uniquely and completely describe terrigenous sediments. These are grain size, textural maturity, and mineralogical composition. Figure 50 presents Folk's (1954) classification of terrigenous sediment type by texture. Cretaceous deposit samples range from sand to gravelly sand to muddy sand to slightly gravelly muddy sand to gravelly muddy sand to slightly gravelly sand to muddy sandy gravel. Alluvial

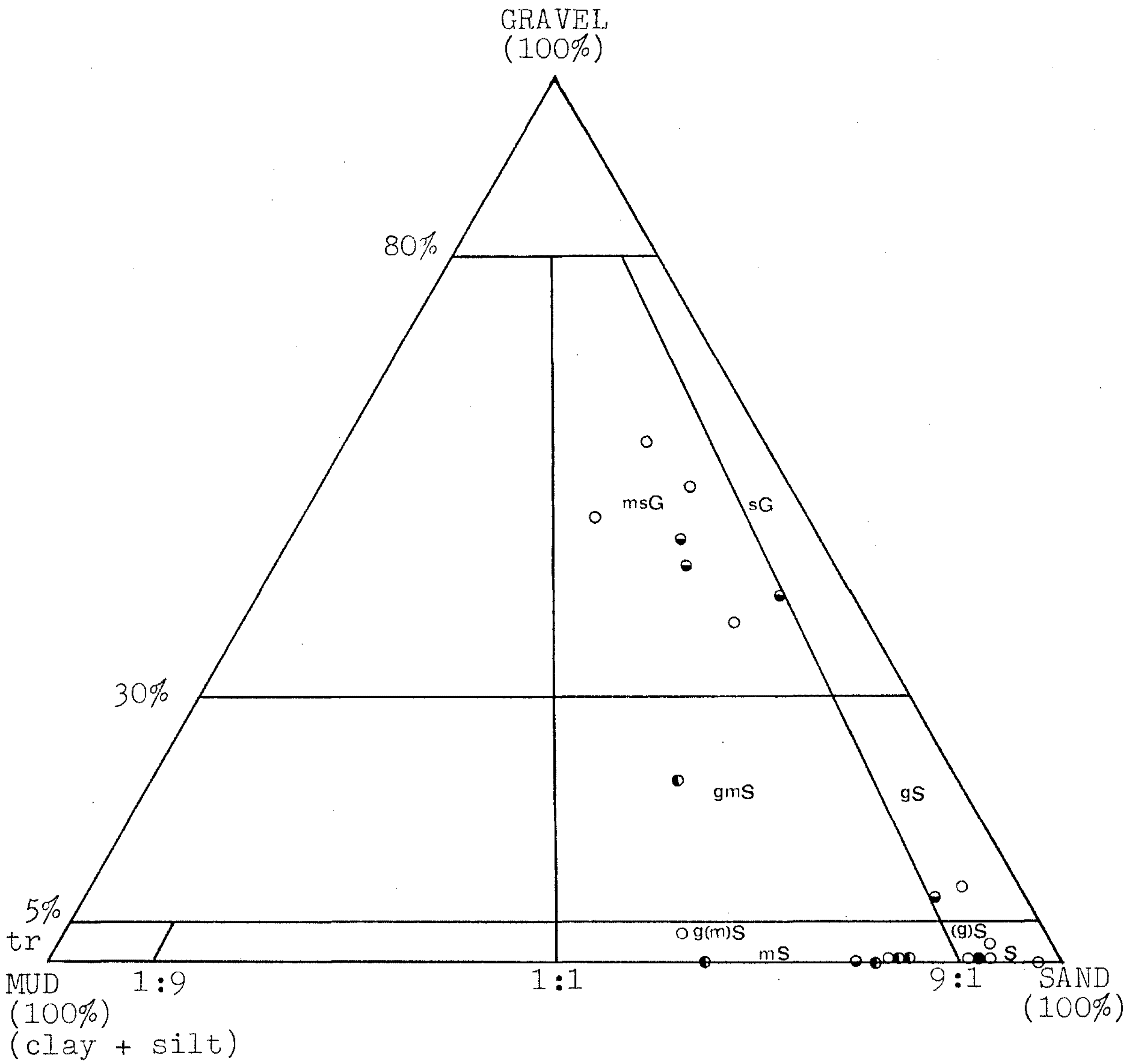


Figure 50. Folk's (1954) textural classification of terrigenous sediments with position of each channel sample (msG = muddy sandy gravel, sG = sandy gravel, gmS = gravelly muddy sand, gS = gravelly sand, g(m)S = slightly gravelly muddy sand, (g)S = slightly gravelly sand, mS = muddy sand, S = sand, ○ = Eoline member (sand), ● = Eoline member (clay), ◐ = unnamed upper member, ◒ = alluvial terrace deposits).

terrace deposit samples range from muddy sand to gravelly sand to muddy sandy gravel. This verbal classification simply reflects the generally poor mean sorting value of both Coker and alluvial terrace deposits. On Folk's (1954) maturity index, Cretaceous samples range from mostly immature to one mature sample with no submature samples being represented. All alluvial terrace deposit samples were immature. The relative immaturity of all these deposits is due to the physical nature of the environment of deposition. Immature sediments accumulate either where current action is weak or deposition is very rapid. Rapid deposition seems to be the most likely explanation, especially for the alluvial terrace deposits.

Mineralogical

Interpretation of the mineralogical analyses of the light sand fraction; heavy sand fraction; clays; and rounded and polished ironstone, and rounded iron-cemented sandstone will be presented in this section.

Light Minerals

Monroe and others (1964) present data on the light fraction mineralogy of samples collected from coreholes in the outcrop area. From these data the average sand rock clan for the two Cretaceous units was determined according to Folk (1968) by plotting total quartz versus rock fragments versus feldspar (QRF) on triangular coordinate paper. The mean QRF composition for the Eoline member falls directly on the line that separates subarkoses from sublitharenites near the quartzarenite end of the diagram (90.80 percent quartz). The mean QRF composition for the unnamed upper member falls barely within the quartzarenite field (95.45 percent quartz). The Cretaceous deposits are in general quartzarenites, subarkoses, and sublitharenites. Examination of the alluvial terrace deposit samples revealed that they would also fall within the range of the quartzarenite to subarkose to sublitharenite clans. Quartzarenites can result from prolonged abrasion or weathering of granitic or metamorphic source terranes; however, they may also be developed rapidly from older sediments. Due to the immature textural nature of most Cretaceous deposits, and to the fact that they fall within or near the quartzarenite clan in QRF composition, it is most likely that one source area for the Coker Formation was the Paleozoic sedimentary rocks of the Appalachian Plateaus and Ridge and Valley provinces. The presence of rock fragments of schist reported by Monroe and others (1964) suggests another source area in the Piedmont province of Alabama and Georgia. Mineralogical composition of the Pottsville Formation reported by Bryan (1963) and Ehrlich (1965) support a northern Alabama Paleozoic source area. Paleocurrent analysis of the Tuscaloosa Group by Tanner (1955) suggests primary transport from the north by rivers with a secondary east-west (probable littoral) mode. It is possible that in Cretaceous time, rivers drained directly from the Piedmont or Blue Ridge far to the north (eastern Tennessee, northern

Georgia, or southwestern North Carolina) directly into the proto-Gulf of Mexico (Monroe and others, 1964).

On the basis of the QRF classification, the present drainage basin of the Black Warrior River, and other previously mentioned evidence, the alluvial terrace deposits were probably derived fairly rapidly from both Cretaceous and Paleozoic sedimentary deposits of the area.

Heavy Minerals

When evaluating a heavy mineral assemblage, it is necessary to consider four independent variable factors. These are: 1) mineralogical composition of, and weathering in the source area (provenance), 2) abrasion and attrition during transport, 3) selective sorting, and 4) post-depositional intrastratal solution and weathering (Pettijohn, 1957; Griffiths, 1967; Folk, 1968; Royse, 1970; Hubert, 1971). Even the analytical techniques used in heavy mineral analysis have been questioned (Blatt and others, 1972). For example, Young (1966) has shown that replicate splits of the same sample can yield differences in the percentages of a given mineral species of up to several percent. Nevertheless, heavy minerals are of great value in the study of the provenance, transportation, and weathering history of a sediment, and for correlation (hence differentiation) of units and paleogeographic investigations (Folk, 1968).

The heavy mineral suites that occur in the Coker Formation and the alluvial terrace deposits of the Cottondale area contain the same mineral species, with varying degrees of concentration, and are of little quantitative value in differentiating the two units. However, certain trends in mean mineral abundance can be noted in the Coker Formation and the alluvial terrace deposits.

The mean garnet composition is greater in the channel samples of the alluvial terrace deposits than in the channel samples of the Cretaceous deposits. Garnet, generally considered to be a metastable heavy mineral, occurs in every alluvial terrace deposit channel sample, whereas, it occurs in less than one half of the Coker Formation channel samples. This could be caused by intrastratal solution, selective sorting (Rubey, 1933; Rittenhouse, 1943, 1944; Briggs, 1965), a difference in source area, or a period of extended weathering in the source area. Mean hydraulic equivalence of garnet for the Coker Formation is significantly different from that of the alluvial terrace deposits. There is no way to tell whether the difference in garnet abundance is due to intrastratal solution, selective sorting, which could be caused by a variety of environmental factors, a difference in source area, or a period of extended weathering in the source area. However, garnet in the soil zone can be used to determine the effects of intrastratal solution in the study area.

The presence of garnet in the leached soil zones of both Coker and alluvial terrace deposits (see table 3) and the fact that garnet is more abundant in the soil samples of the

Eoline member (sand), Eoline member (clay), and alluvial terrace deposits than in the channel samples of these units suggests that no significant intrastratal solution occurred in the study area. In addition, ilmenite, an unstable heavy mineral, is less abundant in the alluvial terrace deposits than in the Cretaceous units. Significant intrastratal solution should have destroyed the ilmenite in the Cretaceous units. Thus, selective sorting or source area effects rather than intrastratal solution caused this relationship.

Rosen (1969) feels that intrastratal solution has not played a major role in altering the heavy mineral suites in the Coastal Plain of Alabama. Hester (1974), however, did find a reduction of garnet, as well as ilmenite, upwards in soil profiles developed in the Cusseta Sand of Cretaceous age in eastern Alabama and Szabo (1972) found an impoverishment of garnet and other iron-rich minerals in the older terraces of the Alabama River.

Selective abrasion during transport can be ruled out as a significant factor in altering the heavy mineral assemblages in the study area due to the abundance of kyanite in most samples. Kyanite should be destroyed by prolonged abrasion (Pettijohn, 1957; Briggs, 1965; Rosen, 1969). Van Andel (1950) in his classic study of Rhine River sediments found no significant selective abrasion. In the United States, Russell (1937) found that the heavy mineral assemblage of the Mississippi River remained remarkably uniform throughout its length.

The alluvial terrace deposits contain the greatest abundance of opaques. This may be due either to selective sorting, a difference in source area, or "lateritic" alteration of iron-rich minerals to opaque minerals.

Table 13 shows mean ZTR maturity indices (zircon + tourmaline + rutile/total nonopaque, nonmicaceous heavy minerals) (Hubert, 1962) for channel and soil samples of the units involved. The channel samples show an inverse relationship between age and maturity. This could be the result of different source areas, weathering in the source area, or selective sorting. The soil samples show no distinctive trends.

Inversions in the ZTR do occur, especially in many slate-phyllite litharenites (Hubert, 1971). This is because the source area rocks contain mostly zircon, tourmaline, and/or rutile.

Kyanite and staurolite are semistable minerals whereas tourmaline and zircon are ultrastable (Hubert, 1971). Because these four minerals were the most abundant nonopaque heavy minerals in the samples collected from various units, a mean maturity index consisting of kyanite plus staurolite divided by tourmaline plus zircon was calculated for each unit (table 13). Results were the same as those determined for the ZTR maturity indices.

In order to eliminate the effects of selective sorting, a mean maturity index of kyanite divided by tourmaline was calculated for each unit. Mean hydraulic equivalence (Rubey, 1933; Rittenhouse, 1944; Briggs, 1965) for the kyanite and

Unit Sampled	Zircon + Tourmaline + Rutile / Total nonopaque, nonmicaceous heavy minerals		Kyanite + Staurolite / Tourmaline + Zircon		Kyanite / Tourmaline		Ilmenite / Total opaques – magnetic fraction	
	Channel	Soil	Channel	Soil	Channel	Soil	Channel	Soil
Kes	.41	.62	1.47	.66	1.03	.64	.41	.51
Ku	.48	.54	1.10	.96	.80	.66	.48	.26
Qt	.62	.59	.62	.75	.74	.90	.11	.34

Table 13. Various heavy mineral maturity indices for the Eoline member (sand)(Kes), unnamed upper member (Ku), and alluvial terrace deposits (Qt).

tourmaline from each unit was calculated and found to be similar. Again, there was an inverse relationship between maturity and age of the channel samples (table 13). Therefore, in this case all variables that affect heavy mineral assemblages have been eliminated except source area.

The soil samples for the kyanite to tourmaline ratio, however, show the expected direct relationship between maturity and age. This is probably due to the effects of intrstratal solution in the leached soil zone masking the effects of source area. Intrastratal solution in sands has been generally proven (Pettijohn, 1941; Allen, 1948; van Andel and Poole, 1960; Neiheisel, 1962; Blatt and Sutherland, 1969; Hester, 1974) though some authors dispute its importance (Krynine, 1942; van Andel, 1959).

Temple (1966) and a host of others have determined that chemical weathering alters ilmenite, an unstable heavy mineral, to leucoxene and pseudorutile. Thus, ilmenite to other opaques excluding the magnetic fraction mean maturity indices were determined for channel samples of each unit involved. This resulted in a general inverse relationship between age and maturity (table 13) and could be due to the effects of source area or selective sorting. The Pottsville Formation heavy mineral assemblage, which is probably the major source area for the alluvial terrace deposits (see p. 137), is dominated by leucoxene (Bryan, 1963). This suggests that source area is the major cause for the inverse relationship between age and maturity in the case of ilmenite.

Selective sorting may or may not have played a dominant role. In addition, "lateritic" weathering of the alluvial terrace deposits may have enhanced the inversion.

Other workers have reported the occurrence of heavy minerals in the Tuscaloosa Group (Monroe and others, 1964; Rosen, 1969; Davis and Sullivan, 1971). Davis and Sullivan (1971) report the presence of cassiterite in the Tuscaloosa Group in Tuscaloosa County. This mineral could not be definitely identified in any of the samples analyzed by the author due to the small number of samples and because of the difficulty in distinguishing cassiterite from rutile. The reported presence of this mineral is important since cassiterite is highly diagnostic of a granitic (pegmatitic) source terrane.

Heavy minerals also have been studied in the alluvial deposits of the Alabama River (Davis and Sullivan, 1971; Szabo, 1972); Tombigbee River (Parnell, 1962); Tallapoosa, Coosa, Pea, Choctawhatchee, Conecuh, and Tensaw Rivers (Saffer, 1955; Cazeau and Lund, 1959; Davis and Sullivan, 1971) of Alabama. These authors have concluded generally that the ultimate source areas for the heavy minerals of these alluvial deposits are the igneous and metamorphic rocks of the Alabama and Georgia Piedmont province and the Paleozoic rocks of northern Alabama. Therefore, due to the Black Warrior River's proximity to the above rivers, and the fact that its drainage basin heads in northern Alabama, the ultimate source areas for the heavies of the Black Warrior should be similar.

Studies of the heavy minerals of the Pottsville Formation by Bryan (1963) reveal a suite dominated by opaques (principally leucoxene with traces of hematite and magnetite, though one shale analysis yielded 4 percent hematite), euhedral garnet, and euhedral to rounded zircon. Lesser amounts of apatite, rutile, and tourmaline, and trace amounts of kyanite, staurolite, and monazite also were reported. Glauconite was also found in the Pottsville, thus the occurrence of glauconite in the Eoline member (sand) and unnamed upper member could be detrital. Bryan's (1963) descriptions of these mineral species are similar to the descriptions of the Cretaceous and alluvial terrace deposits found in the Cottondale area.

The occurrence of angular and rounded tourmaline and euhedral and rounded zircon such as that reported from the Cretaceous and alluvial terrace deposits in the Cottondale area indicates multiple source areas for both units (Folk, 1968). An abundance of rounded tourmaline and zircon can mean either that prolonged abrasion and/or chemical attack has taken place or that the minerals were reworked from older sediments (Folk, 1968). Both Potter (1955) and Pettijohn (1957) have stated that rounded zircon grains suggest a mature sedimentary source area. Van Andel and Poole (1960) suggest a source area in the Paleozoic rocks of northern Alabama for the rounded zircon grains of the East Gulf Coastal Plain region.

It has been noted by Szabo (1972) that when one proceeds westward in the Alabama River drainage basin, the rounded zircon content of the alluvium increases as a result of the closer association of the river basin with the Ridge and Valley and Appalachian Plateaus provinces of northern Alabama. Rounded zircon dominates the Tombigbee River heavy mineral assemblage in western Alabama where the source area lies primarily in the Paleozoic rocks of northern Alabama (Parnell, 1962). Rounded zircon dominates the nonopaque heavy mineral assemblage of the alluvial terrace deposits in the Cottondale area.

Therefore, on the basis of previous mineralogical and morphological data and considerations of Tanner's (1955) paleocurrent studies, the Coker Formation heavy mineral content of the Cottondale area was derived both from the Paleozoic rocks of northern Alabama by fluvial transport and directly from the Piedmont province by littoral and possible fluvial transport. The primary source of heavies was probably the Piedmont province due to the abundance of staurolite and kyanite (metasedimentary source in the Piedmont) in the Coker Formation, plus the reported occurrence of cassiterite (granitic Piedmont source). However, due to the predominance of rounded zircon and tourmaline, the presence of garnet that resembles the garnet of the Pottsville Formation, and consideration of the present drainage basin of the Black Warrior River, the alluvial terrace deposits probably were derived primarily from the northern Alabama Paleozoics (especially the Pottsville Formation), with a secondary source from the reworked Coker Formation (Maxwell, 1971, suggests this possibility for the alluvial terrace deposits of the Alabama River). This would account for the greater abundance of rounded tourmaline and zircon in the alluvial terrace deposits and the reversals of various indices of maturity because the source area for these deposits is entirely sedimentary.

Other possible causes for the maturity reversals include the following: 1) A period of extended weathering took place in the source area. Blatt (1967) states that ". . . greater destruction . . . of accessory minerals . . . [may occur] within the soil profile than occurs during the first few hundred miles of stream transport." 2) Possibly the prevalent clay units of the Coker Formation have effectively protected the less stable heavy minerals from intrastratal solution where clay beds overlie the sand units that contain heavy minerals, whereas the exposed, permeable alluvial terrace sand and gravel may have been subjected to alternate wet and dry periods of the Pleistocene (Szabo, 1972), which would cause post-depositional weathering and intrastratal solution to be very effective (van Andel and Poole, 1960).

