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SOUTHEASTERN GEOLOGY

Table of Contents

Vol. 6, No. 3

1965

1. Geology of the Carolina Slate Belt west of the Deep River-Wadesboro Triassic Basin, North Carolina

James F. Conley
George L. Bain 117

2. The use of X-ray diffraction for the quantitative analysis of naturally occurring multicomponent mineral systems

Charles A. Moore, Jr. .. 139

3. Bathymetry of the Miami Terrace

John W. Kofoed
Richard J. Malloy 159

4. The stratigraphic significance of an Upper Miocene fossil discovery in Jefferson County, Florida

J. William Yon, Jr. 167

GEOLOGY OF THE CAROLINA SLATE BELT WEST OF THE DEEP RIVER-WADESBORO TRIASSIC BASIN, NORTH CAROLINA

by

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ABSTRACT

Recent geologic studies have demonstrated that the metavolcanic and metasedimentary rocks of the Carolina slate belt of North Carolina can be divided into natural, mappable, rock-stratigraphic units. A set of nomenclature is proposed for the rock-stratigraphic units and their areal extent. Structure and lithology are described.

The oldest rocks recognized are a sequence of predominantly subaerially deposited, felsic pyroclastics with occasional interbedded felsic flows, and mafic pyroclastics, comprising the Uwharrie Formation. The widespread deposition of the Uwharrie Formation was followed by formation of the Troy anticlinorium and simultaneous deposition of two different water-laid sequences on opposite flanks of this structure. East and northeast of the Troy anticlinorium andesitic tuffs, graywacke, conglomerate, and greenstone comprising the Efland Formation were deposited. West and southwest finely laminated shales and thin graywacke beds comprising the Tillery Formation were deposited. During Tillery time, deposition of the Tillery Formation spread into the area east and northeast of the Troy anticlinorium causing the Tillery to overlap or interfinger with the top of the Efland Formation.

The rest of the stratigraphic succession is absent east and northeast of the Troy anticlinorium. On the west flank of the anticlinorium the McManus Formation, consisting of tuffaceous argillite, the Yadkin Graywacke, and the aforementioned Tillery Formation

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* Publication approved by the Director of the U. S. Geological Survey.

comprise the Albemarle Group.

The Albemarle Group and the Uwharrie Formation on the western flank of the Troy anticlinorium are unconformably overlain by air-laid pyroclastics and flows called the Tater Top Group. The unconformity at the base of the Tater Top Group is thought to represent destruction of the basin at the end of Albemarle time.

INTRODUCTION

The Ground Water Branch of the U. S. Geological Survey and the N. C. Division of Mineral Resources have recently completed a number of geologic studies on the Carolina slate belt in the central part of North Carolina. These studies include both detailed and reconnaissance geologic mapping. They demonstrate that the metavolcanic and metasedimentary rocks of the slate belt can be grouped into natural, mappable, rock-stratigraphic units.

The purpose of this paper is to name these units; describe their areal extent, structure, and lithology; and to present on one map the latest geologic interpretation. Except for Anson County this study is limited to that part of the slate belt west of the Deep River-Wadesboro Triassic basin.

Previous Studies

Olmstead (1822) described rocks from areas now known to be underlain by the Carolina slate belt. In 1825 he referred to the "Great Slate Formation", which "passes quite across the State... covering more or less the counties of Person, Orange, and Mecklenburg". Ebenezer Emmons (1856) placed these rocks in his "Taconic system" which he divided into an upper and a lower member. He considered these rocks to be some of the oldest in this country. His upper member consisted of clay slates, chloritic sandstones, cherty beds, flagstones, and brecciated conglomerates. His lower member consisted of talcose slates, white and brown quartzites and (on his cross section, Plate 14) conglomerate. Emmons, not recognizing volcanic rocks in his series, considered them water-laid sediments. The division of his system into an upper and a lower member is used, with modifications, in this report. Kerr (1875) described the rocks of the Carolina slate belt and proposed that they were of Huronian age. Williams (1894) was the first to recognize volcanic rocks in the Carolina slate belt.

The name "Carolina Slate Belt" was first applied by Nitze and Hanna (1896). They recognized volcanic rocks interbedded with the slates, and proposed that the volcanic rocks were laid down during times of volcanic outbursts, followed by inactivity during which time the slates were deposited. They observed that some of the rocks had true slaty cleavage, whereas others were schistose. They proposed that these rocks were altered by "dynamo" and "hydrometamorphism". Laney (1910) described the Gold Hill Mining District of North Carolina. In this report he divided the rocks into slates, interbedded felsic and mafic flows, and tuffs. He stated that the slates differ from the fine, dense tuffs only in the amount of land waste they contain, indicating that the slates, in part, were derived from volcanic material. Pogue (1910) described the Cid Mining District, and Laney (1917) described the Virgilina Mining District. Interpretations in these reports are, in general, expansions of ideas as expressed in Laney's report of 1910.

Stuckey (1928) presented a report which included a geologic map of the Deep River region of Moore County. He divided these rocks into slates, felsic tuffs, rhyolites, volcanic breccias, and andesite flows and tuffs. He noted that the schistosity dipped to the northwest and interpreted the structure as a closely compressed synclinorium with the axes of the folds parallel to the strike of the formations. He stated (p. 23),

> "The minor folds dip steeply to the northwest side of the troughs and flatten out to the east. The synclinal troughs pitch and flatten out in places as is indicated by the way the slate bands, which are all synclinal in structure, occur in long narrow lenses often pinching out. This pinching and flattening indicates some cross folding."

He noted that the slates seem to have consolidated readily and to have folded as normal sediments; whereas, the tuffs and breccias remained in a state of open texture and tended to mash and shear instead of folding. Stuckey, from a comparison of his investigation with work by Laney and Pogue, concluded that the rocks of the whole slate belt are of the same general types. He noted that metamorphism is not uniform throughout the area.

F. O. Bowman (1954) studied the structure of the Carolina slate belt near Albemarle, North Carolina. He recognized sedimentary rocks, volcanic tuffs and flows, and mafic intrusives in the area. He proposed that the structure was a series of undulating open folds. Several geologists contributed to the reconnaissance mapping used to prepare the current State Geologic map (Stuckey and Conrad, 1958).

More recent studies include geologic mapping of the Albemarle Quadrangle (Conley, 1962), Moore County (Conley, 1962), the Hamme Tungsten District (Parker, 1963), and a reconnaissance study of Orange County (Butler, 1963).

Reports in preparation by the U. S. Geological Survey include a detailed study of the geology of the Denton quadrangle by Arvid A. Stromquist, a detailed study of the Mt. Pleasant quadrangle by Harold W. Sundelius, a reconnaissance study of Anson, Stanley, and Union Counties by E. O. Floyd, a reconnaissance study of Chatham, Orange, Durham, Person, and Randolph Counties by George L. Bain, and a reconnaissance study of Granville, Franklin, Vance, Warren, and Wake Counties by V. J. May. E. P. Allen of the North Carolina Division of Mineral Resources is currently mapping Orange County geology in detail.

Acknowledgements

The authors wish to acknowledge their indebtedness to E. O. Floyd and V. J. May for contributing unpublished geologic maps of parts of the area of this report. John M. Parker III pointed out two gabbro bodies and a synclinal structure in northern Granville County. The paper was critically reviewed by J. L. Stuckey and G. G. Wyrick. An additional debt of gratitude is owed to E. O. Floyd for drafting the illustrations.

GENERAL GEOLOGY

Low-rank metasedimentary and metavolcanic rocks of the Carolina slate belt crop out in a northeast-trending zone from central Georgia to south-central Virginia. In Piedmont North Carolina this zone, as shown on the North Carolina State map, is about 70 miles wide near the Virginia State line, 130 miles wide in the central section, and only 50 miles wide on the South Carolina State line. The "slate belt" is overlapped to the east by Coastal Plain sediments and is in contact to the west with igneous and high-rank metamorphic rocks belonging in part to the Charlotte belt. Younger rocks of Triassic age are exposed in a graben-like structure called the Deep River-Wadesboro Triassic basin which is in the central part of the slate belt. East of Raleigh the slate belt has been intruded by a large granitic pluton, which has metamorphosed the surrounding country rock into gneisses and schists. Smaller plutonic intrusives ranging in composition from granite to gabbro are scattered throughout the slate belt.

The major rock type in the Carolina slate belt is not slate. Rock types are both felsic and mafic and include lithic and crystal tuffs, welded flow tuffs, flows, volcanic breccias, volcanic conglomerates, graywacke conglomerates, argillites, slates, phyllites, thin limestone beds, and almost every conceivable gradation between these rock types.

Structural elements within the slate belt have a pronounced northeast lineation. The largest of these is the Troy anticlinorium. West and southwest of the Troy anticlinorium northeast-trending open folded synclines and anticlines predominate. East, southeast, and northeast of the Troy anticlinorium the intensity of the folding increases. The rocks are tightly compressed into northeast-trending, asymetrical folds whose axial planes usually dip steeply to the northwest. Argillite has been converted into slate and phyllite in many places. Major folds are indicated on Figure 1.

Most rocks of the slate belt show effects of low-rank metamorphism. The greenschist facies of the chlorite grade is usually attained. Locally the metamorphic grade is higher where the rocks are sheared or where intruded by plutonic rocks. Metamorphic grade and shearing are usually more intense east of the Troy anticlinorium than west of the structure, except along the extreme western edge where the slate belt is in contact with, and has been locally metamorphosed by, igneous rocks of the Charlotte belt.

STRATIGRAPHY

The stratigraphy of the area of this report can be divided into four distinct sequences of rocks. The slate-belt rocks constitute a stratigraphic succession at least 30,000 feet thick.

Uwharrie Formation

The oldest rocks thus far recognized in the slate belt are a sequence of predominantly subaerially deposited felsic pyroclastic rocks here named the Uwharrie Formation after the Uwharrie Mountains in which they are best exposed and least metamorphosed. The Uwharrie Formation outcrops in a belt that is 41 miles long and as much as 18 miles wide along the axis of the Troy anticlinorium (Figure 1). In addition, it reappears in the areas of anticlinal folds along the western border of the slate belt in Union County, in central Orange County, in Durham County northwest of the Triassic basin, and in southeastern Person County.

The lower contact of the Uwharrie Formation is not known to be exposed. The Uwharrie Formation is overlain by finely laminated, low-rank metasediments in the area west and southwest of the Troy anticlinorium. Elsewhere in the slate belt the Uwharrie is overlain by a sequence of water-laid, andesitic tuff which contains interbeds of conglomerate, graywacke, greenstone, argillaceous beds, and mafic flows. The total thickness of the Uwharrie is conjectural due to the unknown lower limit. However, if the Uwharrie Formation has not been repeated by faulting and folding, its exposed part is at least 20,000 feet thick.

The best exposures of the Uwharrie Formation are found along N. C. 27 from 1 mile east of the Pee Dee River eastward to Troy (Figure 1). Here interbedded felsic-lithic tuffs, crystal and lithic-crystal tuffs, welded flow tuffs, flows, occasional mafic-pyroclastic beds, and rare, bedded argillites are exposed.

Other outcrop areas belonging to the Uwharrie Formation are recognized along N. C. 86 about 4 miles south of Hillsboro, along the northwest side of the Deep River-Wadesboro Triassic basin in Durham County, in the southeast corner of Person County, west and northwest of Moriah, in Union County south of Monroe, and in western Moore County (Figure 1).

The rocks composing the Uwharrie Formation are usually light grey in color and weather to white clay. They are especially susceptible to spheroidal weathering, and in many places the outer surfaces are covered by a thin, white weathering rind. The rocks are exceedingly dense, and break with a conchoidal fracture. They have been closely jointed and many of the joint planes have been healed by thin veins of quartz, some of which are not over 3 mm thick. Bedding in the Uwharrie Formation becomes more pronounced near the top. In general, axial-plane cleavage is poorly developed.

The Uwharrie Formation is composed predominantly of felsic-lithic tuff with interbeds of crystal tuff and welded flow tuff. The lithic fragments consist of red and gray rhyolites containing flow banding, light-gray felsite, felsic-porphyries, crystal tuffs, and rare mafic porphyries and crystal tuffs. Red rhyolite fragments are common in the Uwharrie Formation and have been observed only in this formation. The subrounded to angular fragments are poorly sorted and range in size from 5 mm to over 60 cm in diameter. Some of the felsite fragments are spindle shaped and have pitted or amygdular surfaces, indicating they were liquid when ejected.

The cyrstal fragments in the lithic tuffs are composed of beta quartz and feldspar. The quartz crystals are somewhat spheroidal in outline, whereas the feldspars occur as both broken laths and euhedral crystals. They range in size from 1 mm to over 3 mm in width. Feldspars make up from 3 to 5 percent of the rock and are predominantly orthoclase, with some oligoclase, and rare sanidine (?) and andesine. About 30 percent of the rock is composed of quartz. The quartz occurs as embayed beta crystals, but more often as lenticular-shaped, granular masses. Except for rare porphyritic specimens, the lithic fragments are too fine grained to be identified. The groundmass, which makes up approximately 60 percent of the rock, is also exceedingly fine grained, but appears to be predominantly granular masses of quartz, with sericite, kaolinite, numerous small crystals of pyrite, and aggregates of chlorite.

The mostly subaerially deposited pyroclastics of the Uwharrie Formation are overlain by a thick sequence of water-laid pyroclastics and sediments. West and southwest of the Troy anticlinorium argillite and thin-bedded graywacke predominate. East and northeast of the Troy anticlinorium a thick sequence of andesitic tuffs, graywackes, and conglomerates are present between the Uwharrie Formation and the argillite above it (Figure 2).

