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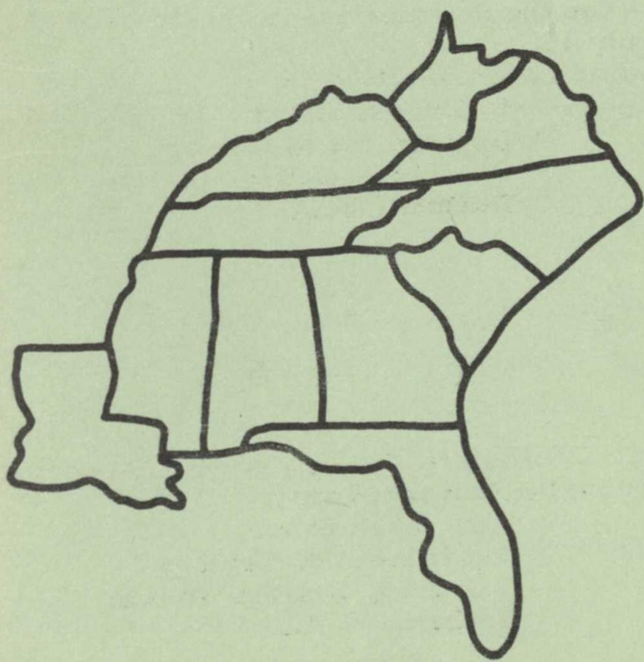

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SOUTHEASTERN GEOLOGY

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CLAY MINERALOGY OF SOME CAROLINA BAY SEDIMENTS

By

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ABSTRACT

Kaolinite, a 14 A° clay mineral, and illite were identified in 23 samples collected from five Carolina Bays in southern North Carolina. The 14 A° clay mineral does not have the characteris · tics of any of the usual 14 A° clay minerals and can with some justification be called expanded illite, vermiculite, chlorite, or montmorillonite. White Lake and Singletary Lake, both near Elizabethtown, have a kaolinite - 14 A° clay mineral - illite assemblage; and three small sediment-filled bays near Laurinburg have a kaolinite - 14 A° mineral assemblage. The availabl : facts are consistent with the conclusion that the clay minerals in the bay sediments were washed or blown into the bays from surrounding surficial Pleistocene (?) sediments and that they have undergone little alteration since deposition.

INTRODUCTION

The clay minerals in 23 samples of Carolina Bay sediments were identified by X-ray diffraction methods in order to determir e: (1) the clay minerals that characterize these bay sediments, and (2) whether or not the clay minerals were altered during or after deposition.

Carolina Bays are elliptically shaped, northwest - southeast oriented depressions that are very numerous on many parts of the Coastal Plain from Virginia to Georgia. The origin of these bays has been attributed to a number of causes: meteorites, Pleistocene winds, solution, artesian springs, eddies, and others

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Note: These studies were aided by a grant from the Duke University Research Council.

Most of these bays are now sediment-filled shallow depressions, but some have not been completely filled and contain lakes.

In each of the Carolina Bays so far examined, there is a layer of blue or light gray clay between the most recent black mud and the lower-most lake sediment. In Singletary Lake, Bladen County, North Carolina, Frey (1953) found that the blue clay contained pollen of cold climate vegetation including spruce. Material from just above the blue clay had a radiocarbon date of 10,000 years. Thus the blue clay in all the bays examined was deposited during Pleistocene time. There is considerable similarity between the blue clay layers although the bays examined were located up to a hundred miles apart.

There may have been a dominant role of wind and wind-driven lake waves in the final formation of the bays as suggested by several authors. The blue clay may have been wind-blown or reworked during the period of ice advance and maximum winds and lake waves (Odum, 1952). The blue layer may be a stratigraphic key horizon marking a regime of cold strong winds and dust over North Carolina. A 7 inch blue clay layer also underlies Lake Mendota, Wisconsin, (Murray, 1955), and blue clay occurs in lakes of Pleistocene age in New Jersey (personal communication, Dr. Paul Pearson, Department of Zoology, Rutgers University).

METHODS

Short cores of sediments were taken in two of the bay lakes and in three of the sediment-filled bays (Fig. 1). The bay lakes are White Lake and Singletary Lake, both located near Elizabethtown, Bladen County, North Carolina. Here Pleistocene surficial sands overlie the Cretaceous Black Creek formation. The three sediment-filled bays are located near Laurinburg, Scotland County, North Carolina. Here Pleistocene surficial sands overlie the Cretaceous Middendorf (Tuscaloosa) Formation.

The nature of the clay minerals and the general distribution of these clay minerals were determined by studying the X-ray photographs of the untreated clay-size material from each of the 23 samples. In order to make more positive identifications and to study the properties of the clay minerals, more detailed studies were made of a few selected samples. For these selected samples X-ray photographs were made after Ca^{++} saturation, NH_4^+ saturation, ethylene glycol or glycerol solvation, and heating at various temperatures up to 550° C. Some of the samples were sealed in glass capillary tubes after heating and X-rayed immediately in order to minimize rehydration effects. X-ray patterns were made with a Hayes diffraction unit equipped with 114.6 mm diameter

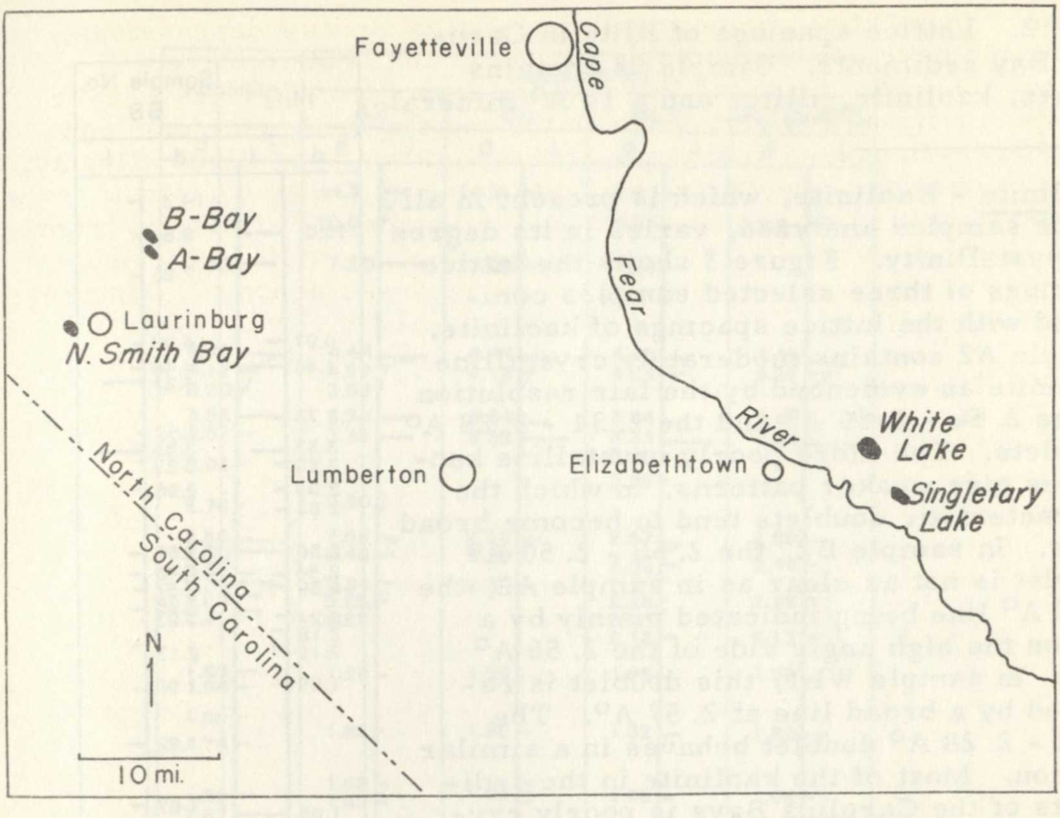

Fig. 1. Index map showing location of Carolina Bays from which clays were studied.

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cameras. Samples, placed in either thin-walled cellulose acetate or glass tubes 0. 5 mm in diameter, were exposed to filtered radiation.

RESULTS

Mineralogy

Kaolinite, illite, and a 14 A° clay mineral were identified.

Illite - Illite is present in all of the samples from the lakes. Figure 2 shows the lattice spacings of Sample S8 compared with the lattice spacings of illite. Because of the small amount of illite present, only the stronger lines are seen. Because of the presence of quartz, kaolinite, and a 14 A° mineral in this sample, only a few lines (10. 0, 3. 20, and 2. 98 A°) are produced entirely by illite.

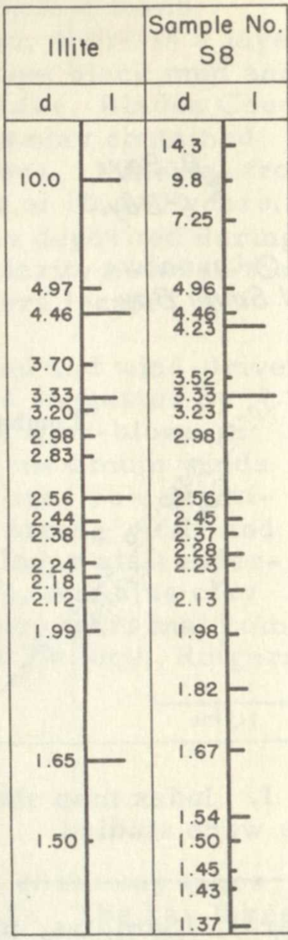

Fig. 2. Lattice spacings of illite in Carolina Bay sediments. Sample S8 contains quartz, kaolinite, illite, and a 14 A^{o} mineral.

Kaolinite - Kaolinite, which is present in all of the samples analyzed, varies in its degree of crystallinity. Figure 3 shows the lattice spacings of three selected samples compared with the lattice spacings of kaolinite. Sample A2 contains moderately crystalline kaolinite as evidenced by the fair resolution of the 2.56 - 2.50 A^{o} and the 2.34 - 2.28 A^{o} doublets. The more poorly crystalline kaolinites give weaker patterns, in which the characteristic doublets tend to become broad lines. In sample B2, the 2.56 - 2.50 A^{o} doublet is not as clear as in sample A2, the 2.50 A^{o} line being indicated mainly by a tail on the high angle side of the 2.56 A^{o} line. In sample WL1, this doublet is replaced by a broad line at 2.57 A^{o}. The 2.34 - 2.28 A^{o} doublet behaves in a similar fashion. Most of the kaolinite in the sediments of the Carolina Bays is poorly crystalline.

Because of the presence of a 14 A^{o} line that did not shift after glycerol solvation, the possibility existed that the 7 A^{o} line attributed to kaolinite was the second order basal line of chlorite. After heating the samples to 500-550^{o} C, however, the 7 A^{o} and other kaolinite lines disappeared. Heat treatment tests indicate that the 7 A^{o} line can be attributed to kaolinite.

14 A^{o} Clay Mineral - A 14 A^{o} clay mineral is present in all the samples. This 14 A^{o} clay mineral does not have the properties of any of the usual 14 A^{o} minerals - vermiculite, chlorite, or montmorillonite. Identification and characterization of this mineral is difficult because the 14 A^{o} line is the only line remaining after the lines of the other minerals known to be present are eliminated. Most of the lines of this mineral overlap lines of other clay minerals and quartz. See figure 4.

The mineral is definitely not typical montmorillonite as the 14 A^{o} line does not shift to 18 A^{o} after glycerol solvation. Tamura (1958, p. 146), however, after treating a somewhat similar 14 A^{o} mineral with sodium citrate, obtained a 16-18 A^{o} spacing following glycerol solvation. He suggests that the mineral is of a montmorillonite type. None of the Carolina Bay samples

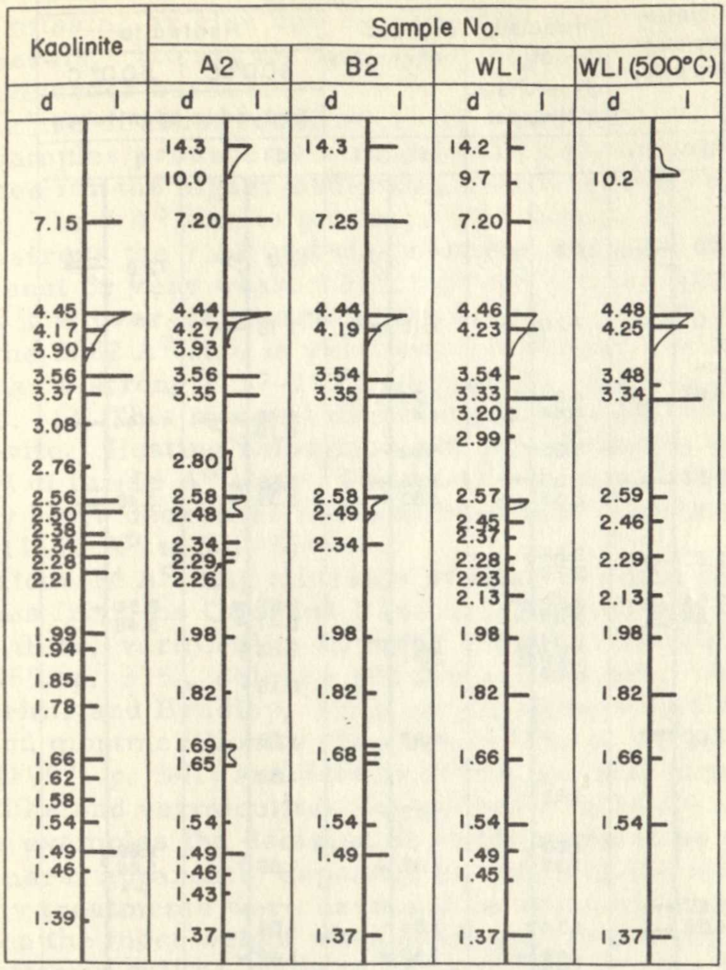

Fig. 3. Lattice spacings of kaolinite in Carolina Bay sediments. All samples contain quartz, kaolinite, and a 14 A° mineral, and sample WL1 contains a small amount of illite.

