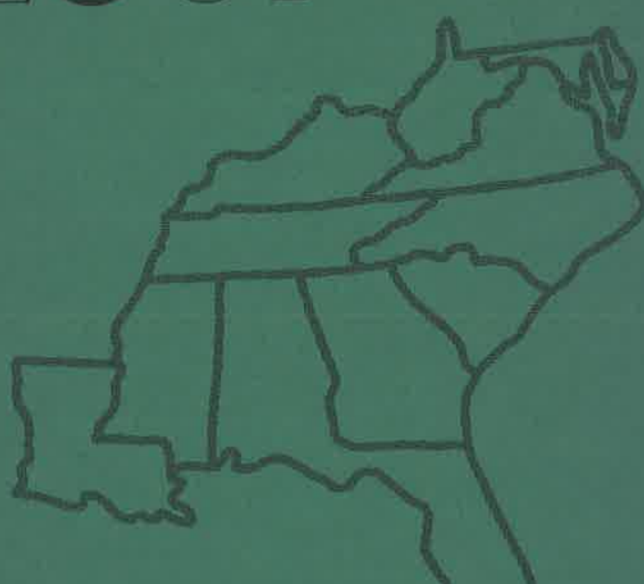
SOUTHEASTERN GEOLOGY



PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL.7 NO.3 JULY, 1966

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

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SOUTHEASTERN GEOLOGY

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Vol. 7, No. 3

1966

TRACE METALS IN QUARTZ BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

by

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ABSTRACT

Quartz from various sources was analyzed by atomic absorption spectrophotometry for Li, Zn, Cu, Ag, Au and Fe. This relatively new method of analysis is simple, rapid, and highly sensitive. Results indicate that the metal content of vein quartz is a good indicator of the total metallic mineralization of the vein.

INTRODUCTION

Very few analyses of apparently pure quartz are available in the literature. Deer and others (1963) indicate that Al and Ge may substitute for Si, Al being accompanied by alkalies to balance the charge. They further state that most trace constituents are thought to be localized in mineral and liquid inclusions (see also Goñi and Guilleman, 1964). A good general discussion of trace elements in quartz is given by Stavrov (1961). He presents new data on Li and references analyses for Na, K, Al, Fe, Mg, Li, B. U, Be, Sn and Mo. Shcherbakov and Perezhogin (1964) report an average of .011 ppm Au in quartz separated from igneous rocks; they point out a covariance between Mg, Au, and Cu.

Atomic absorption spectrophotometry is a newly developed and very sensitive method of analysis that permits rapid analyses for most metals in trace concentrations. Table 1 gives approximate detection limits in aqueous solution for the elements studied. Slavin (1965) discusses geological applications of this method and reports excellent agreement between atomic absorption and fire assays for Au.

Acknowledgments

The authors wish to thank the North Carolina Board of Science and Technology for support of this project through an equipment grant to P. C. Ragland.

Table 1. Approximate detection limits in aqueous solution for the elements studied.

Element	det. limit, ppm.
Li	.005
Cu	.005
Ag	.02
Au	.1
Fe	.05

ANALYTICAL METHOD

Analyses were performed with the Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer. The procedure was that of the manufacturer's instructions and only two aspects of procedure are outstanding enough to warrant discussion:

1. After adjusting the air - acetylene ratio to the value indicated in the instructions a slight increase in sensitivity was achieved by adjusting the acetylene flow to maximize absorption of a dilute (10 mg/l) sample.

2. Impedance or scattering of the light beam by salt particles in the flame is recorded by the instrument as if it were due to absorption by the metal sought. Light scattering was a problem only in analyses for Au and Zn. This error tends to give high results and was corrected by subtracting sample absorption at a nearby non-resonant line from that at the resonant line. An example of light scattering correction for Au is given in Table 2. Billings (1965) discusses light scattering and the method of correction used above.

Table 2. Method of elimination of light scattering error.

Sample No.	%A, 2387Å		%A, 2423Å		%A due to Au
5	1.75	-	0	=	1.75
7	1.3	-	1.4	=	0
12	2.1	-	1.9	=	0.2

Calcium generally yields the greatest light scattering error but has no noticeable effect on the elements analyzed, even at concentrations of several hundred ppm Ca.

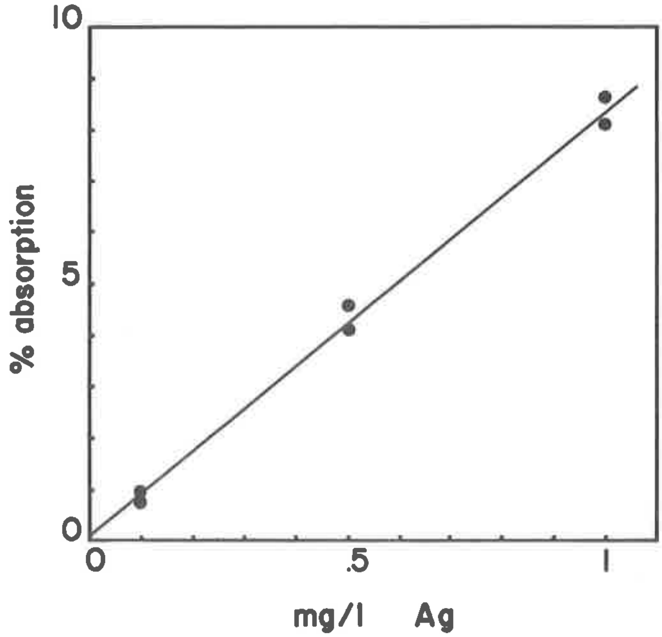

Figure 1. Silver calibration curve.

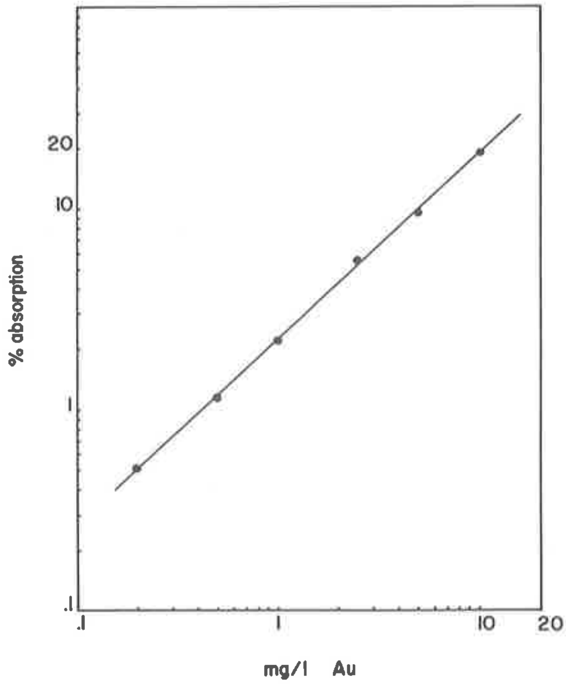

Figure 2. Gold calibration curve.

Sample Descriptions	Mineralogy of vein	Metals produced in area
1. Waxy-white saccaroidal quartz bearing galena and pyrite along fractures. From an inactive silver mine near King's Mt., N. C.	Quartz, galena, pyrite, sphalerite?, barite?	Pb, Ag
2. Apparently barren but fractured and saccharoidal quartz from the Wesley Martin Mine, York Co., S. C.	Quartz, pyrite, pyrrhotite, chalcopyrite, native gold, tellurides?	Au, Cu, Ag
3. Massive white quartz float from Wesley Martin vein 200' SW of the mine shaft	"	"
4. Fairly massive, white, apparently barren quartz from the Ross-Carroll Mine, York Co., S. C.	"	"
5. Ore from Wesley Martin Mine. This sample contained 50% sulfides: Chalcopyrite and pyrrhotite.	"	"
7. Quartz - carbonate - chlorite shear zone material cutting the Wesley Martin vein.	Quartz, calcite, chlorite, magnetite	"
8. Clear glassy quartz, Jackson Co., N. C.	Granitic-pegmatitic terrane	None?
9. Ilmenite - quartz vein, Lexington Co., S. C.	Quartz, ilmenite	None
11. Glassy quartz vein from granite quarry near Salisbury, N. C.	Quartz with minor muscovite and feldspar	No metal production in the immediate area, Au and Ag deposits of Rowan Co. may be related to plutonic rocks in the Salisbury area.
12. Vein from Cranberry Iron Mine, N. C.	Quartz, calcite, pyrite, magnetite	Fe
13. Clear grey glassy quartz from alaskite quarry, Spruce Pine, N. C.	Quartz, feldspar, micas, very minor sulfides, oxides, etc.	None
14. Very thoroughly weathered saccaroidal float, Gold Hill, N. C.	Quartz, pyrite, chalcopyrite native gold, etc.	Au, Cu, Ag

Table 3. Descriptions of Samples and Localities.

Standards were prepared from reagent grade salts. Working curves for Ag and Au are presented as Figures 1 and 2. Many references to analytical work on Cu, Zn and Li can be found in the Atomic Absorption Newsletter (e.g. Slavin, 1965).

PREPARATION OF SAMPLES

Samples were chosen to represent a wide variety of quartz occurrences (Table 3). They were ground to -100 mesh with a uniform particle size grinder and sieved, retaining only the -100-200 mesh fraction. This fraction was washed with water to remove dust and a pure quartz separate was obtained with heavy liquid (bromoform) and magnetic separations. After crushing and separation microscopic checks of purity were made on the samples. All samples were noted to contain varying amounts of fluid and mineral inclusions. Samples 8 and 11 were notably free from inclusions and 7 was notably high. Sample 9 contained occasional inclusions of red and opaque minerals, some as radiating needles (rutile and ilmenite). Samples 3, 4, and 11 were noted to be relatively impure and 3 contained many grains stained by hematite. Sample 12 contained about 1% carbonate.

In rock analysis it is impractical to dissolve more than a gram or so of sample due to the formation of R_2O_3 precipitates and insoluble fluorides, sulfates, etc. Pure quartz, however, is readily soluble in HF in large quantities. In this study from 2 to 15 grams of sample were dissolved in HF and HNO_3, the solution evaporated to dryness and the residue taken up with HCl and HNO_3, and diluted to 50 ml. This procedure allows trace analysis in quartz without chemical concentration procedures such as cation exchange.

DISCUSSION OF RESULTS

Analytical data for all samples are given in Table 4.

Samples 2, 3, 4, 5 and 14 were selected from veins known to contain Au in significant amounts; of these only Sample 5 contained an anomalously high Au value. Sample 7, although from the same mine as 5, did not contain detectable Au or Ag; field relations indicate that it was collected from a later, barren vein.

Sample 14 was collected from a known Au and Cu producing area but was extremely weathered. Weathering may account for the low Cu, Ag and Zn content. Note the positions of Sample 14 on Figures 3 and 4.

Sample 13 contained a significant amount of Au (3.5 ppm) but very little Cu or Zn as compared to the concentration of these metals in quartz from Au producing areas. The Li content of this sample (2.16 ppm) compares favorably with an average of 2.32 ppm reported from pegmatite quartz of the Karelia and Mama Districts, USSR (Stavrov, 1961).