Efland Formation

The water-laid sequence east and northeast of the Troy anticlinorium consisting of andesitic tuffs with interbedded greenstones,

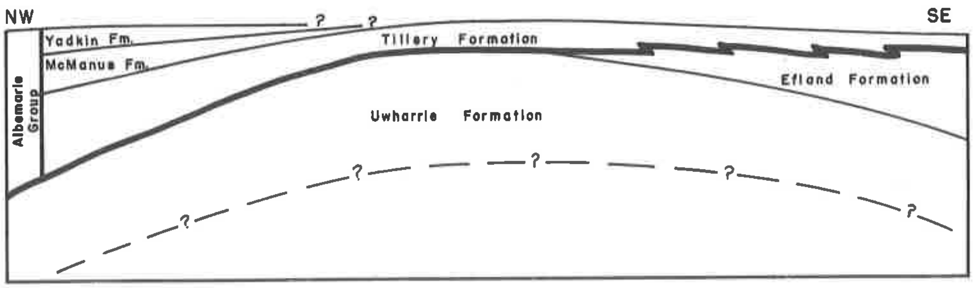

Figure 2. Diagrammatic section transverse to the axis of the Troy Anticlinorium showing stratigraphic relationships of the Efland and Uwharrie Formations to the Albemarle Group.

conglomerates, graywackes, and flows is here named the Efland Formation after the town of Efland in Orange County. The Efland Formation occurs only east of the Troy anticlinorium and is traceable from northern Moore County to northern Person County. It conformably overlies the Uwharrie Formation and grades upward into rhythmic-bedded slates of the overlying formation. The total thickness of the Efland Formation may be as much as 10,000 feet. The Efland Formation was first recognized in Moore County, but the most typical part of the formation is best exposed in the Duke University quarry between Efland and Hillsboro. At this locality the major rock type is a volcanic breccia which occurs as a distinctive ridge on which the quarry is located. It is composed of dark-gray and blue-gray, wafer-shaped fragments which probably were highly vesicular and were flattened by primary compaction. These fragments were later sheared along planes of schistosity, giving the rock a pronounced lineation. The matrix is a dove-gray, fine-grained, meta-ash. Interbedded with the breccias are thin beds of dark-green chlorite schist, dove-gray argillaceous beds showing rhythmic bedding, and greenish-brown graywacke beds up to one foot thick. The rocks in the quarry have, in places, been hydrothermally altered along planes of cleavage in bands up to 5 cm wide. Alteration products include chloritoid, sericite, and magnetite. The rocks are well jointed. The Efland Formation is exposed outside the quarry along U. S. 70-A from 1 1/2 miles east of the intersection of N. C. 86 and U. S. 70-A to 2 1/2 miles west of the intersection.

The Efland Formation has been mapped in the north-central part of Moore County. It is poorly exposed along N. C. 705 northwest and southeast of Robbins. In Moore County it consists of nearly equal parts of greenstones and andesitic tuffs.

The greenstones usually are sheared. They have a grayish-green or olive-green color when fresh, becoming dun brown on weathering, by the oxidation of iron. Topsoils developed on these rocks are tan-colored silty loams; the subsoils are usually dark-brown to chocolate-brown, heavy clay loams. The greenstones in general, are andesitic in composition, but contain some material that might be classed as basaltic. They are composed of clastic lithic fragments ranging from 2 mm up to 45 cm in diameter, and crystal fragments ranging from microscopic up to 5 mm in diameter and a matrix composed of fine debris. From place to place, the ratio of crystals to lithic fragments is exceedingly variable, as is the size of the fine grained clastic constituents of the rock.

The matrix of the greenstones appears to be made up almost entirely of chlorite bands oriented parallel to shearing planes. Feldspars have been altered to sericite and kaolinite. In highly sheared rocks, phenocrysts have been rolled parallel to schistosity and have an augen-like appearance.

The lithic fragments appear to be of different composition than the matrix of the rock. Some specimens are composed of interlocking lath-shaped feldspar crystals about 0.02 mm in length, with chlorite filling the interstices. Augite, not altered to chlorite, is present in rare isolated fragments. The groundmass of some of the fragments is composed of sericite and kaolinite rather than chlorite.

In general, the greenstones are not bedded. However, in the area north of High Falls in Moore County they contain numerous interbeds of graywacke. These interbeds range from a few tens-of-feet to more than one-hundred feet in thickness. The graywacke is greenish grey when fresh, becoming light brown on weathering. It is composed of quartz, feldspar, rock fragments, and a small quantity of argillaceous material. The rock exhibits graded bedding consisting of rock fragments up to 2 cm in diameter, and coarse to fine sand at the base; which grades upward into fine sand at the top of the beds. The rock fragments, so prominent in hand specimen, appear in thin section as aggregates of kaolinite, chlorite, and sericite. This suggests that the fragments are completely altered and are only recognizable in hand specimen by the preservation of relic structures.

The andesitic-tuff phase of the Efland Formation in Moore County is composed of interbedded crystal tuffs, lithic-crystal tuffs, argillaceous lithic conglomerates, argillaceous beds, and questionable basalt flows. These tuffs are highly susceptible to shearing and usually have well developed axial-plane cleavage. Many of them are phyllites in which primary fragments are flattened and elongated in the direction of shearing. The andesite tuffs have a distinctive grayish-purple color when fresh, and on weathering become a lighter purple. This coloring is due to primary hematite in the rock. Topsoil developed on the andesite tuffs is a dark-red clay loam, and the subsoil is a dark-maroon to maroonish-purple, heavy, plastic clay.

Crystal fragments in the more tuffaceous phases of the Efland Formation rarely exceed 40 per cent of the rock. They consist almost entirely of lath-shaped feldspar fragments and rare euhedral crystals, ranging in length from microscopic to 3 mm. The feldspars are highly sericitized and show carlsbad and albite twinning. Gross composition is approximately that of andesine. In addition to feldspar, lath-shaped masses of chlorite are also present. This chlorite probably represents altered amphibole and pyroxene.

Lithic-crystal tuffs are readily differentiated from argillaceous lithic conglomerates. The fragments are angular and the matrix contains crystal fragments in the lithic tuffs, whereas the fragments are rounded and the matrix is argillaceous in the lithic conglomerates. The rock fragments in both the tuffs and conglomerates are similar in composition. They rarely exceed 5 cm in diameter in the conglomerates, but range up to 25 cm across in the tuffs. These fragments are of two types. One is a massive aphanite, and the other is a crystal flow rock. Microscopically the aphanite fragments are composed almost entirely of sericite and hematite; the flow rock fragments appear as an aggregate of unoriented feldspar laths, averaging about 0.02 mm in length, in a matrix of hematite. Aside from flow lines and crystals, the original composition and texture of the flow rock fragments are masked by hematite.

The groundmass of the tuffs is so fine grained that it can not be resolved under the microscope. It appears to be composed predominately of elongate masses of opaque hematite, sericite, chlorite, and kaolinite. The matrix of the argillaceous rocks is even finer grained than that of the breccias and also is obscured by hematite.

The Efland Formation becomes more argillaceous near the top and bedding is more common. As the contact with the overlying formation is approached, graded bedding, so common in the overlying metasediment, begins to predominate in the laminae.

In some places a distinctive quartz conglomerate bed occurs at or near the upper contact of the Efland Formation. In some places this conglomerate may be traced overland for distances of several miles. The conglomerate usually has a graywacke matrix and sometimes grades into graywacke sandstone. It is not to be confused with tuffaceous lithic-conglomerates and lithic-breccias of which there are several in the Efland Formation. This conglomerate has also been recognized by E. Willard Berry (personal communication).

The best exposures of this conglomerate are found in eastern Person County and western Chatham County. One of the best exposures is in the roadcut at Denny Store in Person County, and is here named the Denny Conglomerate Member after this locality. The Denny Conglomerate Member is present at the upper contact of the Efland Formation at most localities in Person County. In Chatham County the conglomerate is exposed intermittently from 4 miles northeast of Siler City westward to Staley and south and south-eastward along the contact to the county line due south of Pittsboro.

The prominent lithologic type found in the Denny Conglomerate Member is quartzite. Pebbles of felsic volcanic rocks, feldspathic quartzites, quartz-hornblende gneisses and jasper (?) or red rhyolite are also present. Individual pebbles are well to sub-rounded and range in size from 7 mm to over 15 cm. Sphericity, roundness, and sorting are low.

Albemarle Group

The Uwharrie Formation west and southwest of the Troy anticlinorium and the Efland Formation east and northeast of the anticlinorium are overlain by water-laid pyroclastics and sediments. This water-laid sequence is here named the Albemarle Group after the City of Albemarle near where it is best exposed. West and southwest of the Troy anticlinorium the Albemarle Group is thickest and most typically developed. It is divisible into three formations. East, northeast, and southeast of the anticlinorium only the basal formation of this group is present (Figure 2). The Albemarle Group is unconformably overlain to the west and southwest by subaerially deposited pyroclastics and flows. East and northeast of the Troy anticlinorium the overlying flows and pyroclastics have not been recognized.

Tillery Formation

The basal formation of the Albemarle Group is here named the Tillery Formation after Lake Tillery, along whose shoreline it is typically exposed. At the type locality the Tillery Formation essentially is a finely laminated meta-shale exhibiting graded bedding. West of the Troy anticlinorium the formation has been metamorphosed into argillite showing well developed bedding-plane cleavage and poor axial-plane cleavage. Exceptions to this can be found where the formation is in contact with igneous rocks of the Charlotte belt and have been metamorphosed to a higher grade. East and southeast of the Troy anticlinorium the Tillery Formation has been regionally metamorphosed into slate. Metamorphic grade gradually increases to the east, so that in southern Wake County the Tillery is represented by phyllites and phylonites.

East and northeast of the Troy anticlinorium the Tillery Formation grades downward into the Efland Formation. West of the Troy anticlinorium the Efland is absent and the Tillery rests directly on the Uwharrie Formation.

East and northeast of the Troy anticlinorium the basal part of the Tillery Formation contains graywacke and greenstone beds which grade upward into laminated slate. On the northeast side of the anticline the Tillery Formation is thickest along the Person-Granville County border, (Virgilina synclinorium). In Person County the Tillery grades upward into greenstone flows. West of the Troy anticlinorium in the Albemarle quadrangle the graywacke beds are much less numerous and the basal greenstones are absent. In this area the basal part of the Tillery Formation contains thin beds of felsic pyroclastic rocks, which resemble lithologies of the underlying Uwharrie Formation.

The type locality of the Tillery Formation is on N. C. 109, on the southeast side of the bridge crossing the Uwharrie River. The laminated argillite is blue-gray, when unweathered, olive green when partially weathered, and finally weathers to ocherous reds and browns. A few beds of graywacke and tuff are present. Argillite beds ranging in thickness from 3 mm to 2 cm, tuff beds up to 5 cm thick, and graywacke beds up to 15 cm thick are exposed. The argillite of this exposure is intruded by quartz veins, and has well developed bedding-plane cleavage. In addition, it is deformed into undulant, open folds which plunge steeply to the northwest.

The graded beds are 1.5 mm to 12 mm thick. Although graded bedding can sometimes be seen megascopically, it is most easily observed in microscopic thin section. The bedding is composed of a bottom silt layer which grades upward into a clay layer. The silt sized particles are predominantly angular quartz grains with some feldspar fragments, as well as relic outlines of ferromagnesian minerals changed to chlorite. The clay layers have been altered to sericite. Chlorite and kaolinite occur sparingly in all thin sections observed.

McManus Formation

The Tillery Formation is overlain by the McManus Formation, formerly known as the Monroe slate. The Monroe slate was named by Nitze and Hanna (1896) who proposed that it was the youngest formation in the slate belt because it was less metamorphosed than surrounding rocks. The type locality of the Monroe slate was an old quarry near Monroe in Union County. This pit is no longer accessible. The name Monroe slate is abandoned.

The McManus Formation is confined to the area west and southwest of the Troy anticlinorium. The bottom contact is gradational with the Tillery Formation. The McManus Formation is overlain by a thick graywacke sequence. The McManus Formation is thickest near Albemarle, Stanley County where it is 10,000 feet thick.

The type locality of the McManus Formation is the McManus Quarry in Stanley County on county road 1963, 0.3 mile north of its intersection with county road 1964. Individual beds of argillaceous tuff range in thickness from 1.5 mm to 5 cm. The rock weathers to dark shades of dun brown. It is well jointed and some joint planes are coated with calcite. Calcite also occurs as lenticular shaped concretions that range from 5 to 20 cm in length. Pyrite is present on some bedding planes and as a coating around the calcite concretions.

A reference locality near Albemarle is on the south side of N. C. 27 bypass 100 yards east of its intersection with N. C. 52. Massive, waterlaid, argillaceous tuff beds, ranging in thickness from 3 inches to 2 feet, are here exposed. Beds of limestone up to 3 cm thick are interbedded with the tuff beds. The unweathered rock is a darker gray than that at the McManus type locality.

Another reference locality is at Bakers Quarry in Union County approximately 5 miles west of Monroe on the south side of U. S. 74. The bedded argillaceous tuff exposed in this quarry is similar to that in the McManus Quarry except that the beds are slightly thicker and the rock is more felsic in composition than that in the McManus Quarry. A few beds of graywacke are exposed. The tuff in this quarry is well jointed.

The major rock type of the McManus Formation is a felsic tuffaceous argillite. It is coarsely bedded with beds ranging in thickness from 15 cm to 60 cm. It is medium gray when fresh, but weathers light gray, becoming creamy white when completely decomposed. The fresh rock breaks into splintery fragments oriented at right angles to bedding planes; whereas, the weathered rock breaks with a conchoidal fracture.

In hand specimens, the felsic tuffaceous argillite appears to be a fine, dense tuff containing a few feldspar fragments scattered throughout the matrix. Wispy particles, which might represent devitrified glass shards, are scattered through some beds, and are in places concentrated at the base of the beds. The best outcrop of rock containing these particles is exposed north of Badin along Highway N. C. 740, 50 yards west of the Southern Railway tracks. From Albemarle southward, thin beds and lenticular masses of impure calcite, usually not over 7 cm to 10 cm thick, form interbeds within the felsic, tuffaceous argillite. These carbonates probably represent thin, primary limestone beds. When fresh they are lighter gray than the tuffaceous argillite, but readily weather brown. In the zone of weathering these beds are usually completely decomposed, leaving a silty clay along the bedding planes.

In addition to tuffaceous argillite, the McManus Formation contains felsic-crystal and lithic-crystal tuffs, felsic-vitric tuffs and mafic, lithic-crystal tuffs. These beds are excellent horizon markers. One such interbedded sequence, referred to as the Flatswamp Mountain sequence by Stromquist and Conley (1959), has been traced overland for more than 35 miles.

Yadkin Graywacke

The Yadkin Graywacke occurs only west of the Troy anticlinorium. It crops out along the axis of a southwest plunging fold called the New London syncline (Stromquist and Conley, 1959) which is west of the Troy anticlinorium. The graywacke crops out in an area about 5 miles wide and has been traced along the axis of the syncline by E. O. Floyd (personal communication) from New London southward to west of Monroe, a distance of over 35 miles. Although thin beds of graywacke occur in the Tillery Formation, the McManus Formation, and the upper part of the Uwharrie Formation; the Yadkin Graywacke is the only thick sequence of these sediments in the Carolina slate belt.

The Yadkin Graywacke is conformably underlain by the Monroe Formation and unconformably overlain by mafic pyroclastics of the overlying group, making it the youngest formation in the Albemarle Group. Although the upper part of the formation has been removed by erosion, that which remains is calculated to be at least 3,000 feet thick.

The type locality of the Yadkin Graywacke is a road cut on the west side of N. C. 8 about 100 feet south of where Riles Creek crosses the road, one mile north of the intersection with U. S. 52. The graywacke exposed in this cut is blue green when fresh and olive green when partially weathered. Upon complete decomposition it produces a sticky, sandy clay. It has a massive blocky appearance in outcrop due to the wide spacing (30 cm to 150 cm) of major bedding and joint planes. This wide spacing of the joint planes and major bedding planes makes the graywacke unusually susceptible to spheroidal weathering. Stratification in the form of graded bedding and, less common, southwest-dipping cross-bedding, exists between these planes. The contact between individual graded beds is in many places irregular. The coarse graywacke found in the north-central part of the quadrangle grades to the southeast into finer-grained equivalents.