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were given the Tamura treatment.

Although the pattern of the untreated material bears a close resemblance to the pattern of vermiculite, there are too many discrepancies for the mineral to be identified as typical vermiculite: (1) Some of the most characteristic vermiculite lines are missing or else can be explained by the presence of other minerals. For example, vermiculite has a moderately strong line at 1.53 A° (Fig. 4), but all of the intensity of the line is needed to take care of the quartz in the samples as the 1.82, 1.53, and 1.37 A° quartz lines are of about equal intensity. (2) This mineral does not react to chemical and heat treatments as does good vermiculite. Boiling vermiculite in a 1 N NH_4Cl solution for 5 minutes causes the 14 A° line to shift to 11 A°; the 14 A° mineral in the

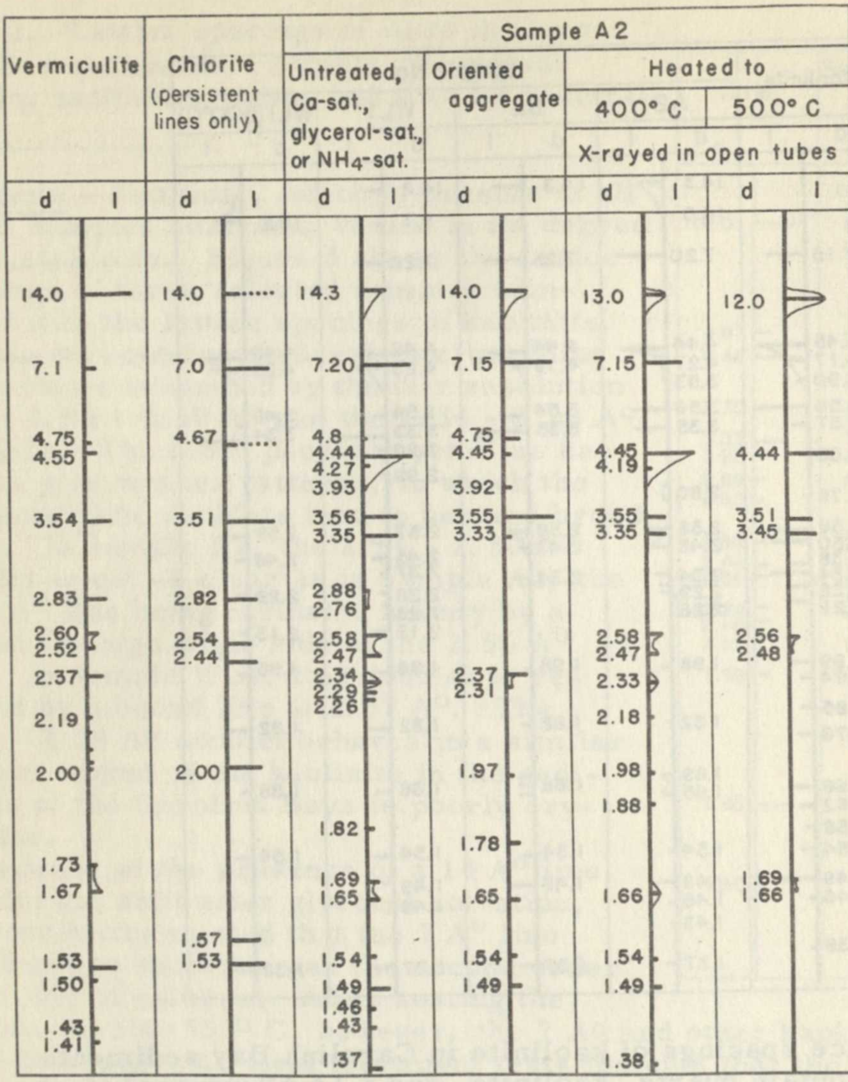

Fig. 4. Lattice spacings of a 14 A° mineral in Carolina Bay sediments. Sample A2 contains quartz, kaolinite, some illite, and a 14 A° mineral.

Carolina Bay sediments is not affected by the ammonium chloride treatment. Heating vermiculite in a thin-walled glass tube at temperatures above 110° C followed by immediate sealing of the tube to prevent rehydration causes the 14 A° line to shift to 11. 8 A° (Walker, 1951, p. 203). Sample NS1 was subjected to this treatment (heated to 175° C) with the 14 A° line shifting only to 13. 6 A°.

By the process of elimination this 14 A° mineral should be chlorite, but many of the properties of this mineral are not those of ordinary chlorite: (1) Some of the most characteristic chlorite lines are missing or else can be explained by the presence of other minerals. Except for the iron-rich chlorites, the first four or five order basal lines (14.0, 7.0, 4.7, 3.50, and 2.82 A°) of chlorite are of about equal intensity. Since the 14 A° mineral in these samples produces a strong 14 A° line, it should give strong lines for the higher order basal reflections. Such is not the case. The 7 A° line is produced by kaolinite as heating to 500° C destroys the 7 A° and other kaolinite lines. The 4.7 A° line is absent or very weak. The 3.50 A° line is absent or so weak that it is over-shadowed by the strong 3.56 A° line of kaolinite. The 2.82 A° line is very weak or absent. In addition, chlorite has a strong 1.57-1.53 A° doublet, which is absent in the Bay clays. (2) This mineral does not react to heat treatments as does chlorite. Heating chlorites up to temperatures of 700° C results in no shift of the 14 A° line. The 14 A° spacing of the mineral in the Bay clays decreases some at moderate temperatures and drops to 11-12 A° at 500-550° C.

Anomalous 14 A° clay minerals similar in many respects to the one or ones from the Carolina Bays have been called various names: expanded illite, vermiculite (Brown, 1953, p. 64; Rich and Obenshain, 1955, p. 335), chlorite (Brown and Ingram, 1954, p. 198; Johns, Grim, and Bradley, 1954, p. 243; Klages and White, 1957, p. 20), and montmorillonite (Tamura, 1958, p. 146). Johnson and Jeffries (1957, p. 541) and Schultz (1958, p. 367) identified both chlorite-like and vermiculite-like minerals in 14 A° complexes. In the above examples the decision as to the name to be given to the 14 A° mineral apparently depended on which of the many possible pre-X-ray treatments were used and on which of the evidences were given the most weight when evidences conflicted. At this time no attempt will be made to name the 14 A° clay mineral in the Carolina Bay sediments.

Some of the 14 A° lines have tails on the 10 A° side indicating 10-14 A° mixed layer lattices.

Distribution

Estimates were made of the relative abundance of the different clay minerals in each of the samples on the basis of visual estimation of the intensities of the basal diffraction lines. Although this method of determining frequencies is not very accurate, it does give a general picture of the frequency distribution. These relative abundancies are given in Table 1.

Table 1 shows that: (1) the bay lakes, White Lake and Singletary Lake, have a kaolinite - 14 A° clay mineral - illite assemblage, (2) the sediment-filled bays near Laurinburg have a kaolinite - 14 A° clay mineral assemblage, and (3) only minor variations in the relative abundance of the clay minerals exist vertically in a given core.

Table 1. Clay mineral composition and lithology of Carolina Bay sediments

Sample No.	Depth	Lithology[1]	Clay Mineralogy[2]			
			Kl	Il	14 Å	Amorp.
		WHITE LAKE				
	water.					
WL1	0 in	medium gray carbonaceous clayey silty sand (C)	5	1	4	
WL2	24	medium light gray carbonaceous clayey silty sand (C)	5	1	4	
		SINGLETARY LAKE				
	water					
S1	0 in	black humus				10
S2	2	black humus				10
S3	14	black sandy (M) humus				10
S4	18	black sandy (M) humus				10
S5	24	black sandy (M) humus				10
S6	29	light olive gray sandy (M) clayey silt	3	4	3	
S7	30	dark olive gray sandy (M) clayey silt	2	3	5	
S8	32	light greenish gray sandy (M) clayey silt	3	2	5	
S9	34	very light gray clayey silty sand (C)	5	2	3	
		"A" BAY				
A0	0 in	brownish black sandy (F) humus	3		2	5
A1	2	dark brownish gray carbonaceous sandy (M) clayey silt				10
A2	6	medium dark gray sandy (M) clayey silt	6	?	4	
A3	9	medium light gray sandy (M) clayey silt	6		4	
A4	13	light gray sandy (M) clayey silt	6		4	
A5	19	light gray sandy (M) clayey silt	6		4	
		"B" BAY				
B1	0 in	dark gray carbonaceous clayey silty sand (F)				10
B2	9	dark gray sandy (F) clayey silt	4		6	
B3	17	light gray sandy (C) silty clay	6		4	
B4	28	light gray sandy (C) silty clay	7		3	
B5	48	yellowish orange sandy (C) silty clay	7		3	
		NEIL SMITH FARM BAY				
NSF1	12 in	medium gray clayey silty sand (C)	4		6	
NSF2	24	light gray clayey silty sand (VC)	6		4	
NSF3	30	light gray clayey silty sand (C)	6	1	3	

[1] Almost all of the samples are quartz wackes, being composed of phenograins of quartz sand embedded in a matrix of silt and clay. The abbreviations after words "sand" or "sandy" give the maximum sand size in the sample.

[2] The abundance of the clay minerals is given by "abundance numbers" ranging from 1 to 10. As these numbers are based on visual estimation of the intensities of the basal diffraction lines, they should not be considered to give very accurate estimates of percentage.

Origin of the Clay Minerals

Reves (1956, p. 20-22) and Heron (1958, p. 102) found that kaolinite and a 14 A^{o} mineral are both plentiful in the surficial Pleistocene (?) sediments at the same elevation of the bays studied (Coharie, Sunderland, and Wicomico terraces-?) and that illite is present in small amounts in some places. The formations underlying the surficial sediments are seldom exposed and have clay mineral compositions distinct from the composition of the bay clays. The clays in the Middendorf formation are composed primarily of kaolinite, and the clays in the Black Creek formation are composed primarily of a mixture of montmorillonite and kaolinite. The distribution features listed above are consistent, therefore, with the conclusion that the clay minerals in the bay sediments were washed or blown into the bays from the surrounding surficial sediments and that they have undergone little alteration since deposition.

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RECENT STUDIES ON THE PLEISTOCENE OF THE SOUTH ATLANTIC COASTAL PLAIN

By

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ABSTRACT

Recent work on the marine Pleistocene deposits of the Atlantic Coastal Plain between New Jersey and Florida is reviewed. There is paleontological evidence of one shoreline (Pamlico) at elevation about 25 feet as well as physiographic evidence of a shoreline at about 90 feet. Both are regarded as of Sangamon age. There is less definite evidence of older Pleistocene marine transgressions.

In many cases the marine sands and clays of the Pamlico-Cape May formations are overlaid by non-marine sands and gravels. Until detailed field work can be completed, these are merely termed the "upper member."

Correlation of the Atlantic Coastal terraces with those of the Mediterranean is discussed. Shorelines representing three interglacials are recognized in the Mediterranean, whereas only one interglacial shoreline is definitely recognized in America. Various possible reasons for this difference are discussed.

INTRODUCTION

Between 1933 and 1940 the present writer made extensive collections of marine Pleistocene mollusks from the east coast of North America from Hudson Bay to the Gulf of Mexico. Various reports on these fossils and their correlation have been published (1933, 1936, 1938, etc.). At the present time the writer is bringing to completion an illustrated report on the Pleistocene mollusks from localities between Hudson Bay and Georgia. It, therefore, seems appropriate at this time that we review some of the recent work and ideas on Pleistocene correlation along the south Atlantic coast (between New Jersey and Florida). This will be based partly upon the previous work of the writer supplemented by later observations, and partly upon the work of others.