Though the previously mentioned trends can be recognized in the Coker Formation and the alluvial terrace deposits, no statistically valid criterion based on heavy mineral content can be used for differentiation of the two units. In addition, it appears that the data indicate a general increase in the sedimentary nature of the source area with a decrease in the age of the deposit (i.e., the source area for the alluvial terrace deposits is entirely sedimentary, while the source areas for the Cretaceous deposits are metamorphic, igneous, and sedimentary).

Clay Minerals

Clay minerals are predominately the weathering products of igneous and some metamorphic rocks, and occur largely as detrital constitutents of sedimentary rocks (Folk, 1968; Carroll, 1970). Thus, clay minerals in sedimentary rocks are largely controlled by source area. Clay can also form diagenetically, or can be diagenetically altered. Illite, kaolinite, and montmorillonite, the clay minerals that are most abundant in the Cottondale area, all appear to arise from the weathering of a variety of rocks under different conditions (Pettijohn, 1957).

For example, volcanic ash or feldspar in basic to intermediate igneous rocks can alter to montmorillonite with little leaching due to an original alkaline environment (Pettijohn, 1957; Folk, 1968; Keller, 1970; Weaver and Pollard, 1973), but with strong chemical leaching (moist warm climate), montmorillonite may alter to halloysite to kaolinite to gibbsite (Carroll, 1970). Detrital montmorillonite changes diagenetically to mixed layered chlorite-vermiculite (Carroll, 1970), or mixed layered montmorillonite in the marine environment (Folk, 1968). Hester (1974) has found in eastern Alabama that montmorillonite in the soil zone weathers to kaolinite.

Hester (1974) also states that illite can weather to mixed layered illite and montmorillonite minerals. Illite can be detrital or it can form diagenetically, and it is the clay most commonly found in soils and unconsolidated sediments (Carroll, 1970; Royse, 1970). It is most commonly a product of incomplete leaching of acidic rocks and its structure is, therefore, generally disordered and its crystallinity is imperfect. It can weather from K-feldspar, plagioclase, or volcanic ash (Keller, 1970; Blatt and others, 1972). Weaver and Pollard (1973) note that the high potassium to hydrogen ion (K^+/H^+) ratios necessary for the stability of illite occur both in oceanic and continental environments; however, they feel that at present more illite is forming on land from the weathering of K-feldspar than in the ocean. Simple disaggregation of older clay-bearing rocks would yield chiefly illite with lesser amounts of chlorite, montmorillonite, and kaolinite (Folk, 1968). Under the right conditions (humid, warm, or temperate climate), illite can ultimately break down to kaolinite by stripping of K^+ (Pettijohn, 1957; Folk, 1968; Blatt and others, 1972; Hester, 1974).

Kaolinite forms where intense weathering takes place [i.e., in an acidic leaching environment (Pettijohn, 1957; Folk, 1968; Carroll, 1970; Keller, 1970)]. It can also be detrital (Folk, 1968) and is usually highly crystalline (Royse, 1970). Most kaolinite, however, is formed from the acid leaching of alkaline rocks (Weaver and Pollard, 1973).

The predominant clay minerals that occur in the channel samples of the outcropping Coker Formation and the alluvial terrace deposits of the Cottondale area are illite and kaolinite (see tables 10 and 11). K/I X-ray peak intensity ratios are lower in the alluvial terrace deposit samples than in the Cretaceous deposits. Moreover, kaolinite and illite X-ray peaks are relatively low and diffuse in the alluvial terrace deposits, whereas, they are well defined in the Cretaceous deposits. In addition, trace amounts of vermiculite, montmorillonite, glauconite, and chlorite were found and the presence of various mixed layered clay species was suspected in the various units (see table 11). Clay minerals have apparently been effectively removed from the A soil horizon in many of the Coker Formation and alluvial terrace deposit samples, and thus too few ratios could be calculated to be meaningful. However, it appears that the older A_2 soil horizons of the Eoline member (sand) contain more illite than do the younger A_2 soil horizons of the alluvial terrace deposits (table 10). This may result from selective eluviation of kaolinite with respect to illite. Illite and kaolinite X-ray peaks of Pottsville clay samples from the same area resemble alluvial terrace deposit X-ray peaks.

Clay minerals of the Coker Formation in the subsurface of the Cottondale area (Boykin core hole) were studied by Monroe and others (1964). Eoline member samples contained major to trace amounts of kaolinite, minor to trace amounts of illite, and major to trace amounts of montmorillonite.

Mean order of abundance was kaolinite, illite, and montmorillonite. The unnamed upper member contained major to trace amounts of kaolinite, minor to trace amounts of illite, and minor amounts of montmorillonite. Mean order of abundance was kaolinite, illite, and montmorillonite.

Clarke (1965) sampled the clay minerals of the Coker Formation in outcrop in Tuscaloosa County and reported that a typical analysis consisted of 30 to 40 percent montmorillonite, 5 to 10 percent illite, and minor kaolinite. Otis M. Clarke (1974, oral communication) also reported 4 percent gibbsite in the B soil horizon of high alluvial terrace deposits near Tuscaloosa. A sample taken in the B soil horizon of a high alluvial terrace deposit of the Alabama River northwest of Montgomery contained 5 percent gibbsite, 50 percent kaolinite, and 25 percent illite (Clarke, 1971). Thus, it appears that the clay minerals that are present in the Cottondale area in major amounts are illite, kaolinite, and montmorillonite.

According to Neiheisel and Weaver (1967), soils contribute most of the suspended clay load to the streams of the Southern Appalachians. A general map of surficial clay mineral distribution in the Southeastern United States presented by Neiheisel and Weaver (1967) shows that the Cumberland Plateau section and Ridge and Valley province soils are mainly illitic, the Piedmont and Tuscaloosa Group soils are mainly kaolinitic (though kaolinite is abundant, the Tuscaloosa Group soils are still mainly illitic in the Cottondale area), and the rest of the Coastal Plain province soils are montmorillonitic. Thus it appears that in the Cottondale area, the high X-ray K/I peak intensity ratios for the channel samples of the Coker Formation reflect a primary source area for the clay minerals in the Piedmont province of Alabama and Georgia with secondary sources in the Paleozoic rocks of northern Alabama. The lower K/I X-ray peak intensity ratios reflect a northern Alabama sedimentary source area for the clay minerals of the alluvial terrace deposit channel samples [Bryan (1963) and Ehrlich (1965) both report abundant mica in the Pottsville Formation] with possible secondary sources in the Coker Formation. The low, diffuse nature of the kaolinite and illite X-ray peaks of the alluvial terrace deposits probably results from both the paucity of clay in the alluvial terrace deposits and "lateritic weathering" of these deposits.

The reason that montmorillonite was not found to be abundant in the surficial Cretaceous and alluvial terrace deposits by this author in the Cottondale area is probably due to the alteration of this mineral to kaolinite. High montmorillonitic compositions found by Clarke (1965) in the Coker Formation probably result from differences in location of sample sites (i.e., the clay mineral content of various units within the Coker shows considerable variation both laterally and vertically).

The occurrence of glauconite, which is actually a rock term applied to earthy green pellets composed of various iron-rich clay minerals (Burst, 1958; Wermund, 1961; Weaver and

Pollard, 1973), reported in both the Eoline member and unnamed upper member of the Coker Formation (Drennen, 1953a) is of environmental significance only if the glauconite is authigenic. Authigenic glauconite is indicative of a marine environment with an Eh of 0 to -150 mv. and pH of 7 to 8 (Carroll, 1970). The method of authigenesis may be as follows: montmorillonite (nontronite) in reducing conditions $\rightarrow$ nontronite + K(Ca,Mg) $\rightarrow$ glauconite (Md) + pressure and aging $\rightarrow$ glauconite (1M)(Carroll, 1970). Weaver and Pollard (1973) report the occurrence of non-marine glauconite also. Berner (1971) and Weaver and Pollard (1973), however, state that glauconite occurs predominately in saline environment with low rates of deposition. Glauconite is stable in an environment of intermediate, and probably fluctuating, redox potential (Berner, 1971). Therefore, it follows that it would be most abundant in the Eoline member (clay), whose environment probably approached that described by Berner (1971) and Weaver and Pollard (1973). Its paucity in the Eoline member (sand) and unnamed upper member may be due to either depositional rates, or differences in environment of deposition. It is generally associated with organic material (Berner, 1971), which is abundant in the Eoline member (clay), but generally absent in the Eoline member (sand) and unnamed upper member. In addition, since glauconite has been reported in the Pottsville Formation (Bryan, 1963), some Coker glauconites may be detrital.

Rounded and Polished Ironstone and Rounded Iron-cemented Sandstone Clasts

The possible origin of the rounded and polished ironstone and rounded iron-cemented sandstone clasts and their use in the differentiation of alluvial terrace deposits have been discussed previously without regard to the mineralogy or geochemistry of these clasts. Thus a brief discussion of their mineralogy and geochemistry follows.

Table 14 shows that the major iron minerals present in the ironstones and iron-cemented sandstone clasts of the alluvial terrace deposits are goethite and hematite. It is believed that these clasts were derived from reworked Coker Formation ironstone ledges, altered siderite clasts, or with rare exceptions, from ironstone ledges or altered siderite in the soil zone of the present drainage basin of the Black Warrior River above Tuscaloosa. However, no siderite was found in any of the clasts that were X-rayed; therefore, either complete alteration has taken place, or siderite was not a precursor to the goethite or hematite.

Berner (1971) has pointed out that goethite is a common constituent of modern sediments and weathered outcrops, and is typically formed under oxidizing conditions as a weathering product of iron-rich minerals in soils. The iron-rich minerals are reduced in surface soil layers, rendered soluble to slightly acidic downward and laterally percolating soil waters, and then are oxidized and precipitated as geothite in layers as ironstone ledges, especially above

Relative abundance of species	Rounded and polished ironstone clasts	Rounded iron-cemented sand-stone clasts
Major	Goethite	Goethite
	Quartz	Hematite
		Quartz
Minor	Hematite	
	Kaolinite	
	Illite	
	Vermiculite	
Possible	Magnetite	Magnetite
	Maghemite	Maghemite

Table 14. Mineralogical composition of rounded and polished ironstone and rounded iron-cemented sandstone clasts as determined by routine X-ray analysis.

impermeable clay layers. Relevant discussions of the reactions and stability fields involved are found in Garrels and Christ (1965), Krauskopf (1967), and Berner (1971). Eluviation with subsequent illuviation of iron-rich colloids and gels may occur also. Goethite may dehydrate to hematite (Berner, 1971), thus accounting for the presence of hematite in the ironstones and iron-cemented sandstones. Some small amounts of geothite and hematite may be detritus cemented in the clasts.

The presence of clay minerals (kaolinite and illite) would be expected in a soil that has undergone the eluviation of these constituents from the A horizon and subsequent illuviation of them in an ironstone or iron-cemented sandstone ledge of the B horizon.

The presence of magnetite is not too surprising for it is probably a detrital constituent of the ironstone and iron-cemented sandstone and has been protected from oxidation by a coating of hematite. Also, the Eh-pH stability fields for magnetite and goethite overlap slightly (Garrels and Christ, 1965). Maghemite may be expected to act similarly to magnetite.

Most of the quartz present is probably detrital, but may be in part diagenetic.

Geochemical

As has been previously stated, too few whole rock geochemical analyses were performed to develop statistically valid geochemical criteria for distinguishing alluvial terrace deposits from the Coker Formation; however, trends were noted. The alluvial terrace deposit channel samples generally are higher in total iron content than the Coker Formation channel samples (table 12). This could be due to source area, transportational and depositional medium, or the weathering history of the sediments involved. The iron in the alluvial terrace deposits may be detritally derived as discrete iron-bearing minerals, coatings, or colloids from source areas north of Tuscaloosa, or may be derived by direct precipitation of hydrated iron oxides from the rivers draining the area north of Tuscaloosa. The soil samples are lower in iron due to leaching and eluviation.

Moore and Dennen (1970) found that aluminum/iron (Al/Fe) ratios of most sedimentary rocks fall between 1.5 to 2.5 (the exception being arkoses), but may be modified by extended periods of weathering. The mean Al/Fe ratio for the channel samples of the Eoline member (sand) is 3.3; Eoline member (clay), 3.9; and unnamed upper member, 8.3; while the mean Al/Fe ratio for the alluvial terrace deposits is 1.7, which falls within Moore and Dennen's (1970) limits (table 15). Soil samples show higher Al/Fe ratios.

Sample Number		Aluminum/Iron
CSKes-	3	4.8
	5	6.3
	6	2.8
	7	1.2
	8	2.4
	10	3.6
	11	2.5
$\bar{x}$		3.4
CSKec-	1	4.0
CSKu-	1	12.3
	2	4.3
$\bar{x}$		8.3
CSQt-	2	1.4
	3	2.2
$\bar{x}$		1.8
SSKes-	1	3.1
SSQt-	1	3.3
	3	3.2
$\bar{x}$		3.3

Table 15. Aluminum/iron ratios for selected channel (CS) and soil (SS) samples (see table 10 for explanation of sample numbers).

Both textural (Appendix 2) and X-ray data (table 10) indicate that the alluvial terrace deposit samples have a lower clay content, and thus a lower aluminum (Al) content, than do the Coker Formation samples. Iron (Fe) content of the alluvial terrace deposit samples is generally higher (table 12) than that of the Coker Formation samples. Thus, the increased clay and decreased Fe content of the Coker Formation samples with respect to the alluvial terrace deposit samples causes an increase in the Al/Fe ratios of the Coker Formation samples.

The most recent summary of the chemical composition of sandstone types has been made by Pettijohn (1963). Using his data, Pettijohn and others (1972) have derived a classification scheme for sandstone based on chemical composition (fig. 51). From this scheme it can be noted that most channel samples analyzed fall in the arkose field while one falls in the sublithic arenite field, and one in the graywacke field. This chemical classification differs somewhat from the QRF classification of Folk (1968), for the samples fall in the quartzarenite, subarkose, sublitharenite fields. The reason for this discrepency is that Folk's (1968) QRF classification totally ignores the clay content and matrix of sandstones. Al in the Cretaceous sands is much higher than in the average sandstone (Pettijohn, 1963) which probably is due to the higher than normal clay content of the Cretaceous sediments. Soil-sample Al content is lower than channel-sample Al content due to leaching and eluviation.

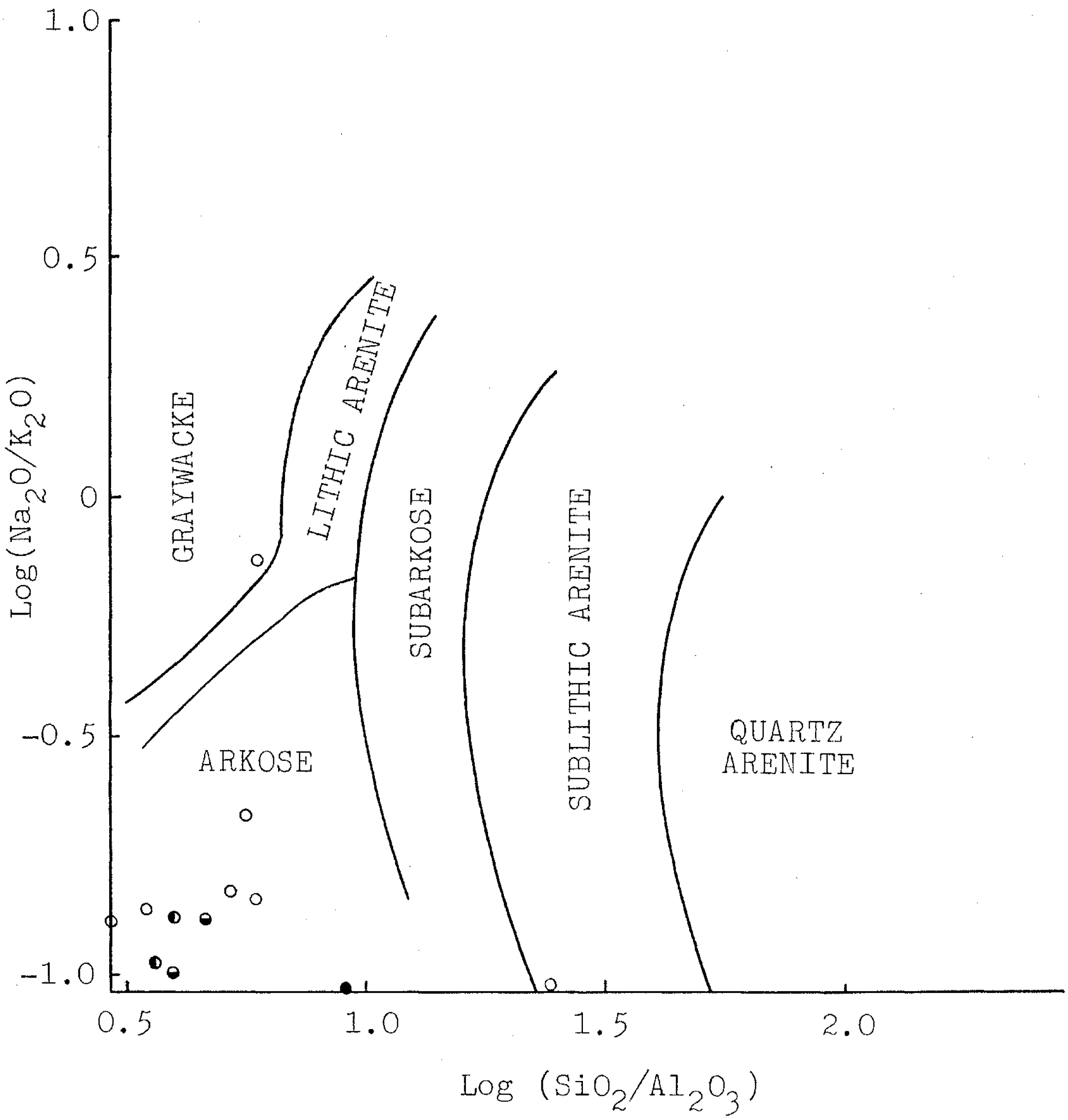


Figure 51. Chemical classification of selected sand channel samples after Pettijohn and others (1972)(Eoline member (sand) = ○ , Eoline member (clay) = ● , unnamed upper member = ◐ , alluvial terrace deposits = ⊖).

Pettijohn and others (1972) would classify most channel samples collected in the Cottondale area as chemically immature due to the relatively low SiO_2/Al_2O_3 ratios and predominance of potassium over sodium, which is in agreement with Folk's (1954) maturity classification. Chemically, however, most of the samples analyzed would fall in the arkose clan.

Thus it can be seen that as Pettijohn and others (1972) have stated, "sandstones' chemical analyses do not fit so neatly with mineralogical analyses."

