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THE FORMATION OF JOINTS AS A POSSIBLE CAUSE OF CERTAIN SEISMIC PHENOMENA

By

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ABSTRACT

Computations of the order of magnitude type indicate that sufficient elastic energy may be liberated during the formation of major joints to produce such "crypto seismic" effects as light localized earth tremors, underground rumbling sounds, and the like.

* * * *

Everyone who has watched quarrying operations, or who has employed a sledge hammer in an attempt to "make little rocks out of big ones!", must have been impressed with the amount of energy required to rupture solid rock. Although very few of us have ever had the opportunity to watch the actual formation of a natural joint, perhaps the nearest to this which may be actually observed, is when, in the north country, during a protracted spell of cold weather, the sheet of ice covering a large lake contracts in sub-zero weather. Under these conditions it often develops tensional stresses in excess of its strength, and splits from shore to shore with an almost bell-like ringing "spang" that can be felt as a sharp impulsive vibration as well as heard.

This noisy cracking of ice on a frozen lake is quite analogous to the formation of tensional joints in, for example, a granitic batholith or stock. Hence the development of such joints might be expected to give rise to audible or even felt vibrations in the immediate area. Such relatively feeble, but alarming and long continued explosive noises and vibrations as were involved in the "Bald Mountain Disturbances" in McDowell County, N. C. in 1874, the similar events reported from Deerfield, N. H. in the 1840's, and the much better known "Moodus Noises" which have been occurring in Connecticut since pre-colonial days, are examples of the sort of phenomena one might expect during the formation of major joints. Similar occurrences have been reported elsewhere and, although there is some discussion in the literature of these phenomena, no generally accepted conclusion regarding their origin seems to have been reached other than that they are probably some variety of what might be called "crypto-seismic" phenomena. Similar but artificially induced phenomena accompany "rock bursts" in many mining areas.

* * * *

When a block of material is stressed under tension to the breaking point, energy is stored up in it during the period of stress accumulation in the form of elastic deformation, and is suddenly released when rupture takes place. This can be testified to by anyone who has stretched a rubber band between his hands until it ruptured. When this occurs, the band immediately snaps back to its original dimensions, and administers a stinging lash as it does so. The actual amount of energy thus released during rupture depends upon the elasticity of the material as specified in terms of Young's Modulus, upon the strength of the material, and upon the dimensions of the body which is being ruptured. Here it is only the volume of the material which is important: a long, thin rod breaking under tension will release exactly the same amount of energy as would a cube of the same volume subjected to the same tensile stress.

The elastic constants of rocks and their various strengths - strength under tension, strength under compression, etc., - vary considerably under different conditions of temperature, external supporting pressures, and the like although, since strength and elasticity tend to go up and down together, the ratio between them does not vary to the extent one might at first suppose.

If we take some generally accepted values from the literature, we find that the average strength of granite under tension is about 40 kg/cm^2 (Billings, 1954, p. 17) and that Young's Modulus for this material as determined by the values for 13 different granites is about 4.6×10^{11} $dynes/cm^2$ (Birch et al, 1942, p. 73-74). Using these values, the energy released by rupturing a cube of granite under tension may be computed as

$$\frac{1}{2}\left\{\frac{(40 \times 10^6)^2}{4.6 \times 10^{11}}\right\} V \text{ ergs},$$

where V is the volume in cubic centimeters. This works out, in round numbers, to be 1700 $ergs/cm^2$, or about 17×10^8 ergs per cubic meter.

To take a specific example, let us consider a cube of solid granite one kilometer on edge. Such a cube contains 10^9 cubic meters, and the energy released if it splits under tension into two blocks would be some 1.7×10^{18} ergs, which is certainly an impressing sounding number. Further repetition of this process, reducing the original one kilometer cube to smaller and smaller fragments would release proportionate amounts of energy. All of this energy would of course not be available for the production of seismic phenomena. Much of it would very quickly be dissipated as heat, and that portion which did travel out into the surrounding material in the form of elastic waves would eventually be absorbed and meet the same fate. However, let us make what seems to be a rather safe assumption: that at least one tenth the total energy so released would appear as vibrational energy. This would, then, amount to about 1.7×10^{17} ergs.

Although there seems to be no general agreement as to the amount of energy involved in a minimal or just perceptible earthquake, most suggested values in the range of 10^{10} to 10^{12} ergs (Richter and Nordquist, 1948, p. 261; Richter, 1959, p. 366; Jacobs et al, 1959, p. 35). For the largest known shocks the suggested values are from 10^{25} to 10^{26} ergs. Thus the 1.7×10^{17} ergs which we are considering as present in the form of vibrational energy during the formation of our hypothetic giant joint cutting through a cubic kilometer of solid granite would be more than sufficient by 5 to 7 orders of magnitude to produce a minimal shock, but would fall short by 7 or 8 orders of magnitude of being sufficient to produce a great earthquake.

It is not suggested that individual joints splitting a cubic kilometer of otherwise solid rock are common or even probable. Yet, if we divide the figure of 1.7×10^{17} ergs by 1000, corresponding to the energy released in splitting a granite cube 0.1 km on edge, we still find available energy in the range of 10^{14} ergs. This is still in excess of the requirements for a minimal shock by at least 2 orders of magnitude. The cube just considered would be approximately 327 feet on edge, and a single joint cutting completely through such a mass of rock is surely not too unreasonable a supposition.

Only tensional forces have been here considered. Since in all cases rocks are stronger under compression than under tension, joints formed under compressional stress should release even more energy than is here computed.

On the basis of these admitted rough computations, it appears quite probable that certain small, localized, and repetitive earth tremors, together with various subterranean rumbling and explosive noises, may be the surficial accompaniment of, and evidence for, the formation of joints at relatively shallow depths.

My thanks are due Lawrence M. Slifkin, of the Physics Department, University of North Carolina, who has been so kind as to check my physical theory and mathematical computations.

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BASEMENT BENEATH THE EMERGED ATLANTIC COASTAL PLAIN BETWEEN NEW YORK AND GEORGIA

By

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ABSTRACT

Basement is defined, for the purposes of this article, as the metamorphic and/or igneous rocks below which there is no known stratigraphic or structural break.

At least 500 holes have penetrated basement beneath the Mesozoic and Cenozoic sediments of the Atlantic Coastal Plain between New York and Georgia. Approximately 90 per cent of them penetrated basement at elevations higher than -1000 feet M. S. L. The 10,054-foot Esso #1 Hatteras Light well, which encountered the top of basement at -9954 feet M. S. L., is deepest.

Drill hole and geophysical data support the following tentative conclusions:

Basement rocks are Precambrian and Paleozoic metamorphic and igneous (including volcanic) rocks, similar to those exposed on the Piedmont to the west. Many of these rocks have been highly fractured and sheared.

Part of the rocks accumulated in a Pre-Mesozoic eugeosyncline.

Since at least late Mesozoic time the basement surface has been a differentially warping platform.

At least four periods of diastrophism are known to have affected the basement of this area.

The regional structural (and topographic) trend is northeast-southwest.

The surface of the basement is an old age erosion surface - commonly referred to as the Fall Zone Peneplane - with sporadic fault troughs, ridges, valleys, and "arches".

Locally some of the rocks have been weathered to depths exceeding 150 feet.

The basement surface dips generally seawardly about 15 to 45 feet/mile (with about 35 feet/mile typical) to approximately the -2400-foot M. S. L. contour and seaward from this contour it steepens to about 100 to 125 feet/mile.

Oil may possibly occur in commercial quantities in weathered zones on or fractured zones in the basement, or in sedimentary rocks that lens out against topographic highs of the basement surface.

* * * *

This paper was presented at the 1960 annual meetings of the American Association of Petroleum Geologists. It is essentially a preliminary synthesis of previously published data and unpublished well data, most of the latter of which were supplied to me (as a member of the Basement Rocks Project Committee of A. A. P. G.) by U. S. G. S. Groundwater Branch

Geologists and State Geological Survey personnel. The paper consists chiefly of formulating problems that need to be investigated. Peter T. Flawn and Wallace D. Lowry criticized the original manuscript. The speaker gratefully acknowledges these aids.

* * * *

"Basement" may be defined either on a utilitarian basis, such as any rock unit(s) below which it is believed that no petroleum exploration is warranted or it may be defined on a strictly theoretical basis, such as the rock units that pass without marked break into the "granitic crust" proper. The "basement" to which I will allude probably lies somewhere between these extremes. It is geologic and may or may not be geophysical. It has no inherent age restriction. Simply, it is the metamorphic and/or igneous rock units below which there is no known stratigraphic or structural break.

The area to be considered is the Atlantic Coastal Plain between New York and Georgia (Figure 1). More than 500 holes have penetrated basement buried beneath Mesozoic and Cenozoic sediments in this area. Although most of them were drilled within a few miles of the western edge of the province, i. e., near the "Fall Line" which marks the boundary between the area underlain by the Coastal Plain sedimentary rocks and sediments and the area to the west which is underlain chiefly by metamorphic rocks, nearly 40 are rather widespread and have penetrated basement at elevations below -1000 feet M. S. L. (Figure 2). Geophysical data is also available (see summary in Woolard, Bonini, and Meyer, 1957).