Table 4. Analytical Data (concentration in ppm).

Sample No.	Zn	Cu	Ag	Au	Li	Fe
1	15.9	10.4	9.7	1.7	.24	1420
2	4.9	17.5	0.8	2.0	.17	610
3	7.3	33.1	< 0.8	<1.7	<.08	2020
4	1.5	29.7	< 0.8	<1.7	.14	1010
5	18.0	138.	6.3	12.6	<.08	1180
7	13.8	30.4	1.0	<2.1	.74	2560
8	2.0	7.0	< 1.2	<2.4	.36	180
9	1.4	9.5	< 1.2	3.0	<.12	2620
11	1.6	5.7	2.0	<1.9	.18	230
12	2.0	3.7	1.2	0.7	<.04	840
13	0.6	2.7	.15	3.5	2.16	32
14	2.1	4.1	< .75	3.5	<.08	460

Vincent and Crocket (1960), in a study of some rocks from the Skaergaard complex, reported that in the absence of Cu in the magma the distribution of Au between sulfide and silicate liquids is about even. Samples with copper sulfides, however, indicate a partition coefficient of 2,000 for Au between the Cu sulfide and silicate liquids. The present writers infer that Cu may be a necessary consort if any Au present is to be concentrated into an ore forming fluid.

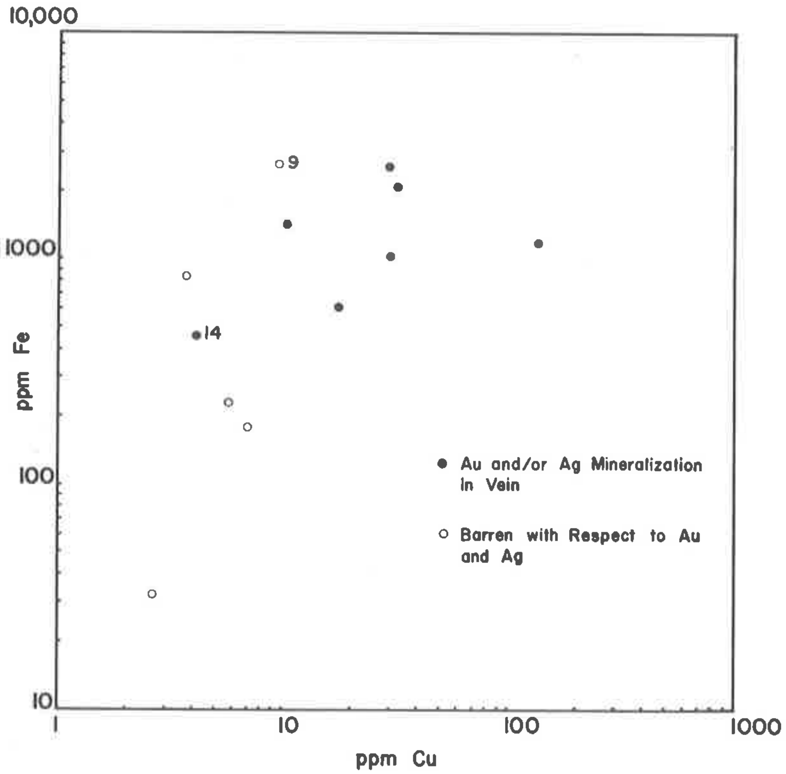

Figure 3. Plot of Fe vs Cu in vein quartz.

CONCLUSIONS

Iron in quartz sampled from a vein reflects the total amount of metallic mineralization in the vein. Copper and Zn in quartz seem to correlate well with the presence of Ag and Au in a vein, although Ag and/or Au may not be detectable in a given quartz sample from the vein. These relations are illustrated graphically in Figures 3 and 4.

From these relationships it is concluded that the metal content of a sample of quartz taken from a vein may be interpreted in such a way that predictions of the presence of metals, themselves forming discrete minerals elsewhere in the vein, might be made with some certainty.

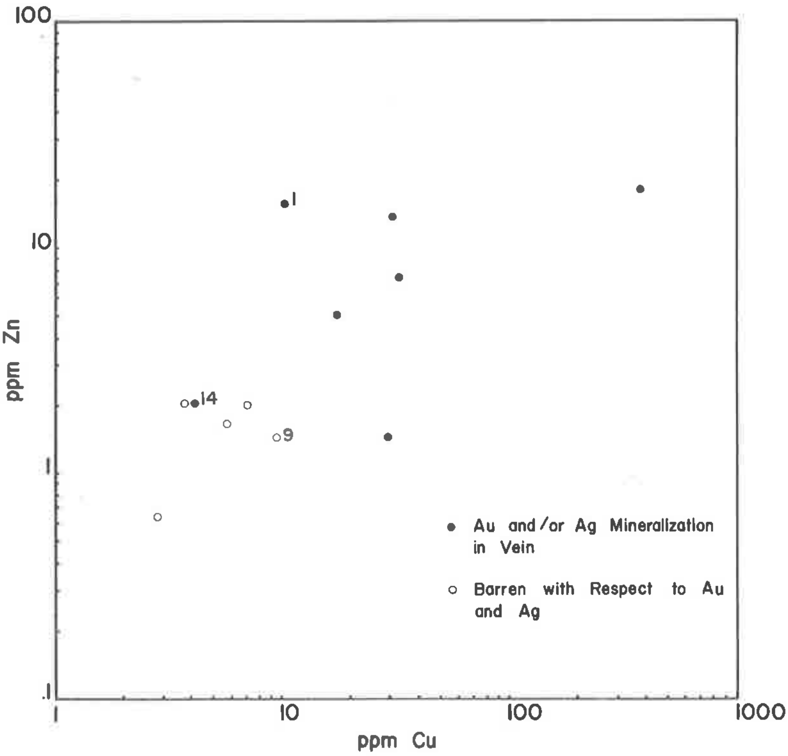

Figure 4. Plot of Zn vs Cu in vein quartz.

Stavrov and Khitrov (1960) and Stavrov (1961) report that Li and B are fixed in quartz from intrusions and associated pegmatites which contain Li and B minerals. The term quartzimetry is coined and it is suggested that this might become valuable as a prospecting tool and in the establishment of genetic connections between veins and intrusives.

The possibility of using quartz analysis as a prospecting tool is strongly suggested by the present work. Much experimentation remains to be done, however, with a number of metals. The correlation of metal content with certain non-metals such as As, Sb, Bi, Se and Te should be investigated.

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GEOMORPHOLOGY OF RIVER VALLEYS IN THE SOUTHEASTERN ATLANTIC COASTAL PLAIN

by

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ABSTRACT

Atlantic Coastal Plain rivers in the Southeastern United States generally do not possess mature valley topography between their valley walls and channels although most of them are observed flowing close to grade. Aerial photograph mosaic, topographic and soil map, oceanographic chart and field surficial and subsurficial examination indicates two cycles are operative which explain this anomaly, and five stages are present.

The continental emerged or emerging cycle is the well-known Davisian fluvial geomorphic cycle. It consists of youthful and mature stages that are recognized on the basis of landforms, lithofacies, soils and, where isolated, paleobiota. The continental submerged or submerging cycle consists of three stages, estuary, marsh and valley head delta. Estuaries form scoured surfaces that modify relict valley walls and channels and through time are infilled by lateral marsh deposition as well as seaward migration of valley head deltas.

The two cycles are independent with respect to Neogene, Pleistocene and Holocene eustatism. Thus relict stages of the merged cycle may lie in juxtaposition to any of the three stages of the submerged cycle. Also, any of the three stages of the submerged cycle may lie within relict stages of previous submerged cycles, and mature stages of the emerged cycle may lie within relict mature stages of previous cycles.

Atlantic Coastal Plain river valleys are bounded by flights of terraces, but the terraces are not separate fluvial terraces, and they are not necessarily indicative of unique base levels individually. They are usually interrelated stage landform sequences of one or several eustatic fluctuations that are not essentially still stands of the sea.

INTRODUCTION

The Atlantic Coastal Plain in the Southeastern United States is characterized in divide areas by flat terraces composed of constructional and destructional landforms of continental and marine origin separated by scarps. The terraces result from sea level fluctuation accompanying marine transgression and regression and concordant erosion and deposition landward and seaward of the migrating shoreline.

Several terraces (Table 1) have been recognized and regionally correlated (Cooke, 1936; MacNeil, 1949; Doering, 1960).

Table 1. Atlantic Coastal Plain Terraces

Maximum Altitude of Terrace Surface in Feet	Name
320	Unnamed
250	Hazelhurst
210	Coharie
180	Sunderland
130	Okefenokee
108	Wicomico (and Penholoway)
40	Talbot (and Pamlico)
17	Princess Anne
8	Silver Bluff

At least the last four result from unique emerged-submerged-emerged cycles and are of Pleistocene age. Terraces above the Wicomico are apparently older from present evidence.

Terraces are expressed not only along divide areas of the Atlantic Coastal Plain but within river valleys as well. It is the purpose of this paper to examine the geomorphic expression of several dominant Recent environments and, generally, outline some of their volumetric, lithic, structural and soil characteristics in order to provide a mechanism for further Coastal Plain mapping.

Acknowledgments

Support of the National Science Foundation through grants GP-1817 and GP-4559 is acknowledged.

RECENT VALLEY TOPOGRAPHY

The Continental Emerged Cycle

Ideally, river valleys show two progressions of landforms proceeding seaward from landward areas in the vicinity of the Atlantic Coast (Figures 1 and 2). Landward rivers are observed to be incised within meandering, relatively straight or irregular courses. Downcutting is dominant since there is no apparent evidence of meander scars, point bar accretion or other features of lateral planation that are related to the Recent slope of the river. No floodplain related to Recent river channels has been constructed, though floodplains or other

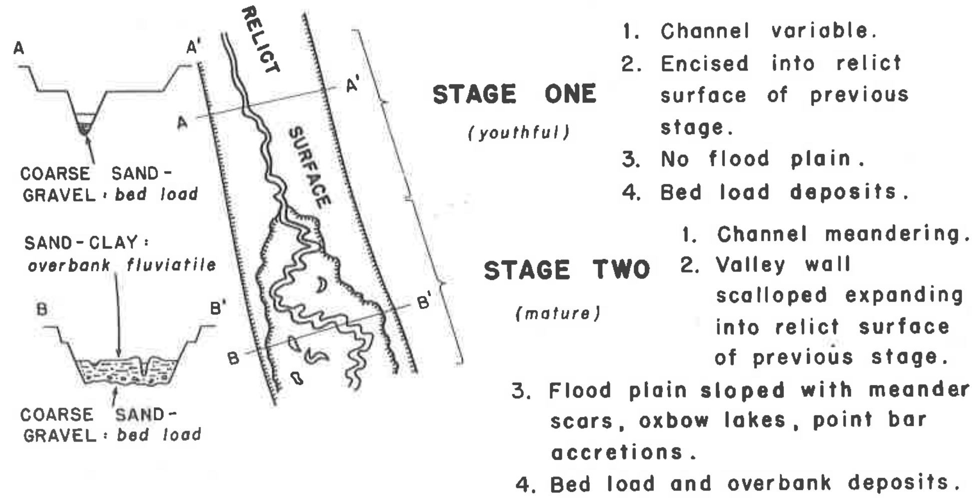

Figure 1. Continental emerged cycle.