DISCUSSION AND CONCLUSIONS

The various field, textural, mineralogical, and geochemical data, plus the occurrence of various foraminiferal, molluscan, decapod, pollen, spore, and land plant remains (see Monroe and others, 1964) suggest highly varied and complex environments of deposition for the Coker Formation. These include predominate shallow- to marginal-marine to brackish- to fresh-water environments of deposition, with their associated processes of deposition and deposited material. Thus the Coker Formation would constitute a mixed sedimentary environment as defined by Crosby (1972).

The considerable range in degree of sorting and the presence of abundant clay and silt suggest rapid accumulation in shallow marine to brackish embayments or estuaries in sheltered coastal areas. Lagoonal and swampy conditions must also have existed. The presence of some well-sorted units indicates brief incursions of shallow agitated marine waters. The relief on the Pottsville erosional surface and extreme lenticularity and diversity of each unit further support the probable existence of a strongly indented shoreline of moderate relief. Conant in Monroe and others (1964) suggests also that detritus may have been supplied to the Cottondale area by an ancestral (Cretaceous) Black Warrior River that may have been connected to the Sequatchie River of Tennessee.

Various textural, mineralogical, and geochemical data suggest a variety of source areas for the Coker Formation. These include metamorphic, granitic, and sedimentary source terranes.

The alluvial terrace deposits, however, are of known environment of deposition and transportational agent (fluvial), but were derived totally from a sedimentary source area. Thus, the mineralogy alone of the alluvial terrace deposits should serve to distinguish them from the Coker Formation. Weathering history (intrastratal solution) has altered some of the mineralogical and geochemical relationships; however, the effects of source area seem to have overwhelmed the effects of weathering. Unfortunately, a fair amount of mixing of the Coker Formation with the alluvial terrace deposits has taken place. This mixing has masked in part the effect of different source areas. Therefore, though textural, mineralogical, and geochemical trends can be noted by applying simple statistical techniques, generally no one sample of an alluvial terrace deposit can be differentiated from another sample of a Cretaceous deposit based on any single criterion. Table 16 summarizes those criteria that can be used in a general way to distinguish between the two deposits.

It can be concluded, therefore, that a combination of field, textural, mineralogical, and geochemical considerations greatly increases the probability of correct differentiation between alluvial terrace deposits and the Coker Formation.

Data Type	Qualitative estimate of reliability and/or applicability[1]	Coker Formation (Cretaceous)		Alluvial terrace deposits [Pleistocene(?)]
		Eoline member	Unnamed upper member	
Field	+	General absence of rounded and polished ironstone and rounded iron-cemented sandstone clasts.		General presence of the same.
	+	Almost total absence of rounded Pottsville clasts.		General presence of the same.
	+	Dense, compact chert.		Tripolitic, friable chert.
	+	Generally micaceous.		Generally nonmicaceous.
	0	Presence of laminated clay units.		General absence of the same.
	0	Presence of glauconite.		General absence of the same.
	0	Generally light tan to light red sand.		Generally deep red sand.
	-	Presence of phosphate nodules, amber, pyrite, or manganite.	-	General absence of the same.

[1]Reliability-applicability index: + = good; 0 = fair; - = poor.

Table 16. Criteria for distinguishing alluvial terrace deposits from the Coker Formation.

Data Type	Qualitative estimate of reliability and/or applicability[1]	Coker Formation (Cretaceous)		Alluvial terrace deposits [Pleistocene(?)]
		Eoline member	Unnamed upper member	
	–	–	Presence of selenite crystals.	General absence of the same.
	–	Presence of siderite and/or marcasite nodules		General absence of the same.
	–	Presence of diagnostic fossils.		General absence of the same.
	–	Elevation of contacts and thickness of units.		
	–	Topographic surfaces generally severely dissected.		Some topographic surfaces flat.
	–	Pebbles generally small, colored, disc-shaped and quartz-rich.	Pebbles generally small, angular, and chert-rich.	Quartz pebbles generally iron-stained, frosted, pitted, and larger and more rounded than Cretaceous pebbles.
	–	General bedding characteristics.		
Textural	–	Very poorly sorted.		Very poorly sorted, but slightly more so than the Cretaceous samples.

[1]Reliability-applicability index: + = good; 0 = fair; – = poor.

Table 16. Continued.

Data Type	Qualitative estimate of reliability and/or applicability[1]	Coker Formation (Cretaceous)		Alluvial terrace deposits [Pleistocene(?)]
		Eoline member	Unnamed upper member	
		Positively skewed.		Less positively skewed.
Mineralogical	+	Generally fewer opaques than alluvial terrace deposit samples.		Opposite.
	+	Kaolinite/illite (K/I) peak intensity ratios generally higher than alluvial terrace deposit sample peaks.		Opposite.
	+	Kaolinite and illite peaks higher and less diffuse than alluvial terrace deposit sample peaks.		Opposite.
	0	Minor garnet.		Garnet present in all channel samples and generally more abundant than garnet in Cretaceous samples.
	0	Inversion of zircon-tourmaline-rutile, kyanite + staurolite /tourmaline + zircon, kyanite/tourmaline, and ilmenite/ total opaques mean maturity indices in channel samples.		
	0	Direct relationship between age and kyanite/tourmaline mean maturity index in soil samples.		

[1]Reliability-applicability index: + = good; 0 = fair; - = poor.

Table 16. Continued.

Data Type	Qualitative estimate of reliability and/or applicability[1]	Coker Formation (Cretaceous)		Alluvial terrace deposits [Pleistocene(?)]
		Eoline member	Unnamed upper member	
	0	Mean order of abundance of heavy minerals: opaques, staurolite, kyanite, tourmaline, zircon.	Mean order of abundance of heavy minerals: opaques, tourmaline, staurolite, kyanite, zircon.	Mean order of abundance of heavy minerals: opaques, zircon, tourmaline, kyanite, staurolite.
Geochemical	0	Generally lower in total iron.		Opposite.
	0	Mean aluminum/iron ratios generally higher than alluvial terrace deposit samples.		Opposite.

[1]Reliability-applicability index: + = good; 0 = fair; - = poor.

Table 16. <u>Continued</u>.

SELECTED REFERENCES

Adams, G. I., 1930, Origin of the white clays of Tuscaloosa age (Upper Cretaceous) in Alabama, Georgia, and South Carolina: Econ. Geology, v. 25, p. 621-626.

Adams, G. I., Butts, C., Stephenson, L. W., and Cooke, C. W., 1926, Geology of Alabama: Alabama Geol. Survey Spec. Rept. 14, 312 p.

Allen, V. T., 1948, Weathering and heavy minerals: Jour. Sedimentary Petrology, v. 18, p. 38-42.

Andel, T. H. van, 1950, Provenance, transport and deposition of Rhine sediments: Wageningen, Netherlands, H. Veenman en Zonen, 129 p.

_______ 1959, Reflections on the interpretation of heavy mineral analyses: Jour. Sedimentary Petrology, v. 29, p. 153-163.

Andel, T. H., van, and Poole, D. M., 1960, Sources of Recent sediments in the northern Gulf of Mexico: Jour. Sedimentary Petrology, v. 30, p. 91-122.

Applin, P. L., and Applin, E. R., 1947, Regional subsurface stratigraphy, structure, and correlation of Middle and Upper Cretaceous rocks in Alabama, Georgia, and North Florida: U. S. Geol. Survey Oil and Gas Inv. Prelim. Chart 26.

Bates, J. D., and Bates, B. H., 1960, Evaluation of heavy mineral separations using artificial samples: Jour. Sedimentary Petrology, v. 30, p. 148-153.

Berman, Robert, 1953, A nomogram for obtaining percent composition by weight from mineral-grain counts: Jour. Sedimentary Petrology, v. 23, p. 120-123.

Berner, R. A., 1971, Principles of chemical sedimentology: New York, McGraw-Hill Book Co., 240 p.

Berry, E. W., 1917, The delta character of the Tuscaloosa Formation: Johns Hopkins Univ. Circ., W. S., no. 3, p. 216-222.

_______ 1919, Upper Cretaceous floras of the eastern Gulf region in Tennessee, Mississippi, Alabama, and Georgia: U. S. Geol. Survey Prof. Paper 112, p. 18-19.

Blatt, Harvey, 1967, Provenance determinations and recycling of sediments: Jour. Sedimentary Petrology, v. 37, p. 1031-1044.

Blatt, Harvey, Middleton, Gerard, and Murray, Raymond, 1972, Origin of sedimentary rocks: Englewood Cliffs, New Jersey, Prentice-Hall Book Co., 634 p.

Blatt, Harvey, and Sutherland, B., 1969, Intrastratal solution and nonopaque heavy minerals in shales: Jour. Sedimentary Petrology, v. 39, p. 591-600.

Briggs, L. I., 1965, Heavy mineral correlations and provenances: Jour. Sedimentary Petrology, v. 35, p. 939-955.

Brock, E. J., 1974, Coarse sediment morphometry: a comparative study: Jour. Sedimentary Petrology, v. 44, p. 663-672.

Brown, E. O., III, 1968, Black Warrior River, in Goodrum, J., Brown, E. O., III, Smith, G. C., Southerland, K., Stephenson, S. X., Windham, K. T., Stewart, J. G., Smith, J. P., and Flirt, J. A., Rivers of Alabama: Huntsville, Alabama, Strode, p. 28-51.

Bryan, J. H., 1963, A petrologic study of the Pottsville Formation at Holt Dam site, Alabama: Alabama Univ., unpub. Master's Thesis, 41 p.

Burst, J. F., 1958, "Glauconite" pellets: their mineral nature and applications to stratigraphic interpretations: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 310-327.

Carroll, Dorothy, 1958, The role of clay minerals in the transportation of iron: Geochim. et Cosmochim. Acta, v. 14, p. 1-27.

_______ 1970, Clay minerals: a guide to their X-ray identification: Geol. Soc. America Spec. Paper 126, 80 p.

Carver, R. E., ed., 1971, Procedures in sedimentary petrology: New York, Wiley-Interscience, 653 p.

Cazeau, C. J., and Lund, E. H., 1959, Sediments of the Chattahoochee River, Georgia-Alabama: Southeastern Geology, v. 1, p. 51-57.

Clarke, O. M., Jr., 1965, Clay deposits of the Tuscaloosa Group in Alabama: Alabama Geol. Survey Rept. Ser. 9, 15 p.

_______ 1971, Gibbsite in coastal plain soils, southeastern United States: Southeastern Geology, v. 13, p. 77-90.

Clifton, H. E., 1973, Pebble segregation and bed lenticularity in wave-worked versus alluvial gravel: Sedimentology, v. 20, p. 173-187.

Conant, L. C., 1967, The pre-Selma Cretaceous strata, in Geol. Soc. America Guidebook 80th Ann. Mtg., New Orleans, Louisiana, 1967: p. 4-11.

Conant, L. C., Eargle, D. H., and Monroe, W. H., 1947, Pre-Selma Upper Cretaceous stratigraphy in the McCrary, McShan, Gordo, Samantha, and Searles quadrangles, Alabama and Mississippi: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 64.

Conant, L. C., Eargle, D. H., Monroe, W. H., and Morris, J. H., 1945, Geologic map of Tuscaloosa and Cottondale quadrangles, Alabama: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 37.

Conant, L. C., and Monroe, W. H., 1945, Stratigraphy of the Tuscaloosa Group in the Tuscaloosa and Cottondale quadrangles, Alabama, in Conant, L. C., Eargle, D. H., Monroe, W. H., and Morris, J. H., Geologic map of Tuscaloosa and Cottondale quadrangles, Alabama: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 37.

Copeland, C. W., ed., 1968, Geology of the Alabama Coastal plain: a guidebook: Alabama Geol. Survey Circ. 47, 97 p.

_______ 1972, Upper Cretaceous series in central Alabama, in Tolson, J. S., ed., Guide to Alabama geology, Geol. Soc. America, Guidebook for field trip, 21st Ann. Mtg. Southeastern Sec., p. 2-1 - 2-45.

Crosby, E. J., 1972, Classification of sedimentary environments, in Rigby, J. K., and Hamblin, W. K., eds., Recognition of ancient sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, p. 4-11.

Davis, E. G., and Sullivan, G. V., 1971, Recovery of heavy minerals from sand and gravel operations in the southeastern United States: U. S. Bureau Mines, Rept. Inv. 7517, 25 p.

Drennen, C. W., 1950, Geology of the Piedmont-Coastal Plain in eastern Alabama and western Georgia: Alabama Univ., unpub. Master's Thesis, 84 p.

_______ 1953a, Reclassification of outcropping Tuscaloosa Group in Alabama: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 522-538.

_______ 1953b, Stratigraphy and structure of outcropping pre-Selma Coastal plain beds of Fayette and Lamar Counties, Alabama: U. S. Geol. Survey Circ. 267, 9 p.

Eargle, D. H., 1947, Profiles showing the geology along highways in the vicinity of Tuscaloosa, Alabama: U. S. Geol. Survey Oil and Gas Inv. Prelim. Chart 31.

Eargle, D. H., Monroe, W. H., and Morris, J. H., 1946, Geologic map of the Aliceville, Mantua, and Eutaw quadrangles, Alabama: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map. 50.

Ehrlich, Robert, 1965, The geologic evolution of the Black Warrior detrital basin: Louisiana State University, unpub. Ph.D. Dissert., 64 p.

Fairbank, N. G., 1956, Methods and preliminary results in a study of minerals from the eastern Gulf of Mexico: Jour. Sedimentary Petrology, v. 26, p. 268-275.

Fairbridge, R. W., 1968, Fall Line, zone, _in_ Fairbridge, R. W., ed., The encyclopedia of geomorphology: New York, Reinhold, p. 1117-1124.

Fenneman, N. M., 1938, Physiography of the eastern United States: New York, McGraw-Hill, 714 p.

Folk, R. L., 1951, Stages of textural maturity in sedimentary rocks: Jour. Sedimentary Petrology, v. 21, p. 127-130.

_______ 1954, The distinction between grain size and mineral composition in sedimentary-rock nomenclature: Jour. Geology, v. 62, p. 344-359.

_______ 1968, Petrology of sedimentary rocks: Austin, Texas, Hemphill's, 170 p.

Folk, R. L., and Ward, W. C., 1957, Brazos river bar: a study in the significance of grain size parameters: Jour. Sedimentary Petrology, v. 27, p. 3-27.

Friedman, G. M., 1961, Distinction between dune, beach, and river sands from their textural characteristics: Jour. Sedimentary Petrology, v. 31, p. 514-529.

_______ 1967, Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands: Jour. Sedimentary Petrology, v. 37, p. 327-354.

Frye, J. C., and Leonard, A. R., 1954, Some problems of alluvial terrace mapping: Amer. Jour. Sci., v. 252, p. 242-251.

Galehouse, J. S., 1969, Counting grain mounts: number percentage vs. number frequency: Jour. Sedimentary Petrology, v. 39, p. 812-815.

Garrels, R. M., and Christ, C. L., 1965, Solutions, minerals, and equilibria: Harper and Row, 450 p.

Goldstein, A., Jr., 1942, Sedimentary petrologic provinces of the northern Gulf of Mexico: Jour. Sedimentary Petrology, v. 12, p. 77-84.

Graybeal, F. T., 1971, Atomic absorption major element analysis using a lithium metaborate fusion technique and some possible applications to ore finding: Arizona Geol. Soc. Digest, v. 9, p. 95-102.

Griffin, G. M., 1971, Interpretation of X-ray diffraction data, in Carver, R. E., ed., Procedures in sedimentary petrology: New York, Wiley-Interscience, p. 541-569.

Griffiths, J. C., 1967, Scientific methods in analysis of sediments: New York, McGraw-Hill Book Co., 508 p.

Hains, C. F., 1973, Floods in Alabama: Montgomery, Alabama, Alabama State Highway Dept. and U. S. Geol. Survey, 164 p.

Hester, N. C., 1974, Post-depositional subaerial weathering effects on the mineralogy of an Upper Cretaceous sand in southeastern United States: Jour. Sedimentary Petrology, v. 44, p. 363-373.

Hilgard, E. W., 1860, Report on the geology and agriculture of the state of Mississippi: Jackson, 391 p.

Houten, F. B. van, 1968, Iron oxides in red beds: Geol. Soc. America Bull., v. 79, p. 399-416.

_______ 1972, Iron and clay in tropical savanna alluvium, northern Columbia: a contribution to the origin of red beds: Geol. Soc. America Bull., v. 83, p. 2761-2772.

Howard, A. D., Fairbridge, R. W., and Quinn, J. H., 1968, Terraces, fluvial-introduction, in Fairbridge, R. W., ed., The encyclopedia of geomorphology: New York, Reinhold, p. 1117-1124.

Hubert, J. F., 1962, A zircon-tourmaline-rutile maturity index and the interdependence of the composition of heavy mineral assemblages with the gross composition and texture of sandstones: Jour. Sedimentary Petrology, v. 32, p. 440-450.

_______ 1971, Analysis of heavy-mineral assemblages, in Carver, R. E., ed., Procedures in sedimentary petrology: New York, Wiley-Interscience, p. 453-478.

Hunt, C. B., 1972, Geology of soils; their evolution, classification, and uses: San Francisco, Freeman, 344 p.

Hunter, R. E., 1967, A rapid method for determining weight percentages of unsieved heavy minerals: Jour. Sedimentary Petrology, v. 37, p. 521-529.

Hutton, C. O., 1950, Studies of heavy detrital minerals: Geol. Soc. America Bull., v. 61, p. 635-710.

Johnson, D. W., 1944, Problems of terrace correlation: Geol. Soc. America Bull., v. 55, p. 793-818.

Johnston, W. E., Jr., 1930, Physical divisions of northern Alabama: Alabama Geol. Survey Bull. 38, 48 p.

Jones, D. E., ed., 1967, Geology of the Coastal Plain of Alabama, Guidebook 80th Ann. Mtg. Geol. Soc. America, 1967: New Orleans, Louisiana, 113 p.

Keller, W. D., 1970, Environmental aspects of clay minerals, in Symposium of environmental aspects of clay minerals: Jour. Sedimentary Petrology, v. 40, p. 788-813.

Kelley, J. C., and Whetten, J. T., 1969, Quantitative statistical analysis of Columbia River sediment samples: Jour. Sedimentary Petrology, v. 39, p. 1167-1173.

Klovan, J. E., 1966, The use of factor analysis in determining depositional environments from grain-size distributions: Jour. Sedimentary Petrology, v. 36, p. 115-125.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill Book Co., 721 p.

Krynine, P. D., 1942, Provenance versus mineral stability as a controlling factor in the composition of sediments (abs.): Geol. Soc. America Bull., v. 53, p. 1850-1851.

Langdon, D. W., Jr., 1891, Variations in the Cretaceous and Tertiary strata of Alabama (with discussion by C. A. White): Geol. Soc. America Bull., v. 2, p. 587-605.