On the Atlantic Seaboard south of the Terminal Moraine there is a series of terraces and terrace remnants that occur from 25 to 270 feet above sea level, and possibly higher. Generally, the terraces have been regarded as coextensive with formations of the same name. McGee gave the name Columbia to the group of formations, while various later writers have recognized several subdivisions.

Differences of opinion have arisen as to whether these terraces are marine or fluvial. Cooke (1930, 1933, etc.), for example, recognized the horizontality of the terraces and correlated them with various high stands of the sea of the different interglacial stages. Other writers, notably Campbell (1931) and Wentworth (1930), favored a non-marine origin.

Cooke has proposed several correlations of the Pleistocene terraces of the south Atlantic coast. The following table is adapted from several of his papers and is quoted from Richards (1950, p. 37).

Altitude of shore line (feet)	Name of terrace	Age
?	-----------	Nebraskian glacial
215	Coharie	
		Aftonian interglacial
170	Sunderland	
?	-----------	Kansas glacial
140	Okefenokee	
100	Wicomico	
		Yarmouth interglacial
70	Penholloway	
42	Talbot	
?	Horry clay	Illinoian glacial
25	Pamlico	Sangamon interglacial
?	-----------	Wisconsin glacial

The marine origin of the lowest terrace (Pamlico) is easily demonstrated because of the extensive marine fauna. No marine fossils have been found in the higher (older) terraces, which would either suggest that they are non-marine or that the fossils have been weathered. Possible exceptions are localities in South Carolina to be discussed later.

The fauna of the Pamlico Formation indicates a climate slightly warmer than that prevailing in the same latitudes today and has been correlated with the last major interglacial (Sangamon). The fauna indicates shallow water. It consists of about 275 species of mollusks as well as a few other invertebrates (New Jersey to Georgia); there is a much richer fauna in Florida.

Flint (1940, 1942) objected to the correlations of Cooke and presented evidence to show that the higher terraces are of fluvial origin and that only two definite shorelines are demonstrated. He did not correlate these with any of the terrace names but used Wentworth's name Suffolk scarp for a line approximately equivalent to the inner edge of the Pamlico. Its toe is between 20 and 30 feet in elevation. The higher shoreline (Surry scarp of Wentworth) has an elevation at its toe of 90 feet. The marine origin of the higher scarp is largely based upon physiographic evidence, although, as stated later, there is some fossil evidence in South Carolina.

PLEISTOCENE OF THE SOUTH ATLANTIC COASTAL PLAIN

Let us now summarize the present status of our knowledge of the Pleistocene of the South Atlantic Coastal Plain:

NEW JERSEY

The Cape May formation has been dated from the Sangamon interglacial (Richards, 1933; MacClintock and Richards, 1936) and is thought to be at least partly equivalent to the Pamlico formation of farther south. The fauna suggests a climate slightly warmer than that prevailing in the region today. With few exceptions the Cape May fossils have come from excavations or dredgings below present sea level. The fossiliferous sands and clays of the Cape May formation are overlaid by sands and gravel, which are devoid of fossils; they extend to 30 or more feet above sea level. It is possible that we are dealing with two distinct members (1) a marine phase dating from Sangamon time and (2) a later sand and gravel of Wisconsin or later age.

The two members were clearly demonstrated in excavations for the Cape May Canal (Richards, 1944). Here the marine phase was below sea level while the material exposed in the banks of the Canal consisted of non-fossiliferous sands and gravels.

Excavations for the Cape May Canal showed another interesting feature. The spoil banks contained two distinct faunas, completely mixed. One consisted of warm water species similar to those found at other localities in the Cape May formation and consequently correlated with the Sangamon. The other material suggested a colder climate and has been correlated with the Wisconsin glacial stage. The presence of Wisconsin age fossils near the present shore line seems at first difficult to explain since it is generally thought that sea level was low at this stage and the shoreline was some 90 miles or more beyond the present beach. However, it is believed that this locality might represent an estuary of the Delaware River rather than the open ocean. That the ancient Delaware River cut across the Cape May peninsula is suggested by unusual thickness of Pleistocene deposits (Cape May formation?) at the county airport well near Rio Grande, New Jersey (Richards, 1945, p. 896).

No evidence of marine fossils has been found in the older Pleistocene formations (Pensauken and Bridgeton), which are sometimes regarded as a single unit (MacClintock and Richards).

DELAWARE

No evidence of marine Pleistocene has been found in Delaware higher than about 25 feet above sea level. These localities have been referred to the Cape May of New Jersey or the Pamlico of farther south. Studies now being conducted by the Delaware Geological Survey may result in the subdivision of the Pleistocene of that state and its correlation with deposits north or south.

MARYLAND

Some 19 marine fossil localities have been reported from the Pleistocene of Maryland (Richards, 1936). These were originally referred to the Talbot formation, but are now regarded as part of the Pamlico terrace-formation as redefined by Cooke.

The best known locality is Cornfield Harbor (Wailes Bluff) near the mouth of the Potomac River where some 78 species have been listed (Richards, 1936; Blake, 1953). It is noted that here, as at Cape May, New Jersey, the marine clays are overlaid by non-fossiliferous sands and gravels. In some places a disconformity is suggested. Perhaps it would be well to recognize two members here.

No marine fossils have been found in the higher (older) gravels of Maryland. Cooke (1952) believes that these older gravels represent older interglacial stages and that the shoreline features are not evident because of later dissection. On the other hand Hack (1955) on the basis of mapping in the Brandywine area of Prince Georges and Charles counties believes that the terraces are non-marine and that there is no evidence of Pleistocene marine transgressions at elevations higher than 100 feet. Cooke (1958) in reviewing Hack's work presents further evidence for the higher shorelines.

Rasmussen and Slaughter (1955, 1957) in discussing the subsurface formations of the Eastern Shore of Maryland recognize the following Pleistocene formations:

WISCONSIN	Parsonburg sand
Sangamon	Pamlico and Talbot formations
ILLINOIAN	--------------
Yarmouth	Walston silt
KANSAS	--------------
Aftonian	Beaverdam sand
NEBRASKAN	-------------

Marine fossils are recognized only in the Pamlico, although the authors believe that the higher terraces are also of marine origin.

VIRGINIA

The present writer recorded 17 marine fossil localities in the Pamlico formation of Virginia and no fossils in any of the higher formations.

Moore (1956) in a paper presented before the Geological Society of America in Tallahassee, Florida, described three new Pleistocene formationsthat underlie some of the terraces but are not coextensive with them. Until the full paper is published, it is impossible to evaluate the correlation and dating of these formations.

NORTH CAROLINA

Little recent work has been done on the Pleistocene of North Carolina. Some 18 marine fossil localities were reported by the present writer in 1936 with a few additional ones in 1950. All of these are referred to the Pamlico formation and contain a fauna indicating slightly warmer climate than that of today. Again, many of the localities occur at or below sea level. In a few places, however, such as along the Neuse River 10 miles below New Bern, the marine deposits are overlaid by non-fossiliferous sands, probably equivalent to the upper member of the section at Cape May, New Jersey; Cornfield Harbor, Maryland; and elsewhere.

As would be expected little evidence of a Wisconsin (low sea level) fauna is found south of Long Island. However, excavations at Manteo, North Carolina, in 1946 yielded some cold-water species including Neptunea stonei (Pilsbry). It is suggested that this indicates a Wisconsin estuary similar to the one reported near Cape May, New Jersey.

The Pleistocene deposits above the level of the Pamlico formation (25 feet) have yielded no marine fossils.

SOUTH CAROLINA

Some 17 marine fossil localities are assigned to the Pamlico formation with faunas indicating a slightly warmer climate than that of South Carolina today. For a number of years the bones of various Pleistocene mammals such as mammoth, mastodon, bison, horse and camel have been washed onto the beaches of South Carolina at Edisto Island and elsewhere. It is thought that these lived during one of the glacial stages when the land extended far beyond the present beaches.

The excavations for the Santee-Cooper Canal in 1941 revealed a bed of shells lying above the Eocene deposits. The fauna was a mixture of Pliocene and Pleistocene species. The age of this deposit is uncertain. It may represent a very late Pliocene deposit not recognized elsewhere along our coast, or an early Pleistocene deposit possibly equivalent to the Penholloway terrace-formation (Richards, 1943).

Taber, in a paper read before the Southeastern Section of the Geological Society of America*in Columbia, S. C., in April, 1954, presented evidence for two Pleistocene submergences in South Carolina, the older one for which he used the old name "Lafayette" of early Pleistocene age and a younger one (Pamlico) dated as Sangamon. Taber would correlate the Santee-Cooper bed as well as some marine diatoms from McBeth, S. C., identified by Dr. A. Hyyppa and quoted by Flint (1940) with the older marine transgression.

GEORGIA

The Pleistocene of Georgia was recently reviewed by the present writer (Richards, 1954). The several marine fossil localities were referred to the Pamlico formation, and no evidence of marine transgression was noted above the 25-foot contour.

On the other hand MacNeil (1950) on physiographic evidence recognized four marine shore lines in Georgia and Florida as follows:

Okefenokee (Sunderland)	150 feet	Yarmouth
Wicomico	100 feet	Sangamon
Pamlico	25-35 feet	Mid-Wisconsin
Silver Bluff	8-10 feet	Post-Wisconsin

FLORIDA

Considerable work has been done on the marine Pleistocene

*Personal communication from Dr. Stephen Taber.

of Florida. The writer still holds, in general, to his correlation table published in 1938, namely, that the Anastasia Formation, Miami Oolite, Key Largo limestone, and at least most of the Fort Thompson Formation, can be correlated with the Pamlico and should be correlated with the Pamlico and should be dated from the Sangamon.

Parker and Cooke (1944) recognizing that the Fort Thompson Formation consists of alternating freshwater and marine limestone exposed along the Calosahatchee River, suggested that the formation represented the various glacial and interglacial stages from Aftonian to Sangamon. The various bands are very thin and the fossils of the various marine and freshwater zones are repeated. It seems entirely possible that alternation of marine and freshwater conditions could occur within a relatively short period of time, and therefore it seems more logical to regard the Fort Thompson as representing a single interglacial stage (Richards, 1945, p. 404).

A revisit to the area on a field excursion of the Miami Geological Society in January, 1959, led to further convictions on this matter. The same conclusion was expressed by Schroeder (1954, p. 29).

Parker and Cooke (1944, p. 286-90) included in the Pamlico Formation all marine Pleistocene deposits of Florida younger than the Anastasia. In the region around Lake Okeechobee and the Caloosahatchee River the Pamlico Formation overlies the Fort Thompson Formation. The Pamlico in this area generally consists of barren quartz sand. If the Anastasia and Fort Thompson are correlated with the Pamlico of farther north and are dated as Sangamon, the Pamlico as used in Florida may be equivalent to the barren sands overlying the fossiliferous Pamlico in northern Florida (Rose Bluff on St. Mary's River), in the Carolinas and Maryland, and overlying the marine Cape May in New Jersey. Until further field work can be done, it is proposed that this upper, barren sand be termed the "upper member" generally of non-marine origin as contrasted to the Pamlico proper which is marine.

DuBar (1958) in his recent summary of the Miocene, Pliocene and Pleistocene of Florida dates the Caloosahatchee formation as Pleistocene. This formation has always been regarded as Pliocene mainly on the basis of its extensive molluscan fauna. The Pleistocene date is based mainly upon the evidence of a few vertebrate fossils, especially a tooth of Equus leidyi, and seems to be outweighed by the evidence of the extensive invertebrate fauna.

There is some evidence of a marine Pleistocene deposit older than the Anastasia-Miami from fossils obtained at the depth of 118 feet in a well at Delray, Palm Beach County, and from a well at Kissimmee, Osceola County, although this latter fauna may be Pliocene (Richards, 1938, p. 1281-1287).

SUMMARY OF DATA ON ATLANTIC COASTAL PLAIN

1. There is paleontological evidence of one Pleistocene shoreline (Pamlico) at elevation about 25 feet from New Jersey to Florida. This is approximately equivalent to the Suffolk scarp. A Sangamon age is indicated.

2. There is physiographic evidence for a shore line at about 100 feet approximately equivalent to the Surry scarp. It is suggested that this also dates from the Sangamon with no low sea level stage between it and the Pamlico shoreline.

3. There is less definite evidence for an older Pleistocene marine transgression.

CORRELATION WITH THE MEDITERRANEAN

In parts of the Mediterranean area fossiliferous Pleistocene beaches have been correlated with all three of the interglacial stages. The present writer has visited many of these localities in Italy, Spain, Lebanon, Israel, Tunisia and Algeria, and will report elsewhere in more detail on their probable correlation with the Pleistocene of the Atlantic Coastal Plain. Suffice it to say at this time that the shorelines are high above sea level in Lebanon, decreasing to only slightly above sea level in Israel, probably below sea level in Egypt (near the mouth of the Nile) and well above sea level in Tunisia and Algeria. Probably some of the differences in elevation are due to subsidence caused by sediments carried down by the Nile River. The Pleistocene of the Coastal Plain of the Gulf of Mexico is similarly depressed by the Mississippi River sediments.