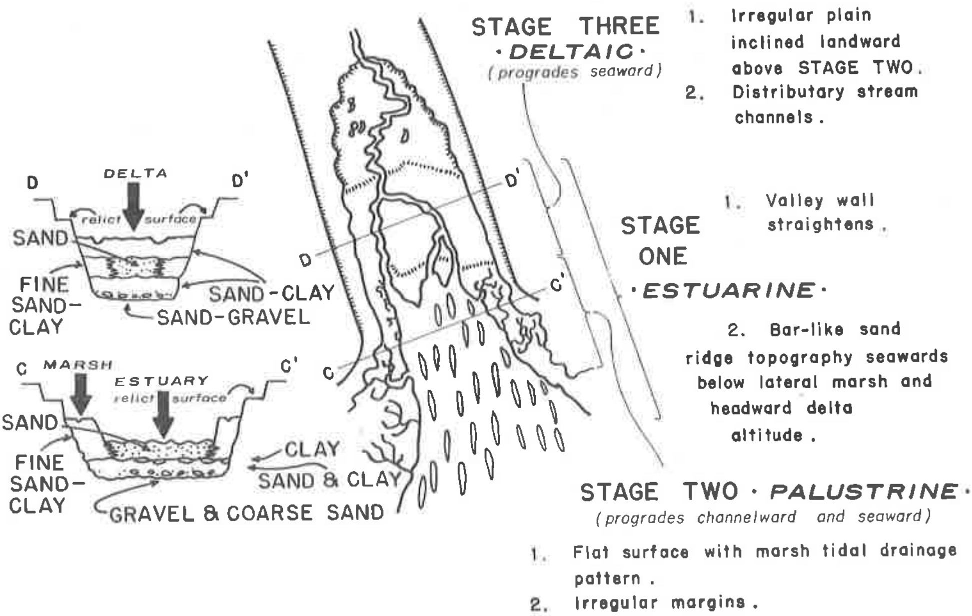

Figure 2. Continental submerged cycle.

terrace surfaces may bound the encised stream laterally. Seaward, the valley walls of the Recent stream retreat laterally from the course of the river and depict a "scalloped-like" planimetric shape reflecting fluvial cutbank erosion. The river meanders. Meander scars, point bar accretions and other features characteristic of lateral planation become common and are related to migration of the present river channel.

Thus, two distinct stages which are related to fluvial scour, can be recognized and mapped. Stage one in which downcutting is dominant, the river channel patterns are variable, no flood plain is present, and the valley walls lie adjacent to the channel; and stage two in which the river channel meanders, a flood plain has been constructed laterally, and the valley walls have retreated from the earlier channel course and depict a scalloped surface characteristic of fluvial cutbank erosion. These stages are those of the Davisian youthful and mature fluvial cycle.

The Continental Submerged Cycle

Adjacent to the present ocean, river valleys show a second progression of landforms both on the flanks of the channels and below the channel surface. These surfaces form from continental submergence resulting from sea level rise with the melting of Wisconsin glaciation and consequent natural processes operative since sea level attained its present elevation range. The submergence of river valleys initiates a series of changes in topography that, given sufficient time, will fill in the drowned valley to allow direct introduction of river sediment into the ocean itself. Three major landform surfaces may be recognized in this sequence today as shown by aerial photography mozaics, topographic maps, coastal charts, and field examination; the estuary sediment-water surface, the bounding marsh surface and the valley head delta. It is recognized that this is an idealized condition. Valleys with large Piedmont draining streams generally lack large estuaries in the Southern Coastal Plain. The sequence development is a function of time, sediment supply, past history and geographic position. Table 2 summarizes a few of the geomorphic characteristics involved in the sequences.

Thus, three stages resulting from submergence can be noted considering Recent Atlantic Coastal Plain rivers: estuary, marsh and delta. Each of these surfaces is usually present to a certain extent in any river valley where it reaches the sea, but the relative development of any of these stages varies. Progression toward stage three is enhanced by Piedmont draining streams of high annual discharge. Abundant development of stage one is favored by Coastal Plain draining streams of low discharge, particularly where maturity has been reached in the previous emerged cycle and a broad floodplain has been produced.

In summary, considering the emerged and submerged cycles, five major surfaces can be noted within river valleys adjacent to the present coast.

Emerged Cycle--	Stage one.	Youth
	Stage two.	Maturity

Stage	Environment and Example	Regional Valley Shape (Relict)	Environment Pattern and Shape	Valley Wall Bounding Environment
One	Estuary Port Royal Sound, Winyah Bay, S. C. ; Altamaha Sound, Ga.	Narrow to broad depending on stage attained in previous cycles at or above present sea level. May possess relict valley wall-flood plain, marsh plain, estuarine plain or deltaic plain between valley wall and Recent channel; or bury divide features of marine successions.	Narrow landward. Broadening toward relict valley walls seaward. Often buries former features seaward. Relatively narrow, shallow, irregular plain land underlain by bedrock. Bar-like plain with sand bars elongated parallel to channel furthest seaward.	Similar to stage attained previously landward. Straightening seaward by estuarine scour if attached by estuary itself.
Two	Marsh St. Helena Sound, S. C.; Ossabaw Sound, Ga.	As above	Broad landward becoming more narrow seaward between estuary channel and relict valley surfaces. Relatively flat to low hummocky plain with irregular tidal channel drainage. Overlies estuary surface as well as former relict land surface.	Reflects previous environment whether estuarine or other stages of previous cycles.
Three	Delta (e. g., Santee and Savannah River valleys adjacent to Atlantic Ocean.)	As above	Irregular plain with several channels. Inclined higher landward. May show meander cut-off features as well as tidal channel drainage. Overlies former land surface, continental emerged stages, estuarine, palustrine and marine stages.	Often as above, but distributary channels may erode valley wall.

Table 2. Geomorphic Characteristics of Recent Valley Environments.

Submerged Cycle--	Stage one.	Estuary
	Stage two.	Marsh and headward delta
	Stage three.	Delta

The two cycles are independent. The continental emerged cycle may operate locally during a low eustatic stand of the sea to produce a mature river valley. Subsequent rise of the ocean may allow any of the submerged stages to be found adjacent to it. Submerged stages of previous cycles may lie in juxtaposition to submerged stages of a more recent cycle. Thus, though river channels on the Coastal Plain may lie close to grade, their valleys are a complex melange of geomorphic stages which may be deciphered through mapping and reveal important data concerning Coastal Plain-Ocean relationships in the Neogene, Pleistocene, and Holocene. It is thus observable that Coastal Plain river valleys contain landforms that are often not associated with mature valley topography.

Lithology, Structure and Soils

Each geomorphic stage is characterized by particular grades of lithology, structure and soils as well as contained biota where preserved. The mineralogy of each particular stage is governed by source, history of transport, diagenesis and subsequent weathering. Piedmont rivers commonly contain feldspathic minerals and kaolinitic clays in their loads, and these are found commonly within their sediments. Coastal Plain rivers may contain similar deposits if they drain terrains containing these products. Or they may contain other sedimentary suites characteristic of the drained sources.

While the mineralogy may vary within particular stages, volumetric shape, sediment size grade characteristics and structures are perhaps more representative and serve to allow environmental interpretation from known biotal assemblages. It has been noted that channels developed on the subcrop within the continental sequence of terrace formations are of two types (Colquhoun, in press). The first type is 'V'-shaped. The second is more broadly 'U'-shaped. It is thought that the first subsurface channel type is the result of fluvial scour and the second, estuarine scour. Generally, both types of subsurface channels are overlain by coarse grained sediments which, laterally, may grade to finer grained fine sand-silts. Investigation within the Santee River system has shown that generally the fluvial bed load sediments are coarser grained, better rounded, and contain larger feldspar particles than the estuarine sediments. Estuarine bar sands are generally fine to coarse grained, highly angular and more massively bedded. Floodplain sediments are characterized by fine-grained sand-silts with some clay. In headward estuarine areas, clay becomes a dominant sediment constituent both within the channels as well as within the associated lateral marshes. The kaolinite group occurs landward while seaward montmorillonitic group minerals occur with kaolin (Heron and others, 1964). Organic constituents are very common in fresh and salt marsh deposits as well.

Summarizing the various environments, the following general characteristics may be used with the knowledge that weathering and biotal activities may destroy all or some of the diagnostic features (Table 3).

Table 3. Some Volumetric, Lithologic, and Structural Characteristics of Environments.

Environment	Surface Shape	Subsurface Shape	Lithology	Structures
Bedload	Irregular	In V-shaped channels	Quartz, Feldspar, Lithic pebbles-sands. Pebbles rounded.	Scour and fill cross-bedding common.
Overbank	Irregular mature valley floodplain.	Lateral and above bedload	Fine-sand-silt and some clay. Micaceous.	Laminations commonly.
Estuarine	Bar-like plain with ridges parallel to long axis of estuary seaward.	U-shaped landward or rounded, ridged, scoured surface seaward.	Clays and sands landward, coarse sands seaward.	Many
Palustrine (Marsh)	Flat to slightly hummocky plain lateral to estuary. Usually fills depressions between bar-ridges.	Variable	Organic clay-fine-sand	Laminations rare
Deltaic	Irregular plain inclined up toward land. Often cuspate when valley is filled and delta encroaches seaward.	Variable	Fine sediments landward and surficially coarser seaward below sea level	Many

Much of the Atlantic Coastal Plain has been mapped by soil scientists in the past. Though the nature of the classification involves slopes, the texture of the surface sediments, the composition and texture of the subsoil, and the relative drainage of the soil itself, some of which have not been considered to be of major lithologic or stratigraphic importance by many geologists, nevertheless, in general, the soil mapping methods can be related to geological investigation with satisfying results. Similar landforms are found to be underlain by similar soils and lithologies in the surficial Coastal Plain sequences. Thus, where environments are known through isolation of biotic assemblages, extension of these environments can be accomplished through the aid of soil maps. Table 4 summarizes a few of the major landform groups, their interpreted environment and some of the more common soil groups that underlie them. It has been compiled from examination of soil maps of Horry, Georgetown, Berkeley, Charleston, Williamsburg and Orangeburg Counties from areas within which subsurface drill hole information has been obtained close enough for inference.

Table 4. Some Common Soil Types Developed on Known Geomorphic Environmental Surfaces

Environmental Geomorphic Surfaces	Soil Types
Continental Emerged	Norfolk Coarse Sand, Norfolk Sandy Loam
Continental Submerged	
Estuary	
1. Sand ridges	1. Norfolk Sand, Lakeland Sand.
2. Trough-filled surfaces	2. Coxville Very Fine Sandy Loam, Fine Sandy Loam and Loam. Portsmouth Loam, Dunbar Fine Sandy Loam.
Marsh	Coxville Very Fine Sandy Loam, Dunbar Very Fine Sandy Loam, Portsmouth Loam, Bladen Clay, Georgetown Clay.
Delta	Norfolk Sandy Loam, Fine Sandy Loam, Coxville Sandy Loam, Congaree Clay, Georgetown Clay, Dunbar Loam.