In thin section the graywacke is composed of nearly equal parts of slightly rounded, chloritized rock fragments and quartz grains with occasional albite-twinned feldspar laths ranging from oligoclase to andesine. Argillite fragments are relatively rare in the graywacke, but have been observed in some specimens. When graded bedding is present the matrix is composed of a sand layer which grades upward into a silt layer. These beds vary in composition from the base to the top of individual graded beds. The matrix of the sand layer is composed of nearly equal parts of kaolinite and sericite with some chlorite. The chlorite becomes more prominent toward the top of the silt layer, where it almost completely displaces the kaolinite and sericite. Pyrite cubes ranging in size from 1.5 mm to 5 cm are disseminated throughout the rock.

Two lenticular beds of mafic tuff occur within the graywacke unit in the north central part of the Albemarle quadrangle. These tuffs are massive in appearance, and show neither bedding nor cleavage.

One small interbed of felsic lithic-tuff crops out in the graywacke unit approximately 0.2 mile due west of Isenhour. It consists of a fine-grained groundmass, composed of crystalline quartz and sericite, containing angular, dense, white, light-and dark-gray aphanite, and porphyritic rhyolite, as well as rare flattened, mafic fragments. The fragments range in diameter from 5 cm to 10 cm. The fresh rock is light gray with a speckled appearance due to the lithic fragments. On exposure it develops white weathering rinds and weathers to a kaolinitic clay.

Tater Top Group

Rocks of the Albemarle Group and Uwharrie Formation in the center and along the western flank of the Troy anticlinorium are unconformably overlain by subaerially deposited pyroclastics and flows, here named the Tater Top Group after Tater Top Mountain in Stanly County. The Tater Top Group has been recognized by the authors only in the northern part of the Albemarle and the southern part of the Denton quadrangles, and in west central and southwestern Randolph County. This group of rocks is approximately 450 feet thick and rests unconformably on both the Uwharrie Formation and the Albemarle Group. This sequence comprises the youngest rocks thus far recognized in the Carolina slate belt. In fact, they appear to be so much younger than the rest of the slate belt, that the question arises as to whether they should be considered a part of it. From base to top the group is composed of basaltic tuffs and flows, overlain by rhyolite flows.

Badin Greenstone

The basal formation of the Tater Top Group is composed predominantly of basaltic, lithic-crystal tuffs with interbedded crystal tuffs and flows. It is here named the Badin Greenstone after the town of Badin in Stanly County. It attains a maximum thickness of 200 feet, but is usually much thinner. It crops out over a wide area in northern Stanly County, western Montgomery County, and southwestern Randolph County. The greenstone unconformably overlies the Uwharrie Formation and the Tillery Formation of the Albemarle Group. The Badin Greenstone is probably conformably overlain by the rhyolite flows which comprise the upper formation of the Tater Top Group.

The type locality of the Badin Greenstone is represented by continuous exposures along the service road to the Badin Dam from the eastern city limits of Badin to the base of the dam on the western bank of the river. The greenstone at the base is a lapilli tuff composed of bombs, angular fragments, round lava bombs, and water-worn fragments of the Tillery Formation. Above the base the greenstone contains alternating beds of amygdaloidal basalts and non-amygdaloidal basalts or "basites", but predominantly it is composed of mafic-crystal tuff and tuff breccia of intermediate composition. The intermediate-tuff breccia contains crystal and aphanite fragments. The matrix of the greenstone is a fine crystal and ash tuff. It shows widely spaced, obscure bedding. In places, graded bedding is evident. The greenstone is in contact with argillite of the Tillery Formation on the east side of the Badin Dam.

A reference locality for the Badin Greenstone is in western Randolph County 1.7 miles south of U.S. 64 at and near the High Rock Baptist Church. The greenstone is a coarse, lithic breccia. Fragments range from 2 mm to 150 mm. It is interbedded with gray-green fine-grained tuff. The rock weathers dun brown and develops a dark-brown or dark-red soil. The greestone is in discordant contact with the Tillery Formation approximately 0.4 mile to the north of the church along the county road.

An andesite thought to be unconformable with the Albemarle Group is found only in the area around New London. This deposit appears to be for the most part subaerially deposited pyroclastics, flows (?), and flow tuffs of andesitic composition, which in this report is included with the basal member of the Badin Greenstone in the New London area. The andesitic tuffs are massive and bedding can be ascertained only by observing flattened pumice fragments and orientation of lithic fragments. It is gray-black when fresh, but is very susceptible to chemical weathering, developing deep, clayey, maroon-colored saprolite. The partially weathered rock has a red-gray, mottled appearance accentuated by lithic fragments. The rock is spongy in appearance and emits a dull sound when struck with a hammer. The major lithology of this unit is composed of numerous vesicular fragments which resemble scoria and range in diameter from 4 mm to 10 cm. The vesicles are now usually filled with calcite. Many of these fragments contain flow banding and are irregular in outline which suggests they are molten when deposited. In places these fragments have collapsed into lenticular shaped masses which locally comprise as much as 60 percent of the rock. The matrix is a dark-gray, translucent mass with numerous crystals ranging from 0.3 mm to .15 mm in diameter. Large quatntities of hematite are present; locally, masses of hematite make up as much as 25 percent of the rock.

A number of exposures of the basal section of the basaltic tuffs in the area near Morrow Mountain and Badin contain a basal conglomerate composed of mafic-lithic fragments and rounded argillite pebbles-derived from the underlying Tillery Formation-in a matrix of fine-grained mafic tuff. Basaltic flows have been observed near the base of the basaltic tuffs but are not everywhere present. One such flow is in a roadcut a few hundred yards south of Badin Dam. In addition, an amygdaloidal basalt dike, intrusive into the Tillery Formation, is exposed on N.C. 109, about 200 feet north of Blain. This intrusive is similar in composition to a basalt flow found in the Badin Greenstone and was originally mapped as Badin Greenstone (Conley, 1962).

In the north central and northwestern parts of the Albemarle quadrangle the Badin Greenstone shows an inconspicuous, graded bedding characteristic of subaerially deposited pyroclastic rocks and takes on a spotted appearance due to the increase in quantity of lithic fragments. These fragments range in size from 1.5 mm to over 20 cm in diameter. They are rounded to subangular in outline.

In thin section the matrix of the greenstone is composed of interlocking exceedingly fine-grained particles which appear to be mostly chlorite. Intermixed with the tiny particles are numerous needlelike crystallites which appear to be feldspar. Larger crystals of both euhedral and broken laths of feldspar and stubby hornblende crystals are scattered throughout the matrix. The lithic fragments are of different composition than the matrix. They are composed of aggregates of needlelike crystals in a matrix even finer grained than the rock matrix and may represent devitrified glass.

Morrow Mountain Rhyolite

The Morrow Mountain Rhyolite is a dark-gray to black, porphyritic rhyolite usually showing excellent flow foliation. It is here named after Morrow Mountain in Stanly County on which it is typically exposed. In the Albemarle quadrangle (Conley, 1962), both intrusive porphyritic dikes and extrusive (?) flows were included in this formation. The rhyolite flows may be as much as 200 feet thick, and apparently cap only the highest hills in the Albemarle quadrangle. This rock is interpreted to conformably overlie the Badin Greenstone, but where the Badin Greenstone is not present it unconformably overlies the Uwharrie Formation and the Tillery Formation.

The type locality of the Morrow Mountain Rhyolite is in Morrow Mountain State Park, near the bridge over Sugarloaf Creek on the road to the park office; 0.4 of a mile east of the intersection of this road and the road to the top of Morrow Mountain.

The rhyolite at this exposure is a dark-gray, porphyritic rock that shows pronounced laminar-flow banding on weathered surfaces. At or near the base of this exposure the formation contains a bed 2 feet thick of angular lithic breccia composed of rhyolite and felsite fragments. This breccia is common in the basal part of the formation as found in the park but is not universally present. At this locality the rhyolite unconformably overlies the Tillery Formation. This contact is visible approximately 400 feet east of the bridge over Sugar Loaf Creek.

Above the base, the rock is a dark, grayish-black, porphyritic rhyolite containing numerous flow bands. The phenocrysts consist of white feldspar laths, 0.5 mm to 2 mm long; and beta-quartz crystals, 0.5 mm to 1 mm in length. The flow lines are of a lighter color than the rest of the rock. In fresh outcrops the flow lines are relatively inconspicuous. They become accentuated by weathering. Numerous strikes and dips were measured on the flow banding, but the results were too erratic to indicate a reasonable foliation pattern.

The groundmass of the Morrow Mountain Rhyolite cannot be resolved under the microscope, but appears to be a mixture of kaolinite, sericite, and cryptocrystalline quartz. Interlocking, unoriented, lenticular masses of quartz occur parallel to the flow-banding. Sericite masses also seem to be oriented parallel to the flow bands. Unoriented phenocrysts of orthoclase, oligoclase, and beta quartz are sparingly distributed throughout the groundmass. Rare masses of emerald-green chlorite, which may represent alteration of biotite, have been noted.

AGE

The age of the Carolina slate belt has been the subject of much speculation. It has been tenuously assigned to the Precambrian or early Palezoic (?) (Stuckey and Conrad, 1958), early Palezoic (King, 1955), and Ordovician (Laney, 1917).

On the basis of lead-alpha dates obtained from zircons in granitic rocks in the North and South Carolina Piedmont, Overstreet et. al. (1961) postulated the existence of a late Cambrian and a late Ordovician unconformity within the Carolina slate belt. Hadley (1964) has noted a late Ordovician thermal peak in the Southern Piedmont that is recorded by isotopic ages. As thermal peaks are associated with orogeny, this further suggests a late Ordovician unconformity. Field relationships noted by Stromquist and Conley (1959) establishes an angular unconformity below the Tater Top Group. Whether this represents the late Cambrian or the late Ordovician unconformity is not known as the Tater Top Group has not been dated.

Only recently have radiogenic age determinations of zircons been published (White et. al., 1963) and fossils reported (St. Jean, 1964) from the Carolina slate belt in North Carolina. Zircons determined to be Ordovician in age by lead-alpha dating techniques were collected from two localities in the southeastern part of the Albemarle quadrangle (White et. al., 1963). St. Jean (1964) reported two specimens of middle Cambrian trilobites which he identified as Paradoxides. These specimens, occurring in a water worn rock fragment lithologically identical to the McManus Formation, were collected from the area of outcropping McManus Formation in Stanly County. As the stratigraphic succession from the lowest exposed part of the Uwharrie Formation through the top of the Albemarle Group is considered to be conformable, it is difficult to explain an Ordovician date at the base and a middle Cambrian date from near the top of this sequence of rocks. This fact graphically portrays the urgent need for further work on deciphering the age of the Carolina slate belt.

Because of the general agreement that the Carolina slate belt is early Paleozoic age and the lack of agreement of existing facts for a more specific age assignment, it is considered best to omit period designations of the formations until more definite evidence is available. Therefore, the Carolina slate belt in the area discussed in this report is regarded as early Paleozoic age.

TECTONIC SEDIMENTARY CONTROL

The results of the investigations by Floyd, May, Bain, and Stromquist and Conley (1959), and Conley (1962) which have been freely drawn upon for this report, all indicate that the Troy anticlinorium was one of the major tectonic controls of sedimentation during deposition of the rocks which comprise the Carolina slate belt. The wide area distribution of subaerially deposited pyroclastics of the Uwharrie Formation followed by deposition of the Efland Formation only on the east and northeast side of the anticlinorium, in contrast to deposition of the McManus Formation and Yadkin Graywacke of the Albemarle Group only to the southwest indicates that the Troy anticlinorium was a positive barrier to sedimentation from the northwest and southeast, beginning at the end of Uwharrie time and lasting through Efland and most of Albemarle time. An exception is the Tillery Formation which was deposited on both sides and south of the Troy structure. The wider distribution of the Tillery Formation indicates sedimentation possibly from a different source northeast or southwest of the Troy anticlinorium.

It is also noteworthy that the Troy anticlinorium marks the division of the degree of folding and dynamic metamorphism from east and northeast to west and southwest. Minor folds to the east and northeast are either asymetrical or overturned to the southeast. Axial plane dips vary from less than 60° to the northwest to vertical. In contrast, sediments to the west and southwest of the anticlinorium are openly folded and only slightly asymetrical. Axial planes dip steeply to the northwest.

At the end of Albemarle time, destruction of the basin of deposition by re-elevation of the anticlinorium is indicated by the unconformity between the Albemarle and Tater Top Groups. Rocks of this group have not been recognized east of the Troy anticlinorium These thin, subaerial deposits probably originated from local vents. If they were at one time more widespread, they since have been eroded away.
spread, they since have been eroded away.

ERRATUM: In legend of Geologic Map, Figure 1, the letters Pzgn and proper pattern should appear on block labeled Gneiss and Schist.

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THE USE OF X-RAY DIFFRACTION FOR THE QUANTITATIVE ANALYSIS OF NATURALLY OCCURRING MULTICOMPONENT MINERAL SYSTEMS

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ABSTRACT

The use of X-ray diffraction for the quantitative analysis of naturally occurring mineral systems has been investigated both theoretically and experimentally. In order to facilitate the recognition and statistical treatment of experimental variation, the theory is presented in a linear form. A major limitation of presently used methods, the necessity for obtaining pure samples of the components present, is circumvented in the theoretical exposition by a back blending technique. The experimental verification of the theory consisted of the investigation of two bicomponent systems, kaolinite-glauconite and kaolinite-montmorillonite, and one tricomponent system, glauconite-kaolinite-montmorillonite.

INTRODUCTION

The elements of quantitative analysis for mixtures of several structural components by X-ray diffraction were first expounded by Klug and Alexander (1948). Various schemes have since been devised to apply their principles. This paper discusses several points that may limit the application of some techniques in the analysis of naturally occurring systems - the most important of these being the nonavailability of "pure" materials. The basic equation of Klug and Alexander is developed in a mathematical form that (1) results in the linear presentation of quantity versus peak intensity, (2) does not require a sample of the "pure" component, and (3) minimizes the influence of experimental variations.

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NATURAL SYSTEMS

For purposes of this paper a naturally occurring system is defined as a solid material composed of one or more recognizable crystalline structural configurations or units, each unit being associated with some standard configuration but not necessarily having a composition identical to that of the standard. The purpose of this definition is for the recognition of the fact that within a class of materials designated by a common name, there may exist variable degrees of atomic substitution, "hole filling" by extraneous ions, etc., which might appreciably affect the behavior of these materials when investigated by methods of X-ray diffraction.