Various names have been given to the old shorelines of the Mediterranean area and numerous attempts have been made to correlate them with the three interglacial stages. However, at the present time there is no absolute agreement as to the dating of these beaches. The present writer agrees with remarks made by Flint at the meeting of INQUA[1] in Rome in September, 1952, namely that in view of the similarity in elevation of the two well-marked shorelines on the east coast of North America (25 and 90-100 feet) and the two Mediterranean strand lines at about the same elevations, both pairs should be dated from the third interglacial. On the other hand, Zeuner believes that the 90 foot (30 meter) shoreline of Western Europe represents the Great (second) interglacial. (Both remarks quoted at conclusion of paper by Richards, 1956, p. 528).

The question arises as to why three interglacial stages are

[1] International Association for Quaternary Research.

represented in the Mediterranean area with beaches up to 900 feet above sea level, while in eastern North America there is only clear evidence of a single interglacial high stand of the sea. No answer is available that is entirely satisfactory. However, let us consider several possibilities.

1. One possible answer is that the older shorelines and fossils have been obliterated by weathering and erosion. But why has this been so much greater in America than in the Mediterranean area?

2. Another possible answer lies in the movement of the land. It is generally agreed that the higher shorelines of the Mediterranean area have been considerably uplifted and deformed, although the lower beaches (below 90 feet) have not been materially uplifted. Contrary to the situation in Italy, Lebanon, etc., the Coastal Plain of the Eastern United States is thought to have been relatively stable during middle and late Pleistocene time. It is obvious that direct correlation of shorelines on the two sides of the Atlantic entirely on the basis of elevation, as has been attempted by several, has no validity in view of the different diastrophic histories of the two regions.

It is possible that further research will demonstrate that the Atlantic Coastal Plain has been subjected to Pleistocene deformation, possibly of a block or non-warping variety. Hack (1955, p. 38) states that in view of the recognized Pleistocene deformation of parts of the Gulf Coastal Plain, it is difficult to believe that the Atlantic Coastal Plain could have remained stable. It is just as plausible to think that the Atlantic Coastal Plain subsided as to think that the shores of the Mediterranean rose.

Thus, it is possible that the older interglacial shorelines lie below present sea level along the Atlantic Coast due to later subsidence of the land, and are not observable today because they lie beyond the present shoreline.

3. It is generally supposed that the older interglacial shorelines are higher than those of the last interglacial. But this may not necessarily be the case. In Italy and Lebanon the older terraces may be very high because of the later elevation of the land. Sea level itself may have been at about the same elevation during the three interglacials. Thus, the deposits of the three interglacials may be superimposed on each other along the Atlantic Coastal Plain. A possible objection to this theory is the presence of raised beaches up to 128 feet elevation in the British Isles, notably on the island of Jersey, a region that is thought to have been relatively stable.

4. In a paper read before the American Association for the Advancement of Science in Washington, D. C., in December, 1958, Lougee presented evidence to show that there was only a single glaciation in North America without any major interglacial stages. It is, of course, too early to evaluate this paper since only a brief summary has been published. However, according to this interpretation the high level shorelines probably are preglacial and

the differences of elevation could be explained by differences in diastrophic movements of the land.

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ROCK SALT, RHYTHMIC BEDDING, AND SALT-CRYSTAL IMPRESSIONS IN THE UPPER SILURIAN LIMESTONES OF WEST VIRGINIA

By

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ABSTRACT

The Tonoloway and the underlying Wills Creek limestones are of Cayugan age and are the uppermost definitely Silurian formations in West Virginia. The Cayugan Series in large part correlates with the Salina Group of New York. Many lithologic zones of the outcrops of these limestones in eastern West Virginia consist of chemically precipitated, alternately light and dark laminations which were rhythmically deposited under very quiet conditions. Couplets of the laminae appear to be homologous to varves in the sense that each lamina represents a pulse in the accumulation of the dark organic material on the bottom of shallow saline bodies of water. Salt-crystal impressions in zones in the limestone closely associated with the laminated zones indicate an equivalent time relationship to the great salt deposits of the Salina.

It is extremely unlikely that the laminated limestones could have been deposited over such a wide area in an environment of strong tides which must have characterized Silurian seas, and it is concluded that during extended periods of chemical precipitation at least this part of the Appalachian basin of deposition was not connected with the ocean. Associated zones of clastic deposits and zones of intraformational beccias formed from the laminated limestones may have been developed during periods when the sea barrier was below sea level. Support is thus indirectly given to bar or tidalflood theories for the origin of thick rock salt deposits of the Salina.

INTRODUCTION AND ECONOMIC ASPECTS

The uppermost definitely Silurian formations of West Virginia are the Tonoloway Limestone and the underlying Wills Creek Limestone; they are of Cayugan age. Beneath part of the Allegheny Plateau they contain the salt beds or their equivalent horizons that apparently are continuous through Ohio and Pennsylvania with those of the Salina formation of New York. Presence of the Silurian salt beds beneath a large area of the Northern Panhandle and the northwestern part of West Virginia was indicated by the finding of salt

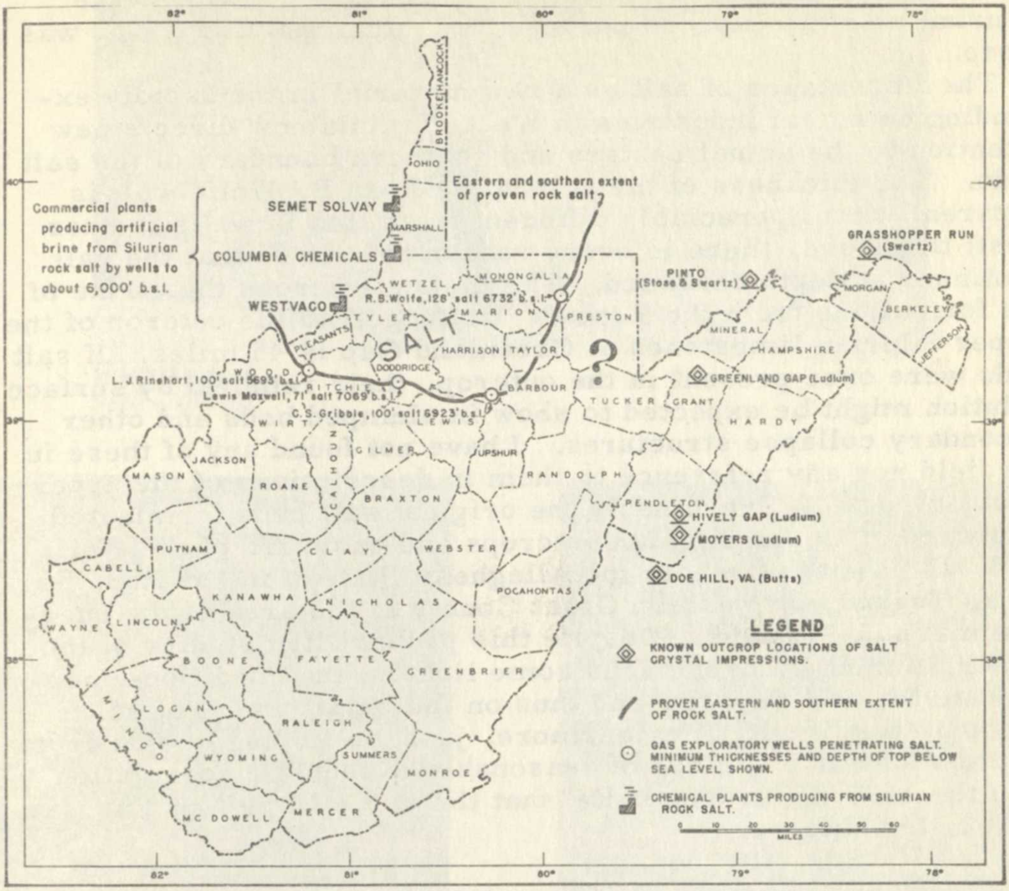

FIGURE I – SILURIAN ROCK SALT AND SALT CRYSTAL IMPRESSIONS IN WEST VIRGINIA

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in the gas-exploratory Lewis Maxwell well (Fig. 1) drilled in 1936 (Martens, 1943). The finding was confirmed and the present proved southern limits further defined by later gas-exploratory drilling, particularly by the C. S. Gribble well completed in 1941 and by the L. J. Rinehart well completed in 1942. Commercial production started in 1942 with the drilling of a number of wells by the Defense Plant Corporation at Natrium to supply artificial brine for an electrolytic caustic-soda plant operated by the Columbia Chemicals Division of the Pittsburgh Plate Glass Company. More recent production has been established for the Semet Solvay plant at Round Bottom to the north and the Westvaco plant at Bens Run to the south (Fig. 1).

The proved area of salt was extended eastward in 1952 as a result of finding it in the Rosa B. Wolfe well. This well was drilled by the Hope Natural Gas Company on the Chestnut Ridge anticline east of Morgantown near the Monongalia County-Preston County line. Drilling to the Oriskany Sandstone of the Lower Devonian did not reveal commercial gas, but a number of companies cooperated to finance deepening the well to the Silurian with the express purpose of determining if the salt was there.

The importance of salt as a raw material in the rapidly expanding chemical industries in West Virginia now directs new attention to the actual eastern and southern boundary of the salt beds. The thickness of the salt in the Rosa B. Wolfe well is apparently not appreciably different from that in wells farther west; therefore, there is every reason to believe that the salt continues at depth eastward. The distance across the strike of the formations from the Rosa B. Wolfe well to the outcrop of the Upper Silurian limestones at Greenland Gap is 45 miles. If salt beds were once present in the outcrop, their removal by surface solution might be expected to show in slumped beds and other secondary collapse structures. I have not found any of these in the field nor any reference to them in descriptions of the upper Silurian rocks. Presumably the original salt beds terminated westward of Upper Silurian outcrops and eastward of the Wolfe well, somewhere beneath the Allegheny Plateau in Preston, Barbour, Tucker, or western Grant County in the area of the question mark in Figure 1. Despite this probability, studies of the Upper Silurian outcrops shed some light on the conditions marginal to the salt deposits and thus on the environment of salt accumulation itself. Furthermore, just the finding of salt crystal impressions at a horizon of reasonably expectable correlation with the salt encourages belief that the salt will be found not far west of the outcrop.

RHYTHMIC LAMINATIONS OR VARVES

The outstanding lithologic feature of the Tonoloway Limestone is the regular alternation of thin, light and dark laminations (Woodward, 1941, p. 176, 207). This feature is also present in thinner zones in the Wills Creek Limestone. In zones where the rhythmic lamination is most regular, the limestone is essentially a carbonaceous, very fine-grained chemical precipitate (Martens, 1943, p. 42). Joint surfaces that have weathered for a few years or more show light-gray, buff, or white laminations alternating with those which are dark gray or black, whereas on fresh or polished surfaces the laminations appear as alternating dark gray and black.

Couplets containing one dark and one light lamination closely resemble varves in which each couplet represents an annual deposit and each lamination represents a pulse, probably seasonal, in the accumlation of organic material on the bottom of quiet bodies of water. Most of the couplets or varves are in the thick-

Plate I

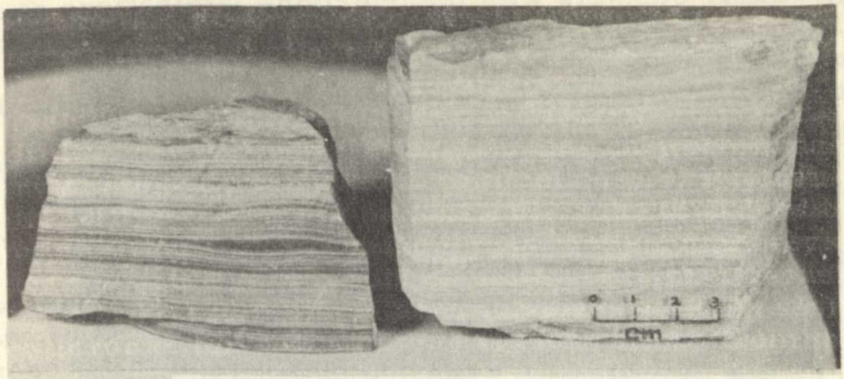

Figure I

Figure 2 cm.

Figure 3 1/2 mm.

Plate 1. Figure 1 shows laminated Tonoloway on right and Green River shale on left. Figures 2 and 3 are microphotographs at different magnifications of thin sections of Tonoloway.

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ness range between .4 and .8 millimeter, but zones in which the average thickness is 2.5 or even 5 millimeters are not uncommon. So close similarity exists between these laminations and laminations described as varves formed in present lakes or in ancient lacustrine environments that I believe they are of essentially the same origin.