In summary, Recent valley environments produce characteristic geomorphic surfaces that can be studied through the use of aerial photograph mozaics, topographic maps and coastal charts. Similar geomorphic surfaces are underlain by generally similar soils, lithologies, structures, and where fossils are not leached, similar biotic constituents. Specific geomorphic sequences can be noted within Recent river valleys adjacent to the Atlantic Ocean. Similar sequences can be noted at higher elevations within Coastal Plain river valleys. Assuming that the present environments and their geomorphic aspect remain generally constant through time, then past environments can be reconstructed wherever generally similar sequential geomorphic surfaces are expressed and reaffirmed through lithic and paleobiotic examination. Mapping of these features allows reconstruction of past sea level relationships with respect to the continent, providing tectonic warping is neglibible.

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PARAGONITE-BEARING PHYLLITES IN THE CENTRAL VIRGINIA PIEDMONT

by

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ABSTRACT

About 15,000 feet of phyllite, argillite, and slightly metamorphosed subgraywacke and graywacke, with minor amounts of metamorphosed mafic igneous rock (greenstone) and quartzite, were mapped between volcanic rocks of the Catoctin Formation (Late Precambrian) and the base of an Ordovician (?) volcanic unit ("Peters Creek Formation") in eastern Albemarle and western Fluvanna Counties, Virginia. X-ray diffraction analyses and thin section studies permitted recognition of a stratigraphic unit composed of interbedded muscovite-paragonite, muscovite-quartz-paragonite, and muscovite-chlorite-paragonite-quartz phyllites within the metasedimentary sequence. The paragonite-bearing unit is believed to correspond to the Candler Formation of earlier workers.

Comparison of chemical analyses of paragonite-bearing phyllites with chemical analyses of weathered volcanic ash and pumices indicates that paragonite-bearing phyllites may have been produced by metamorphism of very fine-grained sedimentary material derived from a deeply weathered volcanic terrain.

INTRODUCTION

Graywacke, subgraywacke, siltstone, argillite, phyllite, and volcanic rock that have been folded, subjected to low grade metamorphism, and intruded by Triassic diabase dikes underlie the Piedmont Plateau in eastern Albemarle and western Fluvanna Counties, Virginia. The Blue Ridge anticlinorium, which bounds the area on the west, has a core of Precambrian granitic and gneissic rocks of the Virginia Blue Ridge complex (Brown, 1958; Nelson, 1962), and is the basement upon which the volcanic-sedimentary sequence was deposited. In general, stratigraphically younger units are encountered from eastern Albemarle County eastward into Fluvanna County (Figure 1). The basal deposit of the volcanic-sedimentary sequence, the Late Precambrian Lynchburg Formation, is overlain by metamorphosed basalt and sedimentary rocks of the Catoctin Formation. Paragonite-bearing phyllites lie within the metamorphosed rock sequence above the Catoctin and below an Ordovician(?) volcanic unit. The Ordovician(?) volcanic unit is overlain by the Arvonia Formation (Upper Ordovician) in easternmost Fluvanna County. The stratigraphy and petrography of these rocks has been described in more detail (Smith, Milici, and Greenberg, 1964).

The paragonite-bearing phyllites are approximately equivalent to those that Nelson (1962) correlated with the Loudoun Formation, and Brown (1958, p. 41) correlated with the Candler Formation in eastern Albemarle County. Detailed descriptions of the Candler Formation have been published by Espenshade (1954), Brown (1958), and Redden (1963).

The purpose of this paper is to suggest a possible origin for paragonite-bearing phyllites of unusual chemical composition in the central Virginia Piedmont.

Acknowledgments

John C. Reed, Jr. and E-An Zen of the U. S. Geological Survey, R. S. Mitchell and Ernest H. Ern of the University of Virginia and James W. Smith, University of Tennessee, reviewed earlier versions of the manuscript.

Field and laboratory studies were pursued while the writers were employed by the Virginia Division of Mineral Resources and most of the basic data were published in Bulletin 79 (Smith, Milici, and Greenberg, 1964). This paper presents a hypothesis for the origin of paragonite-bearing strata derived from ideas that were generated in communications with several of the individuals acknowledged above after the writers had left the Division.

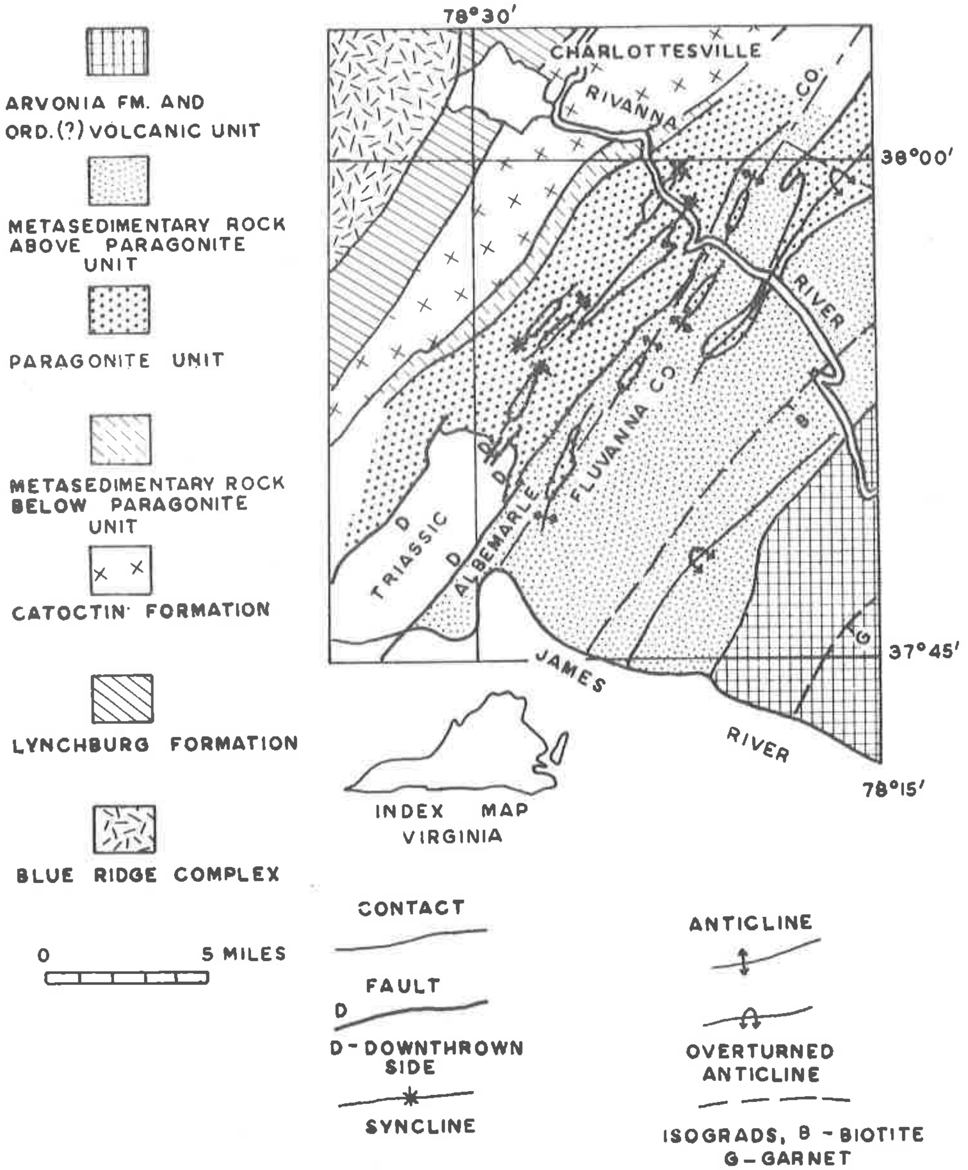

Figure 1. Generalized geologic map of eastern Albemarle and western Fluvanna Counties, Virginia, modified from Nelson (1962), Geologic Map of Virginia (Virginia Division of Mineral Resources, 1963), and Smith, Milici, and Greenberg (1964). Area of this study is between the Catoctin Formation and the upper volcanic unit and the Arvonia Formation. The Everona Limestone occurs at the contact of the paragonite unit and overlying metasedimentary rocks in eastern Albemarle County (not shown). The Rivanna River anticline is in the northeastern corner, and the Hardware anticline is in the south-central portion of the map.

STRATIGRAPHY OF THE PARAGONITE UNIT

Geologic mapping of metasedimentary rocks in eastern Albemarle and western Fluvanna Counties is difficult because of the similar appearance of rocks containing different phyllosilicate minerals (chlorite, muscovite and paragonite), the effects of deep chemical weathering, intense folding, and rock cleavage in some areas. In the early stages of our geologic mapping, X-ray diffraction analyses showed that rocks of similar appearance contained different combinations of chlorite, muscovite, and paragonite. It was then decided to select as map units the rocks that contained similar assemblages of phyllosilicate minerals and, as the study progressed it became apparent that the map units were, for the most part, stratigraphic units (Smith, Milici, and Greenberg, 1964).

The paragonite unit, composed of 1500 to 2000 feet of very fine- to fine-grained phyllite and argillite, is extensively exposed in eastern Albemarle County and in the core of the northwestwardly overturned Rivanna River anticline in western Fluvanna County. About 2000 feet of chlorite and muscovite-bearing subgraywacke, quartzite, argillite, and phyllite lie between the paragonite unit and greenstones (metamorphic fine-grained mafic igneous rocks of the Catoctin Formation. In eastern Albemarle County the Everona Limestone locally overlies the paragonite unit in synclinal structures, but the limestone is not a readily mappable unit in this area. The Everona is composed of fine-grained, banded, sandy, or siliceous metamorphosed limestone (Nelson, 1962, p. 31). It is locally as much as 200 feet thick but generally is thinner. In places limestone is absent and carbonate-rich argillites were observed at or near the same stratigraphic horizon.

Ten thousand to 12,000 feet of metamorphosed graywacke, subgraywacke, argillite, phyllite, and relatively small amounts of interbedded greenstones overlie the paragonite unit. These rocks are in turn overlain by the Ordovician(?) volcanic unit. Subdivisions of these strata and details of their composition have been described previously (Smith, Milici, and Greenberg, 1964).

All of the rocks in eastern Albemarle and western Fluvanna Counties belong to the greenschist facies of Fyfe, Turner, and Verhoogan (1958). Textural changes such as increase in grain size, reorientation of phyllosilicate minerals, and the development of metamorphic minerals indicate that the grade of regional metamorphism increases eastward toward the eastern portion of Fluvanna County where rocks of the almandine-amphibolite facies occur (Smith, Milici, and Greenberg, 1964).

The mineral assemblages observed in the paragonite unit are: muscovite-paragonite, muscovite-quartz-paragonite, and muscovite-chlorite-paragonite-quartz. Iron oxides and potassic feldspar(?)

may or may not be present in a given sample. The paragonite-bearing rocks of this area are all located to the west of the biotite isograd (Figure 1). Paragonite, however, is associated with higher rank metamorphic minerals in the Altavista area to the south (Redden, 1963), and generally it is in the biotite, garnet, and kyanite zones where observed elsewhere (Zen and Albee, 1964, p. 920-921). The position of the biotite isograd may reflect different rock compositions rather than indicate metamorphic grade in this area, and rocks to the west, including the paragonite unit, may also be within the biotite zone.