Naturally occurring systems are divided into two general classes. The first class consists of those deposits that contain varying proportions of the several distinct structural configurations, but of which it may be said that throughout the deposit the composition of like units remains constant. Thus, a deposit containing illite and montmorillonite may have varying proportions of these two minerals present depending on the specific sampling point, but throughout the sampling population the illite can be said to be the "same" chemically due to common origin and history. The defining property of this first class will be homogeniety with respect to the chemical-structural composition of the several recognizable structural configurations. Note that this definition in no way implies that the composition of the illite of the particular formation in questions conforms to the "ideal" illite composition. In general, the conditions of this first class of systems will most often be met in sedimentary deposits.

The second class of natural systems is defined as those systems that do not conform to the defining assumption for systems of the first class. If the chemical composition of a particular structural configuration varies depending on the particular sampling point, then the class one assumption is not met. Thus, the defining property of class two is nonhomogeniety with respect to the chemical-structural composition within the sampling population. The methods presented in this paper will apply only to the first class of natural systems.

THEORY

Notation:

Subscript: A subscript refers to a particular structural configuration unit. Thus there will usually be only a single subscript.

Superscript: A superscript serves two purposes:

1. To identify a particular sample,
2. To relate the composition of that sample to other samples in the case of a blend.

Letters:

I = net peak intensity; this may be defined either as total peak counts per second less background or as the integrated peak intensity less integrated background.

C = constant of the geometry and of the component.

ρ = apparent density of the component.

μ = linear absorption coefficient of the component.

μ_s^* = mass absorption coefficient of the sample.

x = weight fraction of the component in a sample.

P = factor inversely related to x.

Examples of notation:

1. I_2 = net peak intensity of component 2.
2. x_1 = weight fraction of component 1.
3. I^A = one of the net intensities in sample A.
4. I^{AB} = one of the net intensities in sample AB composed of 1 part sample A and 1 part sample B.
5. X_3^{A2B} = weight fraction of component 3 in sample A2B made up of 1 part of sample A and 2 parts sample B.

Klug and Alexander (1948) have shown that the net diffracted intensity of the i^{th} component of an N component mixture may be written:

$$(1) \qquad I_i^R = \frac{C_i\, x_i^R}{\rho_i\, \mu_s^{R*}}$$

or:

$$(2) \qquad x_i^R = \frac{I_i^R\, \rho_i\, \mu_s^{R*}}{C_i} \quad ,$$

but note that

$$(3)\quad \sum_{K=1}^{N} x_K^R = \sum_{K=1}^{N} \mu_S^{R\#} I_K^R \rho_K / C_K = 1$$

$$\therefore (4)\quad \mu_S^{R\#} = \frac{1}{\sum_{K=1}^{N} I_K^R \rho_K / C_K} \qquad \text{SINCE } \mu_S^{R\#} = \text{CONSTANT.}$$

$$(5)\quad \text{THUS} \qquad x_i^R = \frac{(\rho_i / C_i) I_i^R}{\sum_{K=1}^{N} I_K^R \rho_K / C_K} = \frac{R_i I_i^R}{\sum_{K=1}^{N} R_K I_K^R} .$$

Now we may either leave ρ/C in as an implement for correcting for day to day variables or we may consider the ratio ρ_i/C_i = R_i , a constant. In the solution of most problems the x_i will be the unknowns and the I_i will be the measured quantities. Thus it is desirable to develop a solution to (5) in terms of the I_i and, furthermore that this solution statement be in a linear form if possible.

Inverting equation (5) we get:

$$(6)\quad \frac{1}{x_i^R} = \frac{\sum_{K=1}^{N} R_K I_K^R}{R_i I_i^R} .$$

Dividing $R_i I_i^R$ into $\sum_{K=1}^{N} R_K I_K^R$ we get:

$$(7)\quad \frac{1}{x_i^R} = 1 + \sum_{K=1}^{i-1} \frac{R_K I_K^R}{R_i I_i^R} + \sum_{K=i+1}^{N} \frac{R_K I_K^R}{R_i I_i^R}$$

$$(8)\quad \text{OR} \quad \frac{1}{x_i^R} - 1 = \sum_{K=1}^{N} \frac{R_K I_K^R}{R_i I_i^R} \qquad K \neq i .$$

In order to avoid confusion later, denote the sum $\sum_{K=1}^{N} \frac{R_K I_K^R}{R_i I_i^R}$ $K \neq i$ with the $\frac{R_i I_i^R}{R_i I_i^R}$ term removed and transposed by $\sum_{K=1}^{N\#} \frac{R_K I_K^R}{R_i I_i^R}$ so that (8) becomes

$$(9) \qquad \frac{1}{x_i^R} - 1 = \sum_{K=1}^{N\#} \frac{R_K I_K^R}{R_i I_i^R} .$$

For convenience let $\frac{R_K}{R_i} = \beta_{Ki}$ in (9).

Note that $\frac{1}{x_i^R} - 1$ is linearly related to the sum of the ratios of the net peak intensities of all other components to that of component i. For simplicity of writing let $P_i^R \equiv \frac{1}{x_i^R} - 1$ so that once we solve for P_i^R we identically know the weight fraction of component in sample R, x_i^R.

Finally we write: $$(10) \qquad P_i^R = \sum_{K=1}^{N\#} \beta_{Ki} \frac{I_K^R}{I_i^R} .$$

Before discussing the evaluation of the constants β_{Ki}, the fundamental equation (10) is expanded for two and three component mixtures.

1. Consider a sample A composed of two structural configurations, components 1 and 2. We expand in terms of component 1 first, and in terms of component 2 second:

$$P_1^A = \beta_{21} \frac{I_2^A}{I_1^A} = \frac{1}{x_1^A} - 1$$

$$P_2^A = \beta_{12} \frac{I_1^A}{I_2^A} = \frac{1}{x_2^A} - 1 .$$

Note that $\beta_{21} = \frac{1}{\beta_{12}}$ or in general $\beta_{MN} = \frac{1}{\beta_{NM}}$.

2. Consider a sample B composed of three structural configurations 1, 2, and 3 (say kaolinite, glauconite, and montmorillonite).

$$P_1^B = \beta_{21}\frac{I_2^B}{I_1^B} + \beta_{31}\frac{I_3^B}{I_1^B} = \frac{1}{x_1^B} - 1$$

$$P_2^B = \beta_{12}\frac{I_1^B}{I_2^B} + \beta_{32}\frac{I_3^B}{I_2^B} = \frac{1}{x_2^B} - 1$$

$$P_3^B = \beta_{13}\frac{I_1^B}{I_3^B} + \beta_{23}\frac{I_2^B}{I_3^B} = \frac{1}{x_3^B} - 1$$

Note that in the above equations a plot of I_3^B / I_1^B vs. P_1^B is linear and passes through the origin. Similar linear relationships exist for the other ratios. If we have a three component system, some notion of the applicability of the above theory can be gained by actually plotting these functions and observing the degree of linearity. In this way extraneous values due to experimental variations can be located and corrected. Likewise, scattered data can be treated statistically.

In the case of a two component system, a plot of I_2^A / I_1^A vs. P_1^A has a slope equal to β_{21} . Note however that for a three component system a plot of $\frac{I_2^B}{I_1^B}$ vs. P_1^B does not have a slope equal to β_{21}. This plot does have value though in that it should be linear as mentioned before, and also that it should pass through the origin.

An obvious inconvenience is the fact that as x_i^R approaches zero, P_i^R approaches infinity. Thus for x varying from 100% to 50%, P ranges from 0 to 1 respectively; but for x varying from 50% to 0%, P ranges from 1 to ∞ respectively. The divergence is not radical, however, since for x = 10%, P = 9, a manageable number. Also, if x_1 is very small, resorting to x_2 will revert the system to values of P_2 less than 1. A little forethought will avoid difficulties of divergence.

In order to apply equation (10) directly we must evaluate the

β_{K1}. Note that since $\beta_{KK} = 1$, we need evaluate only (N-1) values of β_{Ki} for an N component system.

One convenient means of evaluating the β_{Ki} is the pure component approach of Black (1963). This approach gives $R_i = 1/\mu_i^{\#} I_{io}$ where $\mu_i^{\#}$ is the calculated mass absorption coefficient and I_{io} is the net diffracted intensity of a pure sample of component i. This approach is useful where the structural components involved can be said to be chemically like the standard type and where a pure sample can be obtained. Once the R_i are calculated, the β_{Ki} may be determined directly as R_K/R_i.

A commonly occurring instance of a natural system of the first class finds two or more structural components occurring simultaneously and in varying proportions. However, seldom if ever within the region in question will pure samples of the various components be available. In this case it would be necessary to obtain these pure components from remote locations. This introduces the possibility that the pure samples used would be chemically unlike the component in the system to be analyzed. In the case of clay minerals this would almost certainly be true in the more complex varieties. There is evidence to indicate that even such a relatively simple mineral as kaolinite might give a pure component intensity that is dependent on the source of the sample Arindley and Kurtossy, 1961). In any case the question of likeness is one that deserves consideration.

Fortunately in solving for the values of the β_{Ki} for use in equation (10) it is not necessary to have samples of the pure components. Consider a two component system composed of structural components 1 and 2. Suppose that this system can be said to be a member of the first class, that is, at all sampling points the chemical composition of component 1 is the same, and the chemical composition of component 2 is the same. Now consider samples A and B from this binary system and let sample A have relative proportions of components 1 and 2 different from the relative proportions in sample B. The magnitude of the difference will be discussed later. Now considering component 1 we may write:

$$(11) \quad P_1^A = \beta_{21} \frac{I_2^A}{I_1^A}$$

and

$$(12) \quad P_1^B = \beta_{21} \frac{I_2^B}{I_1^B} .$$

Now blend M parts of sample A with 1 part of sample B and write:

$$(13) \quad P_1^{MAB} = \beta_{21} \frac{I_2^{MAB}}{I_1^{MAB}}.$$

But note that

$$(14) \quad x_1^{MAB} = \frac{M(x_1^A)+x_1^B}{M+1}.$$

Recalling the P is directly related to x, we may, upon choosing a value of M, combine equations (11), (12), (13), and (14). For simplicity let $M = 1$. Note that experimentally it might be more accurate to choose a value other than 1 for M, but the manipulations follow analogously.

With M equal to 1 and putting (11), (12), and (13) into (14) we may write:

$$(15) \quad \beta_{21} = \frac{2\frac{I_2^{AB}}{I_1^{AB}} - \frac{I_2^A}{I_1^A} - \frac{I_2^B}{I_1^B}}{\frac{2 I_2^A I_2^B}{I_1^A I_1^B} - \frac{I_2^{AB} I_2^A}{I_1^{AB} I_1^A} - \frac{I_2^{AB} I_2^B}{I_1^{AB} I_1^B}},$$

where the values of I_K^A, I_K^B, and I_K^{AB} are obtained from diffractograms of sample A, sample B, and sample AB - a blend of 1 part sample A and 1 part sample B by weight. Once the value of β_{21} is determined, any sample from the system can be analyzed by simply running one X-ray of that sample and measuring the net intensities I_1 and I_2.

Clearly, though theoretically correct, use of formula (15) in actual practice must be undertaken only after consideration of the variations that experimental error might impose. As the relative proportions of components 1 and 2 in samples A and B approach the same value, small errors in the measurement of the diffracted intensities may introduce large variations in the value of β_{21}.

Thus it is desirable that sample A, say, have a large amount of component 1 while sample B should ideally have a small amount of component 1. Fortunately the linear nature of the theory lends itself to statistical treatment. For important work a program of blending many samples with each other will yield progressively stronger values of β_{21}. The ramifications of the blending technique are many and the above example serves only to illustrate one possible approach in its application to a natural system.

In the case of a tricomponent system the blending formula becomes, in closed form, a quadratic. The solution statement is best made in the form of two simulteneous equations. Consider samples A, B, and C composed of structural components 1, 2, and 3. Let the relative proportions of the three components differ in the three samples.

The coefficients to be determined are β_{21} and β_{31}. Solution of the two following simulteneous equations yields the desired values.

$$\beta_{21}\left[2\,\frac{I_2^{AB}}{I_1^{AB}} - \frac{I_2^{A}}{I_1^{A}} - \frac{I_2^{B}}{I_1^{B}}\right] + \beta_{31}\left[2\,\frac{I_3^{AB}}{I_1^{AB}} - \frac{I_3^{A}}{I_1^{A}} - \frac{I_3^{B}}{I_1^{B}}\right]$$

$$+ \beta_{21}\beta_{31}\left[\frac{I_2^{A}\,I_3^{AB}}{I_1^{A}\,I_1^{AB}} + \frac{I_2^{AB}\,I_3^{A}}{I_1^{AB}\,I_1^{A}} + \frac{I_2^{B}\,I_3^{AB}}{I_1^{B}\,I_1^{AB}} + \frac{I_2^{AB}\,I_3^{B}}{I_1^{AB}\,I_1^{B}} - 2\,\frac{I_2^{A}\,I_3^{B}}{I_1^{A}\,I_1^{B}}\right.$$

$$\left. - 2\,\frac{I_2^{B}\,I_3^{A}}{I_1^{B}\,I_1^{A}}\right] + \beta_{21}\beta_{21}\left[\frac{I_2^{A}\,I_2^{AB}}{I_1^{A}\,I_1^{AB}} + \frac{I_2^{B}\,I_2^{AB}}{I_1^{B}\,I_1^{AB}} - 2\,\frac{I_2^{A}\,I_2^{B}}{I_1^{A}\,I_1^{B}}\right]$$

$$+ \beta_{31}\beta_{31}\left[\frac{I_3^{A}\,I_3^{AB}}{I_1^{A}\,I_1^{AB}} + \frac{I_3^{B}\,I_3^{AB}}{I_1^{B}\,I_1^{AB}} - 2\,\frac{I_3^{A}\,I_3^{B}}{I_1^{A}\,I_1^{B}}\right] = 0.$$

$$\beta_{21}\left[2\,\frac{I_2^{AC}}{I_1^{AC}} - \frac{I_2^{A}}{I_1^{A}} - \frac{I_2^{C}}{I_1^{C}}\right] + \beta_{31}\left[2\,\frac{I_3^{AC}}{I_1^{AC}} - \frac{I_3^{A}}{I_1^{A}} - \frac{I_3^{C}}{I_1^{C}}\right]$$

$$+ \beta_{21}\beta_{31}\left[\frac{I_2^{A}\,I_3^{AC}}{I_1^{A}\,I_1^{AC}} + \frac{I_2^{AC}\,I_3^{A}}{I_1^{AC}\,I_1^{A}} + \frac{I_2^{C}\,I_3^{AC}}{I_1^{C}\,I_1^{AC}} + \frac{I_2^{AC}\,I_3^{C}}{I_1^{AC}\,I_1^{C}} - 2\,\frac{I_2^{A}\,I_3^{C}}{I_1^{A}\,I_1^{C}}\right.$$

$$\left. - 2\,\frac{I_2^{C}\,I_3^{A}}{I_1^{B}\,I_1^{A}}\right] + \beta_{21}\beta_{21}\left[\frac{I_2^{A}\,I_2^{AC}}{I_1^{A}\,I_1^{AC}} + \frac{I_2^{C}\,I_2^{AC}}{I_1^{C}\,I_1^{AC}} - 2\,\frac{I_2^{A}\,I_2^{C}}{I_1^{A}\,I_1^{C}}\right]$$

$$+ \beta_{31}\beta_{31}\left[\frac{I_3^{A}\,I_3^{AC}}{I_1^{A}\,I_1^{AC}} + \frac{I_3^{C}\,I_3^{AC}}{I_1^{C}\,I_1^{AC}} - 2\,\frac{I_3^{A}\,I_3^{C}}{I_1^{A}\,I_1^{C}}\right] = 0.$$

EXPERIMENTAL PROGRAM

The experimental verification of the theory was organized under three subheadings:

I. Kaolinite-Glauconite Bicomponent.
   a. Verification of linear relationship between P and peak height ratios.
   b. Calculation of β_{21} by pure component approach.
   c. Calculation of β_{21} by blend approach.