Plate 1, Figure 1 shows a specimen of Tonoloway on the right and, for comparison, a specimen of Eocene Green River shale from Colorado on the left. The Green River shale is generally accepted as a good example of a varved sediment (Bradley, 1929). Figures 2 and 3 of Plate 1 are microphotographs of thin sections of the Tonoloway. They show that the laminations are not obscured in enlarged views. The lighter laminations are, in general, thicker than the dark ones, poorer in organic material, and coarser in texture. Their contacts with the overlying laminations are gradational in most places, whereas the contacts of dark laminations with light ones above are usually sharper.

A study was made of a section of the Tonoloway at Hively Gap near Franklin, Pendleton County, West Virginia (Fig. 1) to determine how the indicated rate of deposition compared with that of deposits that are generally considered to be varved. In 80 feet of Tonoloway exposed, counts were made of the laminal couplets in samples 4 to 6 inches thick that appeared to be representative of that particular zone. The resulting estimate was 24, 320 couplets which, if interpreted as annual deposits, would mean that it took 24, 320 years to form 80 feet of the present Tonoloway and that the average thickness representing one year's deposition would be 1 millimeter. It is a coincidence but perhaps significant that this is the same average-thickness figure which has been given for nonglacial lacustrine varves in general (Rubey, 1930, p. 48).

SALT-CRYSTAL IMPRESSIONS

In several zones of the quarry at Hively Gap, numerous partial molds and partial casts of salt crystals are preserved on major bedding planes. Similar impressions were found in the Tonoloway at Moyers Gap, which is 15 miles to the southwest, and at Greenland Gap, which is 35 miles to the northeast (Fig. 1). These three new localities are in the general structural trend between two others to the northeast and one to the southwest. To the northeast, Stose and Swartz (1912, p. 5) found casts of salt crystals in both the Wills Creek Limestone and the lower part of the Tonoloway Limestone at Grasshopper Run, and Swartz (1923, p. 114-126, 169) described others in the upper part of the Wills Creek Limestone near Pinto, Maryland (Fig. 1). To the southwest in Highland County, Virginia, they have been found in float at the position of the Wills Creek Limestone (Butts, 1940, p. 261).

Salt-crystal impressions at the three new localities were not found in the most finely laminated parts of the limestone. At Hively Gap the zones of greatest abundance are in light-colored and, in some cases, rather shaly limestone. At Greenland Gap the impressions are on carbonaceous limestone slabs having bedding planes spaced one-half inch or more apart. The largest impressions found measure 1 inch directly across the square face

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Plate 2. Salt-crystal impressions (partial pseudomorphs or casts) found as projections from lower surfaces of Tonoloway beds. Basal parts of: c-ordinary cubes, p-pyramidal corners of cubes, h-hoppers, s-starlike corners of hoppers.

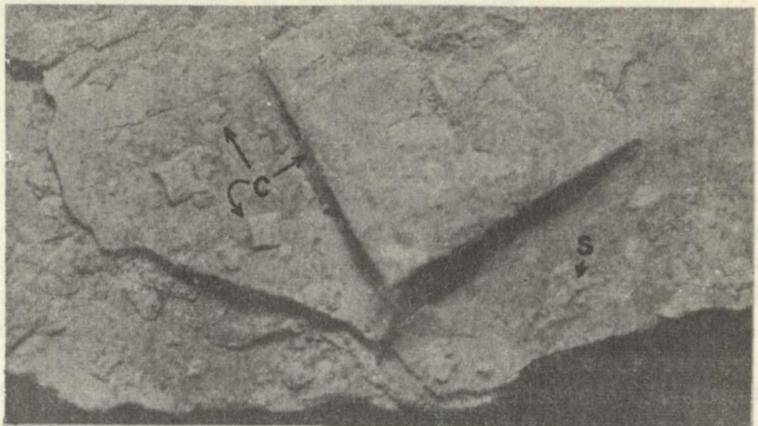

Figure 1   1 inch

Figure 2   1 inch

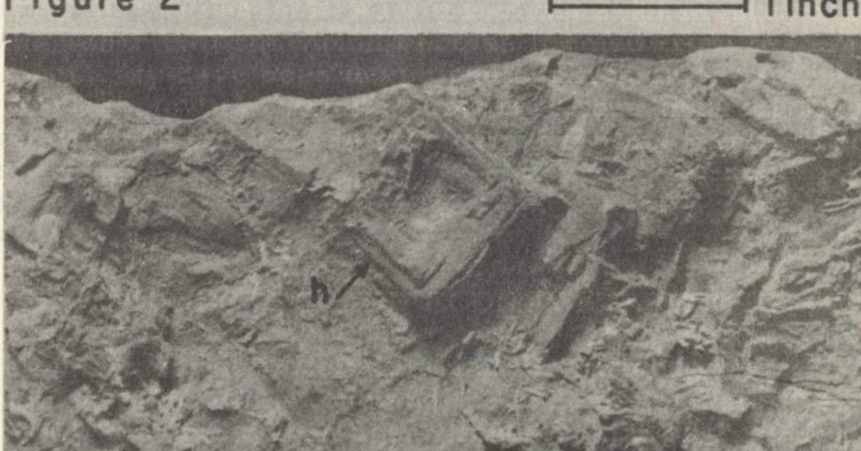

Figure 3   1 inch

(Plate 2, Fig. 1), whereas the smallest measure less than 1 millimeter. Extended weathering, either by waters penetrating along bedrock bedding planes or acting on exposed bedding planes of float slabs, appears necessary to etch out the salt impressions. None were found by forcing apart tight bedding planes.

The most evident forms are casts which project from the bottom of beds (Plate 2). Corresponding molds in the surface of the beds below are not as distinctive nor as easily recognized. There is a downward offsetting of minor color and textural planes in the sediment forming the casts. This seems to indicate that the salt crystals were only partially embedded in the calcareous mud of the underlying bed when covered by sediment now forming the overlying bed. Solution of the salt before lithification was complete produced slumping into the cavity or mold. The material of the cast is therefore that of the overlying bed and consequently the natural parting is along the lower boundary planes of the cast. The forms are only partial pseudomorphs because only those parts of the crystals which were embedded in sediment of the lower beds were cast. The result is that although they are often square in plan, they are shortest in the dimension normal to the bedding and the full cubic form is not duplicated (Plate 2, "c"). The edges of some of the square casts bound a four-sided, terraced, central depression (Plate 2, "h"). These terraces are impressions of the growth lines of the crystal that are related to molecular structure of the salt and give rise to the common salt crystals known as "hoppers".

There are many other variations which represent different crystal orientations with respect to the bedding. Some are three-faced pyramids formed by the corners of regular cubes (Plate 2, "p"). Hopper-shaped crystals of similar orientation have casts in the form of three-pointed stars (Plate 2, "s").

I have observed the precipitation of salt crystals from brine evaporating naturally under room conditions, and there were produced small crystals and crystal groups whose orientation and outlines match the description of all those observed in the Upper Silurian limestones. Crystal growth was initiated on the surface of the brine and continued until a critical size was reached, whereupon the crystals settled to the bottom with random orientation, singly or in groups, and there continued their growth.

PSEUDOMORPHS OF ANOTHER EVAPORITE

Complete pseudomorphs of calcite after another evaporite mineral, probably anhydrite, but possibly trona or glauberite, also were found in several zones in the Tonoloway Limestone at Hively Gap. They form a fine crisscross pattern within thick laminations of the limestone (Plate 3). The pattern form is a

Plate 3

Plate 3. Pseudomorphs of calcite after anhydrite (?). Cross sections shown on freshly broken surface at left, whereas external forms are weathered in relief at right.

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result of a rather even distribution of groups of three or four intergrown crystals of the original mineral. In the few specimens found in which the secondary calcite of the pseudomorphs has weathered out in relief, it has been on joint surfaces rather than on bedding planes (Plate 3, specimen on right).

Apparently these pseudomorphs have not been noted before in descriptions of outcrops of the Tonoloway or Wills Creek in West Virginia despite the frequency with which anhydrite is reported in the Cayugan sections penetrated by deep wells. Their discovery may be of some incidental help in future attemps to project the Wills Creek-Tonoloway boundary westward into records of the deep wells. This cannot now be done with certainty.

SIGNIFICANCE OF SEDIMENTARY FEATURES TO PROBLEMS OF ROCK SALT DEPOSITION

Present correlations show the commercial salt of New York State equivalent to the lower Wills Creek of eastern West Virginia. The position of the salt beds of Ohio has been placed between the Greenfield dolomite (a tentative correlate of the Tonoloway) and the Niagaran rocks below. Salt-crystal impressions in Maryland, Virginia, and West Virginia are most common in the upper Wills Creek and lower Tonoloway. Although the salt crystals were not necessarily formed at the same time as the rock salt farther west, in the absence of other information such a correlation would be reasonably favored. A section including parts of both the Wills Creek and Tonoloway in eastern West Virginia may thus prove a better correlate with the salt of New York State, Ohio, and West Virginia than the lower Wills Creek.

In most of the explanations offered for the accumulation of the thick rock-salt deposits of Cayugan time and other important salt deposits, ocean waters periodically flooded new supplies of salt to the inland basins across shallow, submerged bars (Wilfarth, 1933, 1934; Reed, 1938, 1939). It would seem that the formation and preservation of extensive thick sections of rhythmically laminated or varved sediments would also require barriers to exclude strong tidal activity from the basin of accumulation for repeated periods of many years' duration. Such barriers would be of even greater necessity during the Silurian if, as was probably true, the moon had a smaller orbit closer to the earth (Gutenberg, 1939) and therefore effected tidal activity through a greater vertical range than in present coastal waters. Thus it seems likely that the intercalation of varves and evaporites is not extraordinary because the formation of both requires some of the same environmental conditions.

In addition to barriers that excluded strong marine tides, bottom currents and winds sufficient to produce deep wave action must have been absent for long periods because the Cayugan rocks of eastern West Virginia are not deep-water sediments. Toward the east and northeast they are interfingered and progressively displace by the Bloomsburg red bed facies which was deposited along the southeastern margin of the Cayuga basin. The Bloomsburg facies has been described as an example of primary detrital red beds formed in delta and lower-river-plains environments under implied climatic conditions at the site of deposition, not unlike those of the present tropical savannah type (Krynine, 1948, p. 65, 67). These climatic conditons might be favorable but would not be necessary to the formation and preservation of seasonal deposits in the near-shore shallow water of a closed basin. They would clearly not be the optimum conditions for the accumulation nearby of thick and extensive deposits of evaporites. A tropical-savannah climate might more reasonably have characterized the source area of the red beds, with the actual deposits made by through streams in more arid, low coastal areas. It would seem that if the deposition of the Cayugan red beds was contemporaneous with nearby precipitation of salt, then aridity would be characteristic of both sites, at least for repeated periods of considerable duration. Just on the basis of these associations, without any petrographic study of the Bloomsburg, the possibility is raised that much of the red pigment was formed in an arid climate at the present site of deposition and not introduced from the source area (Miller and Folk, 1955).

In conclusion, it appears that here is an area where the mutual requirements of associated sedimentary features like the rhythmic sedimentation, salt beds, salt-crystal impressions, and red bed facies may more reliably reflect the environments of deposition than even very exacting studies of one feature. I hope that other field workers in the Appalachian Valley and Ridge province will look for these features in the Upper Silurian rocks and write of their findings and interpretations.

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GEOCHEMICAL PROSPECTING IN THE SOUTHEASTERN STATES

By

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ABSTRACT

The deep zone of weathering in the Southeastern States offers an excellent opportunity to apply geochemical methods of prospecting. Geochemical anomolies are sought first by reconnaissance in which samples are taken 500 to 1000 feet apart. Favorable areas are then sampled more closely. Analyses are made of plants, soils, and ground water.

Geochemical prospecting has already located several zinc ore bodies in Tennessee. Other metals that offer good possibilities for geochemical prospecting in the Southeast are manganese, barium, and tungsten.

Editor's Abstract.

INTRODUCTION

In many respects the Southeastern States, since they are unglaciated and consequently covered by deep residual soils, offer excellent opportunities for the successful application of geochemical methods of prospecting. In this region the intense weathering processes resultant from a warm moist climate may, while destroying all vestiges of surficial outcrops of an ore body, simultaneously disperse minute but detectable amounts of one or more of the ore metals throughout the surrounding soil. Thus the process which effectively masks the presence of an ore body from the eyes of the prospector may also create a chemical halo many times the size of the original outcrop; such an area is called a geochemical anomoly.

Furthermore, geochemical prospecting is best applied to near-surface ore bodies; too great a depth below surface prevents detection even by geochemical means. Coincidentally, the Southeastern States are sites of numerous residual deposits, a type which generally tends to occur at relatively shallow depths in residual soils. According to Behre (1950, p. 33) the Southeastern States are "the most typical part of the United States for such deposits." Behre points out that "even in rugged country, such as parts of eastern

Tennessee and northern Georgia, residual concentrates are prominent on the divides, the upper slopes, or the lowest parts of valley walls above alluvial fill."