Leopold, L. B., Wolman, M. G., and Miller, J. P., 1964, Fluvial processes in geomorphology: San Francisco, Freeman, 522 p.

Lyell, Sir Charles, 1849, A second visit to the United States of North America: London, John Murray, 385 p.

Lynd, L. E., 1960, Alteration of ilmenite: Econ. Geol., v. 55, p. 1064-1068.

Martini, I. P., and Ostler, J., 1973, Ostler lenses: possible environmental indicators: Jour. Sedimentary Petrology, v. 43, p. 415-422.

Mason, C. C., and Folk, R. L., 1958, Differentiation of beach, dune, and aeolion flat environments by size analysis: Jour. Sedimentary Petrology, v. 28, p. 211-226.

Maxwell, R. W., 1971, Origin and chronology of Alabama river terraces: Gulf Coast Assoc. Geol. Soc. Trans., v. 21, p. 83-95.

Medlin, J. H., Suhr, N. H., and Bodkin, J. B., 1969, Atomic absorption analysis of silicates employing $LiBO_2$ fusion: Atomic Absorption Newsletter, v. 8, p. 25-29.

Middleton, G. V., ed., 1965, Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 12, 265 p.

Miller, J. D., Jr., 1958, Ground-water in the vicinity of Bryce State Hospital, Tuscaloosa County, Alabama: Alabama Geol. Survey Inf. Ser. 12, 7 p.

Miller, J. D., Jr., and Causey, L. V., 1958, Geology and ground-water resources of Tuscaloosa County, Alabama: Alabama Geol. Survey Inf. Ser. 14, 71 p.

Monroe, W. H., 1941, Notes on deposits of Selma and Ripley age in Alabama: Alabama Geol. Survey Bull. 48, 150 p.

_______ 1947, Stratigraphy of outcropping Cretaceous beds of southeastern states: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1817-1824.

_______ 1955, Cores of pre-Selma Cretaceous rocks in the outcrop area in western Alabama: Gulf Coast Assoc. Geol. Soc. Trans., v. 5, p. 11-37.

Monroe, W. H., Bergenback, R. E., Sohl, N. F., Applin, E. R., Leopold, E. B., Pakiger, H. M., and Conant, L. C., 1964, Studies of pre-Selma Cretaceous core samples from the outcrop in western Alabama: U. S. Geol. Survey Bull. 1160, 108 p.

Monroe, W. H., Conant, L. C., and Eargle, D. H., 1946, Pre-Selma Upper Cretaceous stratigraphy of western Alabama: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 187-212.

Moore, B. R., and Dennen, W. H., 1970, A geochemical trend in silicon-aluminum-iron ratios: Jour. Sedimentary Petrology, v. 40, p. 1147-1152.

Moore, D. B., and Joiner, T. J., 1969, A subsurface study of southeast Alabama: Alabama Geol. Survey Bull. 88, 33 p.

Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal province of North America: New York, Harper and Brothers, 692 p.

Naff, J. D., 1940, The Tuscaloosa-Pottsville contact in Tuscaloosa County, Alabama: Alabama Univ., unpub. Master's Thesis, 18 p.

Neiheisel, James, 1962, Heavy-mineral investigation of Recent and Pleistocene sands of lower Coastal Plain of Georgia: Geol. Soc. America Bull., v. 73, p. 365-374.

Neiheisel, James, and Weaver, C. E., 1967, Transport and deposition of clay minerals, southeastern United States: Jour. Sedimentary Petrology, v. 37, p. 1084-1116.

Omara, S., Bishara, W. W., and Nasr, M., 1974, Grain-size parameters and paleoenvironments of the Nubia sandstone: Jour. Sedimentary Petrology, v. 44, p. 136-144.

Otto, G. H., 1938, The sedimentation unit and its use in field sampling: Jour. Geology, v. 46, p. 569-582.

Parnell, R. H., 1962, A study of old Tombigbee River terrace deposits in eastern Lowndes County, Mississippi and western Pickens and Lamar Counties, Alabama: Mississippi State Univ., unpub. Master's Thesis, 42 p.

Passega, Renato, 1957, Texture as characteristic of clastic deposition: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1952-1984.

_______ 1964, Grain size representation by CM patterns as a geologic tool: Jour. Sedimentary Petrology, v. 34, p. 830-847.

Paulson, Q. F., Miller, J. D., Jr., and Drennen, C. W., 1962, Ground-water resources and geology of Tuscaloosa County, Alabama: Alabama Geol. Survey County Rept. 6, 97 p.

Pettijohn, F. J., 1941, Persistence of heavy minerals and geologic age: Jour. Geology, v. 47, p. 610-625.

_______ 1957, Sedimentary rocks: New York, Harper and Row, 718 p.

_______ 1963, Chemical composition of sandstone--excluding carbonate and volcanic sands: U. S. Geol. Survey Prof. Paper 440-S, 21 p.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1973, Sand and sandstone: New York, Springer-Verlag, 618 p.

Pierce, J. W., and Siegel, F. R., 1969, Quantification in clay mineral studies of sediments and sedimentary rocks: Jour. Sedimentary Petrology, v. 39, p. 187-193.

Potter, P. E., 1955, The petrology and origin of the Lafayette gravel: Jour. Geology, v. 63, p. 1-38; 115-132.

Pryor, W. A., and Hester, N. C., 1969, X-ray diffraction analysis of heavy minerals: Jour. Sedimentary Petrology, v. 39, p. 1384-1389.

Ramesam, V., 1966, Improved methods of heavy mineral separation and counting suitable for fine-grained sandstones: Jour. Sedimentary Petrology, v. 36, p. 639-631.

Riccio, J. F., Isphording, W. C., and Gazzier, C. A., 1972, Neogene sediments of Mobile County, Alabama, <u>in</u> Scarbrough, W. L., ed., Recent sedimentation along the Alabama coast: Alabama Geol. Soc. Guidebook 10th Ann. Field Trip, p. 46-79.

Rigby, J. K., and Hamblin, W. K., eds., 1972, Recognition of ancient sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 16, 340 p.

Rittenhouse, G., 1943, Transportation and deposition of heavy minerals: Geol. Soc. America Bull., v. 54, p. 1725-1780.

______ 1944, Sources of modern sands in the middle Rio Grande Valley, New Mexico: Jour. Geology, v. 52, p. 145-183.

Rosen, N. C., 1969, Heavy minerals and size analysis of the Citronelle Formation of the Gulf Coastal Plain: Jour. Sedimentary Petrology, v. 39, p. 1552-1565.

Royse, C. F., Jr., 1970, An introduction to sediment analysis: Arizona State University, Tempe, Arizona, 180 p.

Rubey, W. W., 1933, Settling velocities of gravel, sand, and silt particles: Am. Jour. Sci., 5th Ser., v. 25, p. 325-338.

Russell, R. P., 1937, Mineral composition of Mississippi River Sands: Geol. Soc. America Bull., v. 48, p. 1307-1348.

Saffer, P. E., 1955, A preliminary investigation of river and bench samples collected in the states of Florida, Georgia, and Alabama: Florida State University, unpub. Master's Thesis, 59 p.

Sahu, B. K., 1964, Depositional mechanisms from the size analysis of clastic sediments: Jour. Sedimentary Petrology, v. 34, p. 73-83.

Saucier, R. T., and Fleetwood, A. R., 1970, Origin and chronologic significance of Late Quaternary terraces, Quachita River, Arkansas and Louisiana: Geol. Soc. America Bull., v. 81, p. 869-890.

Selley, R. C., 1970, Ancient sedimentary environments--a brief survey: Ithaca, New York, Cornell University Press, 273 p.

Smith, E. A., 1892, The Lafayette gravels: Science, v. 19, p. 31.

Smith, E. A., and Johnson, L. C., 1887, Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama Rivers: U. S. Geol. Survey Bull. 43, 189 p.

Smith, E. A., Johnson, L. C., and Langdon, D. W., Jr., 1894, Report on the geology of the Coastal Plain of Alabama: Alabama Geol. Survey Spec. Rept. 6, p. 307-314.

Smith, E. A., McCalley, H., Langdon, D. W., Johnson, L. C., Squire, J., and Gibson, A. M., 1894, Geologic map of Alabama: Alabama Geol. Survey Spec. Map 1.

Solohub, J. T., and Klovan, J. E., 1970, Evaluation of grain-size parameters in lacustrine environments: Jour. Sed. Petrology, v. 40, p. 81-101.

Stephenson, L. W., 1914, Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 9-40.

Stephenson, L. W., and Monroe, W. H., 1938, Stratigraphy of Upper Cretaceous Series in Mississippi and Alabama: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 1638-1657.

Stow, S. H., and Hughes, T. H., in preparation, Geologic map of the Cottondale quadrangle, in Geology and the urban environment, Cottondale quadrangle, Tuscaloosa County, Alabama: Alabama Geol. Survey Atlas Ser.

Szabo, M. W., 1972, Quaternary geology, Alabama River basin, Alabama: Alabama Univ., unpub. Master's Thesis, 84 p.

Tanner, W. F., 1955, Paleogeographic recostructions from cross-bedding studies: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 2471-2483.

Temple, A. K., 1966, Alteration of ilmenite: Econ. Geol., v. 61, p. 695-714.

Thomas, Toab, 1973, Vegetation, in Lineback, N. G., ed., Atlas of Alabama: Alabama Univ., University of Alabama Press, p. 15-17.

Thomas, W. A., and Drahovzal, J. A., 1973, Regional Paleozoic stratigraphy of Alabama, in Carrington, T. J., ed., Talladega metamorphic front: Alabama Geol. Soc. guidebook, 11th Ann. field trip, p. 22-38.

Thornbury, W. D., 1965, Regional geomorphology of the United States: New York, John Wiley, 609 p.

_______ 1969, Principles of geomorphology: New York, John Wiley, 594 p.

Visher, G. S., 1969, Grain size, distribution, and depositional processes: Jour. Sedimentary Petrology, v. 39, p. 1074-1106.

Walker, T. R., 1974, Formation of red beds in moist tropical climates: a hypothesis: Geol. Soc. America Bull. v. 85, p. 633-638.

Weaver, C. E., and Pollard, L. D., 1973, The chemistry of clay minerals: Amsterdam, Elsevier, 213 p.

Wermund, E. G., 1961, Glauconite in Early Tertiary sediments of Gulf Coastal province: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 1667-1697.

Wielchowsky, C. C., and Gilbert, O. E., Jr., eds., 1973, Selected geology of Tuscaloosa, Jefferson, Shelby, and Bibb Counties, Alabama: Alabama Geol. Survey open-file report, 31 p.

Wilson, E. M., 1973, Soils, in Lineback, N. G., ed., Atlas of Alabama: University, Alabama, University of Alabama Press, p. 8-9.

Young, E. J., 1966, A critique of methods for comparing heavy mineral suites: Jour. Sedimentary Petrology, v. 36, p. 57-65.

APPENDIX 1

LOCATION AND DESCRIPTION OF SAMPLE SITES

Sample No.	Location	Description
CSKes-1	NW$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. North side of railroad cut at type section of old Cottondale Formation.	Sampled 1.3 m unit of crossbedded coarse-grained sand and gravel of the basal Eoline member (sand) just below a .3 m gravel lense.
CSKes-2	NW$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. North side of railroad cut 525 m west of CSKes-1.	Sample .6 m unit of crossbedded medium-grained sand above a gravel lense.
CSKes-3	SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. North side of railroad cut 920 m west of CSKes-1.	Sample 1.5 m unit of a fine-grained white and yellow sand containing rounded clay clasts just below an ironstone ledge.
CSKes-4	NW$\frac{1}{4}$NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 30, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. South side of railroad and east side of Echo Lake Road in fresh cut.	Sampled .9 m unit of medium-grained yellow sand below Eoline member (sand) clay lense.
CSKes-5	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Gravel pit.	Sampled 1.5 m unit of medium-grained yellow sand and gravel in a washout of 9 m of exposure.
CSKes-6	NW$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKes-1.	Sampled .6 m thick gravel and coarse-grained sand lense.
CSKes-7	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same gravel pit as CSKes-5.	Sampled .9 m unit of gravel, sand, and clay. Possible colluvial Eoline member (sand).
CSKes-8	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same gravel pit as CSKes-5.	Sampled .3 m lense of gravel and coarse-grained sand containing quartz and chert rounded gravel and clay clasts. This unit is overlain by a red and gray mottled clay unit.

CSKes-9	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same gravel pit as CSKes-5.	Sampled .6 m unit of crossbedded micaceous sand with interspersed gravel and rounded gray clay clasts.
CSKes-10	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same gravel pit as CSKes-5.	Sampled .6 m unit of crossbedded micaceous sand containing a little gravel.
CSKes-11	SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle, Alabama. Cut beside Northwood Hills Baptist Church.	Sampled .3 m unit of crossbedded medium-grained sand below the lowest clay lense in the cut. Sample collected 3 m from base of cut.
CSKec-1	SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle, Alabama. Same locality as CSKes-11, but higher up on cut.	Sampled .3 m bed of crossbedded light yellow micaceous fine-grained sand containing rounded clay clasts about 23 m from base of cut.
CSKu-1	SE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Cut north of road.	Sampled 1.2 m unit of fine-grained micaceous sand just above contact with Eoline member (clay).
CSKu-2	NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama. Cut north of road intersection.	Sampled 1.2 m unit of micaceous and and mottled clay containing clay clasts just below probable alluvial terrace deposits that have been slightly reworked in Pleistocene(?) time.
CSKu-3	NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama. Cut on northeast side of U.S. 82.	Sampled 1.5 m unit of highly micaceous, fine-grained white sand containing rounded purple and gray clay clasts.

CSKu-4	NW$\frac{1}{4}$SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 31, T. 20 S., R. 11 W., Samantha quadrangle, Alabama. South side of U.S. 82, about 5 km west of Coker.	Sampled 1.2 m lense of angular chert gravel, sand, and red and gray mottled clay.
CSKu-5	SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21, T. 21 S., R. 11 W., Coker quadrangle, Alabama. Southwest side of road at old Coker Formation type section.	Sampled 1.5 m unit of light tan, cross-bedded, micaceous sand overlain by a sand unit with large clay clasts.
CSQt-1	NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama. Same cut as CSKu-2.	Sampled .9 m lense of gravel, sand, clay, and rounded ironstone. Gravel was quartz rich and highly angular.
CSQt-2	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 9, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. East side of road near Holt High School.	Sampled 1.2 m unit of chert rich (tripolitic) gravel and coarse-grained red sand. Pottsville and rounded ironstone clasts were present and gravels were frosted and iron-stained.
CSQt-3	NW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 11, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Northeast side of road.	Sampled 1.2 m unit of light to dark red to yellow cross-bedded sand.
CSQt-4	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle, Alabama. Gravel pit on north side of River Road.	Sampled .3 m unit of red coarse sand containing a little chert gravel out of cut 4.5 m high.
CSQt-5	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle, Alabama. Same locality as CSQt-4.	Sampled .3 m unit of iron-stained quartz and tripolitic chert gravel and red coarse-grained sand. Pottsville, rounded and polished ironstone, and iron-cemented sandstone clasts were abundant.

SSKes-1	SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 25, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKes-3.	Sample collected from .2 m A_2 horizon beginning 5 cm below land surface. Negligible slope with pines.
SSKes-2	NW$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 23, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKes-2.	Sample collected from .1 m A_2 horizon beginning 3 cm below land surface. Negligible slope with pines.
SSKes-3	SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle, Alabama. In back of Northwood Hills Baptist Church.	Sample collected from .1 m A_2 horizon beginning 5 cm below land surface. Moderate slope with mixed vegetation.
SSKes-4	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKes-5.	Sample collected from .4 m A_2 horizon beginning 5 cm below land surface. Negligible slope with mixed vegetation.
SSKec-1	NW$\frac{1}{4}$NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 30, T. 21 S., R. 8 W., Cottondale quadrangle, Alabama. Same locality as CSKes-4, but above contact with Eoline member (clay).	Sample collected from .1 m A_2 horizon beginning 1 cm below land surface. No slope with pines.
SSKu-1	SE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKu-1.	Sample collected from .1 m A_2 horizon beginning 1 cm below land surface. Slope negligible with mixed hardwoods and pine.
SSKu-2	SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21, T. 21 S., R. 11 W., Coker quadrangle, Alabama. Same locality as CSKu-5.	Sample collected from .4 m A_2 horizon beginning 4 cm below land surface. Negligible slope with mixed hardwoods and pines.
SSQt-1	NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKu-3 except collected from overlying alluvial terrace deposit.	Sample collected from .3 m A_2 horizon beginning .1 m below land surface. Negligible slope with mixed scrub, grass, and pines.

SSQt-2	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKu-5.	Sample collected from .1 m A_2 horizon beginning 3 cm below land surface. Steep slope with mixed vegetation.
SSQt-3	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 9, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSQt-2.	Sample collected from .2 m A_2 horizon beginning 3 cm below land surface. Negligible slope with mixed vegetation.
SSQt-4	NW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 11, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSQt-3.	Sample collected from .2 m A_2 horizon beginning 8 cm below land surface. Negligible slope with mixed vegetation.
SSQt-5	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle, Alabama. Same locality as CSQt-4.	Sample collected from .1 m A_2 horizon beginning 3 cm below land surface. No slope with mixed vegetation.
ClKes-1	SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle, Alabama. Northwood Hills Baptist Church cut.	Grab sample of Eoline member (sand) laminated clay unit.
ClKes-2	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 21 S., R. 9 W., Tuscaloosa quadrangle, Alabama. Same locality as CSQt-4.	Grab sample of upper massive clay unit of Eoline member (sand).
ClKes-3	SE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Same locality as CSKes-5.	Grab sample of upper massive mottled red and gray clay unit of Eoline member (sand).
ClKes-4	SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 9, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Near locality of CSQt-2 but lower in section.	Grab sample of clay lense of Eoline member (sand).
ClKes-5	NW$\frac{1}{4}$NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 30, T. 21 S., R. 8 W., Cottondale quadrangle, Alabama. Same locality as CSKes-4.	Grab sample of massive gray clay unit of Eoline member (sand).