ORIGIN OF THE PARAGONITE-BEARING ROCKS

Paragonite-bearing phyllites, approximately equivalent to those recognized in the Albemarle-Fluvanna County area, are widespread in the central Virginia Piedmont and they have been identified in the Candler Formation at least as far south as Altavista (Redden, 1963). The Candler Formation has been recognized in reconnaissance from Orange County, north of Fluvanna County, to the Virginia-North Carolina state line (Brown, 1958, p. 31).

In Albemarle and Fluvanna Counties, where it is less metamorphosed than are correlative rocks to the south, the paragonite unit is composed of light-to medium-gray, steel gray or greenish-gray, rarely white or light tan, phyllite and argillite that has a lusterous sheen. In thin section phyllosilicate layers alternate with layers (up to 0.1 mm) that contain interlocked fine quartz and/or albite grains (grains about 0.02 mm across). Quartz content ranges from less than five percent in chlorite-deficient phyllite to about 40 percent in chlorite-bearing phyllite and argillite. Discrete elongate rounded quartz grains are commonly embedded in a phyllosilicate matrix in the chlorite-bearing rocks, but they were not observed in rocks that contained only muscovite and paragonite. In phyllites the mica crystals are uniform in size and are well aligned. Hematite and magnetite occur as grains (about 0.01 mm) that roughly parallel the alignment of the mica (Smith, Milica, and Greenberg, 1964, p. 7-9). The Candler Formation is predominantly very fine or fine-grained phyllite, argillite, or phyllitic schist where mapped elsewhere in Virginia, although it may have a mineral composition indicative of higher metamorphic grade.

Rocks with compositions similar to those of the paragonite-bearing rocks of this study have been reported in Vermont (Rosenfeld, 1956, Zen, 1960), and in the Blue Ridge and Piedmont in Virginia (Reed, 1955), Tennessee and North Carolina (Hadley and Goldsmith, 1963), and Georgia (Hopkins, 1914, p. 305). Paragonite was reported as a constituent of phyllites and schists in the Appalachians by all of the above workers except Reed and Hopkins. In addition paragonite was reported by Dietrich (1956), from Campbell and Franklin Counties,

Table 1. Comparison of chemical analyses of paragonite-bearing phyllite with analyses of weathered volcanic ash and pumices (Smith, Milici, and Greenberg, 1964; Appendix 1; Greenberg, 1964; Aomine and Wada, 1962).

	Paragonite Unit				Weathered volcanic ash and pumices (% oven dry basis) (from Aomine and Wada, 1962, Table 5)			
Number	1	2	3	4	5	6	7	8
Sample* Number	R-2198	R-2162	R-2163	R-2202	Allophanic ash	Halloysitic ash	Allophanic pumice	Halloysitic pumice
SiO_2	45.0	42.0	61.6	55.5	49.99	43.14	51.80	45.70
Al_2O_3	31.3	29.7	18.9	24.1	20.62	26.03	22.91	28.20
Fe_2O_3	10.4	13.6	7.57	3.51	8.75	10.99	5.89	6.93
FeO	0.53	1.20	2.13	4.27				
TiO_2	0.82	1.27	0.84	0.65	1.31	1.44	1.13	1.43
CaO	0.05	N.D.	0.05	0.08	4.68	2.13	3.42	2.70
MgO	0.39	0.67	1.10	1.33	2.88	2.63	0.98	0.89
Na_2O	2.01	2.40	1.14	1.29	2.80	1.08	2.90	1.71
K_2O	3.93	3.88	2.58	3.80	1.45	0.78	1.79	0.75
MnO					0.10	0.11	0.09	0.13
P_2O_5					0.41	0.27	0.23	0.17
CO_2	N.D.	N.D.	N.D.	0.13				
H_2O	4.44	4.58	3.12	4.76	6.99	11.35	8.78	10.35
H_2O -	0.45	0.46	0.25	0.34				
Total	99.32	99.76	99.28	99.76	99.98	99.95	99.92	98.96

*Virginia Division of Mineral Resources Repository Number.

No. 1 - Slightly weathered purple-gray phyllite, homogeneous aphanitic texture. Microscopically, muscovite and paragonite are very fine (less than 0.03 mm), the iron oxide grains are subhedral and quartz and feldspar(?) are found as isolated, fine (less than 0.05 mm), grains. From south side of State Highway 20, 0.95 mile southwest of Rose Hill Church; Albemarle County. Modal analysis (percent): Muscovite-45, paragonite-25, quartz-5, iron oxides-10, potassic feldspar(?)-10, kaolinite-5.

No. 2 - Blue-gray phyllite, a few veins of secondary quartz, some patches of brown iron oxides. Microscopically similar to No. 1. From north side of road, 1.1 miles west of Union Mills, and 0.2 mile west of intersection of road and Oliver Creek; Fluvanna County. Modal analysis (percent): Muscovite-45, paragonite-30, quartz-5, iron oxides-15, potassic feldspar(?)-5.

No. 3 - Blue-gray phyllite, some secondary quartz veins. Microscopically similar to No. 1 except that fine chlorite is intermixed with the muscovite and paragonite. From east bank of Mechum Creek, 1 mile east of Union Church and 0.53 north of intersection of Oliver and Mechum creeks; Fluvanna County. Modal analysis (percent): Muscovite-25, paragonite-15, chlorite-15, quartz-35, iron oxides-5, potassic feldspar(?)-5.

No. 4 - Dark-gray phyllite, almost a slate. Microscopically quartz and feldspar(?) are found as isolated fine grains (less than 0.05 mm) in a matrix of very fine phyllosilicates. From northeast side of State Road 795, 1.4 miles northeast of Blenheim; Albemarle County. Modal analysis (percent): Muscovite-30, paragonite-10, chlorite-30, quartz-20, potassic feldspar(?)-10.

Virginia; by Cook and Rich (1962) from localities near Lynchburg and Orange, Virginia; by Espenshade and Potter (1960) from Buckingham

County, Virginia, Person County, North Carolina, and Abbeville County, South Carolina; by Hurst (1957) from the Mineral Bluff quadrangle, Georgia; by Hatchell (1964) from the Irmo N. E. quadrangle, South Carolina; and by Reed and Bryant (1964) from the Brevard zone, North Carolina.

Of numerous chemical analyses reviewed by the writers, those most similar to analyses of muscovite-paragonite phyllite are of weathered volcanic ash and pumice from the slope of Mt. Aso, Japan, (Aomine and Wada, 1962, Table 5, reproduced here in part in Table 1). The determination of hypersthene, augite and andesine-labradorite as primary minerals in the weathered volcanic materials attests to the mafic character of the original ash and pumice (Aomine and Wada, 1962, Table 2).

By analogy the paragonite-bearing phyllites of this report may in part have had a similar history and may have been produced by metamorphism of very fine-grained sediments derived from residuum on a deeply weathered Late Precambrian volcanic terrain. Reed (1955, p. 893) suggested that volcanic slate overlying the uppermost Precambrian Catoctin Formation near Luray, Virginia "is a metamorphosed saprolite developed at the top of the Catoctin formation prior to the deposition of overlying sediments." Differences in the chemical analyses between the paragonite unit and weathered volcanic ash and pumices may, in part, be a reflection of the transportation, deposition, lithification, and metamorphism of the former. If the sediments that constitute the paragonite unit were derived from residuum formed during the Precambrian-Cambrian time interval, then the paragonite unit represents the basal deposit of the Cambrian Period in this area.

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THE MIDWAY-WILCOX BOUNDARY IN KEMPER AND LAUDERDALE COUNTIES, MISSISSIPPI

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ABSTRACT

Subsurface information in Kemper and Lauderdale Counties, Mississippi, confirms the presence of a persistent lignite layer at the base of coarse sands of the Wilcox Group that overlie fine micaceous sands of the Midway. The fine micaceous sands have been referred to as the Kemper Member of the Naheola Formation. The Kemper Member thins to the north, and in northern Kemper County the Wilcox coarse sand rests directly on the Porters Creek Formation without any intervening lignite or Naheola Formation. The northern limit of the lignite represents an early Wilcox shore line that is marked by fluviatile Wilcox gravels occupying channels in the Porters Creek clay. The lignite is interpreted as the actual line of sea level retreat with the lignite being a swamp deposit laid down behind the retreating shore line.

INTRODUCTION

Roux (1958) has presented a doctoral thesis that gives a comprehensive description of the stratigraphy of the upper Midway and lower Wilcox Groups in Mississippi and Alabama based on surface data. He pointed out that coarse sands of the Wilcox Group unconformably

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overlie the Porters Creek Formation of the Midway Group in Noxubee County, directly north of Kemper County, whereas in Sumter County, Alabama, southeast of Lauderdale County, similar coarse sands are separated from the Porters Creek by the Naheola Formation of the upper Midway. The Naheola consists of about 100 feet of fine sand and clay with a basal glauconitic clay and was subdivided by Roux into an upper sandy Kemper Member, largely restricted in occurrence to Kemper and Lauderdale Counties, a middle more clayey Oakhill Member that increase in thickness to the southeast, and the basal Matthews Landing Member. Roux further pointed out that the basal unit of the Wilcox Group, the Coal Bluff Member, is lithologically the most consistent unit in the upper part of the Midway and lower part of the Wilcox, and remains a coarse sand over most of the area of his study. A lignite at the base of the Coal Bluff Member was considered as part of the Naheola Formation by Roux.

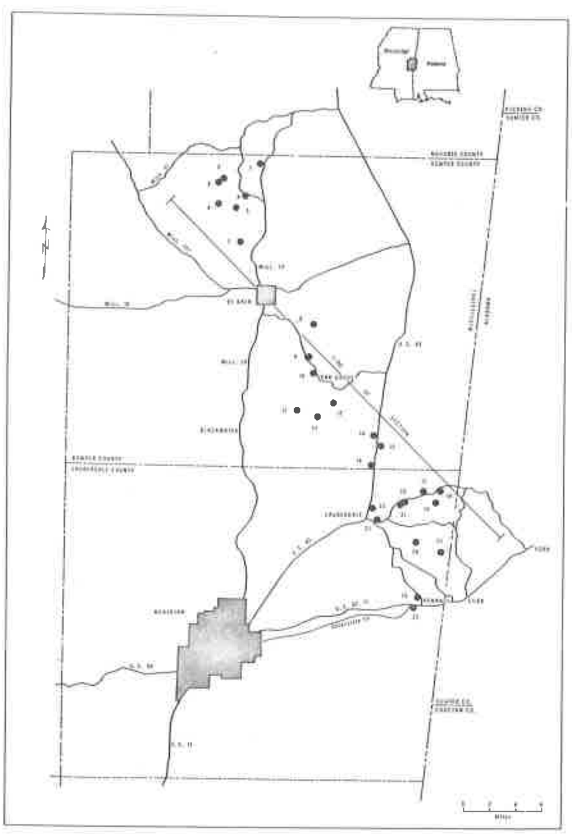

Figure 1. Kemper and Lauderdale Counties, showing locations of holes drilled and line of cross section.