GEOCHEMICAL METHODS

The goal of geochemical prospecting is to locate by rapid analytical procedures the invisible geochemical anomalies and thereby the underlying ore body (if any). To do this the geochemist may analyze numerous soil samples collected on 500- or even 1000-foot centers in reconnaissance surveys. The "hot spots" thereby disclosed will then become sites of sample collection (and analysis) on 50- or 100-foot centers, thus to block out the anomaly. During this survey it is necessary, of course, that the method of analysis used be sufficiently sensitive so that the metal content of the soil of the anomaly may be readily differentiated from that of the ordinary soil adjacent to the anomaly. This latter content is the so-called background content.

Plants growing above an anomaly, as well as the surface or ground waters leading from it, are also likely to contain higher metal contents than comparable materials unassociated with anomalies. Thus analyses of plant materials (biogeochemical prospecting) and of stream sediments or water samples may also aid in locating an anomaly and thereby, perhaps, an ore body. Biogeochemical methods have the advantage that the tree roots penetrate the soil in depth. Thus in areas where an anomaly has been veneered with aluvium or glacial drift, biogeochemical methods may necessarily replace soil analyses; on the other hand, care must be taken to sample the same tree species throughout (as well as the same tree organs). Generally leaf samples and second year twigs have proven most reliable. Water samples, on the other hand, have the advantage of being homogeneous and requiring little preparation prior to analysis. Then, too, if taken from springs, they may once have been in contact with materials deep within the ground. Unfortunately, surface waters are easily contaminated. In addition, the pH of the water, as well as contact with a metal-absorbing material such as clay, may affect its content of metal.

Geochemical methods have a further advantage in that non-technical personnel may be quickly trained in the routine techniques. It should be stressed, however, that the direction of the work and interpretation of the results cannot be undertaken by inexperienced personnel. For example, the location and blocking out of an anomaly does not insure the location of an ore body. The ore body responsible for the anomaly may have been largely destroyed, the anomaly representing only a chemical vestige. On the other hand, the spatial relationship between the anomaly and the ore body must be correctly determined so as to best locate the sites for drilling in probing for any underlying ore body. Numerous spatial relationships between anomaly and ore body exist. Sloping land surfaces, for example, may be associated with a considerable downhill displacement of the anomaly whereas horizontal land surfaces may not (Fig. 1).

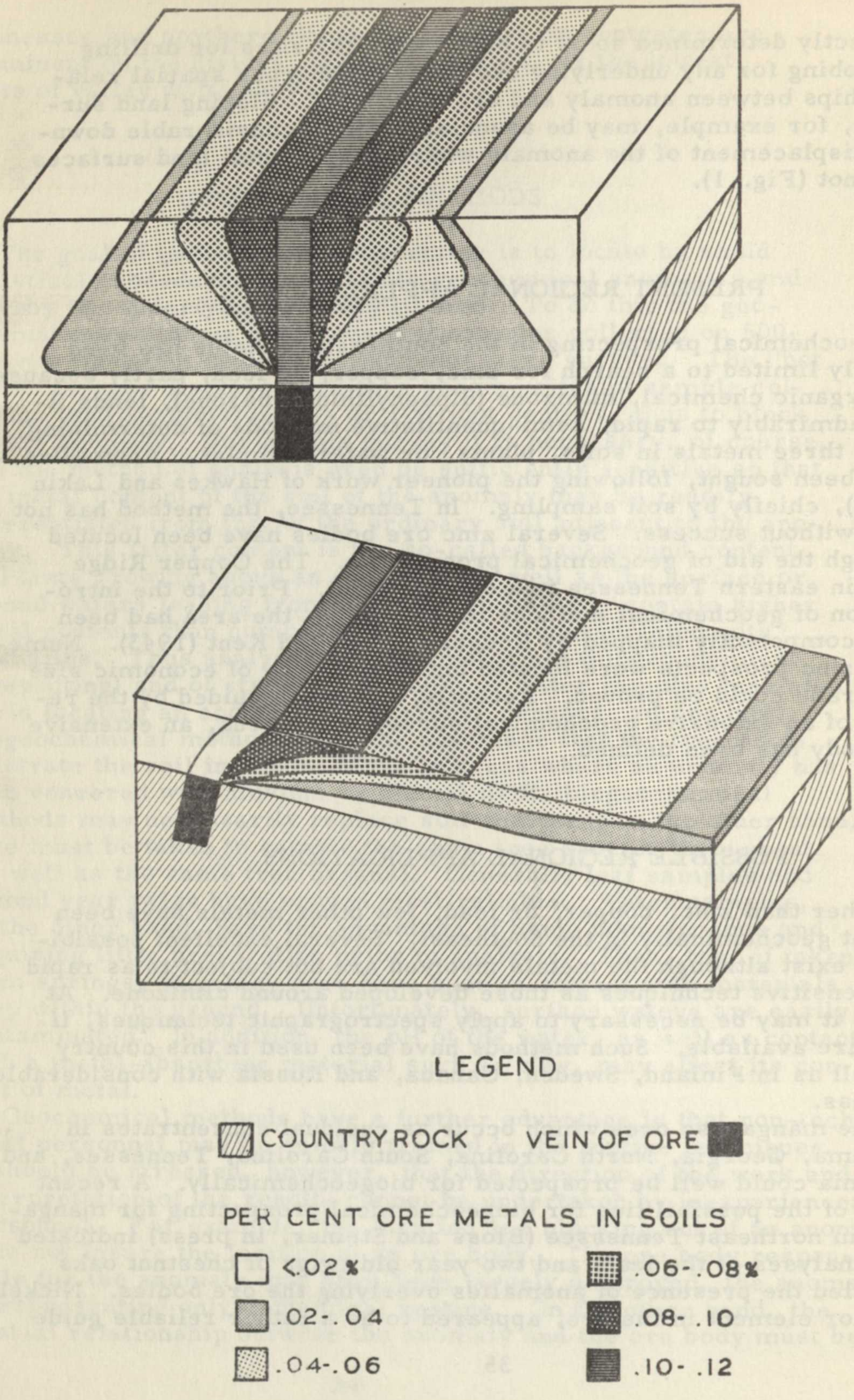
PRESENT REGIONAL APPLICATION

Geochemical prospecting in the Southeastern States has been largely limited to a search for zinc, copper, or lead, partly because the organic chemical, dithizone (diphenylthiocarbazone), lends itself admirably to rapid, semi-quantitative methods of determining these three metals in soils, plants, or water samples. Anomalies have been sought, following the pioneer work of Hawkes and Lakin (1949), chiefly by soil sampling. In Tennessee, the method has not been without success. Several zinc ore bodies have been located through the aid of geochemical prospecting. The Copper Ridge area in eastern Tennessee is a case in point. Prior to the introduction of geochemical methods to the region, the area had been very competently mapped by Rodgers (1943) and Kent (1943). Numerous zinc prospects were located but no ore body of economic size and grade could be proved. Recently, however, guided by the results of an extensive geochemical survey of the area, an extensive ore body has been defined.

POSSIBLE REGIONAL APPLICATIONS

Other than zinc, copper, or lead, few other metals have been sought geochemically in the Southeast. Several excellent possibilities exist although the metals involved are not subject to as rapid and sensitive techniques as those developed around dithizone. At times it may be necessary to apply spectrographic techniques, if they are available. Such methods have been used in this country as well as in Finland, Sweden, Canada, and Russia with considerable success.

The manganese ores which occur as residual concentrates in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia could well be prospected for biogeochemically. A recent study of the possibilities for biogeochemical prospecting for manganese in northeast Tennessee (Bloss and Steiner, in press) indicated that analyses of the leafs and two year old twigs of chestnut oaks revealed the presence of anomalies overlying the ore bodies. Nickel, a minor element in the ore, appeared to be a rather reliable guide


LEGEND
COUNTRY ROCK
VEIN OF ORE
PER CENT ORE METALS IN SOILS
<.02 %
.02-.04
.04-.06
.06-.08 %
.08-.10
.10-.12

to the manganese bodies, if present above a particular amount in the plant ash. Interestingly it was not detectable in the soil.

Work by the writer in collaboration with Dr. George D. Swingle of the University of Tennessee and Mr. Robert Steiner of the Research Laboratories of the Aluminum Company of America appears to indicate that the residual deposits of barite which occur in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia could well be prospected for by geochemical means. All investigations thus far conducted appear to indicate that the barium content of soils overlying the barite deposits is somewhat higher than for normal soil.

Tungsten deposits offer further possibilities. A field method for the determination of tungsten in soils (Ward, 1951) already exists. The method is reported to be capable of detecting as little as 10- to 800-ppm tungsten. Although the present writer lacks personal experience in the area, Espenshade (1950, p. 59) states the Hamme tungsten district of North Carolina to be "a region of low relief . . . [wherein] most of the country rocks have been thoroughly decomposed by weathering and outcrops are few." However, in spite of the fact that a determinative method for tungsten apparently exists (as well as a conducive geological setting of the deposits), no published reports of extensive use of geochemical prospecting for tungsten in the area have come to the writer's attention.

CONCLUSIONS

Geochemical prospecting in the Southeastern States has largely been limited to the search for zinc by means of soil analyses (and then chiefly by the larger companies). Several other types of deposits, chiefly the residual manganese and barite deposits (and possibly tungsten), offer excellent possibilities, in the opinion of the writer, for location by geochemical methods. Furthermore, biogeochemical methods have been largely neglected in the area. In contrast, great numbers of biogeochemical analyses are being turned out per year in Russia, an indication, although indirect, of the utility of biogeochemical methods of prospecting.

Fig. 1. Hypothetical distribution of metal-bearing halos in residual soil overlying an ore vein for level ground (upper) and sloping ground (lower). After Bloom and Walton, 1957, p. 42-43.

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DIFFERENTIAL COMPACTION ORIGIN OF STRUCTURE AND THICK BELTS IN THE INDIAN BLUFF AND GRAVES GAP GROUPS OF THE PENNSYLVANIAN (POTTSVILLE) OF TENNESSEE

By

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ABSTRACT

Several structural highs in the Windrock coal oi the Graves Gap Group are not repeated in the underlying Jellico coal of the Indian Bluff Group. Between these two coal units are six widely developed sandstones. Elongate thick masses of these sandstones overlie one another and thereby compose thick belts. These thick belts contain about 300 feet of sand whereas the intervening thin belts contain less than 100 feet. The original thickness of the section ranged from 650 to 850 feet in the area in question.

The structural highs in the Windrock coal are attributed to post-depositional differential compaction.

The relationships determined here for the Indian Bluff and Graves Gap Groups apparently hold true throughout the upper 2,000 feet of Pennsylvanian strata in Tennessee, and probably in adjacent areas of the Appalachian coal field.

Editor's Absract.

INTRODUCTION

The shaly upper half of the Pennsylvanian System in Tennessee is restricted to a mountainous area in the northern part of the Cumberland Plateau. In this area the most extensive outcrops occur for the interval including the Indian Bluff and Graves Gap Groups (Figure 1). Younger strata generally occupy only isolated mountains, and older strata are buried throughout extensive areas. A general description of these and the other Pennsylvanian strata of Tennessee has recently been published by the Tennessee Division of Geology (Wilson et al, 1956). Because widely developed

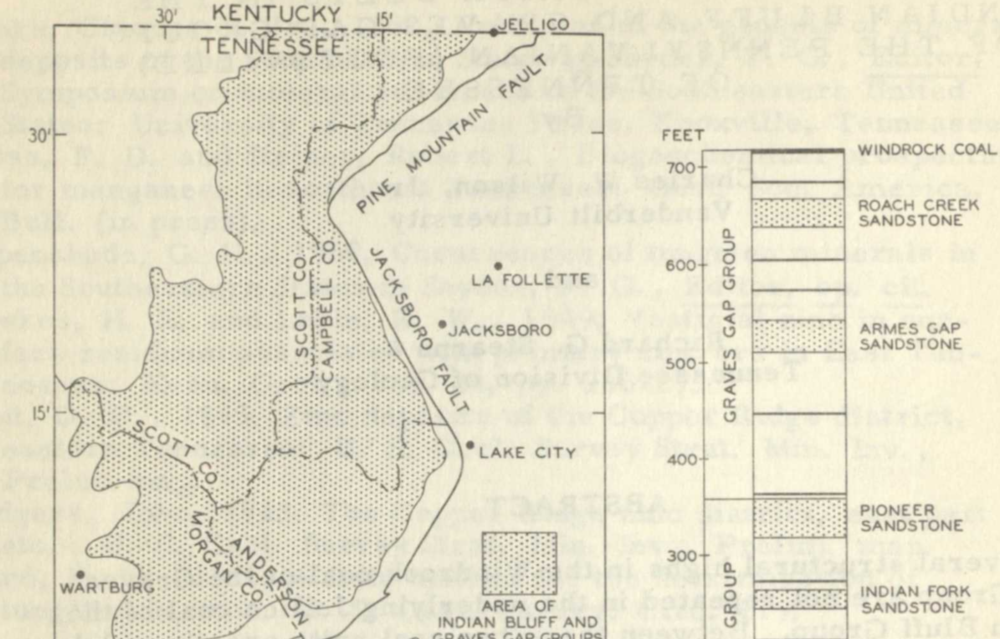

FIG. 1
INDEX MAP AND GENERALIZED STRATIGRAPHIC SECTION

coal beds have been so extensively prospected and mined, they are useful as precise structural datums.