ClKec-1	SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 10, T. 21 S., R. 10 W., Tuscaloosa quadrangle, Alabama. Upper cut at Northwood Hills Baptist Church.	Grab sample of laminated clay unit of Eoline member (clay).
ClKec-2	NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama.	Grab sample of laminated clay unit of Eoline member (clay).
ClKu-1	NE$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 10, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama.	Grab sample of mottled red and white massive clay unit of unnamed upper member.
ClKu-2	NW$\frac{1}{4}$SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 13, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama.	Grab sample of mottled red, gray, and white massive clay unit of unnamed upper member.
ClKu-3	NW$\frac{1}{4}$NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 24, T. 22 S., R. 9 W., Cottondale quadrangle, Alabama.	Grab sample of massive clay unit of unnamed upper member.
ClQt-1	NW$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 22, T. 21 S., R. 10 W., Tuscaloosa quadrangle, Alabama. Cut north of River Road.	Grab sample of mottled red and white alluvial terrace deposit clay lense.
Qal-1	SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 5, T. 22 S., R. 10 W., Tuscaloosa quadrangle, Alabama. Curtis Concrete Company gravel pit in floodplain of Black Warrior River.	Grab sample of Black Warrior River gray floodplain clay unit.
Cpv-1	NW$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Clay exposure on west side of road at Whip-porwill Hill.	Grab sample of massive white to tan probable Pottsville clay unit.
Cpv-2	NW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 36, T. 21 S., R. 9 W., Cottondale quadrangle, Alabama. Collected in slump south of road.	Grab sample of massive gray to white probable Pottsville clay unit.

Cpv-3	SE$\frac{1}{4}$NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 30, T. 21 S., R. 8 W., Cottondale quadrangle, Alabama. Collected below dam at Canyon Lake.	Grab sample of massive gray to white mottled clay unit that is definitely Pottsville.

APPENDIX 2

HISTOGRAMS, CUMULATIVE FREQUENCY CURVES, AND SIZE DISTRIBUTION DESCRIPTIVE MEASURES FOR EACH CHANNEL AND SOIL SAMPLE

EXPLANATION

Md	Median
Mn	Mean
σ_I	Sorting
Sk_I	Skewness
K_G	Kurtosis
Gr	Gravel
Sd	Sand
St	Silt
Cl	Clay

CSKes-1

Md	=	1.00 ϕ
Mn	=	1.08 ϕ
σ_I	=	1.42 ϕ
Sk_I	=	.50
K_G	=	4.51
Gr	=	2.33%
Sd	=	91.80%
St	=	1.20%
Cl	=	4.66%

CSKes-2

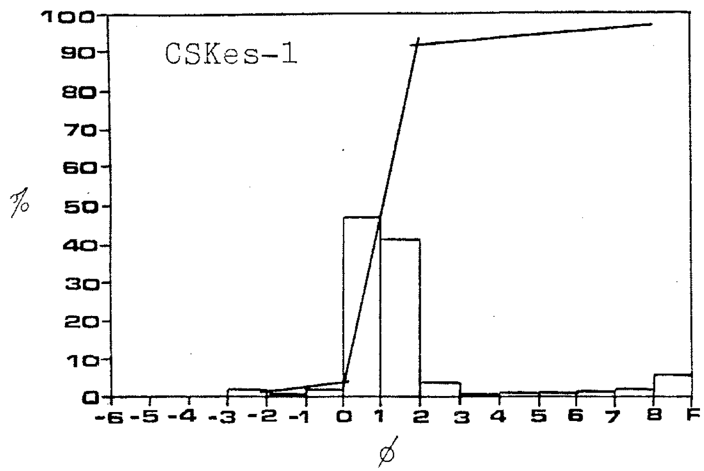
Md	=	2.05 ϕ
Mn	=	3.07 ϕ
σ_I	=	2.18 ϕ
Sk_I	=	.80
K_G	=	4.24
Gr	=	.10%
Sd	=	82.68%
St	=	3.73%
Cl	=	13.49%

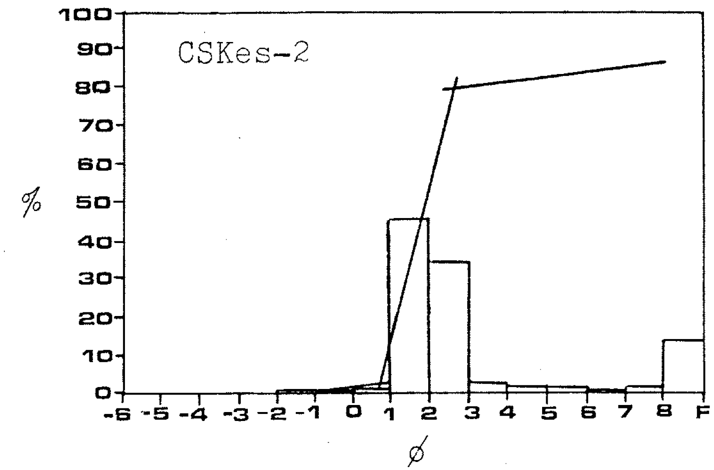
CSKes-3

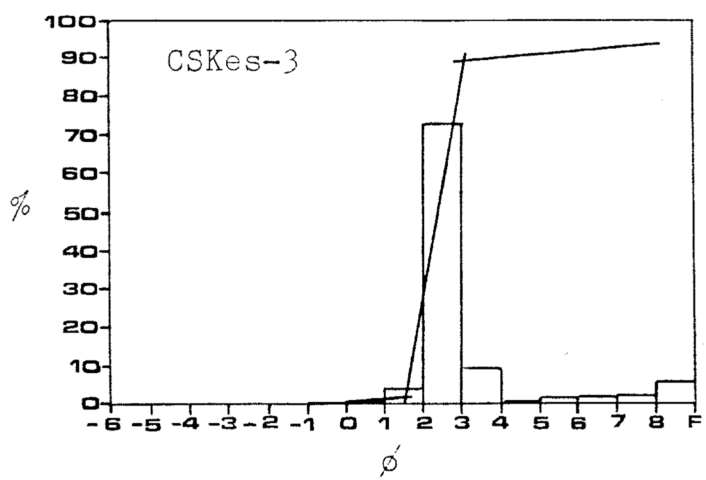
Md	=	2.50 ϕ
Mn	=	2.62 ϕ
σ_I	=	1.16 ϕ
Sk_I	=	.61
K_G	=	4.61
Gr	=	.00%
Sd	=	90.22%
St	=	4.28%
Cl	=	5.50%

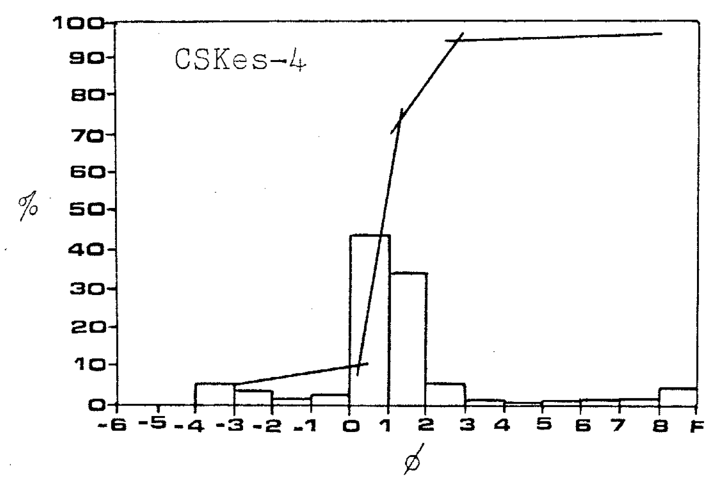
CSKes-4

Md	=	.95 ϕ
Mn	=	1.03 ϕ
σ_I	=	1.78 ϕ
Sk_I	=	.17
K_G	=	5.08
Gr	=	8.95%
Sd	=	85.59%
St	=	1.50%
Cl	=	3.96%


CSKes-1
%
ø
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F


CSKes-2
%
ø
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F


CSKes-3
%
ø
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F


CSKes-4
%
ø
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F

CSKes-5

Md = 1.80 ø
Mn = 1.89 ø
σ_I = 1.31 ø
Sk_I = .45
K_G = 3.18
Gr = .07%
Sd = 92.29%
St = 3.23%
Cl = 4.41%

CSKes-6

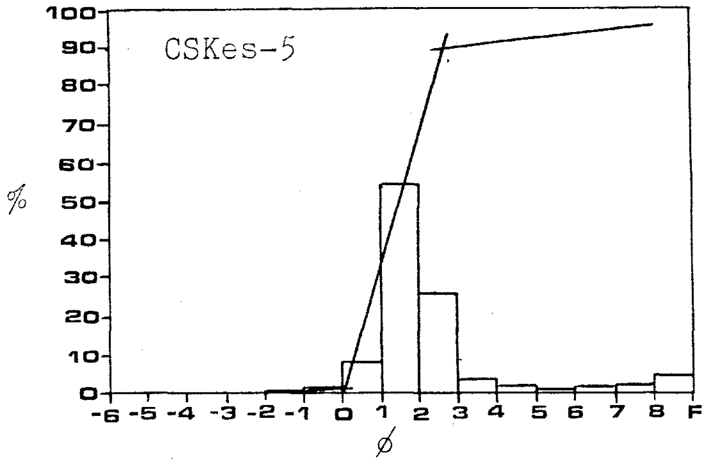
Md = .62 ø
Mn = .07 ø
σ_I = 3.40
Sk_I = .01
K_G = 1.07
Gr = 38.06%
Sd = 48.92%
St = 4.79%
Cl = 8.23%

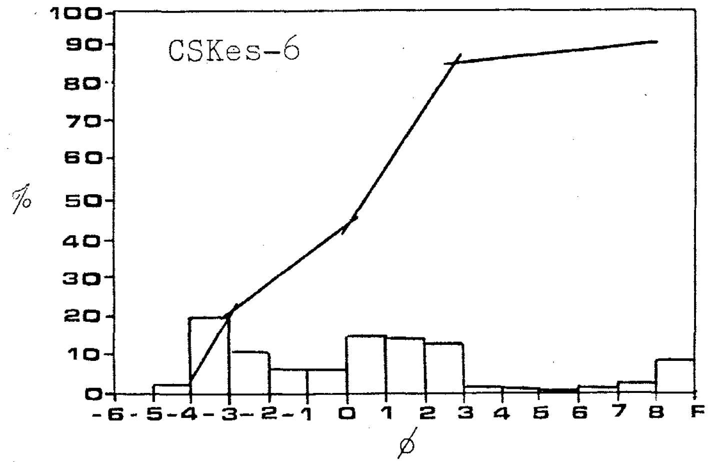
CSKes-7

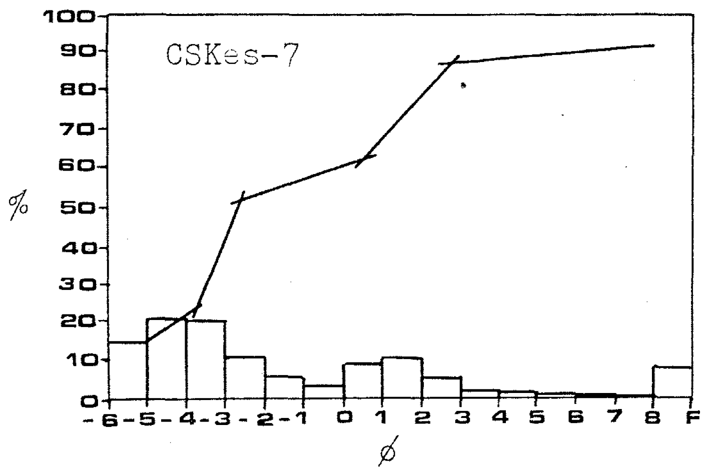
Md = -2.30 ø
Mn = -1.72 ø
σ_I = 3.87 ø
Sk_I = .45
K_G = 1.11
Gr = 58.83%
Sd = 29.63%
St = 3.24%
Cl = 8.30%

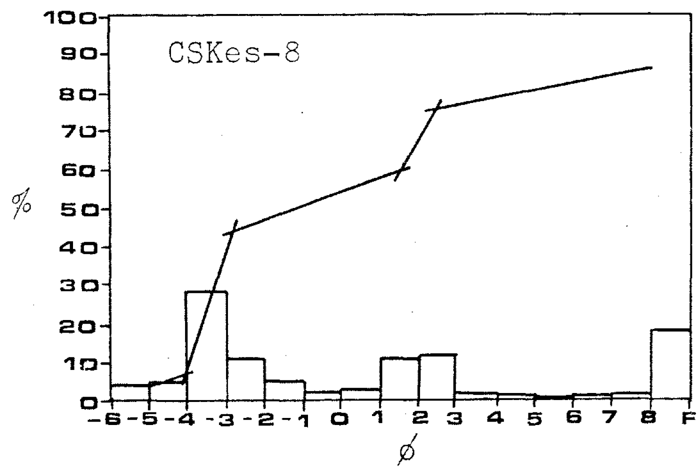
CSKes-8

Md = -1.23 ø
Mn = 1.13 ø
σ_I = 5.04 ø
Sk_I = .57
K_G = 1.01
Gr = 50.09%
Sd = 28.92%
St = 3.47%
Cl = 17.52%


CSKes-5
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


CSKes-6
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


CSKes-7
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


CSKes-8
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ

CSKes-9

Md	=	-2.30 ø
Mn	=	-1.58 ø
σ_I	=	3.90 ø
Sk_I	=	.44
K_G	=	.92
Gr	=	53.77%
Sd	=	36.19%
St	=	2.15%
Cl	=	7.89%

CSKes-10

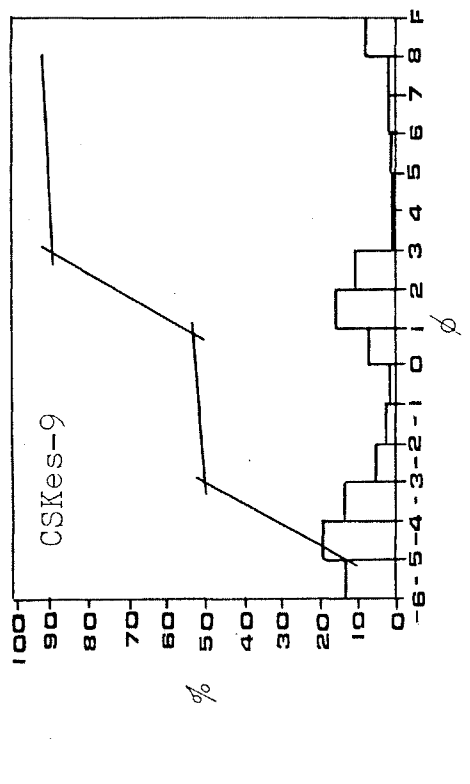
Md	=	2.30 ø
Mn	=	4.13 ø
σ_I	=	3.24 ø
Sk_I	=	.70
K_G	=	.59
Gr	=	3.11%
Sd	=	60.96%
St	=	9.50%
Cl	=	25.34%

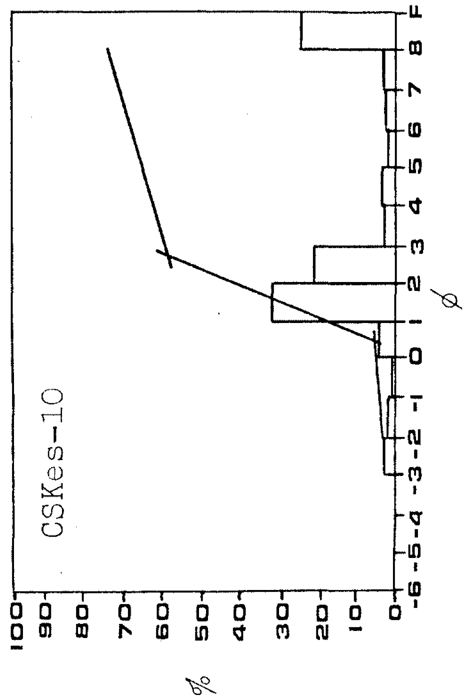
CSKes-11

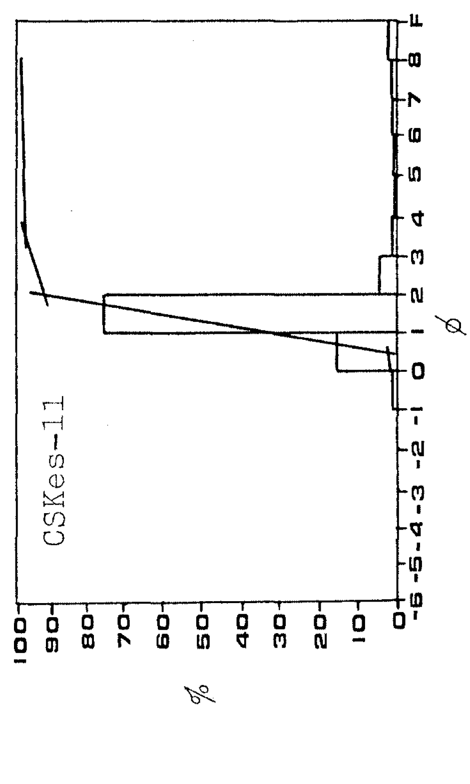
Md	=	1.30 ø
Mn	=	1.34 ø
σ_I	=	.44 ø
Sk_I	=	.31
K_G	=	1.75
Gr	=	.00%
Sd	=	97.35%
St	=	.81%
Cl	=	1.84%

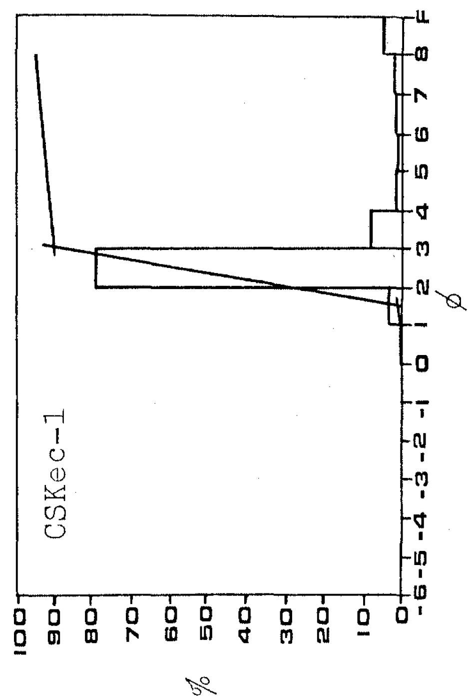
CSKec-1

Md	=	2.55 ø
Mn	=	2.60 ø
σ_I	=	1.04 ø
Sk_I	=	.51
K_G	=	4.39
Gr	=	.00%
Sd	=	91.62%
St	=	3.89%
Cl	=	4.49%


CSKes-9
%
ϕ
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F


CSKes-10
%
ϕ
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F


CSKes-11
%
ϕ
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F


CSKec-1
%
ϕ
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F

CSKu-1

Md = 2.67 ϕ
Mn = 2.86 ϕ
σ_I = 1.58 ϕ
Sk_I = .57
K_G = 2.72
Gr = .01%
Sd = 83.49%
St = 9.03%
Cl = 7.47%