During a program of examination of coastal plain sediments for heavy mineral deposits, attention was drawn to Kemper County, Mississippi, through the shore-line environment interpreted by Roux (1958) and through a Bureau of Mines report on titanium resources of that County (Hahn, 1961). Subsequent reconnaissance drilling during 1963, in Kemper and Lauderdale Counties provided an opportunity to supplement Roux's surface work and this paper briefly describes the results of that drilling program.

The location of the area drilled, and distribution of drill holes, is given in Figure 1.

STRATIGRAPHY

The principal geological formations encountered in vertical sequence in the area drilled are given in Table 1 and described below. The vertical distribution of these formations is shown in Figure 2, a strike section compiled from drilling and outcrops using the lignite at the base of the coarse sand as a datum line. Individual drill hole sections are transposed onto the line of section by making the necessary vertical adjustments for regional dip and minor faulting.

Terrace

A coarse red or tan sand is found along the valley sides of major streams draining the area. In outcrop it is distinguished from the coarse sand member at the base of the Wilcox Group by the presence of waterworn ironstone pebbles. It was observed overlying Porters Creek clay (east side of Pawticfaw Creek Sec. 16, T 10 N, R 18 E), overlying the fine micaceous sand of the Kemper Member (location hole 10), and overlying the cyclic sequence of the Wilcox Group (quarry on north side of paved highway 0.2 miles east of Lauderdale).

Wilcox Group

Cyclic Sequence. This sequence forms a series of medium fine-grained micaceous to non-micaceous sand with interbedded sands and lignites, each cycle ranging in thickness from 15-30 feet. The cyclic sequence consists of (1) lignite overlain by (2) flat-bedded gray sand with gray clay lamellae overlain by (3) cross-bedded sand that contains clay balls and clay fragments along the bedding planes and is cut by worm tubes descending from (4) the overlying clay horizon, which underlies the lignite. The cross-bedded portion of the sand contains abundant heavy minerals. This sequence was cut by drill holes in the Kewanee area, east of Lauderdale and south of Cullum. Excellent exposures are found in the large borrow pit south of the railroad tracks

Table 1. Stratigraphic Section

	Observed Thickness Range (Feet)
Terrace; sands with ironstone pebbles	up to 15
Wilcox Group:	
Cyclic sequence of sands, clays and lignites	up to 140
Coarse sand (? Coal Bluff Member)	20-100
Lignite	0-25
Midway Group-Naheola Formation:	
Kemper Member; fine micaceous sand and clayey sand	up to 70
Oakhill Member; lignitic sands and clays with intermittent basal micaceous sands	up to 60
Matthews Landing Member; glauconitic clay	not measured
Midway Group-Porters Creek Formation: Clay	not measured

at Kewanee, on Highway 45 southeast of Lauderdale and on State Highway 39 north of Blackwater. The full thickness of the cyclic sequence was not ascertained. The sequence is overlain by a thick clay.

Coarse Sand. The coarse sand unit at the base of the Wilcox Group is generally massive, with only crude banding and occasional cross-bedding. It thins to the southeast from over 100 feet north of De Kalb to 20 feet in the Kewanee area. The unit may be the same as that referred to the Coal Bluff by Roux (1958) further south.

The contact between the coarse sand and overlying cyclic sequence was cut in two holes and in each hole is marked by a thin lignitic clay.

The base of the coarse sand unit is distinctive and was used as the principal correlation horizon. In many areas the contact between coarse sand and the underlying fine micaceous sand of the Kemper Member is marked by lignite. Excellent exposures of this lignite can be seen east of Lauderdale (locations of holes 17, 20), on Highway 45

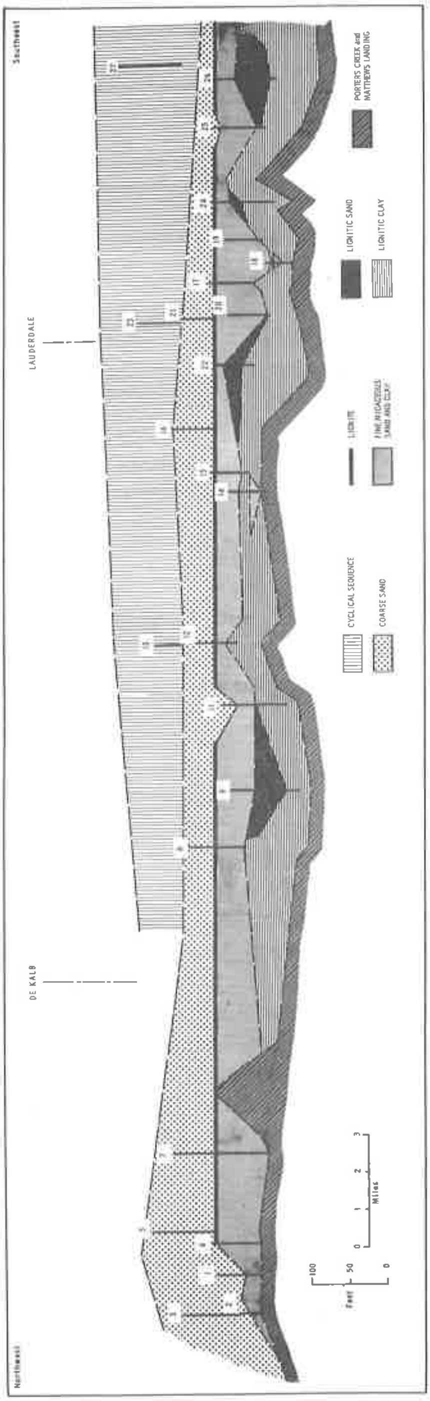

Figure 2. Generalized strike section.

north of Lauderdale and on State Highway 39 north of De Kalb. Where the lignite is absent its location may be indicated by black lignitic clay or white underclay. In several areas, particularly north of De Kalb, the lignite has been removed by erosion and coarse sand fills channels cut into the top of the underlying fine sand. A fine exposure of one such channel can be seen one mile northwest of Cuba near the Alabama-Mississippi line. The contact between the coarse sand and fine, micaceous sand is marked by a clay ball conglomerate at the location of drill hole 19 east of Lauderdale.

Drilling and outcrops north of De Kalb established the northwesterly limit of the lignite at the base of the coarse sand (Figure 3). North of this limit the coarse sand rests directly on the Porters Creek Formation which has been eroded several tens of feet below its normal level. The contact is exposed on State Highway 21 (Section 20, T 13 N, R 16 E). One drill hope penetrated a deep channel filled with coarse sand and gravel (Figure 3).

Midway Group - Naheola Formation

Kemper Member. This unit reaches maximum thickness in three areas; north of De Kalb, in the Cullum-Oak Grove area, and east of Lauderdale. North of De Kalb, a small basin-shaped area of fine micaceous sand is outlined in Figure 3.

The lower part of the fine micaceous sand is horizontally bedded with individual beds less than one-half inch thick. The upper few feet of the formation is crossbedded at

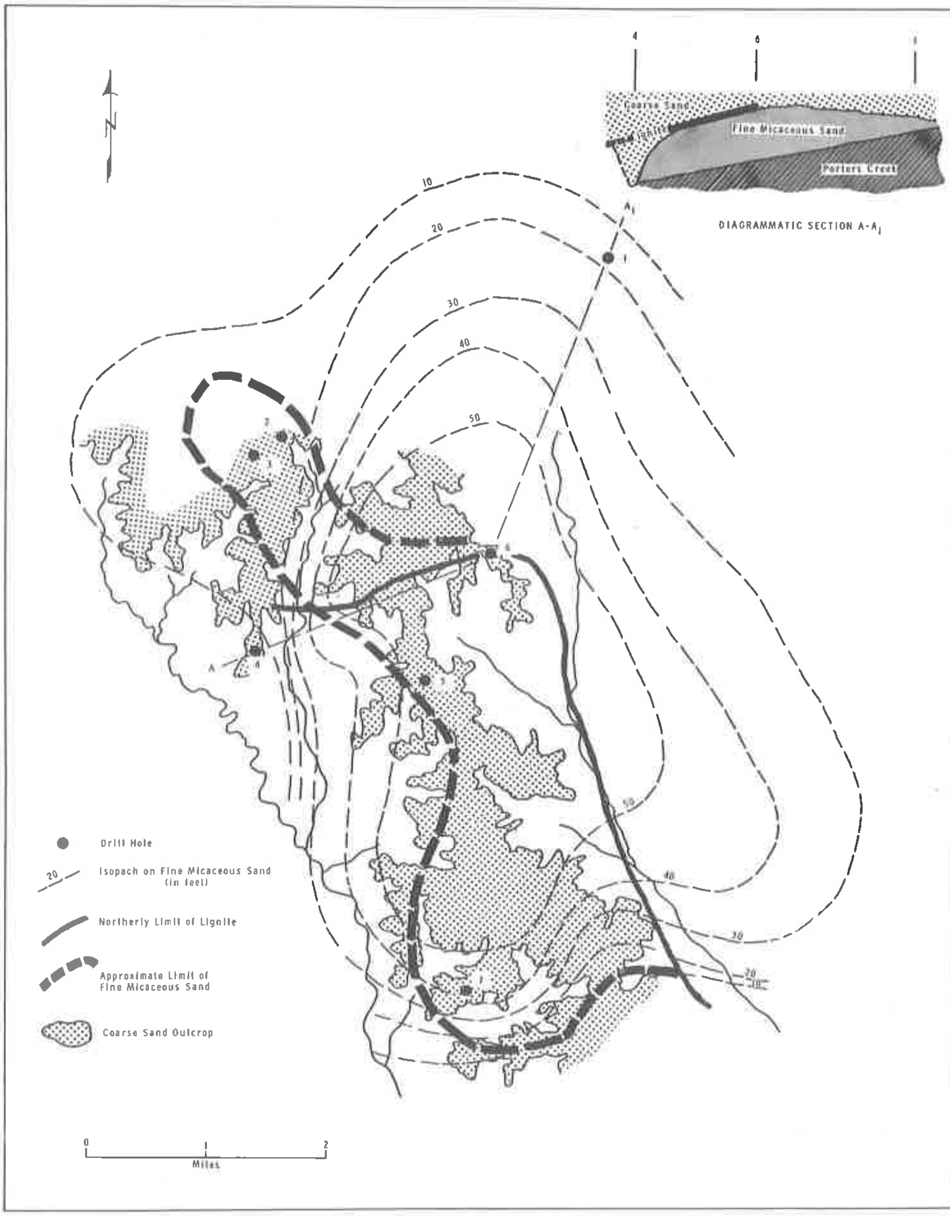

Figure 3. North De Kalb area showing outcrop of coarse sand, limit of lignite, and extent of fine micaceous sand.

most localities.

To the north of Kemper County the fine micaceous sand is cut out by the overlying coarse sand. Toward the southeast the formation becomes more clayey. For example, at the location of hole 6 north of De Kalb, the base of the formation consists of six feet of mixed gray and tan clay, while east of Lauderdale (hole 25), the basal portion includes 24 feet which is largely clay. In southeast Lauderdale County the top of the formation contains numerous laminated gray clay beds, whereas north of De Kalb the upper part of the formation is sandy.