Available data support best, I believe, the following tentative conclusions:

1. The basement is constituted by Pre-Mesozoic metamorphic igneous rocks similar to those exposed directly west of the Coastal Plain. This consanguinity of at least much of the buried basement and the exposed basement to the west is accepted by most workers and has greatly influenced thinking about the concealed basement. Rock designations reported for samples of buried basement include "Algonkian", "Basement Complex", "crystalline rock", "Early Paleozoic or Precambrian", "Fordham gneiss", "granite gneiss", "granite wash", "granodiorite", "Petersburg granite", "Precambrian", "preCambrian or Ordovician Wissahickon", "preCretaceous", and "schist". This apparent heterogeneity may be, to a large degree, confusion. However, such confusion is actually little worse than that associated with the adjacent exposed basement where most exposures are scattered and highly weathered and observed relationships have led to numerous conflicts in interpretations of both age relationships and petrogenetic conclusions (e. g., Stose and Stose, 1948; Cloos and Heitanen, 1941). Many of the buried basement rocks are reported to exhibit features, such as slickensided surfaces and veining, that suggest that they have been highly fractured and/or sheared. Datewise, it appears safe to say that all basement rocks are Pre-Mesozoic, some are Pre-Ordovician, and some are probably Precambrian. Lithologically, most of the rocks are similar to those exposed to the west. This is corroborated permissively by geophysical observations - Woolard, Bonini, and Meyer (1948, p. 87) believe, for example, that their data can be interpreted best as suggestive of a repetitive pattern of lithologies parallel to those of the exposed basement to the west.

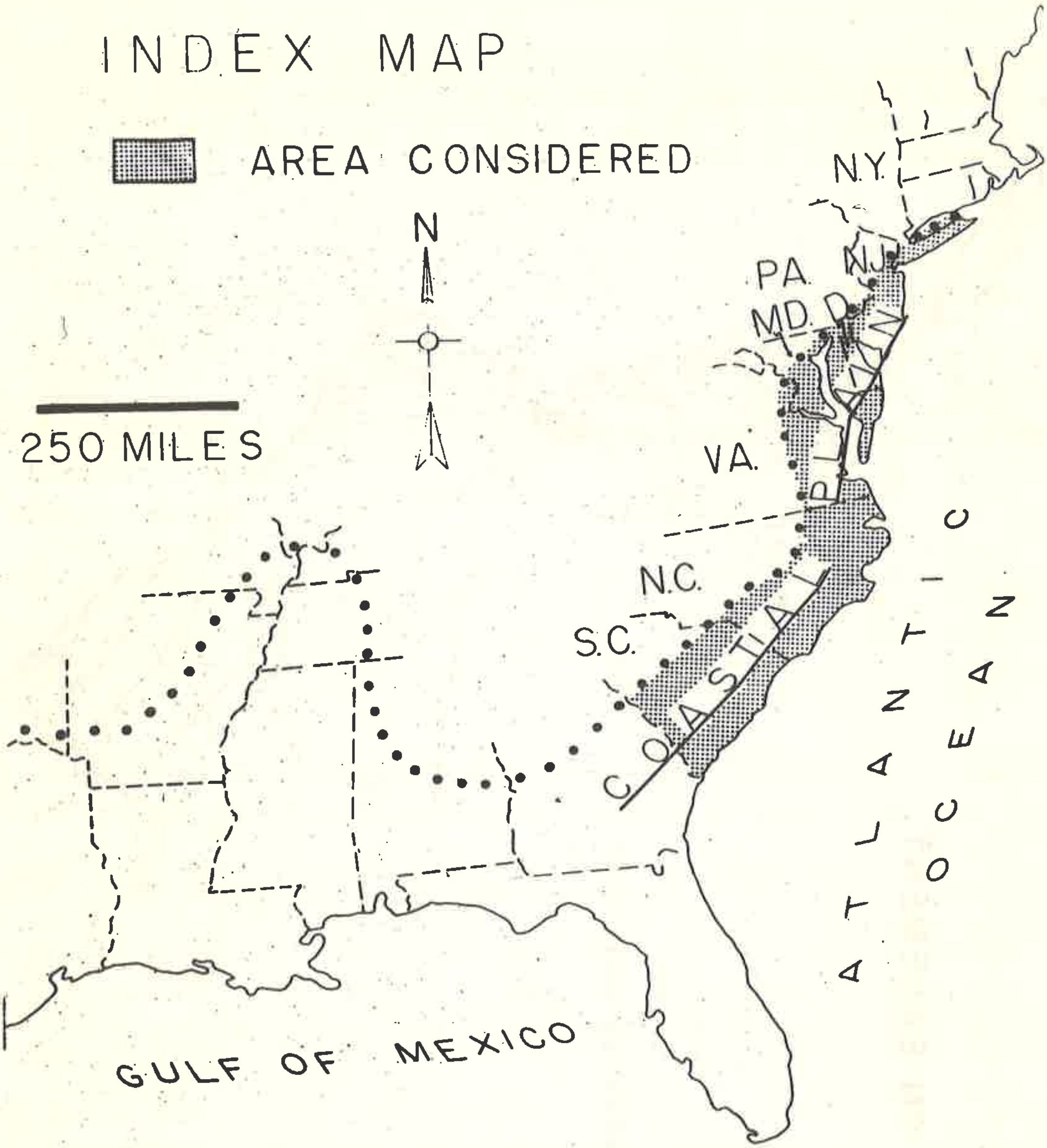

Figure 1. The Area of Consideration.

2. At least some, and possibly most, of the buried basement rocks accumulated in a Pre-Mesozoic eugeosyncline, i. e., in a eugeosyncline the rocks of which underwent deformation (including metamorphism) and uplift before Mesozoic time. If it is accepted that the buried basement and the exposed basement to the west are parts of the same rock sequence, this conclusion appears to be inescapable.

3. Since Early Cretaceous and possibly since Late Triassic time the basement surface has been a relatively stable, although differentially warping, platform. Evidence for this lies in the overall relationship between the basement surface and the horizontal and the general character and age of the sedimentation atop the surface.

4. At least four periods of diastrophism have affected the rocks that constitute basement of the area. The four periods for which evidence

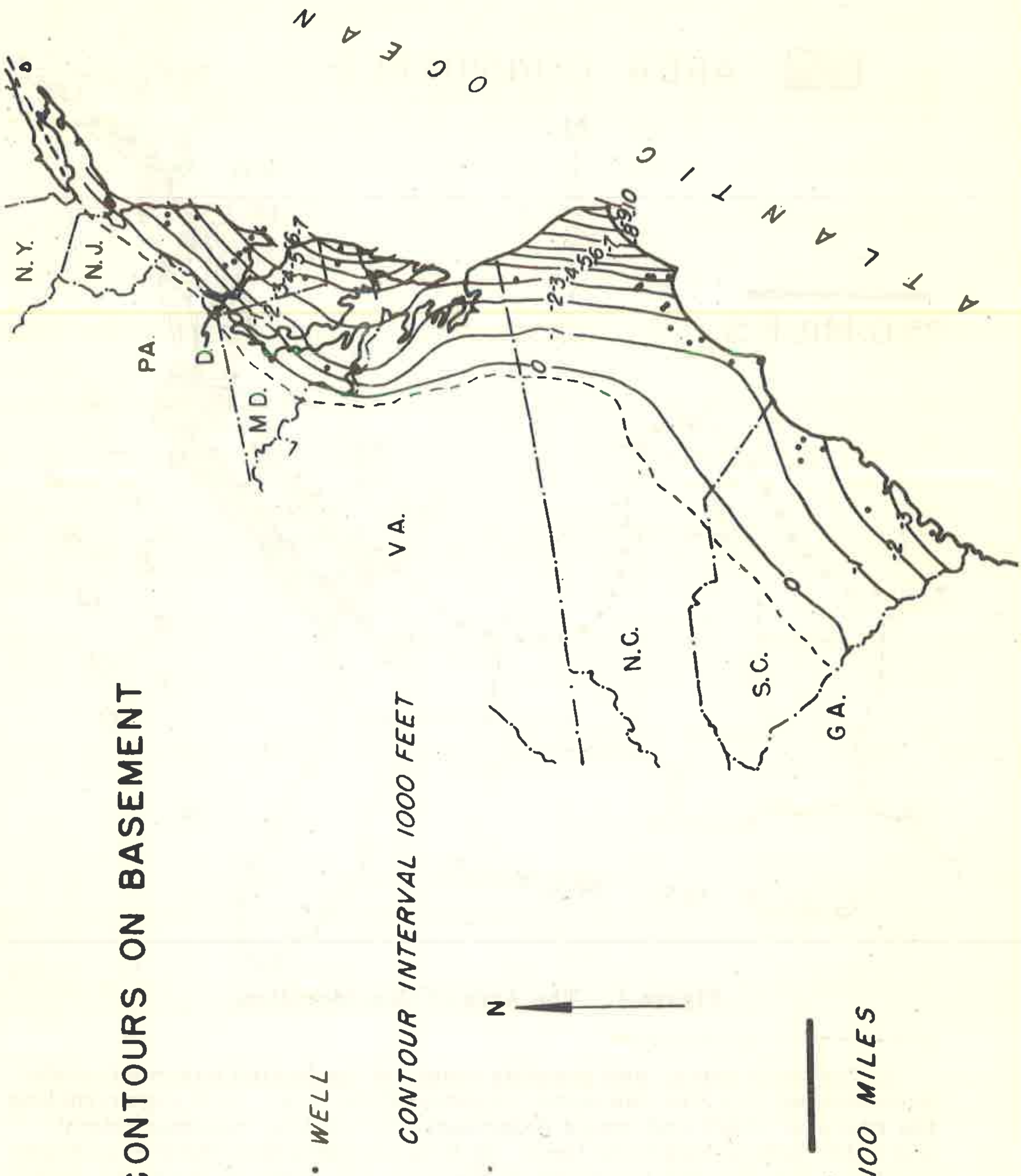

Figure 2. Generalized contours of basement surface; whole numbers refer to elevations in number of thousand(s) feet; only wells that penetrated basement below -1000 feet/M. S. L. are plotted.

appears rather clear-cut are: a. Pre-Ordovician deformation and metamorphism, b. Post-Ordovician - Pre-Late Triassic tight folding and metamorphism, c. Late Triassic (i. e., "Palisades Disturbance") tilting or arching and faulting, and d. Cretaceous to Present differential warping. Also of possible interest with regard to this aspect are the Salisbury Embayment or Basin, the Hampton Roads Fault or Flexure, the Cape Fear Arch or Great Carolina Ridge, the Yamacraw Ridge, and the rather abrupt slope change at about -2400 feet M. S. L. (see conclusions 5 and 6). Radioactive dates found for rocks of the exposed basement adjoining to the west may be indicative of still other periods of diastrophism (see, for example, Rodgers, 1952 and Davis et al., 1958).