Several northwest-trending structural highs in the Windrock coal at the top of the Graves Gap Group (Figure 2) are not repeated in the underlying Jellico coal at the base of the Indian Bluff Group (Figure 3). Although the Jellico coal is not featureless, compared with the higher Windrock it is relatively flat. This situation is of interest because it decreases the confidence that might be placed on interpretations of structural configuration of deeply buried rocks when such interpretations are based largely on coal structure.

The Windrock and Jellico coals are consistently present throughout the area. Such coals are generally believed to have formed

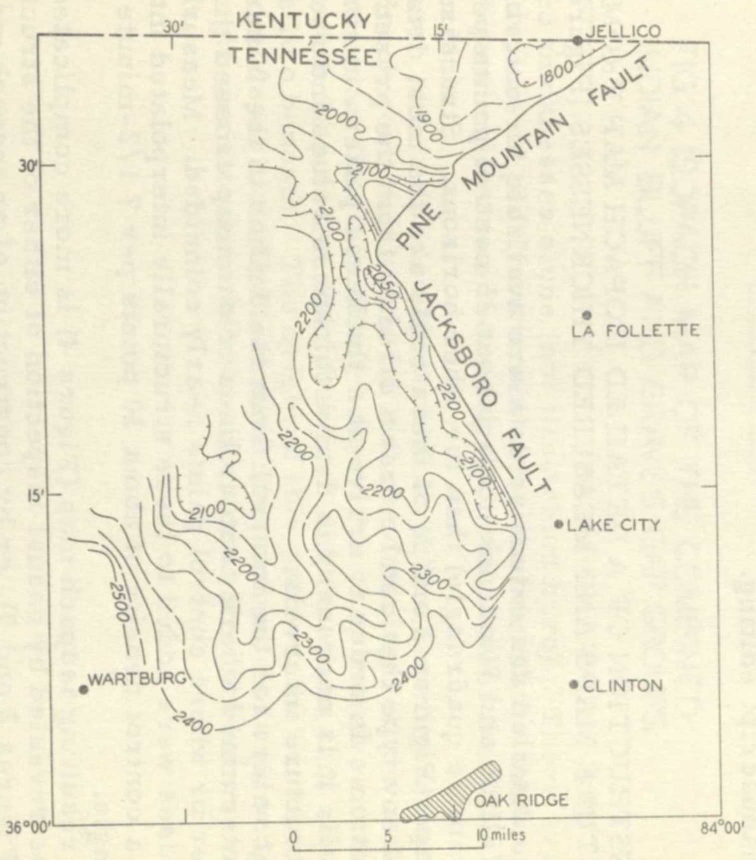

FIG. 2 STRUCTURE OF THE WINDROCK COAL

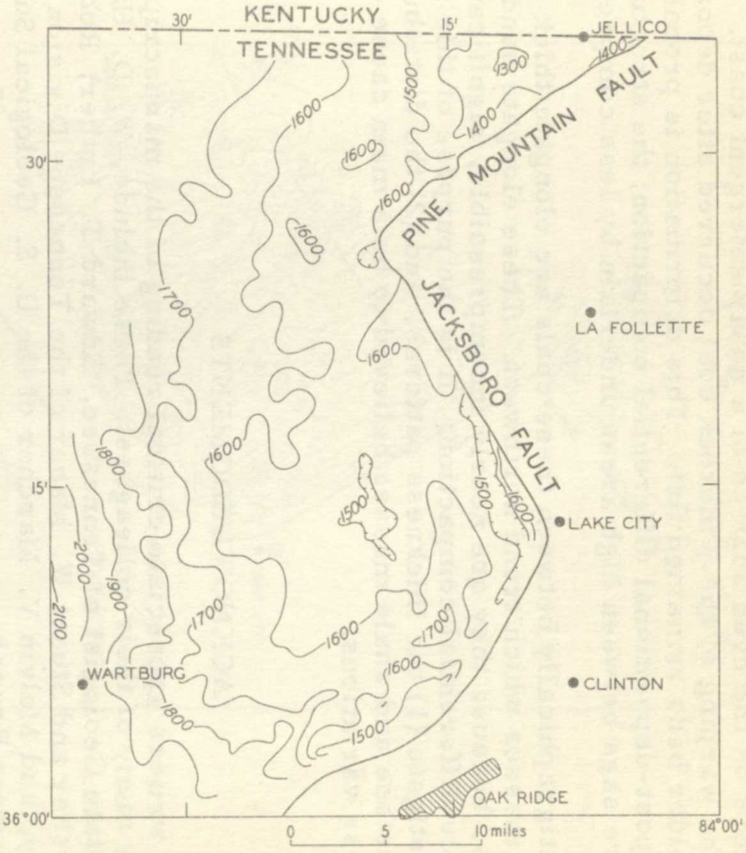

FIG. 3 STRUCTURE OF THE JELLICO COAL

in swamps on the even surface of a newly emergent coast. Therefore, the warping of the Windrock coal occurred after deposition, while older beds remained flat. This deformation is probably due to post-depositional differential compaction; the structural lows are sags between high areas underlain by less compressible strata.

Stratigraphically between these coals are elongate thick sandstone masses which trend northwest. These elongate sandstone masses, because they are nearly incompressible, significantly influence differential compaction. It is the purpose of this paper to investigate (1) the thickness patterns, and (2) the distribution of sandstone and shale masses believed to be a main cause of the thickness variations.

ACKNOWLEDGMENTS

The writers appreciate critical reading of the manuscript done by many of their colleagues. These include, W. D. Hardeman, State Geologist of Tennessee, Edward T. Luther, Robert E. Hershey and Stuart W. Maher of the Tennessee Division of Geology, and Melvin V. Marcher of the U. S. Geological Survey, Groundwater Branch.

Robert J. Floyd of the Tennessee Division of Geology did the final manuscript editing.

CONSTRUCTION OF A DETAILED ISOPACH MAP FROM STRUCTURE MAPS AND MEASURED THICKNESSES (Figure 4)

More detailed and extensive data are available for outcrops of the Jellico and Windrock coals (about 25 control points per 7 1/2-minute quadrangle) than for other horizons. Structure contour maps (Figures 2 and 3) of these coals are the most detailed maps of any type that can be drawn directly from the present information. In order to arrive at a thickness pattern in comparable detail, it is necessary to derive thickness values indirectly from structure intervals.

Point values for the interval from the Jellico to the Windrock were determined where contour lines of one map crossed those of the other or where control points nearly coincided. Measured thicknesses were added to these structurally interpolated intervals to give a control density of about 30 points per 7 1/2-minute quadrangle.

The resulting isopach map (Figure 4) is more complicated than would be revealed by casual inspection of either of the structure maps (Figures 2 and 3), or by construction of an isopach map from

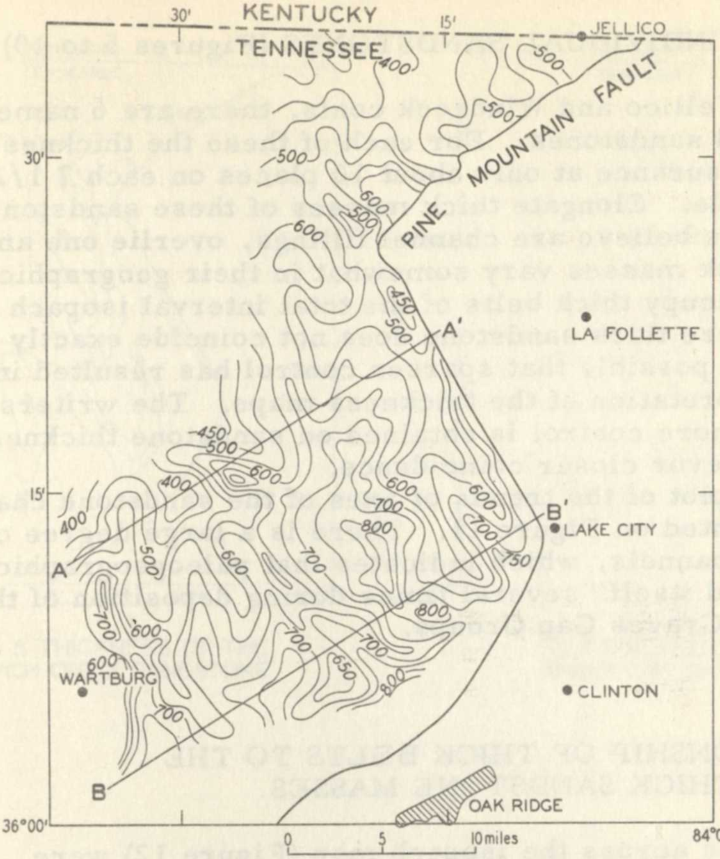

FIG. 4 ISOPACH MAP OF THE COMBINED INDIAN BLUFF AND GRAVES GAP GROUPS

measured thicknesses alone (not illustrated here). There are six thick belts; one is partly removed along the Jacksboro fault, and the northwest ends of two more appear northwest of the Pine Mountain fault.

In effect, this map also shows the structural configuration of the Windrock coal as it would be if the underlying Jellico coals were flattened. Or, in another sense, this map removes from the structure map of the Windrock coal deformations that repeat in the Jellico beneath. The origin of this pattern, believed to be one of post-depositional differential compaction, is to be sought in lithologic variations within the mass of sediments between the two coals.

THICKNESS OF INDIVIDUAL SANDSTONES (Figures 5 to 10)

Between the Jellico and Windrock coals, there are 6 named widely developed sandstones. For each of these the thickness is known with assurance at only about 10 places on each 7 1/2-minute quadrangle. Elongate thick masses of these sandstones, which the writers believe are channel fillings, overlie one another. Although the thick masses vary somewhat in their geographic position, they occupy thick belts of the total interval isopach map (Figure 4). Where thick sandstone does not coincide exactly with thick belts, it is possible that sparser control has resulted in erroneous interpretation of the thickness maps. The writers believe that as more control is obtained on sandstone thickness there will be an ever closer coincidence.

A composite plot of the trends of axes of the sandstone channel fillings is presented on Figure 11. There is a large degree of coincidence of channels, which indicates that paleogeographic "history repeated itself" several times during deposition of the Indian Bluff and Graves Gap Groups.

RELATIONSHIP OF THICK BELTS TO THE THICK SANDSTONE MASSES

Cross sections across the isopach map (Figure 12) were drawn with the datum at the base of the interval (Jellico coal). The thick isopach intervals were therefore drawn as "humps" in the Windrock coal. This approximates the actual structural configuration of the interval as well as the thickness variations. Individual named sandstones were added along the same section from the sandstone thickness contours as a composite mass at the base of the section; the actual stratigraphic positions of these sands is shown on Figure 1. The locations of these cross-sections are shown on Figure 4, the isopach map.

Sandstone occupies a much greater proportion of the total interval in thick belts, and the remaining shaly interval generally is thicker in thin belts. The bulk of the remaining part of the interval (other than that occupied by the 6 named sandstones) by no means consists entirely of shale. Five or more additional thin sandstones were commonly measured within the thick belts. This is not quantitatively significant as it adds only a maximum of 50 feet of sandstone to the thicker belts, but it does suggest a generally greater "sandiness" of the thick belts. Some thick belts apparently have only about as much sandstone as in adjacent thin belts (e. g., near the center of A-A', Fig. 12). This is attributed to lack of exposures of sandstone where the thick belt is derived almost entirely from coal structure.