Table 2. Analyses of heavy minerals from fine micaceous sand north of De Kalb (Hole 6)

Mineral	Percent in fraction SG > 2.96
Ilmenite	53.0
Leucoxene	8.2
Rutile	7.4
Zircon	14.1
Staurolite	5.0
Tourmaline	1.6
Kyanite-Sillimanite	9.8
Monazite	Tr
Sphene	Tr
Spinel	Tr
Hornblende	Tr
Epidote	Tr

The upper contact with the lignite or coarse sand is sharp. The lower contact appears to be transitional with underlying lignitic clays and sands except in the De Kalb area where it overlies the Matthews Landing Member and Porters Creek Formation. This lower contact north of De Kalb can be seen along Highway 39.

The fine micaceous sand contains the greatest concentration of heavy minerals in the area. Heavy minerals are particularly concentrated in the upper few feet of the formation. Furthermore, the fine micaceous sand north of De Kalb contains a greater concentration of heavy minerals than the formation further south. Heavy mineral analyses from different parts of the area show little variation in heavy mineral suite. A typical analysis of the heavy mineral suite is given in Table 2.

Oakhill Member. This unit is absent in the area north of De Kalb. In the remaining areas all the holes drilled through the fine micaceous sand formation bottomed in either lignitic sand or clay. Several holes were drilled tens of feet into this formation, both in search of underlying heavy mineral-bearing sands and to determine stratigraphic location with respect to the basal Matthews Landing Member and Porters Creek Formation. In general, the lignitic sands occur in lenses resting on lignitic clays. The sands are medium- to fine-grained, white, and commonly micaceous. They contain numerous fragments of black lignite, a few heavy minerals, and particles of marcasite, some of which may be pseudomorphous after lignite. Interbedded massive lignites are common. The lignitic clays are blue-black in color, plastic, contain numerous black lignite particles and marcasite crystals and nodules, and have interbedded fine sands. The lignitic sequence is exposed for several miles in road cuts east of hole 20 (Figure 1).

Interbedded fine gray micaceous sand and gray clay occurs as lenses in the lignitic clay and between the clay and underlying Matthews Landing Member and Porters Creek Formation. Typical sands of this nature are exposed on Highway 45 north of Lauderdale and east of the location of hole 18. The lenses range up to 15 feet in thickness.

Matthews Landing Member. Diagnostic clays form the base of the investigated succession. The Matthews Landing Member was identified in drill hole by its glauconitic character. Information is too limited to allow comment on the distribution and thickness of the Matthews Landing Member; however, it seems that north of De Kalb the member was removed by erosion prior to coarse sand deposition.

The Matthews Landing Member overlies the Porters Creek Formation.

STRUCTURE

Drilling has demonstrated that much of the area is cut by faults of from 5-40 feet throw. Many of these faults influence topography. For example, east of hole 18 a 15-foot fault makes a sharp gully in an outcrop of the Porters Creek Formation overlain by fine sand. Close to the fault the bedding in the Porters Creek is near vertical. A second example occurs in the large borrow pit southwest of Kewanee where a northwest trending fault, also topographically marked by a gully, has a 30-40 foot throw.

The regional dip is to the southwest.

HISTORY AND CORRELATION

The stratigraphic section established by the drilling supports

Roux's concept of formational nomenclature in this area. In particular, it confirms the existence of the Kemper Member which is the fine micaceous sand of the present description. The lignitic sands and clays underlying the fine micaceous sand correspond to the Oakhill Member of Roux's usage. In this area the Naheola Formation is subdivided into three members - the Kemper, Oakhill and basal Matthews Landing. The disconformable contact at the base of the coarse sand member of the Wilcox Group, marked in many localities by a lignite, is considered by the writer to mark the boundary between the Midway and overlying Wilcox Groups. The writer prefers to consider the lignite as basal Wilcox because it is a continental type of deposit in contrast to the underlying Kemper Member of the Naheola Formation.

The picture given by the stratigraphic units in this area is one of fluctuating advance and retreat of the sea. The lignitic clays and sands of the Oakhill are thought to represent swamps of a deltaic complex traversed by streams, whereas the overlying fine micaceous sand of the Kemper Member represents deposition in a shallow marine environment. Retreat of the sea is marked by the deposition of coarse fluviatile sand of the Wilcox, and the lignite at the base of the coarse sand member is interpreted as the actual line of sea level retreat, with the lignite being a sea level swamp deposit laid down behind the retreating strand line. The cyclic sequence overlying the coarse sand member marks the onset of another oscillating transgressive period which reached its height with deposition of the overlying clays of the Hatchitigbee Formation..

Heavy minerals are concentrated in the top few feet of the Kemper Member throughout the area studied but are particularly concentrated in this stratigraphic position north of the town of De Kalb. Concentration of heavy minerals north of De Kalb may be due to this particular location being the closest to the shoreline at the time of maximum advance of the sea and thus probably exposed for the longest period of time to wave action and supply of heavy minerals from land. In addition the river channel located west of the De Kalb area (Figure 3) probably supplied heavy minerals for distribution by long shore currents.

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POROSITY INDEX

by

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ABSTRACT

A laboratory method for rapid determination of effective porosity of granular rock employing a Russell-type volumeter is described. Both the procedure and the equipment required are non-complicated, and values attainable compare favorably with data derived from more complicated methods.

INTRODUCTION

Numerous methods for measuring porosity of consolidated rocks have been developed. Amyx, Bass and Whiting (1960) have summarized the results of a laboratory check program involving the routine methods normally used in major petroleum reservoir laboratories. General terms such as gas-expansion, saturation, and mercury injection describe techniques currently employed. Experience has demonstrated that each technique has limitations which, in many cases, tend to introduce significant errors in the resulting determinations. Certain procedures require expensive equipment, some are time consuming, and still others involve variables in physical parameters that contribute to a wide range in values of porosity calculated from repeat runs on an individual rock sample.

As a result of the spread between high and low values observed where porosity of a single sample is measured by various laboratory devices, an experiment was undertaken to confirm that the saturation method, which neither is laborious nor requires complex equipment, will ordinarily provide reproducible data. Values obtained by use of the saturation method probably more nearly duplicate effective porosity of granular rocks under reservoir conditions. As a by-product of the study, it was demonstrated that a good approximation of porosity, herein called Porosity Index, is readily obtainable.

PROCEDURE

The procedure involves use of a saturating fluid with low adhesion and vapor-pressure qualities, such as toluene, and a common Russell-type glass volumeter consisting of a bulb with a graduated stem fitted by a ground-glass joint to a bottle in which the sample is placed. A loosely coiled spring made of a few turns of small-gage wire is inserted in the bottle to hold the sample in position; this will aid in draining the liquid from the surface of the sample.

1. Fill the bulb-end of the volumeter and about 3 or 4 milliliters of the graduated stem with toluene. Lubricate the ground-glass joint, insert the wire spring in the bottle-end and attach the bottle securely to the stem fitting. Invert the volumeter to the normal position with the bottle-end down (position A, Figure 1). Place the volumeter in a rack and allow 3 minutes for the toluene to drain. During the draining process, in each instance, rotate or otherwise "agitate" the device carefully to loosen air bubbles which tend to collect around the joint. Read the volume on the graduated stem to the nearest hundredth of a milliliter and record as <u>a.</u> Care must be taken <u>at all times</u> to prevent the two parts of the volumeter from separating at the joint.

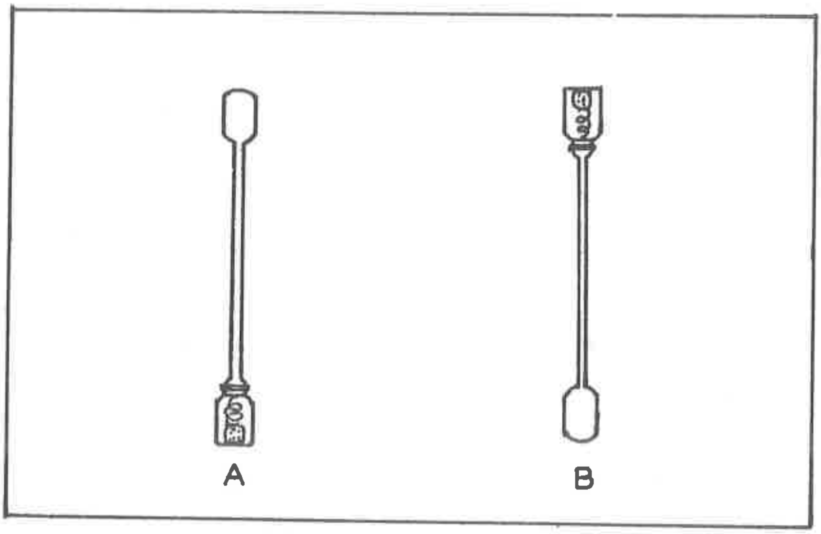

Figure 1. Volumeter positions A and B.

2. Invert the volumeter so that the bulb-end is down and the bottle is up (position B). Allow 3 or 4 minutes for the toluene to drain. Again, agitate the device carefully to aid the draining process.

Read and record the volume as b. (On most volumeters the scale will be inverted; read carefully.)

3. Select an extracted and dried sample about the size of a walnut (must pass through the bottle mouth). Remove the bottle and spring, and place the sample in the bottle. Insert the spring to hold the sample in position. Attach the bottle to the stem, and invert to the original position (A) with the bottle down and the bulb up. Allow 10 minutes for saturating the sample (rotate the volumeter to loosen air bubbles). Read the volume and record as c. Time required to saturate the sample may range from 10 to 15 minutes depending on factors such as permeability; 10 minutes was determined to be adequate in most cases.

4. Invert the volumeter once more to position (B) so that the bulb is in the down-position and the bottle is up. Allow 5 or 6 minutes to drain, during which time again rotate the device to aid in draining the toluene which adheres to the sample and bottle. Read the volume and record as d.

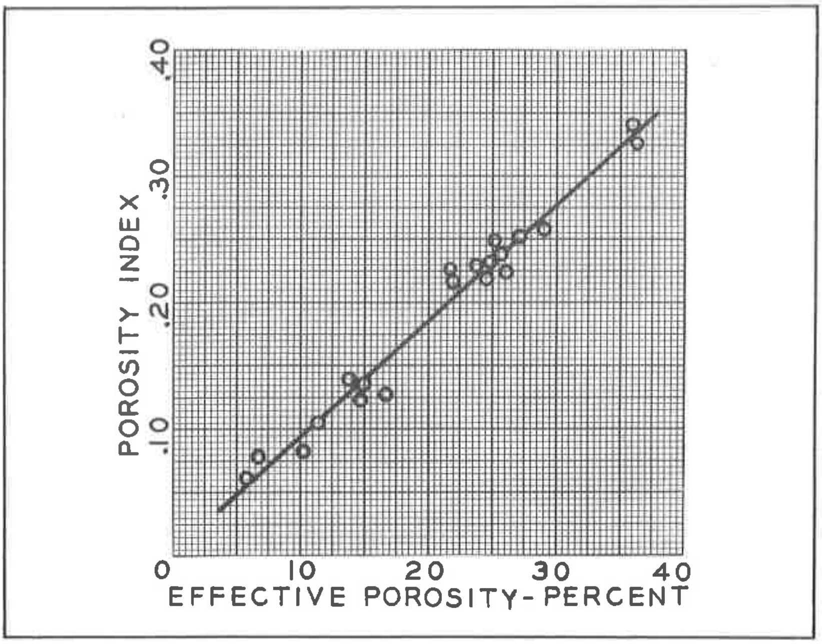

Figure 2. Relation of Porosity Index to effective porosity.