5. The regional structural trend in the buried basement of the Atlantic Coastal Plain between New York and Georgia is northeast-southwest but locally the trend is nearly north-south. Most dips are probably greater than 30 degrees and toward the southeast (this may be an important consideration so far as geophysical interpretations). There are also major structural features - "arches", ridges, and basins - the axes of which are nearly normal to this trend. Considering the general slope and topographic character of the buried surface, it seems safe to presume that there is also a general northeast-southwest topographical trend with a few cross-trending topographical basins and arches. The structural trends in the adjoining exposed basement, the configuration of the boundary between the Coastal Plain sediments and the exposed basement rocks, and geophysical evidence support these conclusions. Well data are too few, except locally near the boundary, to be considered as either corroborative or contradictory.

The regional northeast-southwest trends are marked by contact zones between rock units, by foliation within many of the units, and by at least some of the border faults and flexures of included Triassic basins. The "line" marking the abrupt change of slope near the -2400-foot M. S. L. contour also may have an essentially parallel trend.

There is a great spread so far as the periods of formation of these features. To me, this brings up one of the most interesting and basic of all questions to which at least some answers may be forthcoming from future studies. This question is - why were nearly all of the diastrophic movements that affected these rocks manifest by essentially parallel features? This is particularly interesting because this general type of relationship is of worldwide occurrence (although admittedly not universal). I believe the most probable explanation is that once a trend is established - perhaps even the initial source-area to sedimentation-basin relationship - the trends of all subsequently imposed features have, so to speak, been predestined. Many examples from many parts of the world may be cited in support of this suggestion, part of my more inclusive and unifying "Predestiny Hypothesis." In any case, structural analyses indicate it to be axiomatic that once a definite trend is established in an area, most subsequent diastrophic adjustments will occur along already established "s" surfaces. The exceptional case would be where a later diastrophism involved stresses the components of which were far enough off the established trend, anglewise, and/or of such magnitude that they could not be relieved by adjustments along or essentially parallel to the preexistent "s" surfaces. Along this line, it is extremely significant that in the area under consideration the axes of geologically relatively recent(?) structural(?) arches and basins are nearly normal to the regional trend (i. e., it is important if these are proved to be structural).

Buried Triassic basins have been discovered by geophysical means to occur near Lakewood, New Jersey; east of Petersburg, Virginia; and in Hoke County, North Carolina. Drilling has indicated others to occur near Salisbury, Maryland; near Bowling Green, Doswell, and Ashland, Virginia; beneath Elizabeth, Camden County, North Carolina; and extending from Sumter and through Florence, South Carolina to at least Laurinburg, North Carolina. Supporting geological and geophysical data have been given in numerous reports (e. g., Ewing, et al., 1937; McCarthy, 1934 and 1936; Richards, 1948; Siple, 1959; Spangler and Peterson, 1950; and Woollard, et al., 1957).

The chief features that are considered by some workers to be of relatively more recent origin are, listed from north to south, the Salisbury Embayment (or Basin), the Hampton Roads Fault (or Flexure), the Cape Fear Arch (or Great Carolina Ridge), the Savannah River-Beaufort Basin(s) and the Yamacrow Ridge. The Salisbury Embayment (e. g., Richards, 1948; Balsey, et al., 1946, Ewing, et al., 1950) is a relatively broad, valley-like feature, in the basement, that extends from near Washington, D. C., roughly eastwardly through Ocean City, Maryland. A Pre-Cretaceous existence is indicated by the presence of thicker Cretaceous sediments within the area than to either the north or to the south. The presence of the Hampton Roads Fault of southern Virginia was first suggested by Cederstrom (1945) who interpreted it as being a fault of 300-600 feet displacement with Newport News on the northern downthrown block and Norfolk on the southern upthrown block. He considered geophysical and well data to fit best the interpretation that the "fault" trends west-northwest essentially parallel to the James River. He also noted that warping of the Eocene-Miocene contact suggests movement along this fault as late as Miocene time. Nonetheless, most movement along the zone was interpreted to have been Pre-Eocene because the Eocene sediments are the youngest ones with a markedly greater thickness north of than south of the feature. Woollard (1940) interpreted the same geophysical data alternatively to reflect only differences in compositions of basement rock. However, Woollard, et al. (1957) concluded that all data fit best an interpretation involving the presence of a sharp flexure in the basement of the area. The Cape Fear Arch (e. g., Dall, 1892; Siple, 1959; Woollard, et al., 1957; Ferenczi, 1959) is a positive element the axis of which trends northwest-southeast, roughly parallel to and near Cape Fear River, and plunges towards the southeast. Woollard, et al. (1957, p. 37) believe that the arch is a positive tectonic unit which has been rising throughout most of Post-Paleozoic time. Available data on the period of effective diastrophism are equivocal. The Savannah River-Beaufort Basin(s) is a smaller cross-trending feature or features near the South Carolina-Georgia boundary for which Siple (1959, p. 16) has presented evidence. The Yamacraw Ridge (Woollard et al., 1957; Pooley, et al., 1960) is a basement ridge that trends about S22°W, parallel to the regional structural trend, from near Charleston, South Carolina and plunges southwestwardly. It appears most likely that this feature is a monadnock ridge that existed on the surface before Cretaceous sedimentation. So far as other relatively recent structures (possibly present), Cederstrom (1945) mentioned gently folded Miocene sediments in southeastern Virginia and interpreted them as a reflection of "settling movements" along a preexisting fault or series of faults in the basement; Ferenczi (1959) has published the latest data on the Hatteras Axis (McGee, 1891) and introduced data to support the presence of what he calls the Cape Lookout-Neuse Fault Zone (between the Hatteras Axis and the Cape Fear Arch) and an unnamed "structural zone, parallel to the main Appalachian trends . . . along the eastern boundary of Martin, Pitt, and

Lenoir counties . . ." (North Carolina), all of which appear to have affected Tertiary sedimentation; and, Stephenson (1928, p. 893) has even suggested that faulting of the basement of the Coastal Plain (actually the near offshore area) may have been responsible for the famous Charleston earthquake.

The abrupt change of slope (see especially Spangler, 1950; Prouty, 1946; Berry, 1948) in the basement near the -2400-foot M. S. L. contour is difficult to explain with no more than the meager data available. It may be wholly structural, wholly erosional, or a combination. In any case, at least locally there is a change from approximately 14 feet/mile to approximately 122 feet/mile within about 15 miles. Thence, according to Spangler (op. cit), the slope is more or less constant to about the -5500-foot M. S. L. contour where there is a change in the opposite sense to about 100 feet/mile, the slope that prevails to at least the -10,000-foot M. S. L. contour. As is discussed in the next section, whether or not the first mentioned change is structural and involved an originally single erosion surface may be important economically as well as to overall geological history considerations.

6. Generally the surface of the buried basement is characterized as an old age erosion surface, i. e., with less than 1000 feet local relief except for sporadic monadnock mountains and ridges. This surface is commonly referred to as the Fall Zone Peneplane (Sharp, 1929). Evidence cited is generally threefold - drilling data, geophysical data, and the overall regularity, i. e., straightness, of the boundary along the western edge of the onlapping Coastal Plain sediments. Actually, this is somewhat misleading because the Fall Zone surface truncates not only the crystalline rocks but also Triassic basin rocks. Therefore, the regularity of the surface of the basement as herein defined is interrupted by the Triassic troughs. At least some of these interruptions are of great magnitude, perhaps as much as 20,000 feet. Nonetheless, nearly all maps showing contours atop "basement" actually present contours marking the base of the Cretaceous. In fact, this is about all that can be done until many more data are known and much larger scale maps are used. So, it must always be kept in mind that parts of the basement surface buried beneath the Atlantic Coastal Plain sediments are buried further beneath Triassic rocks.

Another question of importance so far as any consideration of the configuration of the buried surface relates to whether or not the aforementioned abrupt change in slope at about -2400 feet M. S. L. is chiefly an erosional feature or chiefly a structural feature. If it is structural and the original surface represents a single erosion surface and if there was no erosion between the period of attainment of the single erosion surface and deposition of overlying sediments, it can be presumed that the surface seaward of the abrupt slope has less relief than that inland from the area of change. Possibly the surface was warped in conjunction with the large scale epeirogenic movements that must have accompanied Triassic faulting. If, on the other hand, the abrupt change is an erosional feature (e. g., the intersection of two erosion surfaces or a Pre-Cretaceous coast line) or even a feature which at any time witnessed weathering and/or erosion processes on its part with the lower slope which were markedly different from those on its part with the steeper slope, there could be notable differences in the relief characteristics of the two sections. Perhaps a combination of structural and erosional controls obtained. In any case, it is quite obvious that determination of the correct answer may have extremely important bearing on further considerations concerning petroleum occurrence possibilities.