II. Kaolinite-Montmorillonite Bicomponent.
   a. Verification of linear relationship between P and peak height ratios.

III. Kaolinite-Glauconite-Montmorrilonite Tricomponent.
   a. Verification of linear relationship between P and peak height ratios.

The samples used in this analysis were a kaolinite from the Huber Corporation, Huber, Georgia (Cretaceous, Tuscaloosa Formation), an API H-23 montmorillonite, and a glauconite from the Hornerstown Formation (Eocene age) in Monmouth County, New Jersey (Emileys Hill Road, about one mile NW of Creamridge). The preparation of the samples consisted essentially of a 2 micron separation followed by magnesium saturation. Sedimented slides were prepared by depositing 50 mg of clay in suspension on a glass microscope slide. The samples containing montmorillonite were treated with ethylene glycol vapor at 60°C for 2 hours prior to X-ray.

It should be pointed out that the theory depends upon using an experimental technique that allows each component of a multicomponent sample to affect the net peak intensities of the other components linearly. The best procedure for affecting these conditions is to have completely random orientation of the components. This is very difficult to achieve in the laboratory, particularly for routine work in platey minerals such as the clay minerals. Equally acceptable is an experimental technique that results in linear orientation and segregation effects, provided such effects are present to the same degree during the determination of the constants. It is not the purpose of this paper to examine laboratory techniques per se, but investigations are

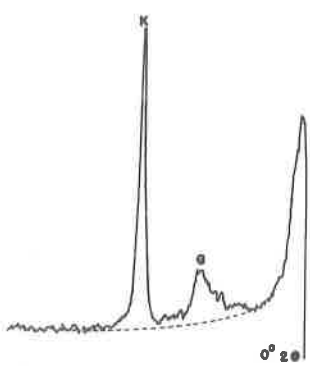

Figure 1.

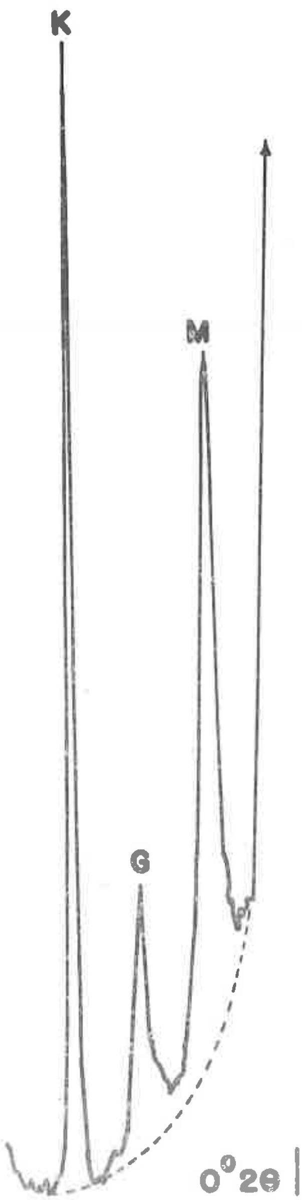

Figure 2.

presently in progress to determine for what laboratory procedure the theory is valid. The results of the present test series indicate that sedimented slides are acceptable, and application of the theory to previously published data of Williams (1959) on randomly oriented samples gave almost perfect results.

The diffractograms were obtained using a Philips X-ray unit and CuKα radiation. For the kaolinite-glauconite series the detector was a Geiger-Muller counter, and for the kaolinite-montmorillonite and the kaolinite-glauconite-montmorillonite series a scintillation counter with pulse height analyser was used. Intensities were determined by averaging a number of peak height traces made by successive oscillations over the peaks involved (001). The time constant was 4 and the scan speed was 1/4 degree 2θ per minute. A value of background to be subtracted was determined by fairing in a background line on a 1° to 15° trace. It should be noted that instrumental problems were not trivial in this investigation. Several modifications have been made to recent models of Philips equipment that should greatly improve the accuracy of these methods. Figures 1 and 2 give typical diffractograms from the kaolinite-glauconite and the kaolinite - glauconite - montmorillonite series.

PRESENTATION AND DISCUSSION OF RESULTS

I. Kaolinite-Glauconite Bicomponent.

a. Verification of linear relationship between P and peak height ratios.
Figure 3 is a presentation of the data obtained in the kaolinite-glauconite bicomponent series. This figure plots the ratio of the net intensity of the glauconite peak to the net intensity of the kaolinite peak versus the percentage factor for kaolinite. Recall that the per-

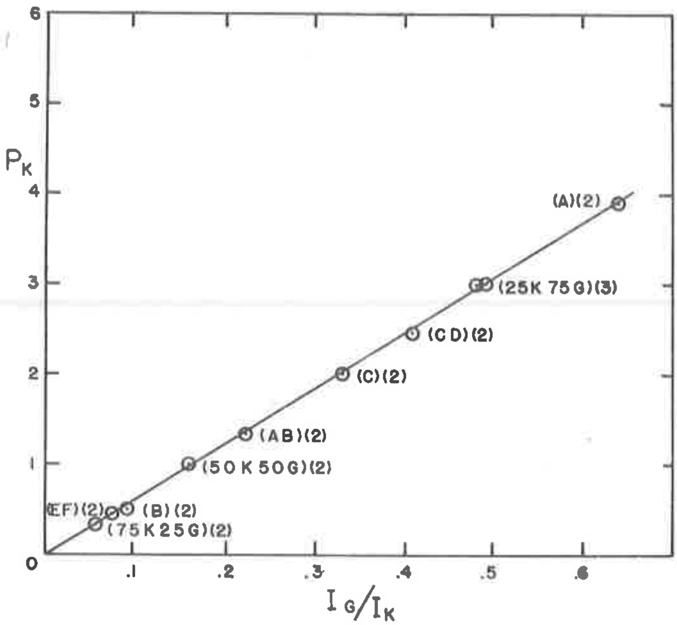

Figure 3.

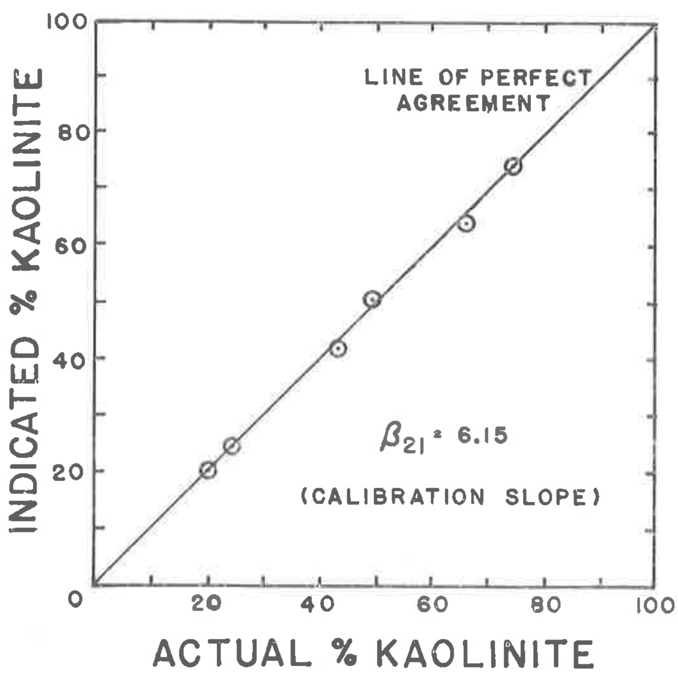

Figure 4.

cent kaolinite is inversely related to the percentage factor. The figures in parentheses indicate the percentage of kaolinite and montmorillonite. The slope of this curve gives a value of 6.15 for β_{21} . Now using the value of 6.15 the indicated percentage of kaolinite can be calculated by applying the experimental peak height ratios individually. Figure 4 is a plot of this predicted value versus the known actual value. The agreement is very good. Thus, if samples of the pure components are available, a linear calibration curve can be prepared by artificially combining them in various proportions. The availability of pure components that are exactly like the components of the binary system is the only requirement of this approach. Naturally, considerable work is involved in the preparation of such a calibration curve.

b. Pure component approach.
In order to apply the pure component approach, it is necessary to calculate the mass absorption coefficient of the various components and X-ray a pure sample of each component. Based on a formula for Kaolinite of $Al_4Si_4O_{10}(OH)_8$ and the use of CuKα radiation, the mass absorption coefficient is calculated as 30.38. Unfortunately, the chemical composition of Glauconite is not definite. A general formula is:

$$(OH)_4(K, Ca_{1/2}, Na)_{1.68}(Si_{7.30}Al_{0.70})(Al_{0.94}Fe_{1.94}Fe_{0.38}Mg_{0.80})O_{20}$$

The relative proportions of K, Ca, and Na in the particular class one system in question is unknown. However, in order to gain an idea of the applicability of the pure component approach, two extreme values of the mass absorption coefficient were calculated assuming all K and no Ca or Na, and assuming all Na and no K or Ca. The value obtained assuming all Ca and no K or Na fell between these other values. For all K, the mass absorption coefficient is 83.66, and for all Na the mass absorption coefficient is 76.71. X-ray diffractograms of pure kaolinite gave a net intensity of 500 counts per second, and for pure glauconite a net intensity of 33.3 counts per second was obtained. The value of R for kaolinite then is 6.58×10^{-5}, and the value of R for glauconite ranges from 3.92×10^{-4} for all Na to 3.59×10^{-4} for all K. Based on these values, the value of β_{21} ranges from 5.44 for kaolinite and K-glauconite to 5.96 for Kaolinite and Na-Glauconite. Figure 5 shows a plot of actual percentage kaolinite versus the predicted percentage range for kaolinite based on the extreme values of 5.44 and 5.96. Here again good agreement is shown. Thus, if pure components are available and the chemical formula for each of these components is known, a calibration factor for a binary class one system can be obtained by simply X-raying pure samples of the two components.

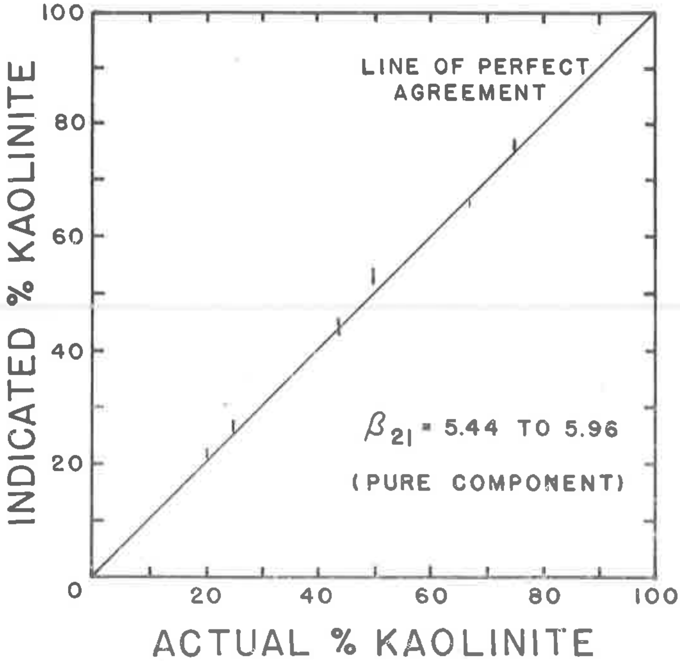

Figure 5.

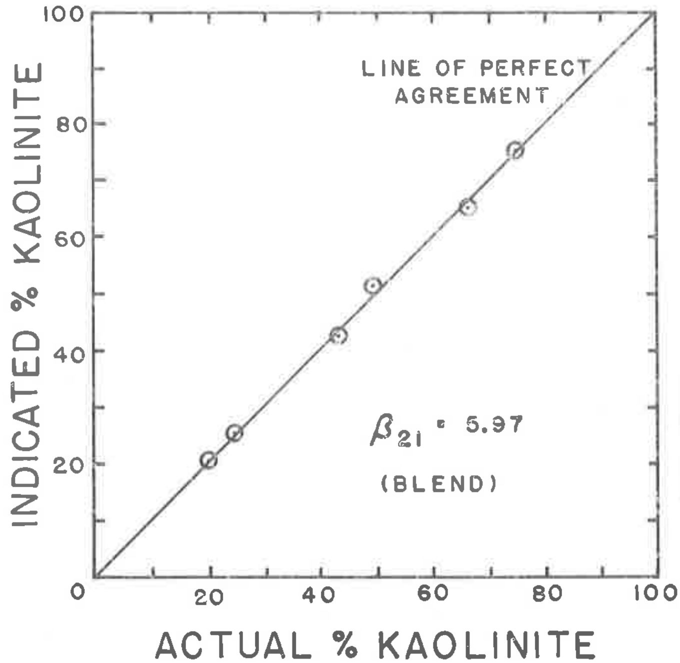

Figure 6.

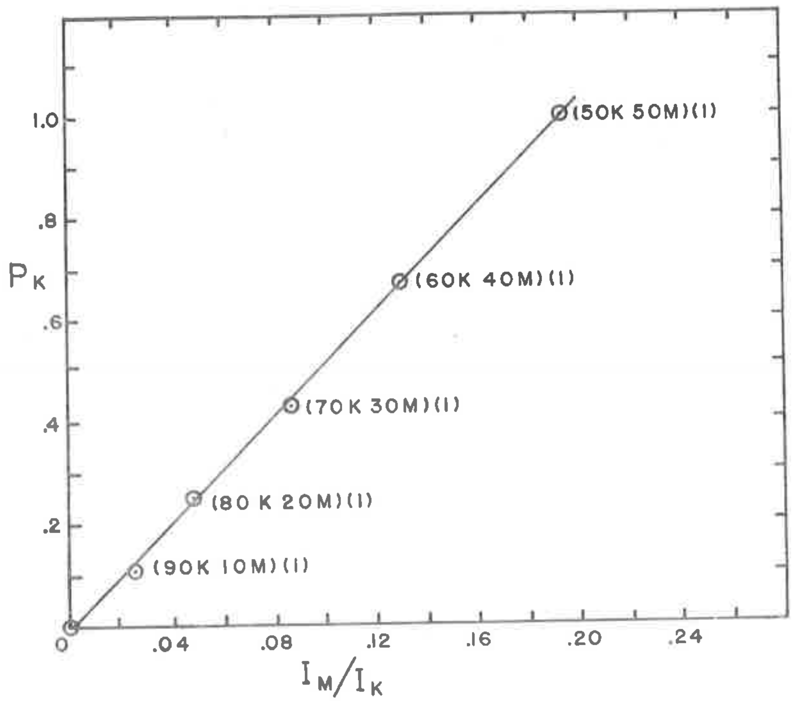

Figure 7.