5. Calculate Porosity Index as follows:

Volume of solids:	$V_s = \underline{c} - \underline{a}$
Volume of pores:	$V_p = \overline{d} - \overline{b}$
Bulk volume:	$V_b = \overline{V}_s + V_p$
Porosity Index:	$P.I. = V_p / V_b$

Porosity Index would obviously be equal to effective porosity if saturation of the sample were complete. Numerous determinations showed that values obtained were uniformly less than porosity derived from the usual method of saturating a sample in a vacuum flask to which the saturating fluid is admitted by means of a separatory funnel and the pore volume calculated from the increase in weight of the saturated sample over the weight of the dry sample. Repeated measurements showed, however, that there is a linear relationship between observed data and effective porosity determined by the conventional saturation method. Figure 2 is a curve constructed from laboratory data showing this relationship.

It will be apparent that a lab technician may, on the basis of hiw own technique in using the volumeter, construct one or more curves which will equate Porosity Index to effective porosity as determined by any method considered reliable.

CONCLUSIONS

Data derived by the procedure as outlined provide a very good index to effective porosity of a granular rock. Advantages of employing this method are several. The equipment is inexpensive and the determination is not time consuming nor is it complicated. The sample is handled only once; only one parameter, volume, is measured. The sample may be of random shape; it is not damaged and may be used for further determinations such as permeability.

Careful operation will result in measurements reproducible within narrow limits. These data may, in turn, be translated into consistent values of effective porosity when related to porosity derived by any reliable technique. Repeat runs of a sample usually result in porosity determinations that differ less than one percent. This compares favorably with values obtained by more involved methods, and is sufficiently accurate for most reservoir volumetric consideration.

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NOTES ON FIVE MARINE PLEISTOCENE LOCALITIES IN NORTHEASTERN NORTH CAROLINA

by

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ABSTRACT

Mollusks are reported from five localities in northeastern North Carolina. A locality near Washington suggests a Pleistocene oyster reef, while one near Terra Ceia suggests slightly more saline water. Faunas from Swan Quarter and Fairfield suggest a more open sea. All the above are referred to the Pamlico Formation of Sangamon age. Shells from Water Lily in Currituck County are regarded as part of an Indian midden.

INTRODUCTION

Numerous localities containing marine fossils have been reported from the Pleistocene of North Carolina. Most authors have referred these to the Pamlico Formation and have dated them from the Sangamon Interglacial Stage (Richards, 1936, 1962). Recent detailed stratigraphic work by Oaks and Coch (1963) in southeastern Virginia suggests the possibility that several different formations are represented in what was formerly called the Pamlico Formation in that area. However, since similar detailed work has not yet been carried out in adjacent North Carolina, the present writer will continue to use the term Pamlico for Pleistocene deposits lower than elevation 30 feet above sea level in North Carolina, at least north of the Neuse River.

Five localities in this area have recently been studied, or restudied, and deserve mention at this time. This work was supported by Grant Nonr (G) 00036-65 of the Geography Branch of the Office of Naval Research.

Localities

Washington, Beaufort County, N. C. Excavations for an irrigation pond on the farm of Mr. Bruce T. Alligood, on old Highway

264, four miles east of Washington, yielded a large number of shells of Crassostrea virginica (Gmelin). According to Mr. Alligood, the shells were encountered about four feet from the surface, and extended laterally about 12 feet.

Many perfect double valves were obtained, and both young and adult specimens were observed. These facts strongly favor a Pleistocene oyster reef rather than an Indian midden.

On a visit to the locality in December, 1965, only oyster shells were observed. However, collections made shortly after the pit was dug, and presented to the Academy of Natural Sciences by Mrs. W. Frank Folger, of Washington, N. C., also included the following:

Mercenaria mercenaria (Linnaeus)
Arca transversa Say
Petricola pholadiformis Lamarck

The pond lies at about the five foot contour line. While the elevation is low enough to be correlated with deposits of the Pamlico Sea, the locality marks the farthest inland for marine Pleistocene fossils of the Pamlico Formation in North Carolina. No marine fossils have been found in the higher (older) Pleistocene formations in the state. In the Washington area, the Pleistocene is underlain at shallow depths by the Yorktown Miocene.

Terra Ceia, Beaufort County, N. C. An artificial drainage ditch along County Road 1612 near Terra Ceia and 3.8 miles northwest of the junction with Highway 264, has yielded abundant molluscan fossils.

This locality was visited on the fourth annual field conference of the Atlantic Coastal Plain Geological Association on October 19, 1963, and was briefly described in the Guidebook (Brown, 1963).

> "At this locality there is a 2 to 3 foot thick bed of dark-gray to weathered brown marl that crops out along the banks of a drainage ditch for a distance of several hundred yards. According to Druid Wilson (personal communication), the age of the marl is late Pliocene to early Pleistocene. The marl is overlain by 4 to 6 feet of tan-colored sand and clayey sand."

At the time of the brief visit, the present author questioned the age determination since the specimens collected were the same as those found at Fairfield and other localities in Hyde County which have been referred to the Pamlico Formation of Late Pleistocene age.

The locality was revisited in March and December, 1965, and a more extensive collection of fossils was obtained, including the following:

PELECYPODA	GASTROPODA
Nuculana acuta (Conrad)	Turbonilla sp.
Arca transversa (Say)	Polinices duplicata (Say)
A. ponderosa Say	Crepidula fornicata (Linnaeus)
Crassostrea virginica (Gmelin)	C. plana Say
Venericardia tridentata Say	Eupleura caudata (Say)
Phacoides crenella Dall	Urosalpinx cinerea (Say)
Divarcella quadrisulcata (d'Orbigny)	Nassarius obsoletus (Say)
Mercenaria mercenaria (Linnaeus)	N. trivittatus (Say)
Mercenaria campechiensis (Gmelin)	N. acutus (Say)
Tellina agilis Stimpson	Busycon canaliculatum (Linnaeus)
Abra angulata Holmes	B. caricum (Gmelin)
Corbula contracta Say	Prunum roscidum (Redfield)
Ensis directus (Conrad)	Olivella mutica (Say)
Mactra soladissima Dillwyn	Terebra dislocate (Conrad)
Mulinia lateralis (Say)	Retusa canaliculata (Say)
Rangia cuneata (Gray)	
Myra arenaria Linnaeus	
Barnea costata (Linnaeus)	

In correspondence with Dr. Wilson, I was informed in a letter dated July 12, 1965, that the notes in the guidebook actually referred to a different locality. He mentioned that during a pre-meeting field trip he had collected specimens of a Pecten of the P. eboreus group from a spoil bank several miles from the Terra Ceia locality, and it was this latter material to which his statement referred. He pointed out that DuBar and Chaplin (1963) list Chlamys solaroides from the Pamlico, but later DuBar (personal communication) believed the specimen to be reworked.

Specimens of Pecten eboreus Conrad have been collected from Fairfield in Hyde County, but since these were associated with species generally characteristic of the Pamlico, they also were regarded as reworked.

At Terra Ceia, the main shell bed grades laterally into an oyster bed which also overlies the main bed in some places. The locality is referred to the Pamlico Formation, and apparently represents slightly more saline water than at the Washington locality; however, it does not represent the open sea.

Swan Quarter, Hyde County, N. C. Excavations for a small canal leading from Pamlico Sound to Swan Quarter encountered the same Pamlico fossiliferous shell beds that have been reported at Fairfield and elsewhere in Hyde County. On a visit to the spoil banks in March, 1965, the following species were collected:

PELECYPODA	GASTROPODA
Arca transversa Say	Polinices duplicatus (Say)
Arca ponderosa Say	Sinum perspectivum (Say)
Pecten irradians Lamarck	Crepidula fornicata (Linnaceus)
Crassostrea virginica (Gmelin)	C. plana Say
Anomia simplex d'Orbigny	Nassarius trivittatus (Say)
Phacoides crenella Dall	Cantharus cancellaria (Conrad)
Divarcella quadrisculcata (d'Orbigny)	Busycon caricum (Gmelin)
Dinocardium robustum (Solander)	B. perversum (Linnaeus)
Marcocallista nimbosa (Solander)	Oliva sayana Ravenel
Mercenaria campechiensis (Gmelin)	Olivella mutica Say
Donax variabilis (Philippi)	Prunum roscidum (Redfield)
Petricola pholadiformis Lamarck	Terebra dislocata (Say)
Ensis directus (Conrad)	**CRUSTACEA**
Mactra soladissima Dillwyn	Balanus sp. (barnacle)
Mulinia lateralis (Say)	**ECHINODERMATA**
Rangia cuneata Gray	Mellita quniquesperforata Leske
Chione cancellata (Linnaeus)	**COELENTERATA**
	Astrangia danae Agiasiz

The fauna is similar to that reported from Fairfield (Richards, 1936, 1962).

Fairfield, Hyde County, N. C. It is regrettable to be required to report that most of the shells in the spoil banks of the Intra-Coastal Canal near Highway 94, three miles north of Fairfield, have been removed presumably by the Highway Department for road construction. A fauna of some 90 species was obtained from this locality (Richards, 1936), but only a few species could be found in 1965. Although fossils obtained from spoil banks are frequently mixed, the general impression of the Fairfield fauna is that of an open sea environment.

Water Lily, Currituck County, N. C. An extensive shell bed occurs on the west side of Currituck Sound, three miles north of the small settlement of Water Lily, and six miles north of Coinjock. There has been some question as to whether this was a natural shell bed or a midden. Careful observations made in December, 1965, strongly favor the latter interpretations for the following reasons: (1) The bed is mainly made up of oyster shells, single valves or broken shells with no juvenile forms. This is in contrast to the Washington locality cited earlier in this paper; (2) the shells are confined to a narrow band at the top of the bluff, in the same manner as the definite Indian shell material along the Nansemond River in Virginia; (3) several pits were observed with special concentrations of the shells; (4) broken pieces of pottery were observed mixed with the shells. According to Dr. Joffre L. Coe, of the Department of Anthropology of the University of North Carolina, the pottery is Indian, probably less than 500 years old. (5) the shells occur at a higher elevation (about 12 feet) than any known marine Pleistocene locality in northeastern North Carolina or southeastern Virginia.

While the great majority of the shells are of the oyster (Crassostrea virginica), numerous specimens were collected of the clam (Mercenaria mercenaria, as well as a few shells of Pholas (Barnea) costata L., Pecten irradians (the scallop), Busycon caricum (conch), Nassarius obsoletum and Littorina irrorata (Say).

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