7. Locally some of the rocks that constitute the buried basement have been weathered to depths of more than 150 feet. In fact, lateritic weathering has been reported to extend to 170 feet locally. Although "granite wash", "weathered bedrock", and similar designations have been given to the material penetrated by drilling beneath the Coastal Plain sediments in many areas, I believe this conclusion must be made with reservations. First of all, none of the supporting data has been supplied by professional geologists who personally examined the material(s) in question. Secondly, possibly some of these materials represent post-burial alteration-decomposition along the contact. Thirdly, it appears that some of the material reported as "granite wash . . . etc." may be buried Triassic arkosic sedimentites atop basement. Commonly, experienced geologists find it difficult to distinguish unequivocally between such materials even at surface exposures. Perhaps of primary importance is the fact that it must be recognized that wherever such zones occur, depth-to-basement interpretations based wholly on geophysical data are likely to be of too great magnitude, i. e., they will indicate basement to be at too low elevations.

8. As previously noted, the basement surface dips generally seawardly from about 15 to 40 feet/mile (with about 35 feet/mile typical) to approximately the -2400-foot M. S. L. contour and seaward from this general elevation it steepens, etc., etc. Numerous other figures have been given for certain profiles. Possible means of accounting for this have been mentioned (e. g., the basins and arches).

These tentative conclusions and the facts and fancies that led to them can, in my opinion, be fitted into the following geologic history:

Precambrian

1. accumulation of sediments and volcanics,
2. orogeny,
3. weathering and erosion with exposure of deformed and metamorphosed rocks;

Precambrian and/or Cambrian and/or Pre-Late Ordovician

4-6. repetition of 1 through 3 - perhaps more than once;

Ordovician

7. accumulation of sediments;

Middle to Late Paleozoic

8. close folding and metamorphism (formation of slates and associated rocks) and igneous intrusion (possibly not concomitant),
9. exposure of these rocks to the surface;

Triassic

10. arching and faulting and concomitant sedimentation, high level intrusion, and local volcanism;

Jurassic

11. weathering and erosion with formation of a low-relief, Pre-Cretaceous, erosion surface,
12. local open folding (arching, etc.);

Cretaceous to Present

13. differential warping and concomitant sedimentation with the shore line near the present "Fall Line" and with local accompanying flexing and/or faulting across the regional structural trend of the underlying rocks.

A fourteenth (with apparently no genetic significance to basement history)

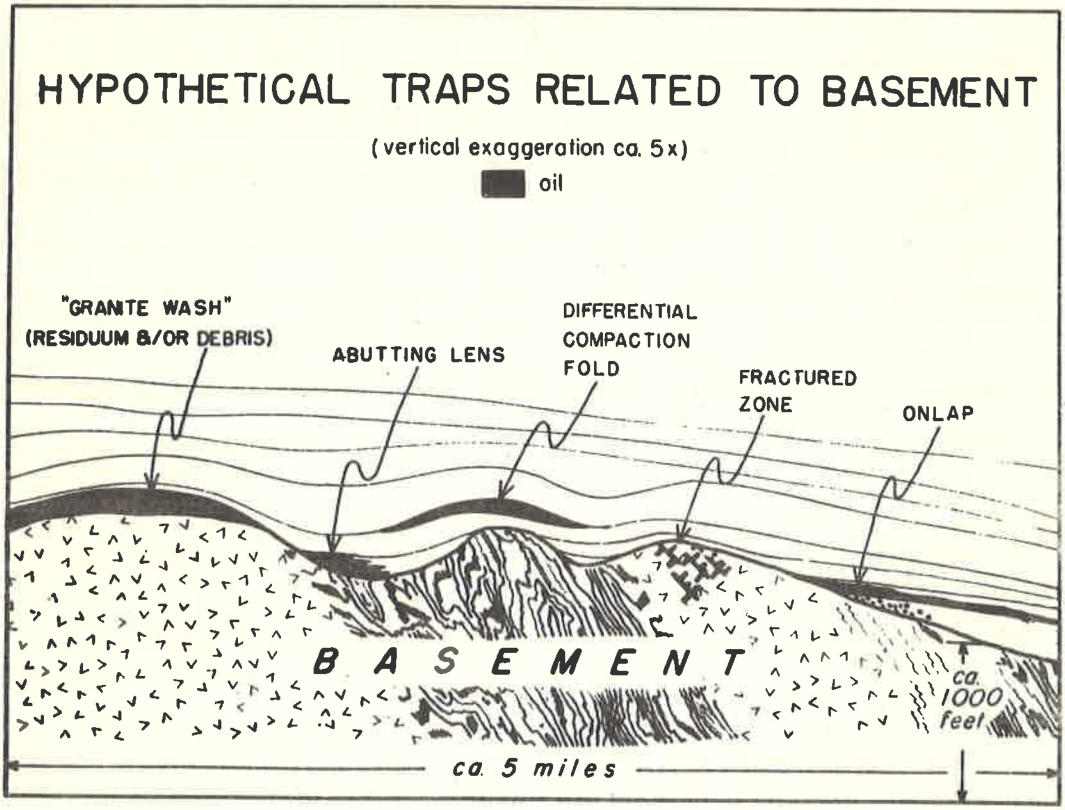

Figure 3.

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can be added - formation of terraces, etc. during the Pleistocene and Recent.

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OIL production possibilities for the province, in general, were considered in the first address (Trumbull, J. and Johnston, J. E., 1960). I merely wish to reemphasize that despite feelings in some quarters that the top of basement is the lower limit of oil and gas occurrence, there are proved occurrences to refute this (e. g., Farquhar, 1957, pp. 102-106; Totten, 1956, p. 195). I offer the hypothetical diagram (Figure 3) for consideration in regard to basement and basement-controlled oil reservoir possibilities. I also raise to you what appears to me to be an extremely pertinent question - what relationships exist between the buried Triassic basin clastics and possible source sediments(?).

Before closing, I wish to add an appeal that everyone give members of the Basement Rocks Project Committee of the A. A. P. G. full cooperation so that important questions, such as those I have raised, that relate to basement may be resolved. I think it is especially important that "basement" samples be made available for our examination. At least this would mean establishment of greater consistency in so far as names applied to the rocks - a necessary first step towards gaining many of the answers.

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IMPRESSIONS RESEMBLING WORM BURROWS IN ROCK OF THE CAROLINA VOLCANIC-SEDIMENTARY GROUP, STANLY COUNTY, NORTH CAROLINA

By

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ABSTRACT

Impressions which resemble worm burrows have been discovered in southern Stanly County, North Carolina. The rock underlying this area is a member of the Carolina Volcanic-Sedimentary Group, popularly known as the Carolina Slate Belt, which has always been considered unfossiliferous. The unit in which the markings occur is an unweathered, slightly metamorphosed, water laid, volcanic tuff. The markings have not been positively identified as organic, however, they do not resemble any reported mineral form or sedimentary feature. In addition the markings are not limited to bedding planes, but weave back and forth as well as up and down through the rock, indicating that they were produced by a mobile form, such as a burrowing organism.

Although not positively identified these markings are quite similar to worm burrows and might be the first fossils discovered in the Carolina Volcanic-Sedimentary Group.

INTRODUCTION

Rock specimens containing impressions which might be of organic origin and which resemble worm burrows were collected in southern Stanly County, North Carolina. These impressions are of particular interest because the rocks underlying this area are considered unfossiliferous. They belong to the Carolina Volcanic-Sedimentary Group, popularly known as the Carolina Slate Belt. This group consists of a sequence of northeast-southwest trending, low-rank metamorphic rocks, composed in part of pyroclastics and flows and in part of water laid sediments, for the most part derived from volcanic rocks. They underlie a great portion of the eastern Piedmont region and are exposed from southern Virginia to Georgia.