At the close of deposition of the Graves Gap Group, the Windrock

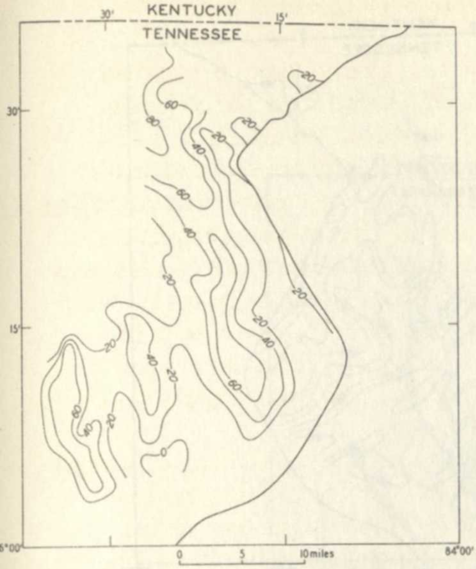

FIG. 5 THICKNESS OF THE ROACH CREEK SANDSTONE

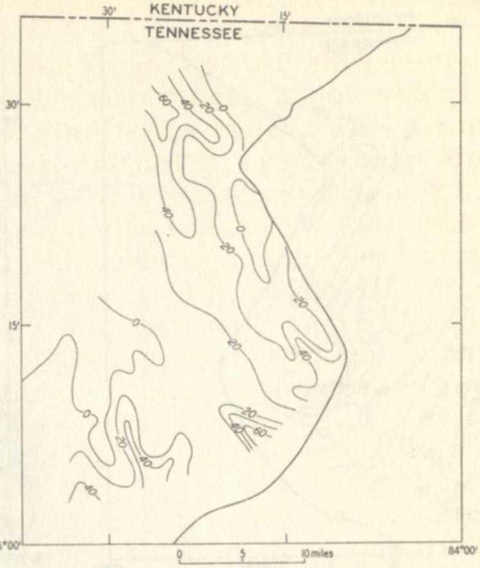

FIG. 6 THICKNESS OF THE ARMES GAP SANDSTONE

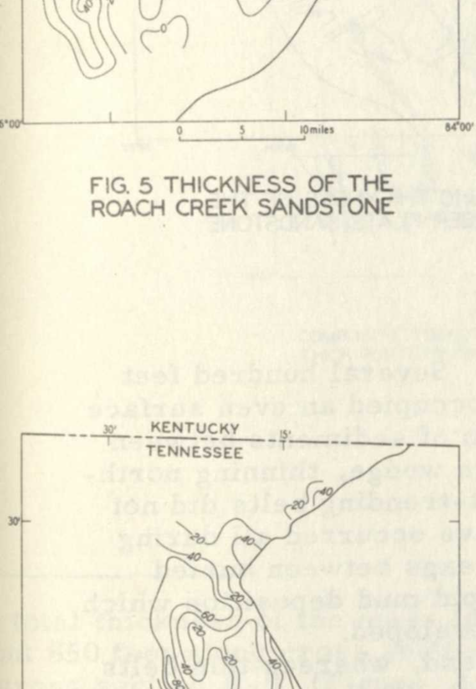

FIG. 7 THICKNESS OF THE PIONEER SANDSTONE

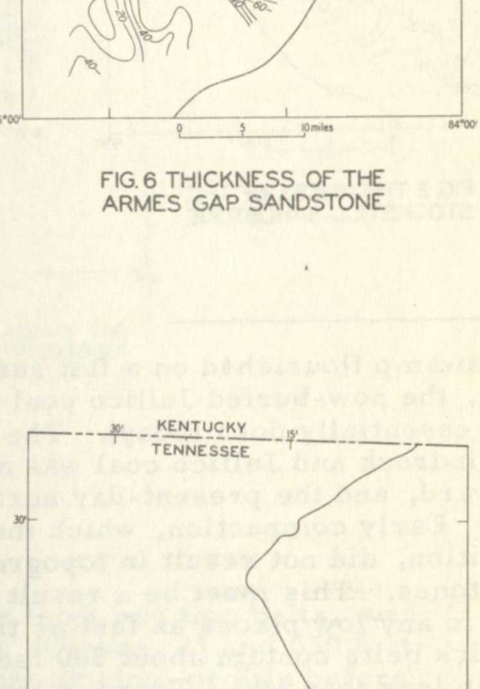

FIG. 8 THICKNESS OF THE INDIAN FORK SANDSTONE

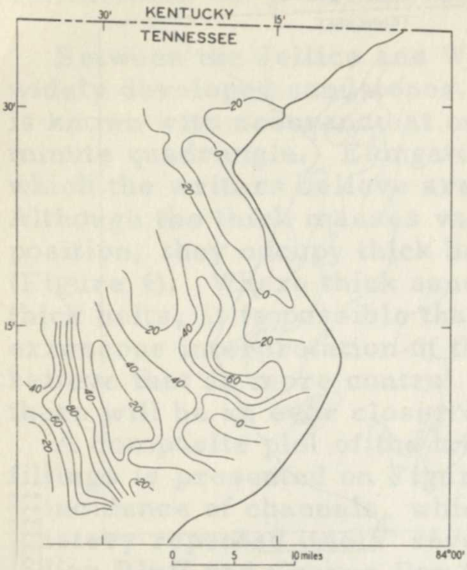

FIG. 9 THICKNESS OF THE
STOCKSTILL SANDSTONE

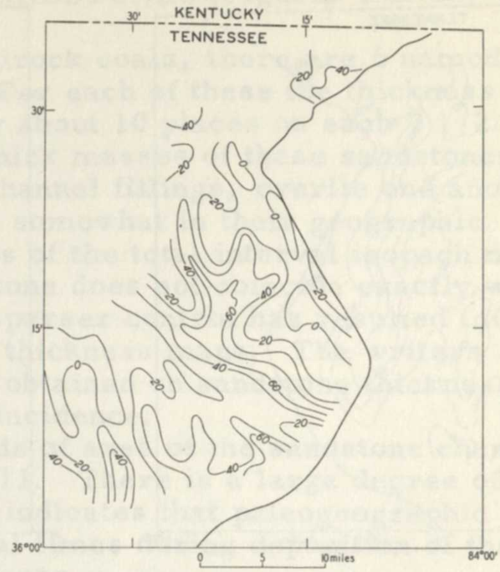

FIG. 10 THICKNESS OF THE
SEBER FLATS SANDSTONE

coal-swamp flourished on a flat surface. Several hundred feet below, the now-buried Jellico coal also occupied an even surface (as it essentially does today). The prism of sediments between the Windrock and Jellico coal was an even wedge, thinning northwestward, and the present-day northwest-trending belts did not exist. Early compaction, which must have occurred all during deposition, did not result in topographic sags between buried sandstones. This must be a result of rapid mud deposition which filled in any low places as fast as they developed.

Thick belts contain about 300 feet of sand, whereas thin belts contain less than 100. There is thus about 200 feet more of sandstone in the thick belts, this difference is believed to have originally been accomplished by removal of compactible mud through channelling and filling the channels with incompactible sandst

The most compaction of 200 feet of mud that could have o is about 40% (Weller, 1959, Fig. 2 and Fig. 7). On this ba about 80 feet of compaction could have occurred in thin belts that did not occur in thick belts. This accounts for only about half of the present total interval difference between thick and thin belts.

In order to fully account for the difference in thicknesses caused by compaction, it is necessary to conclude that shaly beds in the thick belts have, on the average, been compressed only about 1/3 as much as the shaly beds in the thin belts. This difference in amount of compaction is probably due to more thinly interlayered sand in the shaly beds of the thick belts. On this basis, the origi-

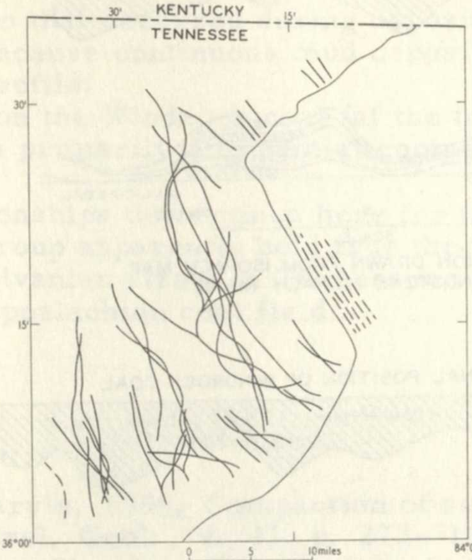

FIG. 11
COMPOSITE TRENDS OF THE AXES OF THE THICK PORTIONS OF ALL THE SANDSTONES

total thickness of the mass for both thick and thin belts, was out 850 feet along cross section A-A' (Figure 4) and 650 feet cross section B-B' (Figure 4). This original profile before mpaction has been restored in cross section on Figure 12.

POST-DEPOSITIONAL DIFFERENTIAL COMPACTION IN OTHER PENNSYLVANIAN STRATA

Elongate sandstone masses are prominent through a stratigraphic erval of nearly 1,000 feet below the Jellico coal and through all the younger Pennsylvanian strata in Tennessee, and thick belts so occur in the overlying and underlying strata (Wilson et al, 56, p. 15). Therefore, the relationships outlined here hold true, general, throughout the upper 2,000 feet of the Pennsylvanian lumn in Tennessee, and perhaps in adjacent areas of southeastern

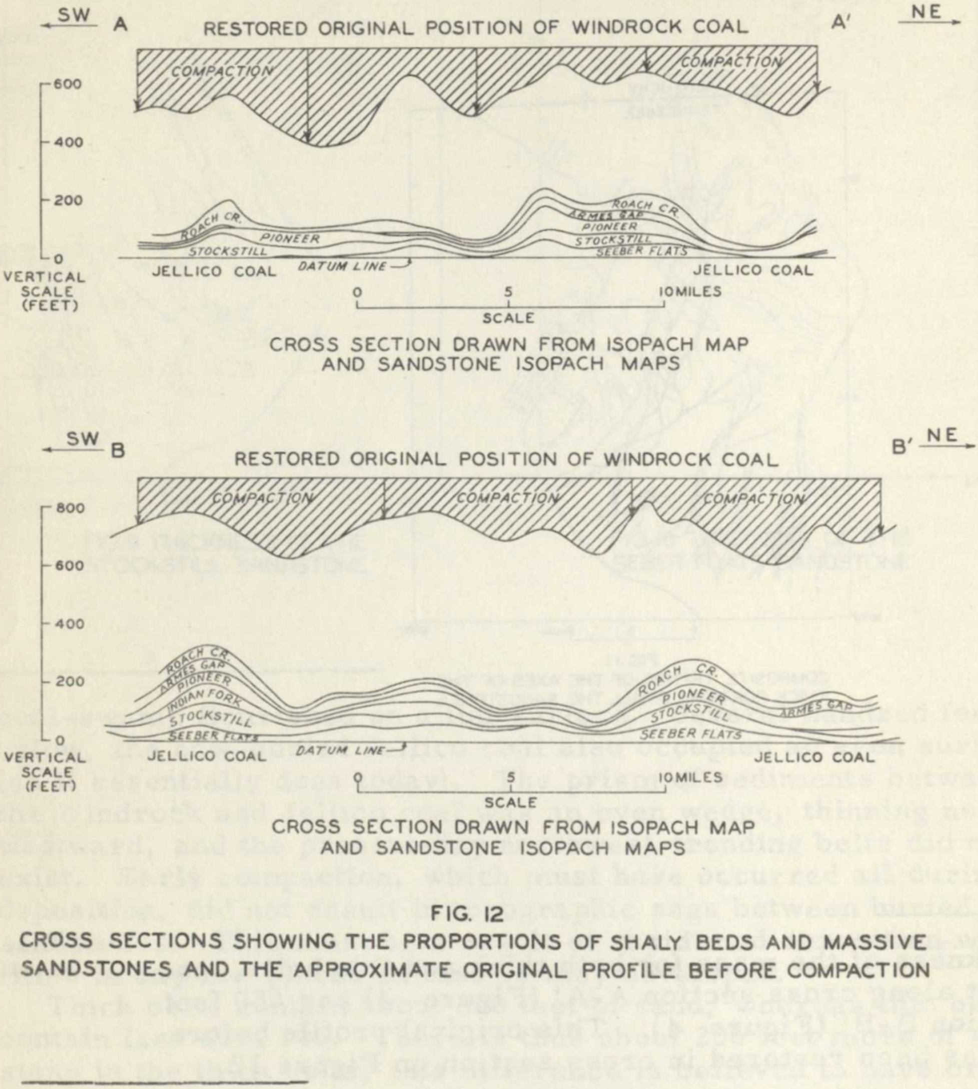

FIG. 12
CROSS SECTIONS SHOWING THE PROPORTIONS OF SHALY BEDS AND MASSIVE SANDSTONES AND THE APPROXIMATE ORIGINAL PROFILE BEFORE COMPACTION

Kentucky and southwestern Virginia where continuations of the same strata occur.

Most of the structure of the Windrock coal reflects thickness variations close beneath and does not even carry through the few hundred feet of strata between it and the Jellico. The structure that does carry though may be due to compaction below the Jellico.

CONCLUSIONS

1. The thick and thin belts originated through differential compaction of sediment of uniform thickness. Thick belts were

compacted less than 5 percent, whereas thin belts were compacted about 30 percent.

2. The smaller amount of compaction in the thick belts is attributed largely to superimposed channel-filling sandstone masses; also shaly beds of the thick belts contain more sand and thus were less compressible.

3. Compaction that occurred during deposition did not influence topography, because continuous mud deposition maintained an even depositional profile.

4. Structure on the Windrock coal (at the top of the compacted mass) reflects primarily differential compaction and not underlying structure.

5. The relationships determined here for the Indian Bluff and Graves Gap Group apparently hold true throughout the upper 2,000 feet of Pennsylvanian strata in Tennessee, and probably in adjacent areas of the Appalachian coal field.

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