CSKu-2

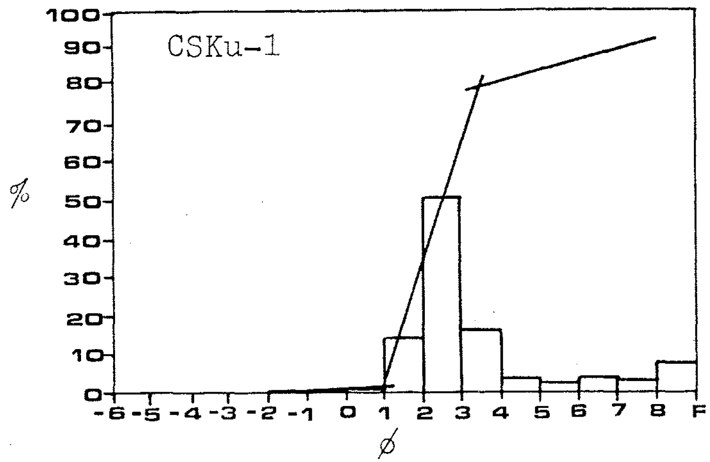
Md = 3.33 ϕ
Mn = 4.85 ϕ
σ_I = 2.52 ϕ
Sk_I = .78
K_G = .76
Gr = .00%
Sd = 64.95%
St = 9.03%
Cl = 21.46%

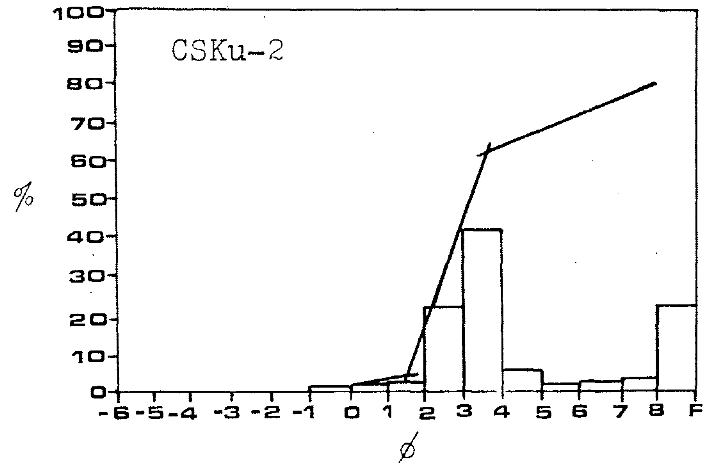
CSKu-3

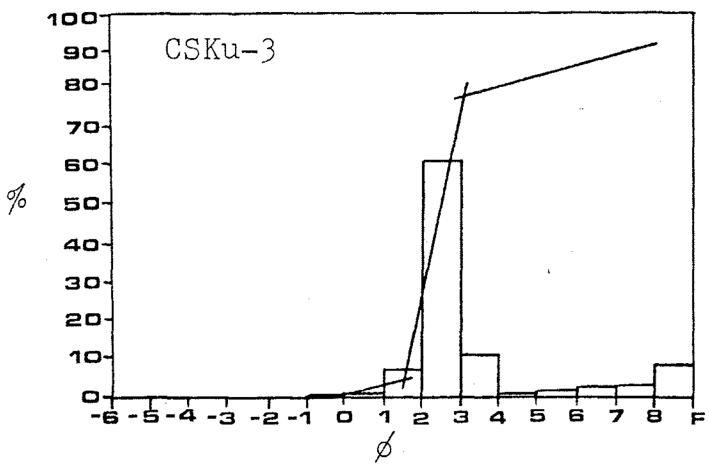
Md = 2.73 ϕ
Mn = 3.55 ϕ
σ_I = 1.90 ϕ
Sk_I = .73
K_G = 3.25
Gr = .00%
Sd = 81.22%
St = 10.24%
Cl = 8.54%

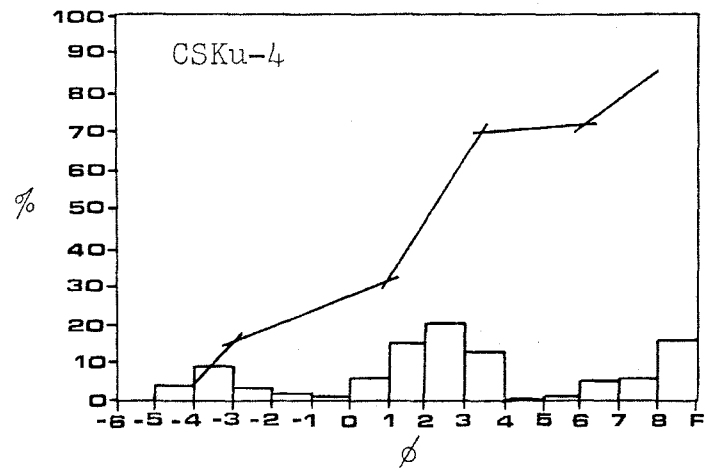
CSKu-4

Md = 2.24 ϕ
Mn = 2.60 ϕ
σ_I = 4.61 ϕ
Sk_I = .09
K_G = .92
Gr = 20.71%
Sd = 51.75%
St = 12.00%
Cl = 15.54%


CSKu-1
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


CSKu-2
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


CSKu-3
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


CSKu-4
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ

CSKu-5

Md	=	3.03 ϕ
Mn	=	3.17 ϕ
σ_I	=	1.29 ϕ
Sk_I	=	.50
K_G	=	3.35
Gr	=	.00%
Sd	=	84.91%
St	=	8.85%
Cl	=	6.24%

CSQt-1

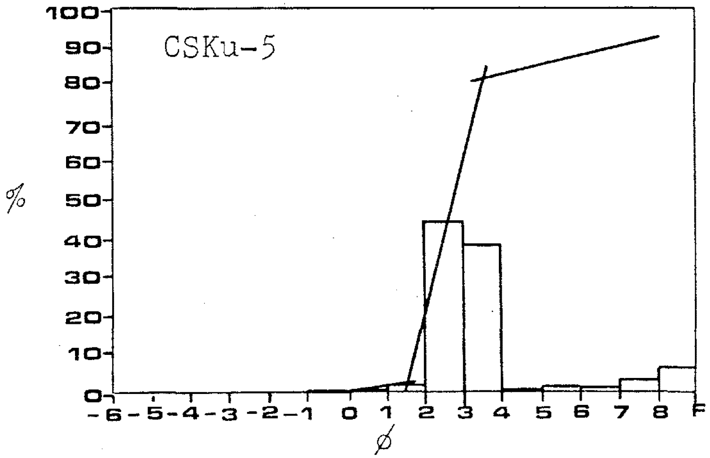
Md	=	.89 ϕ
Mn	=	.15 ϕ
σ_I	=	3.31 ϕ
Sk_I	=	- .08
K_G	=	.93
Gr	=	41.26%
Sd	=	51.47%
St	=	1.96%
Cl	=	5.31%

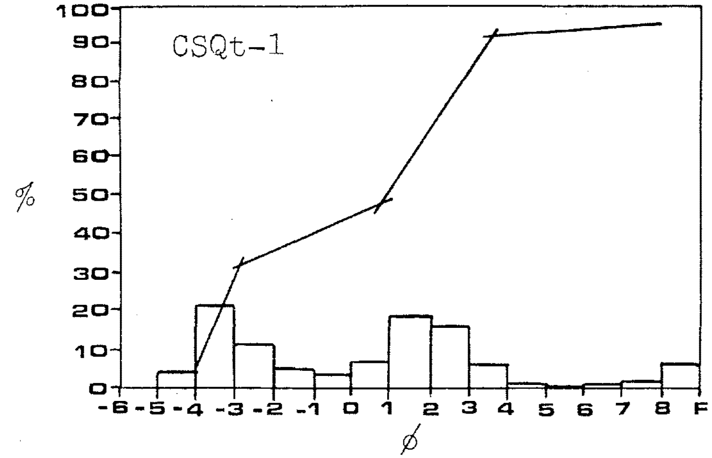
CSQt-2

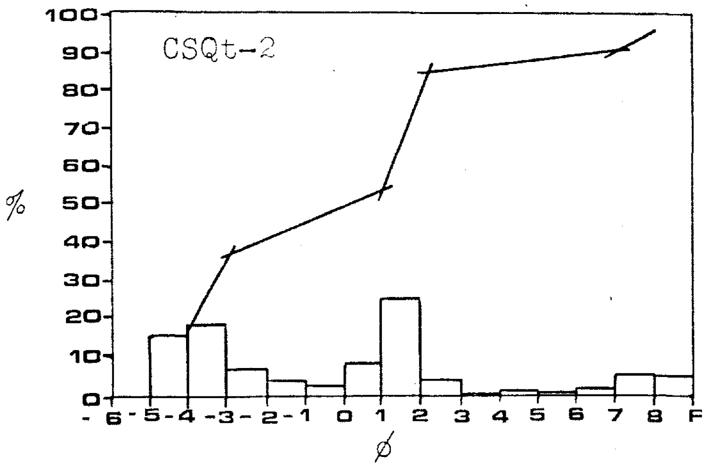
Md	=	.55 ϕ
Mn	=	- .34 ϕ
σ_I	=	3.47 ϕ
Sk_I	=	- .10
K_G	=	.97
Gr	=	44.79%
Sd	=	40.66%
St	=	9.33%
Cl	=	5.22%

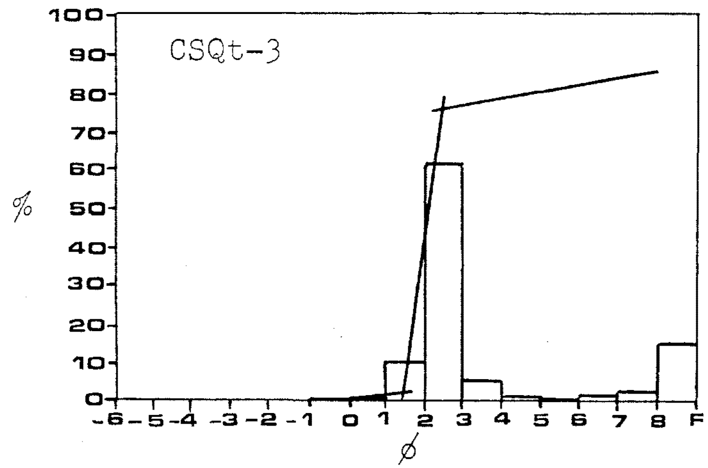
CSQt-3

Md	=	2.45 ϕ
Mn	=	4.08 ϕ
σ_I	=	2.54 ϕ
Sk_I	=	.86
K_G	=	3.00
Gr	=	.00%
Sd	=	79.03%
St	=	5.75%
Cl	=	15.22%


CSKu-5
%
ø


CSQt-1
%
ø


CSQt-2
%
ø


CSQt-3
%
ø

CSQt-4

Md	=	1.18 ϕ
Mn	=	1.16 ϕ
σ_I	=	1.95 ϕ
Sk_I	=	.19
K_G	=	5.10
Gr	=	7.02%
Sd	=	83.07%
St	=	1.52%
Cl	=	8.39%

CSQt-5

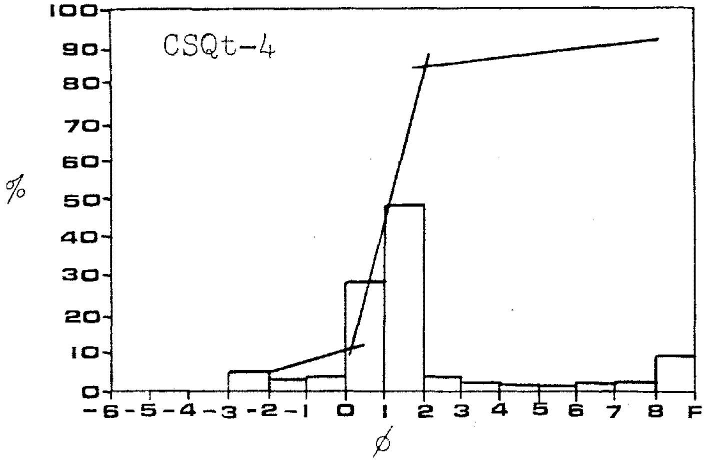
Md	=	- .58 ϕ
Mn	=	- .59 ϕ
σ_I	=	3.73 ϕ
Sk_I	=	.21
K_G	=	1.19
Gr	=	47.91%
Sd	=	38.02%
St	=	4.94%
Cl	=	9.13%

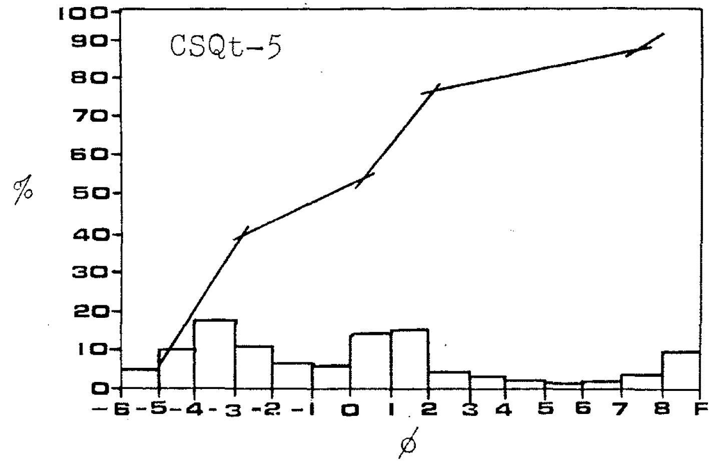
SSKes-1

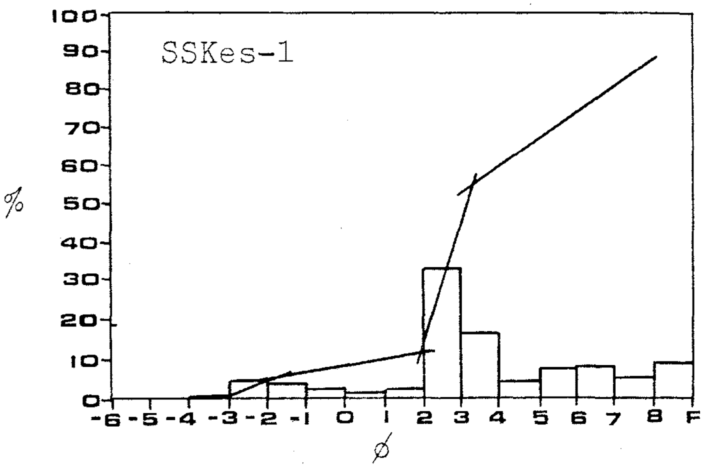
Md	=	3.18 ϕ
Mn	=	4.11 ϕ
σ_I	=	2.79 ϕ
Sk_I	=	.33
K_G	=	1.30
Gr	=	7.37%
Sd	=	55.47%
St	=	27.66%
Cl	=	9.50%

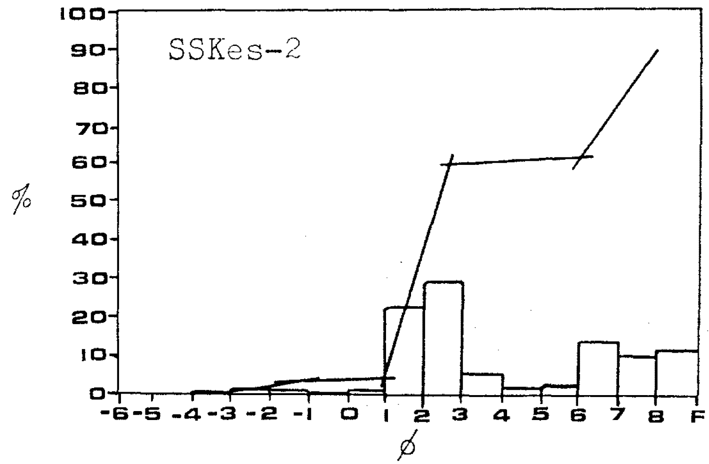
SSKes-2

Md	=	2.63 ϕ
Mn	=	3.98 ϕ
σ_I	=	2.61 ϕ
Sk_I	=	.72
K_G	=	.68
Gr	=	2.85%
Sd	=	58.83%
St	=	26.52%
Cl	=	11.80%


CSQt-4
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ø


CSQt-5
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ø


SSKes-1
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ø


SSKes-2
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ø

SSKes-3

Md = 2.52 ϕ
Mn = 3.42 ϕ
σ_I = 2.15 ϕ
Sk_I = .63
K_G = 1.15
Gr = .18%
Sd = 73.42%
St = 20.37%
Cl = 6.03%

SSKes-4

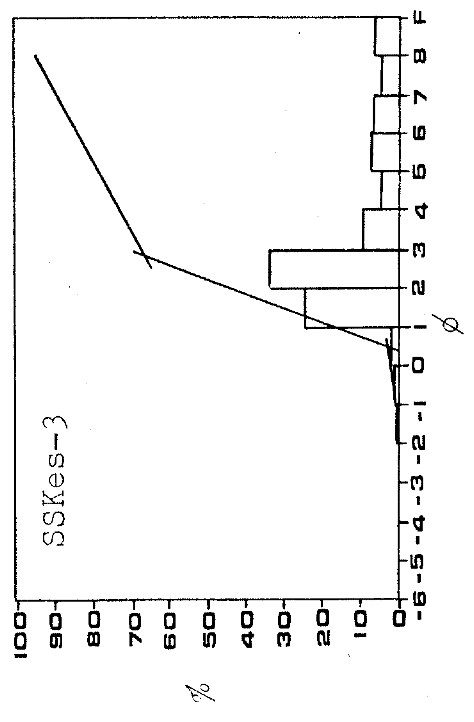
Md = 1.98 ϕ
Mn = 2.15 ϕ
σ_I = 3.86 ϕ
Sk_I = .07
K_G = .78
Gr = 23.04%
Sd = 46.49%
St = 26.02%
Cl = 4.45%

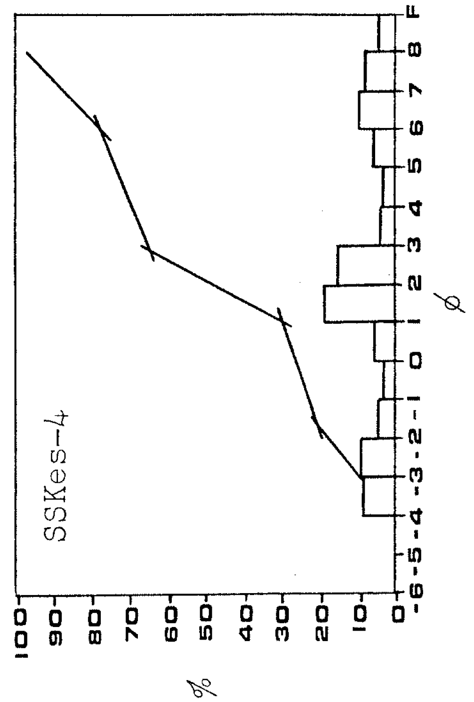
SSKec-1

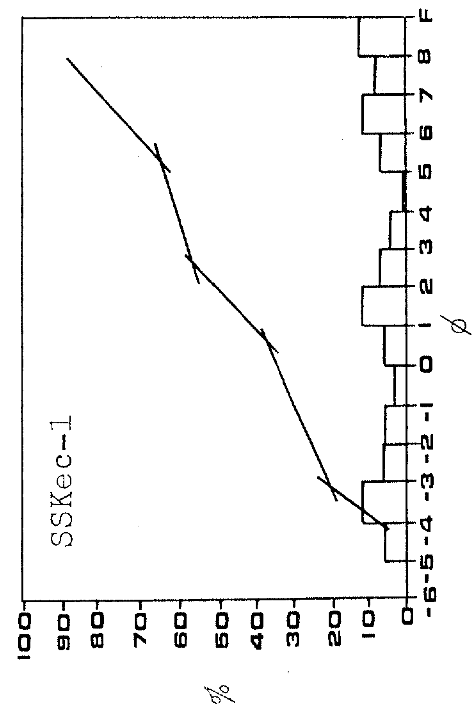
Md = 2.09 ϕ
Mn = 2.17 ϕ
σ_I = 4.64 ϕ
Sk_I = .05
K_G = .66
Gr = 28.37%
Sd = 32.49%
St = 27.19%
Cl = 11.95%