GEOLOGIC SETTING

The impressions resembling organic burrows were discovered in an abandoned State Highway quarry located on the north side of a sharp bend of Rocky River at the intersection with its tributary, Long Creek, two miles southwest of Aquadale, Stanly County, North Carolina (Figure 1). The rock exposed in this quarry is a southern continuation of the tuffaceous argillite unit mapped in the Albemarle and Denton quadrangles (Stromquist and Conley, 1959). This unit has been traced to Monroe,

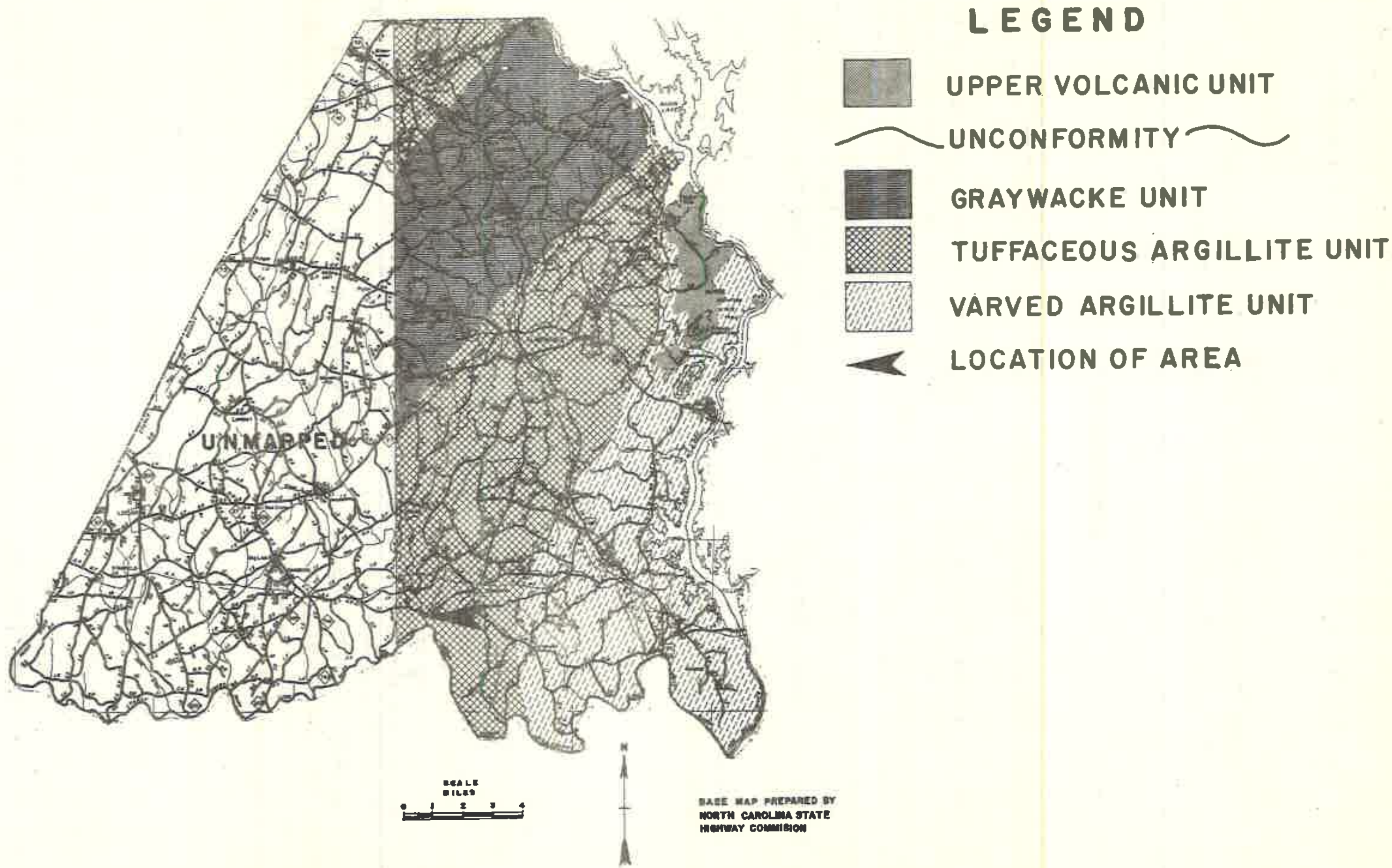

Fig. 1.- GENERALIZED GEOLOGIC MAP, STANLY COUNTY, NORTH CAROLINA

Union County, where it was named the Monroe slates by Nitze and Hanna (1896).

The rock exposed in the quarry strikes N60°E and dips 20°NW toward the axis of the New London syncline. The rock is a very slightly metamorphosed grey colored, fine-grained argillite showing pronounced jointing and a weak bedding plane cleavage. Bedding planes are usually widely spaced, varying from 3 inches to several feet, but averaging about 2 feet. The rock is exceptionally massive and breaks with a conchiodal fracture. It contains elongate wispy flattened particles, up to 2 mm in length, now composed of a kaolinite like clay mineral, which appear from outline to be devitrified glass shards. These usually occur more profusely along bedding planes and are always oriented parallel to bedding. They are found throughout the tuffaceous argillite unit as mapped in the Albemarle quadrangle and appear to be characteristic of the unit.

Study in thin section reveals that the rock of the quarry is composed predominantly of a very fine mosaic of a kaolinite like clay mineral partly altered to sericite and fairly abundant silt size angular quartz grains. In addition broken albite and orthoclase feldspar crystals up to 1/2 mm in length are interspersed as isolated grains throughout the groundmass.

In the areas mapped in detail to the north, the tuffaceous argillite unit contains numerous interbeds of pyroclastics and flows. The finer grained portion of this unit, such as the material exposed in the quarry, probably was a fine volcanic ash which settled directly into a body of water without being reworked or water transported (Stromquist and Conley, 1959). Lack of water transportation is indicated by the angularity of the feldspar grains, as well as by presence of the glass (?) shards which would not have survived much aqueous transport.

OCCURRENCE AND DESCRIPTION OF MARKINGS

The markings, resembling worm burrows, are not restricted to any particular horizon, but have been found in exposures from top to bottom of the quarry face; however, they do tend to be more profuse in certain beds than in others. Individual burrows are not limited to any horizontal plane, such as a bedding plane, but wind back and forth as well as up and down in a sinuous pattern across a broken rock surface (Figure 2). The burrows are up to 6 cm long and about 0.5 of a mm in width, although there is considerable variation among individuals. An individual marking is consistent in width throughout its length. An exception is one specimen which was slightly wider around a sharp bend of its course and also deeper around the outside curve of this bend. In cross section they are ellipsoidal and have a general width to height ratio of about 1 1/2 to 1. The tunnels are not filled in either hard or weathered rock, but remain as open capillaries; however, in weathered rock they are limonite stained while in fresh rock no iron staining has been noted.

IDENTIFICATION

The specimens were submitted for identification to Aurèle La Rocque, Department of Geology, The Ohio State University and G. Arthur Cooper,

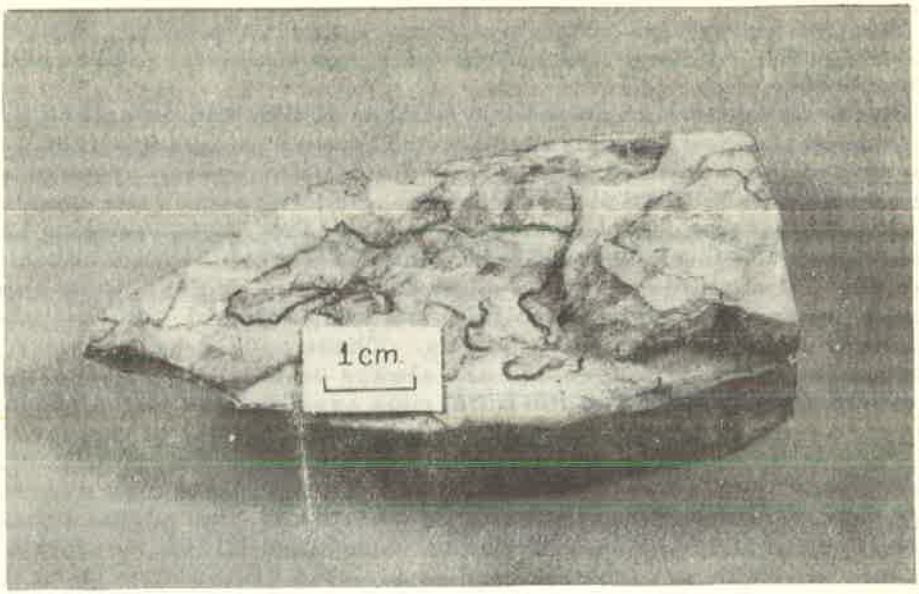

Figure 2. Photography of supposed worm burrows.

U. S. National Museum. La Rocque stated "The specimens you sent are most interesting and I must say that if they are not organic they are exceedingly good imitations. I would not go so far as to call them worm trails; they could have been made by members of several other phyla and they may yet prove to be inorganic". Cooper states, "I am sorry to send you an inconclusive determination on the specimen you submitted for examination. The examination was made by Dr. Switzer, our curator of mineralogy and by me. Dr. Switzer was unable to account for the peculiar markings as anything within the realms of mineralogy. I, too, am unable to account for these markings and feel that it is very unlikely that they are of organic origin".

DISCUSSION AND CONCLUSION

The possibility that these markings might be organic burrows are indicated by the following:

1. The markings occur in fresh unaltered rock twenty feet below the top of the quarry face and could not have been produced by modern tree roots or terrestial burrowing organisms because of the hardness of the rock.

2. No mineral form or sedimentary feature resembles these markings. Volcanic glass fibers (Pele's hair) were considered, but these fibers are not of constant diameter, are not usually serpentine in form and never consistently serpentine in form, and in addition they would lie parallel to bedding.

3. The sinuous irregular pattern is typical of organic burrows. Also, the consistent width of each individual specimen throughout its exposed length suggests a similarity to modern earthworm burrows, which also are consistent in width (and also diameter) throughout their length.

Unfortunately worm burrows as well as other forms of organic burrows are hard to identify with any degree of certainty under the most favorable circumstances. For this reason they are not positively identified unless associated with scolecodonts. They are useless in age determination because they occur in rocks ranging from Cambrian to Recent and in addition impressions resembling worm burrows have been described from the Precambrian (Algoncian) Greyson Shale of Montana (Shrock and Twenhofel, 1953) and Middle Huronian, Ajibik Quartzite of Michigan (Faul, 1949).