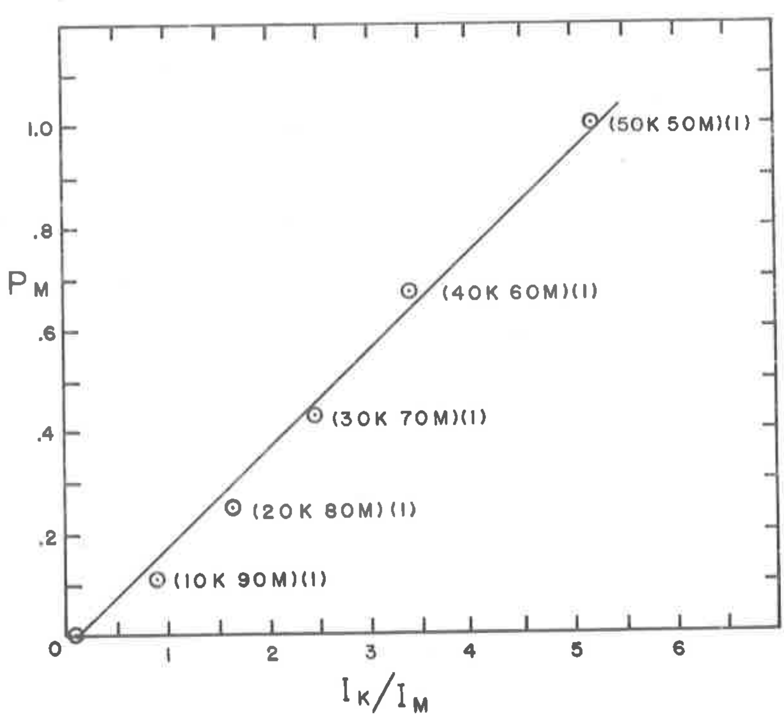

Figure 8.

c. Blend approach.

In order to evaluate the blend approach, two samples, A and B on Figure 1, were obtained. It is to be noted that it is <u>not</u> necessary to know the relative proportions of Kaolinite and Glauconite in either of these two samples. The samples were blended in one to one ratios by weight and the three slides were X-rayed. The intensities obtained were introduced into formula (15) and a value of 5.97 was obtained for β_{21}. Figure 6 shows the actual percentage kaolinite versus the predicted percentage using 5.97. Agreement by this method is as good as or better than that found in the other methods. Note that, in this approach, the only information needed was that the sampling population is a member of class one natural systems. As mentioned before, the accuracy of the method is enhanced if the

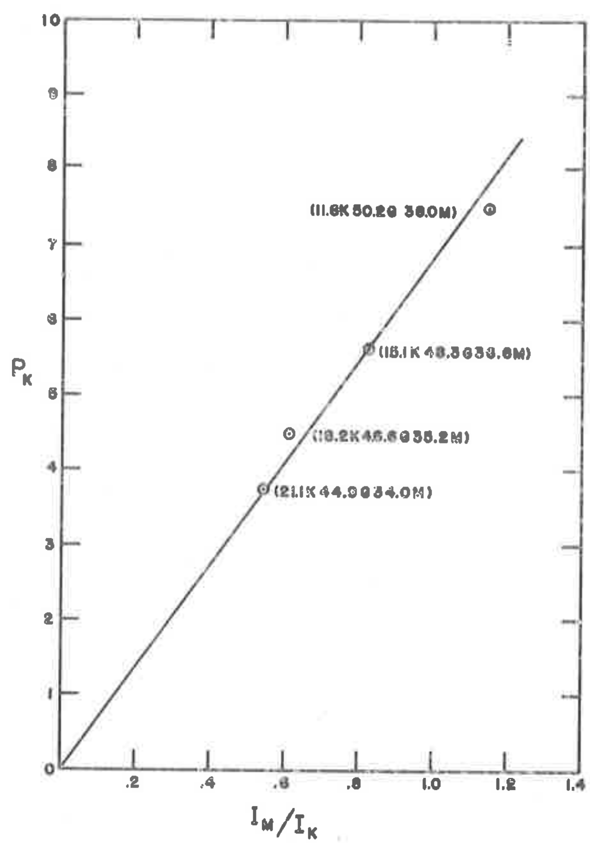

Figure 9.

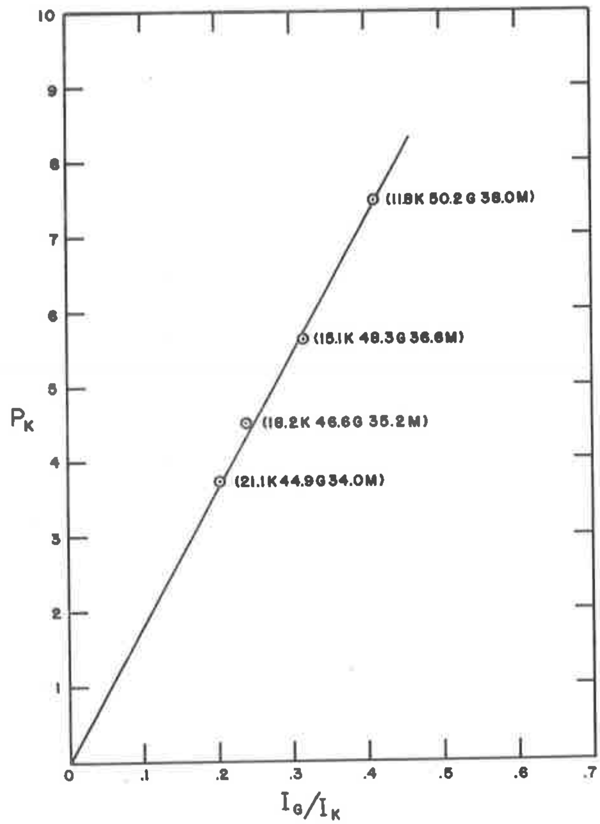

Figure 10.

two samples have widely differing relative proportions of the two components. Indeed, as the difference becomes less, the error will increase rapidly. Tests are presently being planned to determine the minimum difference which will yield sufficiently accurate values.

II. Kaolinite-Montmorillonite Bicomponent.

a. Verification of linear relationship between P and peak height ratios.

Samples were prepared of bicomponent mixtures of kaolinite and montmorillonite varying from 0% to 100% in 10% increments. Figure 7 shows a plot of the ratio of the net intensity of the montmorillonite peak to the net intensity of the kaolinite peak versus the percentage factor for kaolinite for mixtures varying from 50% to 100% kaolinite. Conversely, in Figure 8 the kaolinite to montmorillonite net peak intensity ratio was plotted against the percentage factor for montmorillonite for mixtures ranging from 0% to 50% kaolinite to avoid values of the percentage factor of kaolinite greater than 1. Some scatter is observed on Figure 8, however, there should be no difficulty in determining a calibration slope value.

III. Kaolinite-Glauconite-Montmorillonite Tricomponent.

a. Verification of linear relationship between P and peak height ratios.

Samples were prepared of mixtures of kaolinite, glauconite, and montmorillonite. The ratio of glauconite to montmorillonite was held constant. Figure 9 shows a plot of the glauconite to kaolinite net peak intensity ratios versus the percentage factor for kaolinite. Excellent linearity is found. Figure 10 plots the montmorillonite to kaolinite net peak intensity ratios versus the percentage factor for kaolinite. Linearity is reasonably well demonstrated. The fact that the montmorillonite peak is superimposed on the relatively high radiation background makes fairing in a correct background line difficult. This is demonstrated in Figure 2.

SUMMARY

Three methods are presented and verified for establishing calibration factors for relating net peak height ratios to the percentages of the various components present in a multicomponent system. It is found that by performing an algebraic transformation on the theory of Klug and Alexander, a linear relationship can be established between intensity ratios and the amounts present. The linearity was verified for bicomponent and tricomponent systems. In recognition of the fact that pure samples of the various components are not always available and that often there is some doubt as to the chemical composition of a particular naturally occurring component, a blend technique is outlined whereby the calibration factors can be derived without pure samples or knowledge of composition. This technique is expounded in detail for bicomponent and tricomponent systems and verified for one bicomponent case. It is pointed out that the linear nature of the theory as presented makes evaluation of the quality of the experimental data feasible and allows statistical treatment of scattered data. In addition, communication of test results is greatly enhanced since the ratio-quantity characteristics of an N component system are completely defined by N-1 constants. It should be noted that experimental characteristics are involved in these constants; however, since peak height ratios are used, their effects are minimized.

It is the plan of future investigations to establish the applica-

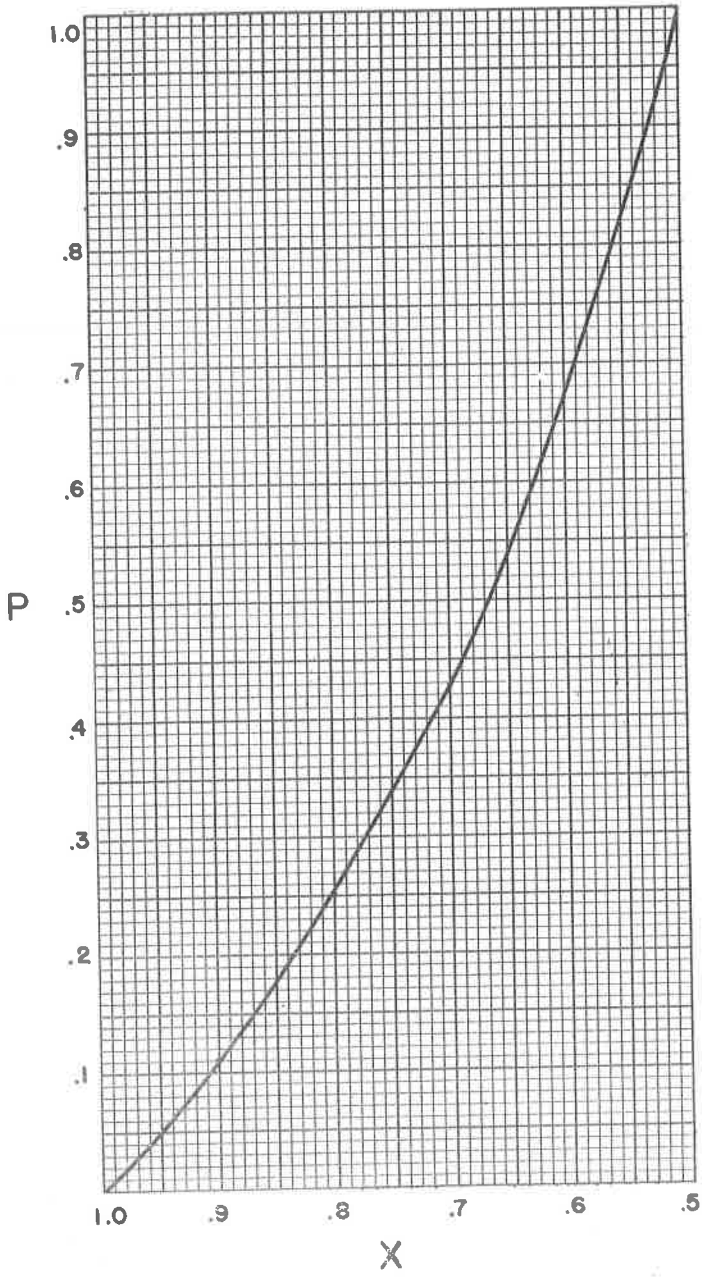

Figure 11.

bility of these techniques to other multicomponent systems with emphasis being placed on systems for which there is little basis for calculating the mass absorption coefficients of the various components, and for systems where pure components are not available. The author would appreciate communication concerning results of the application of the linearization technique to presently existing data. In order to simplify such attempts, the transformation is presented graphically in Figure 11. The percentage is given as the abscissa, and the percentage factor is given as the ordinate. Thus by entering the curve under the known percentage, the factor that should plot linearly against the peak height ratios can be read directly.

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BATHYMETRY OF THE MIAMI TERRACE

by

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ABSTRACT

The Miami Terrace east of Miami in the Florida Straits is a submarine outcrop of the same formation which forms the Pourtales Terrace. The two terraces are separated by a large sediment accumulation and by a major fault along which the Miami Terrace has been dropped a minimum of 460 feet relative to Pourtales Terrace and the Florida mainland. The fault is expressed morphologically for a distance of 70 nautical miles along the ocean bottom.

INTRODUCTION

Because interest in submarine geology and physiography in the Straits of Florida is active both among government agencies and univerisities, the writers are reporting the findings to-date of a current and continuing investigation in the area. The purpose of this preliminary report is briefly to point out the physiographic and geologic relationship of two submarine terraces on the southern end of the Florida Platform.

In this discussion the Straits of Florida is divided into two regions: the Western Straits of Florida west of 80° 30' West, and the Northern Straits east of 80° 30' West and north of 20° 00' North.

On the basis of the existing data it can be shown that these terraces are part of a much larger terrace which is partially obscured by a large accumulation of sediments. One terrace is located on the continental slope off southeast Florida extending from Miami north to Ft. Lauderdale (Hurley, et al, 1962). Heretofore unnamed, "Miami Terrace" is proposed as the name for this feature after the University of Miami, the institution responsible for the initial recognition of this feature. The other, Pourtales Terrace, is located in the Western Straits south of the Florida Keys. The bathymetry and geology of Pourtales Terrace were recently reported by Jordan, et al (1964).