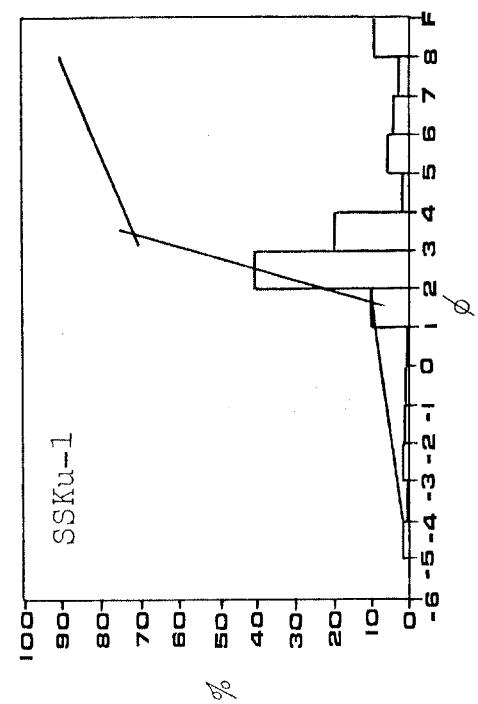
SSKec-1

Md = 2.83 ϕ
Mn = 3.62 ϕ
σ_I = 2.26 ϕ
Sk_I = .42
K_G = 2.39
Gr = 4.63%
Sd = 71.59%
St = 14.86%
Cl = 8.92%


SSKes-3
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


SSKes-4
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


SSKec-1
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


SSKu-1
%
100 90 80 70 60 50 40 30 20 10 0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ

SSKu-2

Md = 5.07 ϕ
Mn = 4.69 ϕ
σ_I = 1.39 ϕ
Sk_I = - .29
K_G = 1.72
Gr = .64%
Sd = 42.88%
St = 46.51%
Cl = 9.97%

SSQt-1

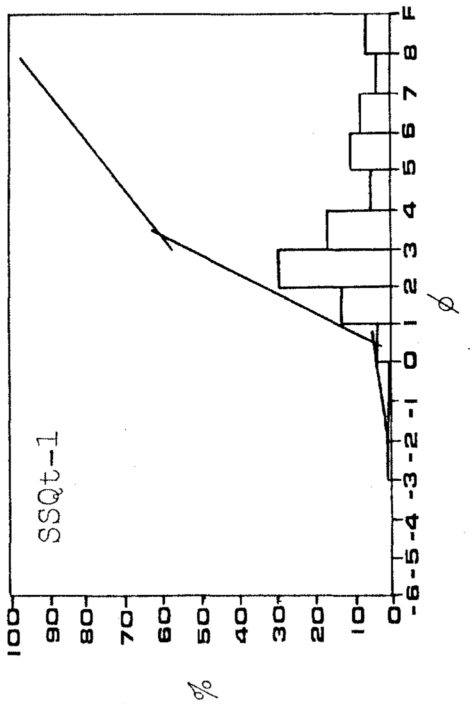
Md = 3.05 ϕ
Mn = 3.73 ϕ
σ_I = 2.20 ϕ
Sk_I = .44
K_G = 7.69
Gr = 1.61%
Sd = 64.09%
St = 28.52%
Cl = 5.78%

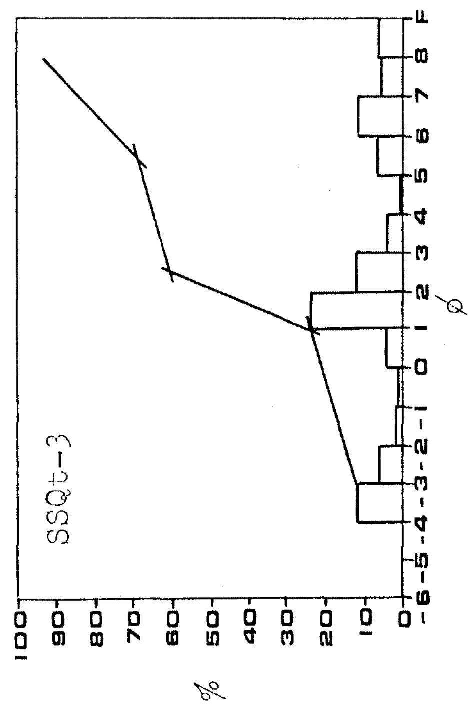
SSQt-2

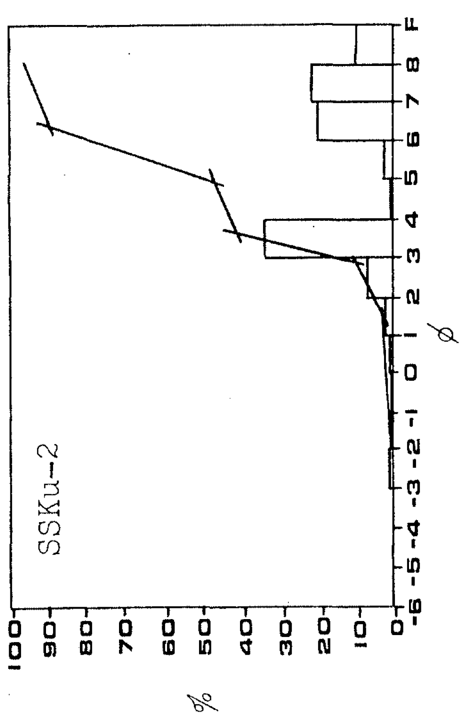
Md = 2.12 ϕ
Mn = 2.19 ϕ
σ_I = 4.18 ϕ
Sk_I = .07
K_G = .94
Gr = 21.58%
Sd = 42.30%
St = 27.66%
Cl = 8.46%

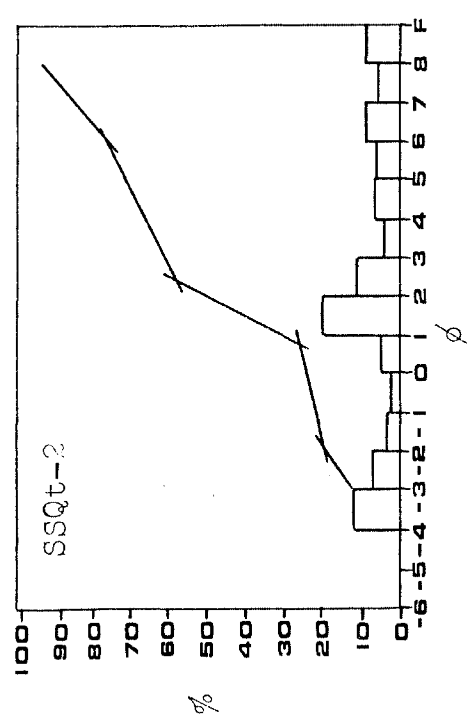
SSQt-3

Md = 2.02 ϕ
Mn = 2.17 ϕ
σ_I = 4.03 ϕ
Sk_I = .09
K_G = .96
Gr = 19.93%
Sd = 47.18%
St = 26.14%
Cl = 6.75%


SSQt-1


SSQt-3


SSKu-2

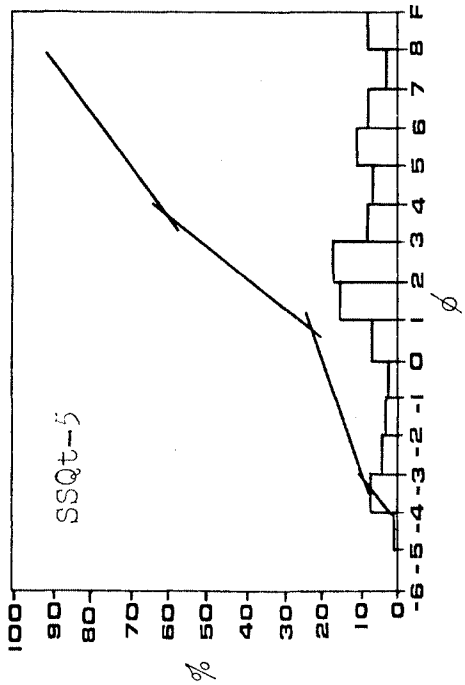

SSQt-2

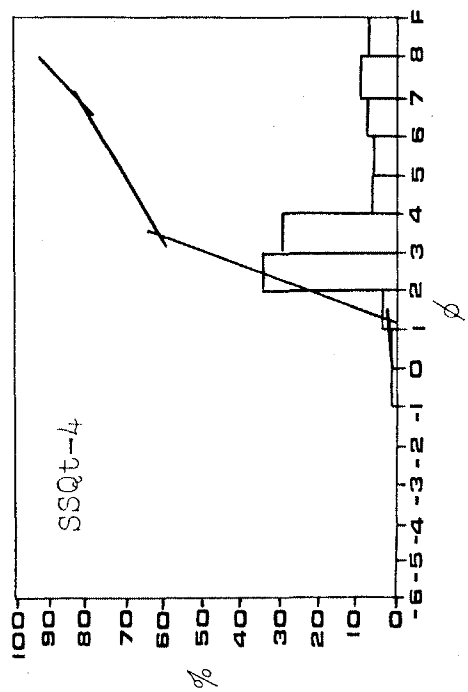
SSQt-4

Md	=	3.29 ϕ
Mn	=	4.26 ϕ
σ_I	=	2.03 ϕ
Sk_I	=	.66
K_G	=	.92
Gr	=	.00%
Sd	=	66.67%
St	=	26.49%
Cl	=	6.84%

SSQt-5

Md	=	2.59 ϕ
Mn	=	2.48 ϕ
σ_I	=	3.74 ϕ
Sk_I	=	- .02
K_G	=	1.04
Gr	=	17.56%
Sd	=	45.54%
St	=	29.10%
Cl	=	7.80%


SSQt-5
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ


SSQt-4
%
100
90
80
70
60
50
40
30
20
10
0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 F
ϕ

APPENDIX 3

HEAVY MINERAL ANALYSES AT $\frac{1}{2}$ ϕ INTERVALS

Heavy Minerals	Heavy Mineral Content per ½ ∅ Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	32.48	20.24	33.52	41.37	44.12	47.41	30.36
Ilmenite	17.15	16.66	31.13	30.83	28.06	23.40	22.30
Magnetite	0	.29	.20	.33	.41	.60	.20
Garnet	0	0	0	0	0	0	0
Kyanite	15.03	22.88	9.60	8.87	7.22	6.32	15.18
Rutile	0	0	0	0	0	0	0
Staurolite	22.24	25.06	13.85	4.98	5.46	6.47	18.53
Tourmaline	10.13	14.88	11.72	4.71	4.00	2.05	11.18
Zircon	0	0	0	8.90	10.68	13.31	1.45
Others	2.96	0	0	0	0	.46	1.25

CSKes-1. Eoline member (sand) channel sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	---*	67.34	50.01	43.65	28.68	34.34	30.36
Ilmenite	---	4.89	13.84	18.52	46.39	43.42	23.68
Magnetite	---	0	.13	.14	t	t	.08
Garnet	---	0	0	.49	.32	2.00	.40
Kyanite	---	8.17	7.83	8.25	3.57	1.54	6.63
Rutile	---	0	0	.53	.34	.36	.29
Staurolite	---	2.39	10.30	8.92	7.94	3.81	7.77
Tourmaline	---	17.20	17.39	18.30	3.10	4.83	13.62
Zircon	---	0	0	1.19	8.89	8.82	3.03
Others	---	0	.51	0	.76	.89	.35

* Only 29 grains counted.

CSKes-2. Eoline member (sand) channel sample 2.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	36.50	32.78	19.45	25.20	26.24
Ilmenite	---	---	8.18	18.37	48.53	38.44	33.37
Magnetite	---	---	.13	.25	.55	.61	.43
Garnet	---	---	0	0	0	0	0
Kyanite	---	---	8.62	4.02	3.48	3.58	4.02
Rutile	---	---	0	0	.20	.20	.11
Staurolite	---	---	14.44	21.96	11.94	8.76	15.57
Tourmaline	---	---	31.21	20.89	6.63	2.86	13.24
Zircon	---	---	0	1.74	9.24	16.95	6.61
Others	---	---	.91	0	0	3.37	.42

* Only 15 grains counted.

**Only 23 grains counted.

CSKes-3. Eoline member (sand) channel sample 3.

Heavy Minerals	Heavy Mineral Content per ½ ∅ Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	27.78	18.96	24.09	24.09	21.90	19.78	23.09
Ilmenite	21.91	21.31	37.55	37.52	53.59	50.29	31.26
Magnetite	0	0	.43	.12	2.19	1.16	.37
Garnet	0	0	0	0	0	0	0
Kyanite	19.92	25.09	15.93	13.06	4.79	3.04	17.58
Rutile	0	.81	2.66	1.02	0	.36	.93
Staurolite	17.96	22.15	10.00	7.14	3.82	4.67	14.17
Tourmaline	12.43	10.88	7.61	10.32	2.77	1.05	9.38
Zircon	0	0	1.26	6.40	10.34	18.52	2.78
Others	0	.80	.46	.33	.62	1.13	.47

CSKes-4. Eoline member (sand) channel sample 4.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	43.12	32.37	26.04	24.30	23.37	22.66	27.05
Ilmenite	14.15	18.34	16.34	38.15	51.82	51.58	30.49
Magnetite	0	0	.15	.62	.79	1.15	.40
Garnet	0	0	0	0	0	0	0
Kyanite	18.63	22.52	20.63	11.59	5.10	4.87	14.88
Rutile	0	0	.49	1.59	.70	1.07	.71
Staurolite	7.95	10.33	15.54	9.43	5.54	5.92	10.23
Tourmaline	16.15	16.44	20.81	11.23	4.95	2.90	13.44
Zircon	0	0	0	3.09	7.40	9.85	2.68
Others	0	0	0	0	.35	0	.06

CSKes-5. Eoline member (sand) channel sample 5.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	65.50	57.65	56.24	55.59	45.85	58.72	56.09
Ilmenite	10.40	13.68	15.46	26.71	36.42	22.22	23.44
Magnetite	1.62	.68	.14	.21	.18	.23	.42
Garnet	0	0	0	0	0	0	0
Kyanite	9.52	13.52	9.35	.78	3.07	2.07	5.41
Rutile	.74	0	2.28	.92	.72	.81	.95
Staurolite	7.81	9.06	3.19	5.62	3.14	1.42	5.18
Tourmaline	4.40	5.41	2.28	7.13	4.25	2.40	4.95
Zircon	0	0	1.52	3.05	6.36	12.10	3.55
Others	0	0	0	0	0	.03	t

CSKes-6. Eoline member (sand) channel sample 6.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	91.73	93.11	92.50	91.67	96.91	95.71	93.48
Ilmenite	2.85	1.19	3.18	5.49	.92	2.82	2.76
Magnetite	0	.07	.02	.16	.08	.03	.06
Garnet	0	0	0	.25	.25	0	.10
Kyanite	1.88	3.10	1.65	.23	.23	.16	1.26
Rutile	0	0	0	0	0	.18	.02
Staurolite	1.92	1.19	2.36	.48	.23	.16	1.08
Tourmaline	1.63	1.35	.29	1.41	.79	.13	.98
Zircon	0	0	0	.30	.59	.81	.24
Others	0	0	0	0	0	0	0

CSKes-7. Eoline member (sand) channel sample 7.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	70.96	44.67	18.92	15.38	12.34	45.47	20.28
Ilmenite	10.52	20.16	30.55	55.08	60.07	34.91	47.20
Magnetite	1.05	.87	1.56	2.49	2.29	3.02	2.10
Garnet	0	0	1.08	0	0	0	.21
Kyanite	6.61	13.75	10.00	2.02	.82	.80	3.94
Rutile	0	.85	3.51	1.35	1.60	.47	1.71
Staurolite	6.40	11.87	12.30	2.65	1.40	1.85	4.79
Tourmaline	4.46	6.90	19.07	4.00	1.19	.69	6.13
Zircon	0	.94	2.59	15.32	19.15	11.94	12.32
Others	0	0	1.43	1.71	1.17	.86	1.31

CSKes-8. Eoline member (sand) channel sample 8.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	38.86	36.35	35.11	32.24	22.43	33.86
Ilmenite	---	14.09	29.12	36.25	51.02	39.76	37.11
Magnetite	---	.50	.86	.78	1.08	.33	.82
Garnet	---	0	0	0	0	0	0
Kyanite	---	27.09	11.39	3.51	1.75	1.00	7.33
Rutile	---	2.01	2.02	.46	.82	.47	1.09
Staurolite	---	9.25	9.20	6.79	2.87	2.66	5.98
Tourmaline	---	8.20	9.28	11.49	5.17	.52	7.65
Zircon	---	0	1.79	5.05	4.54	32.56	5.85
Others	---	0	0	.56	.50	.28	.33

* Only 117 grains counted.

CSKes-9. Eoline member (sand) channel sample 9.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	81.65	52.64	41.64	40.05	38.94	44.62	44.81
Ilmenite	4.40	9.65	23.80	32.39	43.72	31.63	28.65
Magnetite	0	.45	.15	.48	.53	.53	.40
Garnet	0	0	.37	0	0	0	.08
Kyanite	5.07	14.64	12.68	4.89	2.79	1.87	7.03
Rutile	0	.55	1.60	1.14	.73	1.09	.97
Staurolite	.58	13.07	8.78	10.03	5.09	4.14	7.88
Tourmaline	8.30	9.01	10.10	9.24	2.15	.81	6.95
Zircon	0	0	.89	1.69	6.04	15.31	3.22
Others	0	0	0	0	0	0	0

CSKes-10. Eoline member (sand) channel sample 10.