Although these markings cannot be positively identified as organic in origin they are quite similar to worm burrows, and indeed might be the first fossil evidence discovered in the Carolina Volcanic-Sedimentary Group. The author hopes in reporting this find that it will stimulate a further search for fossil evidence in the Carolina Volcanic-Sedimentary Group.

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A STUDY OF THE DISPERSAL OF A CALCAREOUS SEDIMENT

By

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ABSTRACT

A number of samples of a calcareous shale were treated with a standard procedure, but varying reagents and reagent normalities, with the object of dispersing the sediment without dissolving the calcium carbonate content. The stability of the resultant dispersals was tested by determing the degree of dispersal after successive 48 hour periods. The best and most stable dispersal was achieved with 0.300 N sodium hexametaphosphate. The conclusions of this study are not necessarily applicable to all calcareous sediments because only one shale was studied.

INTRODUCTION

Object and Limitations of the Study

A number of samples of a light gray (5Y5/1) calcareous shale (Cretaceous Woodbine Shale from Jewell Street and Boulder Creek, Austin, Texas) containing 38.3% calcium carbonate by weight* were treated with various dispersal reagents to determine which was the more effective in disaggregating the sediment. Ten gram samples were used throughout this study. The dispersal of the sediment was accomplished in every case without prior acid digestion since, in a study of the size distribution of a calcareous sediment, the calcium carbonate is an integral part of the distribution and must therefore be included. The objective, then, of this study was to disperse a sediment high in calcareous content without dissolving the calcium carbonate. Since the study was made on only one calcareous shale, the results of the experimentation may not be generally applicable, but may act only as a guide for determination of the best reagent for a given calcareous sediment.

Review of the Literature

The author found scant mention of calcareous sediments in the literature on dispersal. Rubey (1930, p. 11) suggested prolonged soaking for one month or more in slightly ammoniacal water with frequent and vigorous shaking, and occasional rubbing with a rubber pestle. Olmstead et al (1930, p. 32) obtained stable dispersal of calcareous soils with sodium oxalate but without acid digestion. Krumbein (1933, p. 127) found that he could effect dispersal by use of sodium carbonate, although he suggested that sodium oxalate should be even more effective. Much of

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* This percentage was obtained by weighing a sample, then digesting with 1 N HCl and reweighing the dried residue.

the soil science literature, such as Bodman (1928, p. 464) and Wiegner (1927, p. 381), recommends treatment with hydrochloric acid before dispersal. As mentioned above, this method should only be used when all other lines of attack have been exhausted since it dissolves the primary calcite which might be present, and thereby destroys an important portion of the particle size distribution. Tyner (1940, p. 108) found glassy sodium metaphosphate to be an effective dispersal reagent, and Kilmer et al (1949, p. 17) and Tchillingarian (1952, p. 232) acquired very stable dispersals with sodium hexametaphosphate.

ACKNOWLEDGEMENTS

The author is indebted to Roy L. Ingram for suggestions and aid which he gave during the course of the laboratory experimentation.

METHODS

Test Procedures

A standard procedure was adopted for treatment of the samples used in this study. First, the entire sample was crushed with mortar and pestle so that the largest fragments remaining were less than three or four millimeters in diameter. The crushing was done with care to insure against destruction of the particles of the distribution by fracture. The sample was then split to 10.00 gram increments, which were placed in 600 ml beakers with a sufficient amount of dispersal reagent to make the final 1000 ml settling suspension of the desired normality. Enough de-mineralized water was added to the beaker to make a 400 ml soaking solution. The sample was then allowed to soak for 24 hours. At the end of this soaking period the sample was stirred for 15 minutes with the mechanical stirrer (electric drink mixer), poured into a 1000 ml soil cylinder, and de-mineralized water was added to make the volume of the settling suspension 1000 ml. The percentage by weight in the suspension of material less than 1/256 mm in diameter as determined by the pipette method was used as a relative gauge of the degree of dispersal of the sample.

Dispersal Reagents and Normalities

This study was limited to the three dispersal reagents suggested most consistently in the literature: sodium carbonate, sodium oxalate, and sodium hexametaphosphate. For comparison, the sediment was also dispersed in de-mineralized water.

To obtain a curve of dispersal versus normality of dispersal reagent, a series of suspensions of varying normality was tested for each reagent (Table 1). A few drops of material from the center of the better dispersed suspensions were examined under the petrographic microscope to determine the amount of solution extant on the calcite particles of the distribution.

Finally, to test the amount of flocculation occurring in the dispersed suspensions over a period of time (and thereby the stability of the dispersals), several tests for dispersal were made after the 1000 ml settling

Table 1

REAGENT	NORMALITY	PERCENT CLAY YIELD
Sodium hexametaphosphate	0.001	9.0
	0.003	19.5
	0.005	20.8
	0.010	24.5
	0.020	26.5
	0.050	28.0
	0.100	37.0
	0.200	46.5
	0.300	63.0
	0.400	59.0
Sodium oxalate	0.001	2.6
	0.003	5.5
	0.005	24.5
	0.007	30.5
	0.010	19.0
Sodium carbonate	0.001	4.0
	0.002	23.2
	0.003	5.4
De-mineralized water	-	0.25

Representative normalities of various dispersal reagents, and degree of dispersal for each as measured by percent clay yield.

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suspensions were allowed to soak for 72 and 120 hours (Figure 3).

RESULTS

The results of this study are summarized in Table 1, and Figures 1, 2 and 3.

Best Reagent and Normality

Sodium hexametaphosphate was found to give the best dispersal, and a 0.300 N solution was the most effective concentration of this reagent The dispersal with this normality is 250 times more complete than dispersal in a suspension with no reagent, and over twice as effective as with 0.007 N sodium oxalate, the next best reagent.

A 0.002 N solution of sodium carbonate yielded the best dispersal obtained with this reagent; but even with this normality, degree of dispersal was poor.

Retention of Calcium Carbonate

To determine whether or not dispersion had been attained without dissolving the calcium carbonate in the distribution, slides prepared fron the better dispersed suspensions were examined under the petrographic microscope. When examined under a magnification of 450 X, a few drops

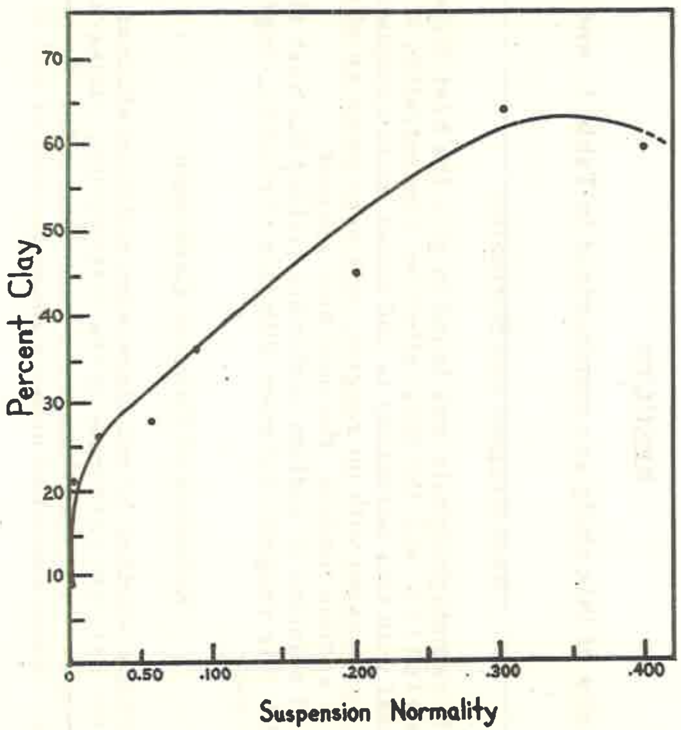

Figure 1: Percent clay yield as a measure of degree of dispersal with varying normalities of sodium hexametaphosphate.

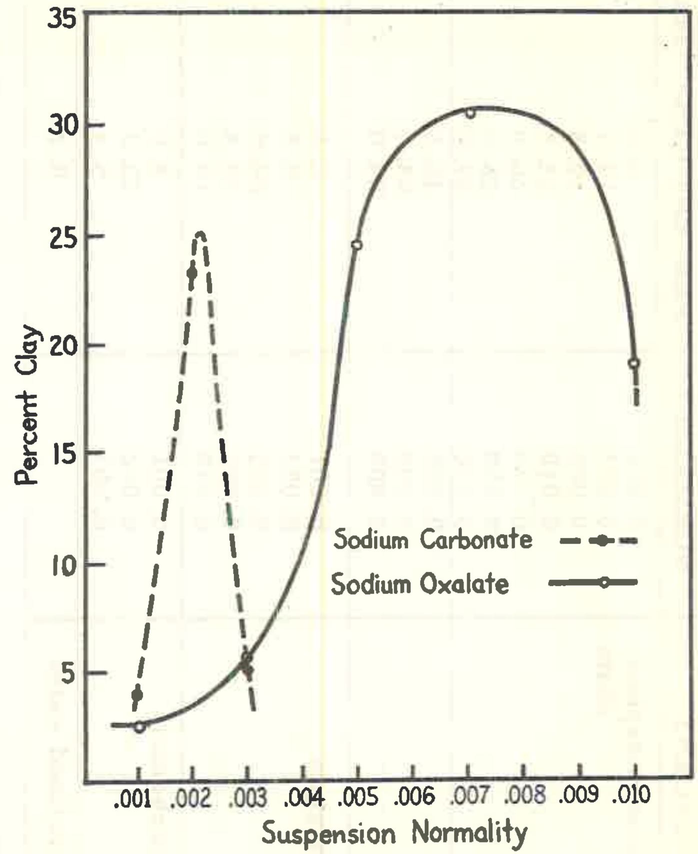

Figure 2: Percent clay yield as a measure of dispersal with suspensions having varying normalities of sodium carbonate and sodium oxalate.