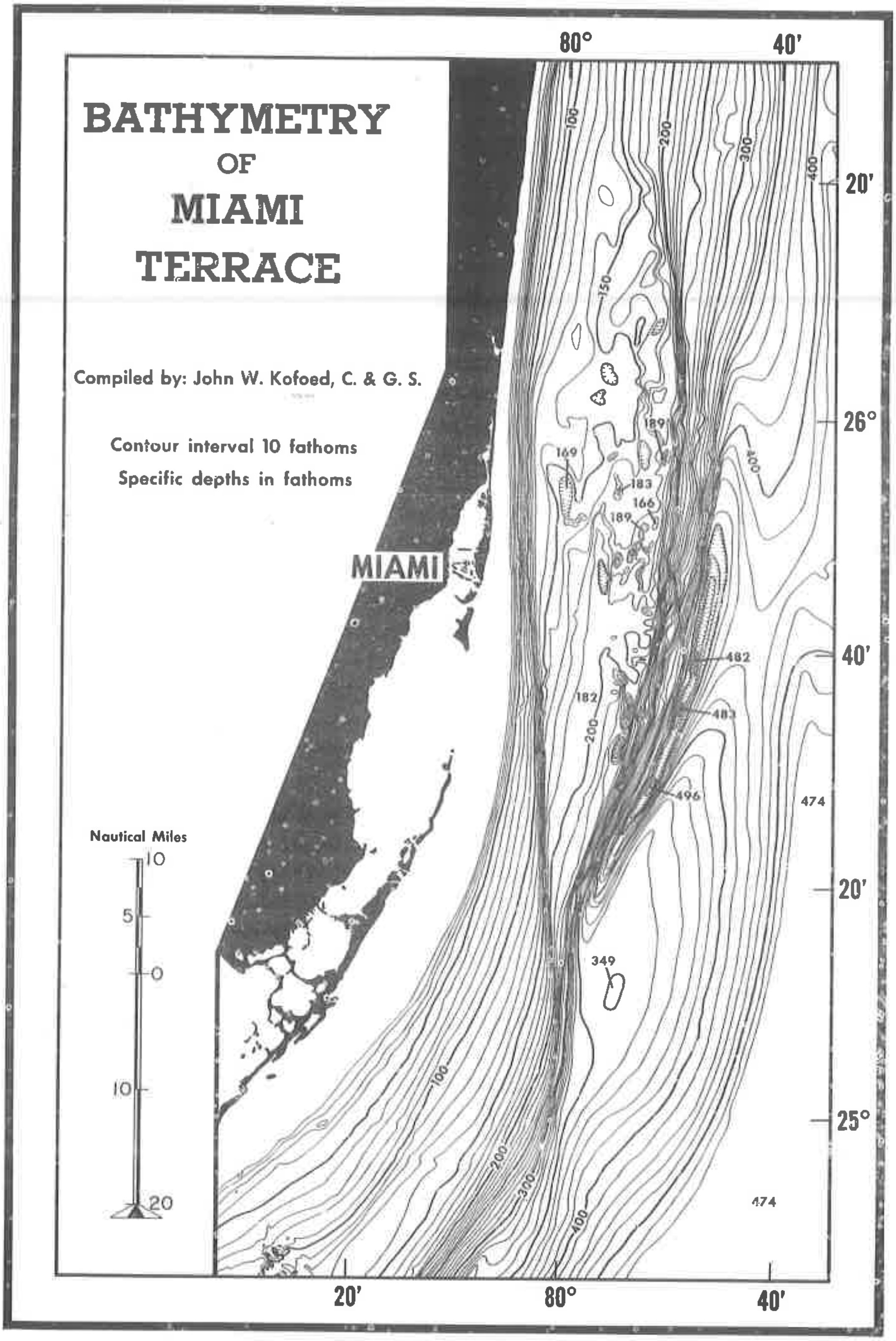

Figure 1. Bathymetric Chart of the Miami Terrace and adjacent areas of the Florida Straits.

Prior to 1958, hydrography in the Northern Straits consisted of a few echo soundings and some old wire-line soundings. In 1958, surveys by the University of Miami enhanced these data by employment of modern techniques and instrumentation, but due to the low sounding density and the quality of the older surveys, the submarine physiography could not be portrayed in detail.

Over the past decade the Coast and Geodetic Survey has been resurveying the sea floor around peninsular Florida. Field work by the USC&GSS HYDROGRAPHER in the Western Straits was supplemented by seismic profiling in 1962 providing the subbottom data for the Pourtales Terrace report (Jordan, et al, 1964). During the field seasons of 1963 and 1964 the HYDROGRAPHER surveyed the Northern Straits providing the hydrographic data for the present report.

BATHYMETRY

The bathymetric data were smooth-plotted at a 1:100,000 scale using corrected values. Contours were drawn at this same scale at a 10 fathom interval. Echo soundings were obtained by a DE-723 fathometer in depths of less than 400 fathoms and at greater depths a AN-UQN 12KC transceiver was used with a Precision Depth Recorder. All navigational control was by Raydist.

The Miami Terrace interrupts the otherwise smooth and regular profile of the Northern Straits of Florida. The terrace extends along the continental slope from just south of Miami north for approximately 65 nautical miles to the Ft. Lauderdale area. It resembles a long, low, obtuse triangle covering approximately 400 square natuical miles. The maximum width is 12 nautical miles (Figure 1). Gradients over the terrace average 30 feet per mile as the depth ranges from 130 to 180 fathoms. Gradient values increase from the center toward both ends of the terrace (Figure 2).

From the outer margin the escarpment slopes from 240 fathoms down to a maximum of 496 fathoms into a long, (40 nautical miles) narrow trough along the southern half of the terrace. The slope gradient is 225 feet per natuical mile (Figure 1).

Immediately east of the trough at 25° 42'N., 79° 42'W. is a saddle-like feature on a long, broad ridge. North of this point the ridge gradually blends into the slope north of the terrace. To the south, however, the ridge axis decreases in depth from 428 fathoms at the saddle to 349 fathoms at the crest of a large oblate dome-like feature at which point this long, low ridge loses its identity. The 349 fathom notation on Figure 1 delineates the crest of this dome-like feature.

On the west side of the southern portion of the Miami Terrace the isobaths converge and assume a preferred north-south orientation. Above 25° 20'N. they converge on the 100 fathom line and below 25° 20'N. they converge on the 200 fathom line and in both cases

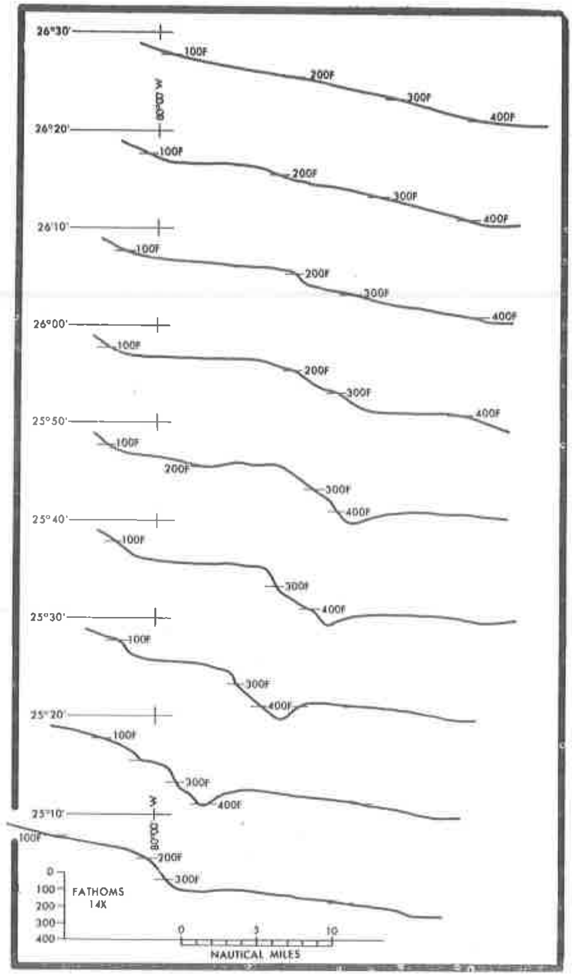

Figure 2. Bathymetric profiles constructed from the Bathymetric Chart, each separated by 10 nautical miles, and oriented due east-west.

along the same trace of a line drawn between 25° 10' North, 80° 00' West and 26° 00' North 80° 10' West.

The outer portion of the Miami Terrace is marked by a number of irregularities in the form of depressions and knoll-like features similar to those found on the eastern portion of Pourtales Terrace (Jordan, et al, 1964). Relief of these features range from 20 to more than 40 fathoms.

DISCUSSION

The Miami and Pourtales Terraces appear to be submarine outcrops of a common formation. The two terraces are separated by a large accumulation of sediment southeast of Key Largo. The Miami Terrace has been dropped a minimum of 460 feet along a clearly defined north-south fault that can be traced for a distance of over 70 nautical miles (Figure 3). This figure also shows Pourtales Terrace projected beneath the sediment cover. Where the fault intersects the steeper part of the slope (200-400 fathoms) an appearance of left-lateral movement is given. However, lateral movement of any significance is not postulated. Reconstruction of the area to pre-fault morphology requires vertical movement only when it is remembered that the relative movement has probably been differentially masked by sedimentation. In addition to the rather conclusive evidence of the scarp, and the too-low position of Pourtales' sister terrace, faulting is further demonstrated by the obvious consistent offset of contours on either side of the scarp. Of particular interest is the large elongated accumulation of sediment with the 349 fathom notation at its crest. The northern and southern slopes cannot be connected by a smooth curve along the crest of this mound unless the contours on the mound north of the fault are moved up 50 fathoms. With this reconstruction the elongate accumulation has one smoothly curving divide. A further indication of this postulated fault comes from a recently reported (Sheridan, et al 1964) subsurface fault.... "the trace of which is nearly coincident with the 100-fathom isobath between Palm Beach and Jacksonville. This fault has a vertical component of displacement of approximately 600 meters."

The fact that the lobes of sediment accumulation point in opposite directions proves that the shape of the accumulation was not formed by deposition, but rather by erosion. This establishes the sequence of events as deposition, then erosion, followed by faulting. The Miami Terrace fault may have kept the Miami Terrace below the sub-aerial environment which was experienced by the Pourtales Terrace. This could explain the absence of micro-relief on Miami Terrace present on Pourtales Terrace, although relative to the smooth slopes of recent sediment, the Miami Terrace exhibits complex relief caused by the contrast between sediment cover and exposed bedrock. The bedrock caused broken core barrels during four coring attempts in 1963 by the HYDROGRAPHER.

The long 40 mile trough at the base of the escarpment is five miles wide and has 64 fathoms of closure. It is almost certainly a feature of erosion. Although this amount of erosion at a depth to 496 fathoms seems incredible, the evidence is so compelling that it seems wiser to try to find out how the Gulf Stream eroded it than to look for other causes. As recently as late Pleistocene the trough was shoaler. Since most of the bottom features of the east coast of the United States are relict features of the Pleistocene, these features may prove to be no exception. That erosion is now shaping the morphology of the Northern Straits is significant in that it further proves that in the past,

probably during late Pleistocene time, a large volume of sediment was brought south along Florida's east coast to form the spit on which

Figure 3. Generalized Bathymetric Chart with bedrock contours added to demonstrate the fault trace.

probably during late Pleistocene time, a large volume of sediment was brought south along Florida's east coast to form the spit on which the Florida Keys have been built, the spit on the east end of the Pourtales Terrace, the bottom accumulation separating the two terraces, and the bottom accumulations now being reshaped by erosion on the western side of the Florida Straits.

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THE STRATIGRAPHIC SIGNIFICANCE OF AN UPPER MIOCENE FOSSIL DISCOVERY IN JEFFERSON COUNTY, FLORIDA

by

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ABSTRACT

The surface deposits of the northern half of Jefferson County have been previously mapped as Miocene, Pliocene, and Pleistocene. A recent discovery of fossil teeth of the late Miocene horse Merychippus sp. provides evidence of a late Miocene age of these beds.

The late Miocene sediments are a heterogeneous deposit of crossbedded sand, interbedded sands and clays, and lenticular clay beds. The maximum thickness of the deposits in Jefferson County is 120 feet, but in many places it is less because surface erosion has removed some of the late Miocene clastics.

These clastic sediments are a unit of a large prograding delta that probably had its inception during the middle Miocene. The clastics of the upper Miocene are a distinct lithologic unit and warrant a new name. However, until such time that regional work can be done so as to ascertain exact boundaries and more precise correlations with equivalent formations, these deposits will be referred to as "Upper Miocene Clastics".

INTRODUCTION

General Statement

An extensive, heterogeneous mass of surface deposits that represent the continental or very near shore phase of a large delta is present in the northern half of Jefferson County, Florida (Figure 1). These sediments have been mapped as the middle Miocene Hawthorn Formation in recent years. The middle Miocene age of these deposits was based soley on stratigraphic position since no fossils from these beds have been reported.

However, a recent discovery of vertebrate fossils in these deposits indicates that, at least in part, they are late Miocene.

In 1961, while mapping the surface geology in Jefferson County, Florida, the writer encountered bone fragments in a roadcut section in the northeastern part of the county. Stanley Olsen, vertebrate paleontologist of the Florida Geological Survey, made a study of these fragments but was only able to determine that they were mammal bone.

Charles Sever, geophysicist with the Ground Water Branch of the U. S. Geological Survey, visited this outcrop at a later date for the purpose of correlating Florida lithologies with similar deposits in Georgia counties to the north, where he was engaged in a ground-water investigation. While observing the outcrop, Sever found a mammal tooth which was identified by Olsen (1963, p. 308) as an upper molar of the Miocene horse Merychippus sp. In later trips to the outcrop by Olsen, Sever, and the writer, additional mammal teeth were found. These, also, have been described by Olsen (1963).

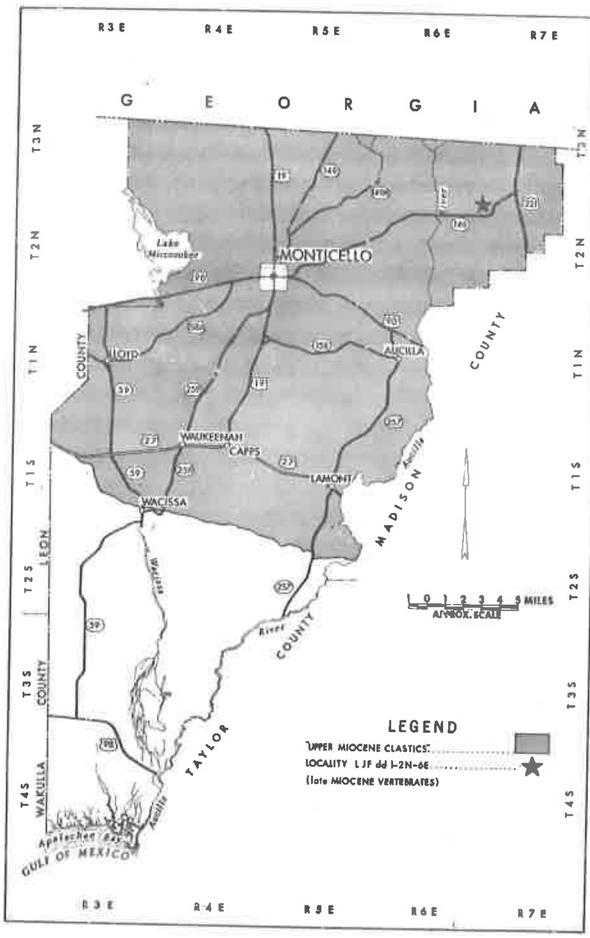

Figure 1. Location of Miocene Locality and distribution of "Upper Miocene Clastics" in Jefferson County, Florida

The discovery of these teeth is important both stratigraphically and paleontologically. Stratigraphically, they date sediments that were thought to be void of fossils, and provide evidence for a more precise age determination. Paleontologically, they are important because they represent the only known late Miocene vertebrate locality in Florida.