Heavy Minerals	Heavy Mineral Content per ½ ∅ Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	42.38	30.44	33.25	55.27	66.92	42.77	38.78
Ilmenite	12.13	13.75	31.86	26.88	20.92	43.13	19.92
Magnetite	0	0	.09	0	.20	0	.04
Garnet	0	0	0	.30	0	0	.02
Kyanite	13.43	22.89	15.20	6.19	4.55	2.64	16.08
Rutile	1.21	.84	1.97	0	.38	.31	1.02
Staurolite	20.11	19.06	9.00	4.90	2.66	2.43	13.92
Tourmaline	10.75	13.02	7.32	2.44	2.25	.46	9.21
Zircon	0	0	1.31	4.01	2.11	7.52	1.02
Others	0	0	0	0	0	.75	.02

CSKes-11. Eoline member (sand) channel sample 11.

Heavy Minerals	Heavy Mineral Content per $\frac{1}{2}$ ϕ Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	64.85	49.83	31.37	17.39	37.43
Ilmenite	---	---	17.29	20.35	50.44	56.79	39.81
Magnetite	---	---	.27	.44	.49	.40	.44
Garnet	---	---	0	0	0	0	0
Kyanite	---	---	5.11	1.72	2.13	1.25	2.12
Rutile	---	---	0	.50	1.66	1.10	1.10
Staurolite	---	---	1.16	8.84	4.37	2.25	5.12
Tourmaline	---	---	11.32	17.19	3.08	1.36	7.67
Zircon	---	---	0	1.12	6.45	19.52	6.29
Others	---	---	0	0	0	0	0

* Only 2 grains counted.

**Only 23 grains counted.

CSKec-1. Eoline member (clay) channel sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	41.25	52.53	46.03	54.09	49.22
Ilmenite	---	---	6.16	7.77	22.47	16.52	16.72
Magnetite	---	---	.19	.20	.24	.25	.22
Garnet	---	---	0	0	0	0	0
Kyanite	---	---	21.45	14.60	8.22	6.45	9.98
Rutile	---	---	0	0	0	0	0
Staurolite	---	---	17.87	13.30	11.67	7.19	11.26
Tourmaline	---	---	12.21	10.55	7.68	3.45	7.51
Zircon	---	---	.87	1.05	3.69	12.05	5.06
Others	---	---	0	0	0	0	0

* Only 6 grains counted.

**Only 33 grains counted.

CSKu-1. Unnamed upper member channel sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	56.98	46.27	31.01	28.81	31.55
Ilmenite	---	---	10.87	23.16	45.16	53.86	47.15
Magnetite	---	---	2.66	3.03	.97	1.40	1.38
Garnet	---	---	0	0	.37	.30	.30
Kyanite	---	---	11.95	8.12	1.71	3.37	3.20
Rutile	---	---	1.64	.45	.80	.33	.55
Staurolite	---	---	4.32	5.95	6.99	1.46	4.15
Tourmaline	---	---	9.75	11.07	11.24	5.36	8.31
Zircon	---	---	1.82	.50	1.77	5.10	3.30
Others	---	---	0	1.44	0	0	.12

* Only 3 grains counted.

**Only 3 grains counted.

CSKu-2. Unnamed upper member channel sample 2.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	65.29	41.68	24.91	18.43	30.17
Ilmenite	---	---	10.48	25.94	53.09	62.35	45.67
Magnetite	---	---	.12	.18	.38	.42	.32
Garnet	---	---	0	0	0	0	0
Kyanite	---	---	7.56	8.34	4.80	5.01	5.86
Rutile	---	---	1.26	.57	2.81	1.17	1.88
Staurolite	---	---	4.98	9.05	5.98	3.08	6.15
Tourmaline	---	---	10.30	13.61	7.14	.87	7.77
Zircon	---	---	0	.64	.89	8.66	2.16
Others	---	---	0	0	0	0	0

* Only 22 grains counted.
**Only 68 grains counted.

CSKu-3. Unnamed upper member channel sample 3.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	84.53	79.35	66.97	54.32	39.11	43.33	55.69
Ilmenite	2.85	2.63	6.15	18.89	38.09	34.72	21.00
Magnetite	2.96	1.84	1.35	.75	.34	.40	.74
Garnet	0	0	.59	0	0	0	.11
Kyanite	1.47	9.99	9.26	12.63	4.93	3.42	7.83
Rutile	0	.51	1.27	1.17	1.60	3.06	1.40
Staurolite	7.55	2.67	6.98	4.77	3.37	3.80	4.56
Tourmaline	.64	3.01	7.08	5.76	4.04	2.47	4.53
Zircon	0	0	.35	1.72	8.52	8.86	3.96
Others	0	0	0	0	0	0	0

CSKu-4. Unnamed upper member channel sample 4.

Heavy Minerals	Heavy Mineral Content per ½ ∅ Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	46.50	34.66	25.48	20.76	25.43
Ilmenite	---	---	19.41	23.56	48.07	46.79	43.96
Magnetite	---	---	1.00	.76	.48	1.21	.78
Garnet	---	---	0	0	0	0	0
Kyanite	---	---	9.21	6.08	2.04	2.62	2.88
Rutile	---	---	0	.62	0	0	.08
Staurolite	---	---	15.10	14.36	8.67	7.24	9.04
Tourmaline	---	---	6.39	15.13	9.48	6.92	9.30
Zircon	---	---	2.39	4.46	4.54	12.04	7.11
Others	---	---	0	.38	1.25	2.43	1.51

* Only 7 grains counted.
**Only 44 grains counted.

CSKu-5. Unnamed upper member channel sample 5.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	83.10	78.97	79.36	67.62	57.37	58.64	71.66
Ilmenite	6.63	4.73	5.15	12.89	28.86	27.52	13.38
Magnetite	.81	.56	.49	.32	.35	.50	.51
Garnet	0	.32	0	0	0	.45	.10
Kyanite	3.18	3.82	5.78	3.03	1.23	1.47	3.20
Rutile	0	1.03	.36	1.57	.24	1.23	.70
Staurolite	3.52	7.53	2.81	2.07	2.09	1.94	3.44
Tourmaline	.85	1.53	2.90	2.91	2.66	1.46	2.12
Zircon	1.91	1.52	3.16	9.59	6.62	6.80	4.82
Others	0	0	0	0	.58	0	.11

CSQt-1. Alluvial terrace deposit channel sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	---*	80.88	72.98	86.48	87.18	87.32	80.69
Ilmenite	---	12.67	15.08	5.35	3.08	3.65	10.53
Magnetite	---	.20	.54	.66	.53	.56	.44
Garnet	---	0	0	0	1.78	3.52	.35
Kyanite	---	2.97	2.45	.89	.88	.11	2.09
Rutile	---	0	.78	.42	.13	0	.31
Staurolite	---	1.22	1.60	.18	.56	.81	1.04
Tourmaline	---	2.06	5.41	.93	.57	.39	2.54
Zircon	---	0	1.16	5.09	5.25	3.64	2.02
Others	---	0	0	0	0	0	0

* Only 105 grains counted.

CSQt-2. Alluvial terrace deposit channel sample 2.

Heavy Minerals	Heavy Mineral Content per ½ ∅ Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	97.85	92.37	77.78	68.03	67.83	79.46
Ilmenite	---	.42	.93	7.75	8.72	11.92	6.05
Magnetite	---	0	0	.04	.18	.20	.08
Garnet	---	0	.31	0	0	.75	.14
Kyanite	---	.43	.29	2.22	1.36	.46	1.21
Rutile	---	.50	0	.97	2.23	1.63	1.08
Staurolite	---	.44	.88	2.84	.84	1.43	1.50
Tourmaline	---	.37	5.22	7.68	1.66	1.01	4.36
Zircon	---	0	0	.72	16.98	14.77	6.13
Others	---	0	0	0	0	0	0

* Only 36 grains counted.

CSQt-3. Alluvial terrace deposit channel sample 3.

Heavy Minerals	Heavy Mineral Content per $\frac{1}{2}$ ϕ Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	91.68	92.46	90.23	92.49	91.18	91.85	91.79
Ilmenite	5.61	2.19	3.12	2.98	3.39	3.07	3.98
Magnetite	2.09	1.51	2.87	2.58	3.05	2.61	2.08
Garnet	0	0	0	0	.84	.71	.04
Kyanite	0	1.56	1.58	.13	.31	.16	.67
Rutile	0	0	0	.16	.54	0	.03
Staurolite	0	.64	.93	.41	.16	.17	.34
Tourmaline	.62	1.63	.98	.35	.13	.14	.91
Zircon	0	0	.29	.70	.40	1.28	.11
Others	0	0	0	.19	0	0	.01

CSQt-4. Alluvial terrace deposit channel sample 4.

Heavy Minerals	Heavy Mineral Content per ½ ϕ Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	71.68	71.87	79.60	86.21	85.89	84.62	76.25
Ilmenite	23.11	16.51	13.55	8.14	9.45	9.53	16.74
Magnetite	4.77	3.94	5.18	4.65	3.06	2.35	4.39
Garnet	0	0	0	0	.63	.77	.09
Kyanite	.22	2.71	.33	.24	0	.48	.83
Rutile	0	0	0	0	0	0	0
Staurolite	.22	1.85	.34	.24	.60	.49	.68
Tourmaline	0	3.13	.57	.21	0	.22	.87
Zircon	0	0	.43	.31	.38	1.54	.18
Others	0	0	0	0	0	0	0

CSQt-5. Alluvial terrace deposit channel sample 5.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	83.25	75.61	57.28	33.18	28.39	41.74
Ilmenite	---	.51	2.96	10.56	39.62	44.98	31.21
Magnetite	---	15.09	11.89	3.30	2.95	2.44	4.08
Garnet	---	0	0	0	0	0	0
Kyanite	---	.39	1.05	2.48	2.96	1.08	2.15
Rutile	---	0	0	.41	1.26	1.57	1.04
Staurolite	---	.60	1.80	4.35	4.42	3.03	3.69
Tourmaline	---	.17	6.69	21.16	6.54	3.50	8.18
Zircon	---	0	0	.46	9.08	14.63	7.73
Others	---	0	0	0	0	.38	.09

* Only 141 grains counted.

SSKes-1. Eoline member (sand) soil sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5-	3.5-4.0	Total for Sample (%)
Other Opaques	---*	37.10	25.16	26.59	19.42	16.39	22.70
Ilmenite	---	26.44	20.00	30.17	44.63	51.68	36.60
Magnetite	---	6.40	1.85	.67	.51	.43	.98
Garnet	---	0	0	0	0	0	0
Kyanite	---	2.59	7.60	8.32	2.72	3.51	5.35
Rutile	---	0	1.27	1.74	1.95	2.98	1.87
Staurolite	---	7.98	10.39	10.36	6.64	6.54	8.42
Tourmaline	---	19.49	33.26	14.44	7.61	2.77	13.62
Zircon	---	0	.47	7.71	16.52	15.71	10.47
Others	---	0	0	0	0	0	0

* Only 15 grains counted.

SSKes-2. Eoline member (sand) soil sample 2.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	60.40	50.17	41.45	31.24	28.77	39.52
Ilmenite	---	7.16	14.14	24.54	42.51	45.06	30.03
Magnetite	---	9.04	4.69	2.65	2.16	3.91	3.54
Garnet	---	0	.35	0	.57	.66	.34
Kyanite	---	3.67	6.43	6.89	2.91	2.14	4.53
Rutile	---	0	.75	.32	1.55	2.50	1.05
Staurolite	---	6.28	8.57	8.75	7.33	4.08	7.45
Tourmaline	---	13.45	14.49	14.33	4.82	2.92	9.54
Zircon	---	0	.42	1.07	6.52	9.52	3.78
Others	---	0	0	0	.38	.44	.19

* Only 93 grains counted.

SSKes-3. Eoline member (sand) soil sample 3.

Heavy Minerals	Heavy Mineral Content per ½ ∅ Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	44.78	23.96	22.03	23.02	27.91	26.35
Ilmenite	---	11.10	31.56	43.96	44.57	38.77	36.50
Magnetite	---	13.07	9.89	5.74	7.74	8.82	8.42
Garnet	---	0	0	0	.54	.52	.18
Kyanite	---	7.24	7.03	5.04	3.52	4.09	5.28
Rutile	---	.50	.95	1.84	1.76	.56	1.34
Staurolite	---	12.23	9.98	7.43	5.15	2.71	7.64
Tourmaline	---	11.08	13.83	4.92	1.96	.42	6.52
Zircon	---	0	2.80	8.58	11.73	16.21	7.63
Others	---	0	0	.45	0	0	.14

* Only 136 grains counted.

SSKes-4. Eoline member (sand) soil sample 4.

Heavy Minerals	Heavy Mineral Content per $\frac{1}{2}$ ϕ Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	83.02	81.91	76.89	75.20	73.45	68.25	78.23
Ilmenite	2.07	3.13	3.42	8.16	8.87	13.46	5.18
Magnetite	13.83	14.00	12.77	11.43	9.74	10.29	12.50
Garnet	0	0	.95	1.63	2.02	1.03	.77
Kyanite	0	0	1.77	.75	.62	0	.48
Rutile	0	0	0	.29	.73	.28	.17
Staurolite	1.08	.96	1.13	.26	1.60	.98	1.03
Tourmaline	0	0	3.07	1.96	1.35	1.66	1.09
Zircon	0	0	0	.33	1.62	3.41	.53
Others	0	0	0	0	0	.68	.05

SSKec-1. Eoline member (clay) soil sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	60.09	60.03	68.51	61.52	52.88	60.47
Ilmenite	---	2.92	5.39	3.98	14.53	21.43	13.03
Magnetite	---	30.99	8.40	2.92	1.32	1.50	3.41
Garnet	---	0	.24	0	.34	0	.16
Kyanite	---	1.54	8.42	8.06	3.42	2.79	4.51
Rutile	---	0	1.30	.74	2.21	2.28	1.79
Staurolite	---	1.26	6.13	6.52	7.75	7.15	6.96
Tourmaline	---	3.20	9.80	8.45	4.37	2.18	5.01
Zircon	---	0	.29	.82	4.49	9.40	4.52
Others	---	0	0	0	0	.40	.10

* Only 179 grains counted.

SSKu-1. Unnamed upper member soil sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	81.61	69.80	63.05	47.23	38.73	51.56
Ilmenite	---	1.99	7.28	15.39	26.80	41.25	26.69
Magnetite	---	14.43	7.35	3.27	.85	.51	3.09
Garnet	---	0	0	0	0	0	0
Kyanite	---	.44	5.64	4.92	3.68	1.59	2.83
Rutile	---	.26	.63	1.80	.86	.93	.91
Staurolite	---	.90	5.23	4.10	6.55	4.36	4.65
Tourmaline	---	.38	3.03	5.87	7.03	7.83	6.10
Zircon	---	0	1.04	1.60	7.01	4.48	4.03
Others	---	0	0	0	0	.32	.13

* Only 169 grains counted.

SSKu-2. Unnamed upper member soil sample 2.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	15.92	16.75	18.50	14.47	18.43	16.64
Ilmenite	---	18.20	28.49	28.68	41.98	44.96	36.87
Magnetite	---	1.11	2.89	7.68	6.75	5.05	5.74
Garnet	---	0	0	0	0	0	0
Kyanite	---	17.96	14.47	8.39	5.43	3.41	7.41
Rutile	---	3.58	4.97	3.04	2.42	2.66	2.99
Staurolite	---	25.59	17.45	12.45	10.60	6.42	11.68
Tourmaline	---	9.12	9.10	8.53	6.95	3.21	6.78
Zircon	---	8.52	5.88	12.75	11.40	15.86	11.88
Others	---	0	0	0	0	0	0

* Only 57 grains counted.

SSQt-1. Alluvial terrace deposit soil sample 1.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	---*	40.24	38.77	36.18	42.44	52.22	41.11
Ilmenite	---	6.41	19.50	26.62	22.64	14.21	19.63
Magnetite	---	21.17	7.90	10.00	18.26	22.61	15.06
Garnet	---	0	0	.62	1.07	.42	.51
Kyanite	---	9.77	9.30	4.27	3.02	1.16	5.29
Rutile	---	.50	.35	1.66	.59	.23	.76
Staurolite	---	9.58	11.06	5.25	3.86	2.97	6.34
Tourmaline	---	11.79	9.62	6.17	1.53	.67	5.66
Zircon	---	.55	3.50	9.23	5.86	5.52	5.47
Others	---	0	0	0	.72	0	.19

* Only 116 grains counted.

SSQt-2. Alluvial terrace deposit soil sample 2.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%)						Total for Sample (%)
	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	
Other Opaques	---*	46.80	35.91	27.86	30.27	31.20	34.04
Ilmenite	---	11.07	19.35	30.70	26.11	31.43	23.39
Magnetite	---	9.34	3.35	2.47	2.26	3.93	3.99
Garnet	---	.47	.36	.35	.38	.62	.41
Kyanite	---	7.88	9.05	5.57	2.82	2.02	5.87
Rutile	---	1.53	.78	2.30	2.88	2.70	1.96
Staurolite	---	12.11	12.03	9.07	7.23	4.74	9.52
Tourmaline	---	7.97	9.59	5.11	5.20	2.00	6.46
Zircon	---	2.84	9.56	16.56	22.85	21.35	14.28
Others	---	0	0	0	0	0	0

* Only 89 grains counted.

SSQt-3. Alluvial terrace deposit soil sample 3.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	---*	---**	79.77	67.38	55.38	41.64	33.69
Ilmenite	---	---	4.03	11.44	19.24	19.42	17.42
Magnetite	---	---	2.92	1.29	.57	.32	.70
Garnet	---	---	1.94	1.47	1.00	.68	1.01
Kyanite	---	---	1.43	3.06	2.15	1.26	1.97
Rutile	---	---	0	1.19	1.44	3.68	2.10
Staurolite	---	---	1.84	3.14	5.05	3.22	4.00
Tourmaline	---	---	7.14	6.19	3.20	2.45	3.60
Zircon	---	---	.93	4.85	11.97	27.33	15.51
Others	---	---	0	0	0	0	0

* Only 4 grains counted.
**Only 30 grains counted.

SSQt-4. Alluvial terrace deposit soil sample 4.

Heavy Minerals	Heavy Mineral Content per ½ ø Interval (%) 1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	Total for Sample (%)
Other Opaques	78.49	60.38	64.97	62.25	52.86	55.22	64.07
Ilmenite	2.00	10.50	12.99	12.66	13.98	9.20	9.71
Magnetite	15.42	15.74	9.09	3.95	5.90	6.36	10.31
Garnet	0	0	.34	.64	1.29	1.63	.51
Kyanite	.77	3.68	3.75	3.54	2.10	1.01	2.49
Rutile	0	.96	1.46	.32	1.40	.88	.78
Staurolite	2.88	5.03	3.20	3.91	4.60	1.80	3.69
Tourmaline	.44	3.19	2.98	7.80	2.34	2.40	3.01
Zircon	0	.53	1.22	4.94	15.53	21.51	5.44
Others	0	0	0	0	0	0	0

SSQt-5. Alluvial terrace deposit soil sample 5.