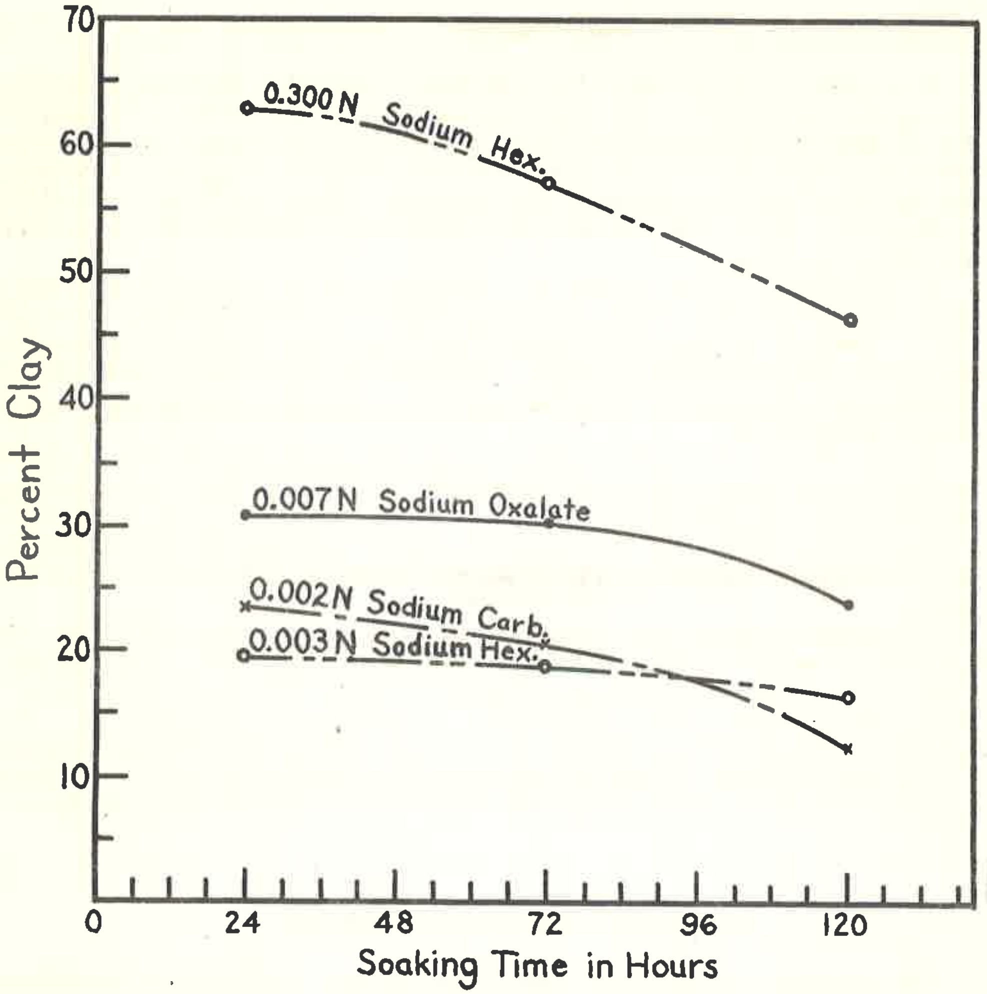

Figure 3: Variability of degree of dispersal with time of soaking in different dispersing reagents.

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from the 0. 300 N sodium hexametaphosphate suspension showed calcareous micro-fossils apparently intact indicating that the dispersal took place without appreciable dissolution of the calcium carbonate in the size distribution. Similar test samples from the 0. 007 N sodium oxalate and the 0. 002 N sodium carbonate suspensions gave similar results.

Stability of Dispersal

The variability of dispersal with time of soaking in the settling suspension is shown in Figure 3. In every case, the percent clay decreased with the length of time of soaking. It will be noted from Figure 3 that sodium hexametaphosphate also yields the most stably dispersed suspensions. The curve for 0. 003 N sodium hexametaphosphate is included for comparison since its degree of dispersal approximates that of 0. 007 N sodium oxalate and 0. 002 N sodium carbonate.

DISCUSSION

It is quite evident, from the extreme variability in degree of dispersal among the reagents tested, that the results of any mechanical analysis of a calcareous sediment will not only depend on the actual size distribution present, but also on the dispersal reagent used, its concentration, and the duration of soaking of the sample. Thus, as Krumbein (1938, p. 69) noted, there may be no truly unique and reproducible size analysis of a given sediment.

An important requirement of a satisfactory dispersal is that the sediment should not flocculate during analysis as noted by Krumbein (1938, p. 67). Sodium hexametaphosphate has a greater retentive power than any of the other reagents tested, and therefore has the added advantage of allowing a margin of error in case the analysis is delayed for any reason (Figure 3).

It was observed in some cases (see the curves for 0. 300 N and 0. 003 N sodium hexametaphosphate in Figure 3) that the higher the normality of sodium hexametaphosphate used, the higher was the clay yield during the first 24 to 48 hours, but also the faster was the reflocculation of the sediment in the suspension over an extended period of time (four to eight days).

The great superiority of sodium hexametaphosphate indicates that, before its use as a dispersal reagent became common, size analysis of calcareous sediments with any degree of accuracy must have been virtually impossible. Any comparison of mechanical analyses of calcareous sediments dispersed in recent years with sodium hexametaphosphate (or its commercial buffered equivalent, Calgon) with older analyses where sodium oxalate or other reagents were used would be meaningless.

SUMMARY AND CONCLUSIONS

The presence of primary calcite particles, including micro-fossils, in some calcareous sediments makes it desirable to disperse these sediments without dissolution of the calcium carbonate. The present study indicates that sodium hexametaphosphate will produce the best and most stable degree of dispersal, with a concentration of 0. 300 N being the most effective solution tested. The other reagents tested in this study were poor dispersal agents when compared with sodium hexametaphosphate. In descending order of their effectiveness they were: sodium oxalate, sodium carbonate, and de-mineralized water.

It must be emphasized that the conclusions of this study may not be readily applicable to all calcareous sediments since, as Krumbein (1938, p. 68) noted, there can be no universally effective dispersal technique for all sediments, or even for all calcareous sediments.

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PHYSICAL AND MINERALOGICAL PROPERTIES OF PLEISTOCENE (?) SURFICIAL DEPOSITS IN THE UPPER COASTAL PLAIN OF NORTH CAROLINA*

By

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ABSTRACT

To evaluate the hypothesis, Pleistocene deposits of the Coastal Plain in North Carolina above an elevation of 100 feet are fluvial in origin and have arisen through reworking of the underlying sediments, samples were collected for analysis from sandy deposits at different elevations. From data obtained through mechanical and mineralogical analyses, it was concluded that the Pleistocene (?) surficial deposits of the Coastal Plain are fluvial in origin and that they have arisen through a reworking of the underlying sediments. Increased sorting occurs from the higher elevations to the lower elevations and also sorting occurs within elevational regions from the ridges to depressional areas. These two factors indicate that local sorting has occurred and is a major factor in the evolution of the Coastal Plain landscape. The mineralogical suites found in the surficial deposits at different locations are conspicuously uniform in nature. These suites are in turn very similar to those of the underlying sediments as has been reported by other investigators.

INTRODUCTION

Pleistocene (?) surficial deposits in North Carolina are very extensive in the Coastal Plain area. According to many investigators these deposits are of marine origin (Shattuck, 1906; Stephenson, 1912; and Cook, 1936). The views of these investigators have been challenged by Flint (1940) who contends that inadequate evidence is offered in support of the proposition that the surficial Pleistocene deposits are completely marine in origin. He proposes that surficial sediments occurring above an elevation of 100 feet are fluvial since few, if any, marine fossils and no continuous shore scarps are found above this elevation. Campbell (1931) also concluded that Pleistocene sediments above an elevation of 100 feet are fluvial. Richards (1950) does not feel that adequate proof has been offered for either fluvial or marine origin. In recent work reported by Howard (1955), the conclusion was reached that the Pleistocene deposits in Sampson County, North Carolina are of combined fluvial and marine origin. The maximum elevation in Sampson County is approximately

*Contribution from the Department of Soils, North Carolina Agricultural Experiment Station, Raleigh, North Carolina. Published with the approval of the Director as paper no. 1165 of the Journal Series.

200 feet, and the lowest elevation is 32 feet. Therefore, these sediments should cut across the fluvial and marine boundary set by Flint (1940).

In view of the conflicting philosophies of the foregoing investigators the hypothesis was advanced that the Pleistocene deposits of the Coastal Plain above an elevation of 100 feet are fluvial in origin and have arisen through reworking of the underlying sediments. To test this hypothesis, samples were collected from sandy deposits above the 100 foot level for mechanical and mineralogical analyses.

SAMPLE SITES

Soil: Eustis Sand, Profile 1, Moore County, North Carolina.
Location: West side of Highway 501, 2.3 miles south of Pinehurst, North Carolina.
Topography: Crest of ridge. A slope downward to the west of 6%.
Elevation: 510 feet.
Sampling Depth*: 32 to 42 inches.