Acknowledgements

The author expresses his appreciation to Stanley Olsen for his work in identifying the fossil teeth. Charles Sever is commended for his astute observation in finding the horse teeth and for donating the specimens to the Florida Geological Survey. Thanks are expressed to Robert O. Vernon and other staff members of the Florida Geological Survey for reading and editing the paper. Gratitude is expressed to Frank Andrews of George Aase and Associates for his constructive criticism of the manuscript.

STRATIGRAPHY

Location of Area

The deposits in which the mammal teeth occur are located on the north side of State Highway 146 in the SE 1/4 SE 1/4 sec. 1, T 2 N, R 6 E in Jefferson County, Florida (Figure 1). Jefferson County is located in what is referred to as the Panhandle of Florida (Figure 2).

Historical Review of Deposits Containing the Fossil Teeth

The clastics in which the teeth occur form a part of a large complex of sediments. The correlation and age determination of deposits have been difficult because of the lack of fossils.

Matson and Clapp (1909, p. 141-145) referred the clastics to the Lafayette Formation of Pliocene age.

Sellards (1917, p. 96-110) felt that these sediments, which Matson and Clapp referred to the Lafayette Formation, should be placed in the lower Miocene Alum Bluff Formation.

Later, Gardner (1926, p. 1-2), on the basis of fossil evidence, raised the Alum Bluff to the rank of group and applied from oldest to youngest the following names: Chipola Formation, the Oak Grove Sand, and the Shoal River Formation. Although not specific, it appears that Gardner believed the Alum Bluff Group was of early and middle Miocene age.

Cooke and Mossom (1929, p. 77-125) included the deposits mapped as Alum Bluff by Sellards in Jefferson County in the Hawthorn Formation. They (Cooke and Mossom, 1929, p. 77-125) considered the Hawthorn Formation an equivalent of the Alum Bluff Group as mapped by Gardner.

Later, Cooke (1945) mapped the complex of sediments as a part

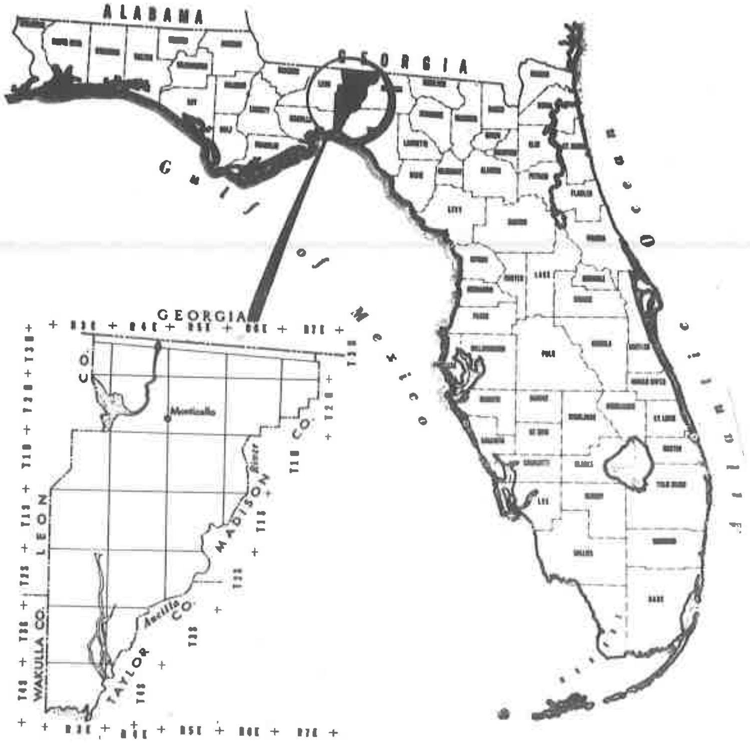

Figure 2. Map of Florida showing location of Jefferson County

of the Hawthorn Formation of middle Miocene age; and Vernon (1951), Yon (1951), and Puri and Vernon (1959) recognized the complex of sediments as a delta of "Hawthorn age."

Doering (1960, p. 182-189) mapped a segment of the clastics in the northern part of Jefferson County, that is stratigraphically related to the deposits containing the fossil teeth, as Pleistocene Citronelle Formation.

On the basis of Olsen's (1963, p. 308-314) identification of the vertebrate fossils found at this locality, the age of the clastics is now known to be late Miocene.

Areal Distribution

The "Upper Miocene Clastics" cover all of the upper half of Jefferson County (Figure 1). These "Upper Miocene Clastics" are not confined to Jefferson County but are widespread deposits that are present both to the east and west. Vernon (1951) mapped them as a part of a large delta plain that wedges out to the east into marine sediments and probably extends southward into the Peninsular of Florida.

Lithology and Thickness

In general, the clastics are composed of highly varied units of clayey sands and clay beds, all of which are highly lenticular and of limited areal extent. The quartz sands are moderately well sorted to poorly sorted, coarse to fine-grained, varicolored, and argillaceous. The sands are interbedded with varicolored sandy montmorillonitic and kaolinitic clay lenses. Quite frequently the sands are crossbedded and also contain thin laminae of white to light gray clay.

The diagrammatic section (Figure 3) and lithologic description of the bone-bearing beds are given as general examples of the sedimentary structure, geology, and occurrence of the "Upper Miocene Clastics."

Locality LJf dd 1 - 2N - 6E: Roadcut on north side of State Highway 146, located in the SE 1/4 SE 1/4 sec. 1, T 2 N, R 6 E

Unit	Description	Thickness (Feet)
F	SAND, quartz, predominantly medium light yellow and red brown, very fine to coarse, very silty and clayey, massive bedding, gradational contact with Unit E, but more clayey than E. The roadcut slopes back and near the top of unit the sediments become a highly weathered yellow tan color with much of the clay leached away - - - - - - -	7.5
E	SAND, quartz, mottled light brown and grayish green, very fine to medium, some coarse, angular to subangular, cemented with iron and clay, thin green laminae of clay, questionably crossbedded, gradational contact with Unit F, but fairly sharp contact with Unit D, weathers irregular, forms a slight bluff - - - - - - - - - - - - - -	2.0
D	CLAY, dark yellow-brown, silty, sandy, waxy, massive, fairly sharp contact with bed below; most of unit covered but to the east it thickens and becomes a dark gray, pale olive color, similar to Unit B -	1.5

Unit	Description	Thickness (Feet)
C	SAND, quartz, mottled yellow-brown, and light gray-green, fine to very coarse, angular to subrounded, contains some pea-size and larger quartz pebbles, clayey, contains blebs of yellow-brown clay and light gray clay granules; contact with the underlying clay Unit B fairly sharp. Unit C upon weathering becomes sufficiently lithified to form a small wall along the side of the roadcut. On the west end of the outcrop, the unit thickens and remains resistant to weathering. This unit contains vertebrate remains - - - - -	2.0
B	CLAY, pale olive, waxy, blocky, has dark brown partings, sandy, very fine to fine, fairly sharp contact with Unit A, unit slopes back along roadcut, a rubble of light gray, very fine-grained sandstone occurs on the surface of this unit - -	4.0
A	SAND, quartz, pale olive to white and yellow-brown, very fine to medium, some coarse, angular to subangular, cemented with silica and clay, very clayey, massive, the outer surface of this unit is case-hardened and forms a thin sandstone layer just on the surface that is very resistant to weathering - - - - - - - - - - - - - - - --- - - -	3.0

The thickness of the "Upper Miocene Clastics" is highly variable because some of the sediments have been removed by erosion since deposition. However, subsurface data indicates that in some parts of Jefferson County the deposits reach a thickness of 120 feet, and this may approach the original total thickness of the "Upper Miocene Clastics." At the fossil locality, LJf dd 1 - 2N - 6E, a core hold penetrated 36 feet of "Upper Miocene Clastics" before entering the older Hawthorn Formation.

STRATIGRAPHIC RELATIONSHIPS

Subsurface data indicates that the "Upper Miocene Clastics" overlie the lower Miocene St. Marks Limestone in some part of Jefferson County. In the southwestern part of the county these clastics are overlain unconformably by Pleistocene sands. The contact between the "Upper Miocene Clastics" and the underlying sediments of Hawthorn age is uncertain because exposures are rare. When exposures of the two deposits are found, weathering has obscured any diagnostic criteria

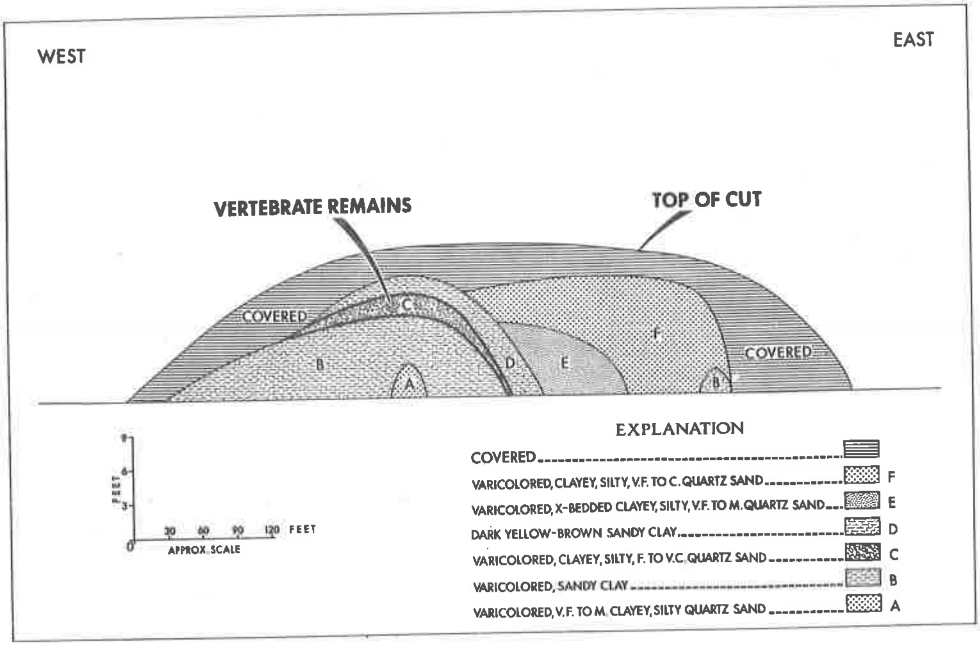

Figure 3. Diagrammatic section of roadcut at locality LJf dd 1 - 2 N - 6E.

for determining the nature of the contact.

The uncertainty of the contact between the Hawthorn Formation and the "Upper Miocene Clastics" may be attributed to the mode of deposition of the two units. Available data seems to indicate that after Hawthorn time, and during the deposition of the "Upper Miocene Clastics," the environment of deposition may have changed from a marine to a near shore or terrestrial environment of a prograding delta without a distinct break in deposition.

The locality containing the vertebrate remains lies about 25 feet above the Hawthorn Formation, and the section probably represents the lower part of the late Miocene in this area.

The stratigraphic relationship of the "Upper Miocene Clastics" to units outside of Jefferson County has not been fully investigated. However, C. W. Hendry (personal communication, May 1964) has mapped similar deposits west of Jefferson County in Leon County, Florida, and reports that the "Upper Miocene Clastics" overlie the upper Miocene Choctawhatchee Formation.

At Alum Bluff in Liberty County, Florida, 45 feet of clastics that overlie the Ecophora zone of the Choctawhatchee Formation were included in the upper Miocene (Puri and Vernon, 1959, p. 139). These sediments are now considered to be equivalent to the "Upper Miocene Clastics" in Jefferson County (Puri and Vernon, 1964, p. 203).

PALEONTOLOGY

Vertebrate Fauna

Olsen (1963) described the vertebrate teeth from locality LJf dd - 1 - 2N - 6E in Jefferson County, Florida, as molars from the horse *Merychippus* sp. and the rhinoceros *Diceratherium* sp. Olsen (1963, p. 312-13) states:

> The Jefferson County horse teeth (some 30 in number) were compared with a large series of Tertiary horses from the western United States. They compared closest to *Merychippus* from beds of pre-Valantine (Low-Pliocene) and post-lower Snake Creek (Upper Miocene.) The Florida material was too fragmentary for all but a generic determination. To place a specific name on these isolated teeth would do little but confuse the already complicated taxonomy of Miocene horses.
>
> The single molar of *Diceratherium* sp. is larger and more advanced than the compared series of this genus from the western Middle Miocene. This would be expected in an animal from a slightly higher horizon.
>
> A new species, *Merychippus gunteri* was described by Simpson (1930) from a fullers earth pit of lower Middle Miocene age at Midway, Florida, some 50 miles to the west of the Jefferson County locality. In the same paper, Simpson also recorded another species, *M. westoni* from the Middle Miocene of Newberry, Florida, 85 miles to the south of the locality under discussion. The *Merychippus* teeth from Jefferson County do not belong to these two species.

SUMMARY

The sediments occurring at the surface in the northern half of Jefferson County are the "Upper Miocene Clastics". Most of the sections observed in the field were roadcuts. The sediments are a heterogeneous type deposit of crossbedded sands, interbedded sands and clays, and lenticular sandy clay beds. Available data indicates the thickness of the unit depends a great deal on the amount of the surface material that has been removed by erosion since deposition. The age of these clastics has long perplexed Florida stratigraphers. A recent discovery of fossil teeth in an outcrop of these sediments in northeastern Jefferson County is of geologic significance because it indicates an age of late Miocene rather than middle Miocene. The teeth are also of significance because they occur in deposits previously thought to be devoid of fossils. Paleontologically, the discovery of the teeth is of great importance because it is the only known late Miocene vertebrate locality in Florida.

Stratigraphically, the "Upper Miocene Clastics" overlie unconformably the lower Miocene St. Marks Limestone and are unconformably overlain by Pleistocene sands. Where the "Upper Miocene Clastics" overlie the Hawthorn Formation the boundary is uncertain. The "Upper Clastics" are believed by the writer to have been deposited as the terrestrial or near shore phase of a large Miocene delta that had its inception during middle Miocene time. Consequently, non-marine deposits merely succeeded the marine sediments of the Hawthorn Formation without a break in deposition.

No separate name has yet been applied to the late Miocene sediments even though they are known to be present outside of Jefferson County and overlie known late Miocene marine deposits.

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