Soil: Eustis Sand, Profile 2, Scotland County, North Carolina.
Location: .8 mi. SE of the traffic light in Laurel Hill on U. S. Highway 74.
Topography: Upland Divide.
Elevation: 250 feet.
Sampling Depth: 38 to 44 inches.

Soil: Eustis Sand, Profile 3, Sampson County, North Carolina.
Location: 100 feet west of U. S. Highway 421, 1.3 mi. north of Midway, North Carolina, on Highway 421.
Topography: Upland Divide, Level.
Elevation: 210 feet.
Sampling Depth: 40 to 50 inches.

Soil: Lakeland Sand, Profile 1, Sampson County, North Carolina.
Location: On a secondary road 1.1 mi. west of the intersection of North Carolina Highway 102 and U. S. Highway 421; South of Pleasant Grove School .5 mi.
Topography: Gently Rolling Upland.
Elevation: 200 feet.
Sampling Depth: 22 to 32 inches.

Soil: Lakeland Sand, Profile 2, Sampson County, North Carolina.
Location: From junction of U. S. 421 and 701 south of Clinton, North Carolina, 1.6 mi. south on 701, 19 mi. east on dirt road, and .6 mi. east on dirt road.
Topography: Upland Divide, slope is 0-1%.
Elevation: 150 feet.
Sampling Depth: 18 to 32 inches.

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*Varied from one site to the next in order to sample below soil development.

PROCEDURE

Particle Size Distribution

These analyses were run according to the hydrometer procedure of Day (1956). Due to the small percentage of less than .002 mm particles, samples of approximately 200 grams were used for analysis. Sodium hydroxide was used as the dispersing agent. A large sample was dispersed and the silt and clay separated from the sand. The sand fraction, in turn, was screened and dried for the determination of the sand subfractions.

Mineralogical Determination

A survey of the entire sample was made to determine what could be expected in the way of heavy or light minerals other than quartz. From this count it was estimated that over 99% of the minerals present were light minerals and included only a trace of feldspar. Therefore, a heavy mineral separation was performed using bromoform with a specific gravity of 2.8; this separation was made on the .25 to .125 millimeter fraction. In each heavy mineral fraction a total of 300 grains was identified by use of a petrographic microscope.

RESULTS AND DISCUSSION

From the data in Table 1, it is apparent that there is a marked difference in particle size distribution between the highest and lowest elevation in the Pleistocene deposits studied. At the highest elevation the major portion of the sample occurs in the 1 to .25 mm fraction while the deposits at the lower elevation have a major portion in the .25 to .125 mm fraction. This particle size distribution may be interpreted in various ways. One explanation is that the deposits at the lower elevation have been more thoroughly reworked by the transporting agencies than those sediments at the higher elevation. Consequently many of the larger particles have been eliminated through sorting or wearing down to a smaller size. If the larger particles were lost through sorting, then the sediments at the lower elevation should have a lower coefficient of sorting (Pettijohn, 1949). This condition of a decreasing coefficient of sorting is supported by the data in Table 1. The sediments at the higher elevations (510 ft.) have a sorting ratio of 1.58; at the lowest elevation in the Eustis-Lakeland sequence the sorting ratio is 1.34.

It should be noted that samples which were taken from the depressional areas have a higher sorting index than those from the adjoining ridges. The Plummer sites in Table 1 are the depressional areas from which these samples were taken. The relationship between the sorting indicies of these sites and the adjoining ridges seems to indicate local sorting within an elevation level. The decline in sorting indicies from Plummer 1 to Plummer 111 supports the data from the Eustis-Lakeland sorting sequence.

An alternative explanation and one that has been proposed by Howard (1955) is that the existing deposits at the different elevations have been derived from a reworking of the underlying sediment, i.e. Cretaceous, Eocene, Miocene, etc. If this is true, the distribution of particles in

Table 1

MECHANICAL ANALYSIS

Depth in inches	2-1 mm	1-.5 mm	.5-.25 mm	.25-.125 mm	.125-.05 mm	.05-.02 mm	.02-.002 mm	.002 mm	[1]$S_o = \sqrt{Q_3/Q_1}$
			Eustis [2]1 (elev. 510 ft.)						
32-42	7.8	47.7	25.0	9.5	5.0	1.8	1.4	1.7	1.58
			Eustis [2]11 (elev. 250 ft.)						
38-44	1.9	28.5	43.8	17.9	3.0	.25	1.2	3.6	1.50
			Eustis [2]111 (elev. 200 ft.)						
40-50	.1	26.9	52.8	11.6	2.6	1.0	3.3	1.70	1.27
			Lakeland [2]1 (elev. 200 ft.)						
22-32	.02	23.7	62.9	5.8	5.0	1.0	1.1	.5	1.20
			Lakeland [2]11 (elev. 150 ft.)						
18-32	.50	4.1	10.1	57.0	20.9	.72	4.7	2.0	1.34
			Plummer [2]1 (elev. 250 ft.)						
0-10	1.7	26.8	30.2	14.6	10.1	3.0	6.3	7.3	2.20
			Plummer [2]11 (elev. 210 ft.)						
0-4	-	6.3	53.2	14.3	8.1	3.5	11.6	3.0	1.94
			Plummer [2]111 (elev. 140 ft.)						
0-4	.04	.59	6.9	44.0	29.0	2.7	13.8	4.8	1.73

1-The Coefficient of Sorting, So, was determined according to Pettijohn (1949).
2-The soil series developed in these deposits.

Table 2

HEAVY MINERAL DISTRIBUTION IN THE . 25-. 125 MM FRACTION OF COASTAL PLAIN PLEISTOCENE DEPOSITS

Mineral	Eustis 1* 32-42" %**	Eustis 11 38-44" %	Eustis 111 40-50" %	Lakeland 1 22-32" %	Lakeland 11 18-32" %
Garnet	.053	.012	.012	.012	.012
Zircon	.021	-	.004	.016	.020
Lexcoxene	.510	.206	.139	.143	.068
Tourmaline	.267	.176	.166	.176	.177
Kyanite	.102	.048	.019	.011	.003
Ilmenite	.056	-	.001	.001	.004
Hematite	.011	.008	.001	.002	.003
Epidote	Trace	-	-	-	-
Unknown	.032	.029	.015	.010	.016
TOTAL	1.055	.479	.357	.371	.303

* - The soil series developed in these deposits.
** - The quantity of each mineral is expressed as a % of the entire .25-.125 mm fraction.

the Pleistocene deposits would depend to a very large degree upon the type of sediments in the underlying sediment. Since the underlying sediments are quite variable and if the assumption holds that local sorting is important, a particle size analysis of the Pleistocene deposits does not yield data which one can use to correlate the two types of sediment. Therefore, a mineralogical analysis was made in an attempt to evaluate the original hypothesis.

As was stated in the original hypothesis, the proposition was made that the Pleistocene deposits above the 100 ft. level in the Coastal Plain are of a fluvial origin. If this hypothesis is acceptable then the sediment must either have come from outside the Coastal Plain or they must be local fluvial deposits and have arisen from the reworking of underlying sediments, or a combination. If the underlying sediments were reworked and remain as fluvial deposits then the mineral suites present in these deposits should be similar to those which exist in the underlying sediments. However, if these deposits have been introduced from an outside source then the mineralogical suites present may vary markedly from the existing underlying sediments in the Coastal Plain.

The mineralogical analyses which are shown in Table 2 indicate that there is a marked degree of uniformity of the mineral suites in the upper Coastal Plain Pleistocene (?) deposits. A comparison of these analyses with those made by Powers (1951) indicates that essentially the same minerals occur in these suites as were found in the Black Creek deposits. The quantities found in these analyses however do not measure up to those found by Powers. The total quantity of heavy minerals is only about 1% of the total fraction from which they were isolated. Powers found that the heavy minerals in the Black Creek formation composed about 5% of the sample. There is a marked break in quantity of heavy minerals between the Eustis 1 and Eustis 11 sites. In fact, the break is so marked and so distinct from the transition which exists between deposits at lower elevations one is tempted to conclude that the deposits at this uppermost elevation are not of the same origin as those at lower elevations. As was pointed out earlier, an alternative source for these deposits would be from outside the Coastal Plain which in this case would be from the metamorphic rocks of the Piedmont. The mineral suites in these deposits are not similar to those reported by Cazeau (1959) as being characteristic of metamorphic assemblages. Neither are they similar to those reported by Stow (1939). The proposal advanced by Howard (1955) that the Pleistocene deposits of Sampson County, North Carolina are reworked underlying sediments seems to be valid in this case also, the decrease in quantity being explained by the normal weathering of heavy minerals as continued sorting occurs.

SUMMARY

In summary one may state that, based on the mechanical and mineralogical analyses of this somewhat restricted series of samples, it would seem the Pleistocene (?) surficial deposits in the upper Coastal Plain are essentially a product of reworked underlying formations. The mineral suites of the underlying sediments are to some degree limited in their scope therefore the mineral suites which one finds in the upper sediments are also limited to a more marked degree than the sediments from which these have been derived.

The quantity of weatherable heavy minerals in these deposits will in all probability limit the amount of secondary silicates which will develop. In some instances a slight staining of the soil profile with iron oxide may be the only indication of profile development which will ever occur.

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ERRATUM

Volume 1, Number 3, p. 113.

Line 18 from bottom of page should read as follows:

> The left bank tributaries of the Neuse and Cape Fear River are longer, and the slopes on the north banks are gently sloping toward the rivers, whereas south of the rivers, the right bank tributaries are steeper, almost escarpment-like.