SYMPOSIUM ON THE PETROLEUM GEOLOGY OF THE GEORGIA COASTAL PLAIN

compiled by
Lynda P. Stafford

BULLETIN 87

Sponsored by
Georgia Southwestern College
Americus, Georgia
and
Georgia Department of Natural Resources
Joe D. Tanner, Commissioner
Earth and Water Division
Sam M. Pickering, Jr., Division Director

ATLANTA
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Georgia Geological Survey Bulletin 87

"Symposium on the Petroleum Geology of the Georgia Coastal Plain"

ERRATA

p. 30. Page heading should read "Oligocene Series".
In "Miocene (and Pliocene?) and Series", delete second and

p. 81. Legend for Ttu should read "Tuscahoma Sand, including overlying Hatchitighee Formation."

p. 106. Caption should read "Figure 3. Present reservoir level on Blufftown Bluff, Blufftown, Georgia. (Pre-reservoir photography by Dr. Norman Sohl.)

p. 110. Caption should read "Figure 6. Present reservoir level on Eufaula Bluff, Eufaula, Alabama. (Pre-reservoir photograph taken by Dr. Norman Sohl.)

p. 158. Line 2, for filled, read fitted.

p. 159. Depths of the dike should be measured in km.

p. 167. Line 17, . . . Henry, Giles and Woolsey, 1973 . . .

p. 173. Plate 3 should read "Plate 6".

p. 176. Plate 6 should read "Plate 3".

p. 182. Plate 15 should read "Plate 17".

p. 183. Plate 17 should read "Plate 15".

p. 187. Line 1 should read "Henry, V. J., Giles, R. T., and Woolsey, J. R., 1973,"

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CONTENTS

INTRODUCTION

The relative lack of petroleum exploration of potentially favorable areas in Georgia, and present interest in domestic energy, made a symposium on our state's petroleum potential desirable. Joint sponsorship was provided by Georgia Southwestern College and the Earth and Water Division, Georgia Department of Natural Resources. The symposium was held in Americus on February 19 and 20, and was very well attended by industry, consultants, universities, and other interested individuals. Twenty papers were read during the two-day session. Texts of those papers which were available for publication are reproduced in these proceedings. A list of participants and registered atendees, with their affiliation, is included in the appendix.

REVISION OF GEORGIA'S OIL AND GAS LAWS

by

James B. Talley

Present Petroleum Laws

Georgia presently has one statute dealing with the production of oil and gas and one statute dealing with the underground storage of gas. The Act which regulates the drilling for and production of oil and gas was passed in 1945 and the Act which regulates the underground storage of gas was passed in 1964.

As initially adopted, the Oil and Gas Act provided for an Oil and Gas Commission as the policy-making body and a Director of Production and Conservation who administered such policies. However, an amendment to the Act in 1959 abolished the Oil and Gas Commission and the position of Director of Production and Conservation and transferred all of the duties, powers and functions provided for in the Act to the Department of Mines, Mining and Geology. Then, in 1972, the Department of Mines, Mining and Geology was abolished and all of its functions were transferred under the provisions of the Executive Reorganization Act of 1972 to the newly created Department of Natural Resources. The administration of the Act was then internally assigned to the Earth and Water Division of the Department of Natural Resources.

The provisions of the Underground Storage Act are administered by the State Public Service Commission but there is a provision in the Act that requires that, prior to any hearing on an application to utilize or operate an underground reservoir, the Director of the Earth and Water Division must investigate the site of such reservoir and file a written report of his findings with the Public Service Commission. In addition, the Director of the Environmental Protection Division of the Department of Natural Resources must also investigate such site and file a written report of his findings with the Public Service Commission.

Exploration in the State

There is no production of oil or gas in Georgia. However, over the years there has been some exploration.

The records on file with this Department reveal that during the period from 1940 through 1950 there was an average of four (4) test wells drilled per year, during the period from 1950 through 1960 there was an average of five (5) tests drilled per year and during the period from 1960 through 1970 there was an average of only two (2) tests per year. In 1971, there was only one (1) test drilled; in 1972, there were only two (2) tests drilled; then in 1973, there was an increase to eight (8) tests drilled. To date, in 1974, two (2) test wells have been drilled to total depth and one (1) is currently being drilled.

Anticipated Exploration

It is anticipated that, due to the present energy crisis and the declared national policy that this country should strive to become independent of foreign oil and gas sources, there will be an acceleration in petroleum exploration activity in all parts of the country, including Georgia, at least in the immediate future.

Decision to Review Present Legislation

Therefore, the present administration felt that the oil and gas laws in Georgia should be reviewed and changed as necessary. A decision was made not to review the Underground Storage Act at this time.

Proposed Legislation Introduced

The present proposed legislation, which has been introduced and is designated as House Bill 1992, is in many respects similar to the 1945 Act, but it does contain some significant differences. The most important aspects of the new Act are the jurisdiction of the Board of Natural Resources, the scope of the Rules and Regulations to be promulgated by the Board, the listing of prohibited activities, the permit system, the enforcement powers and the bonding requirements.

Contents of Proposed Legislation

The new Act contains some fifteen (15) sections.

Section 1 is the Legislature's declaration of policy, which in brief is that it is the duty of this State to protect the principal artesian aquifer and other freshwater-bearing strata while at the same time encouraging oil exploration.

Section 2 provides that the title or name of the new Act is the Oil and Gas Act of 1974.

Section 3 provides for definitions of key words used in the Act or likely to be used in the Rules and Regulations promulgated under the Act. No definition is so unusual as to warrant specific comment here.

Section 4 establishes certain powers, authority and jurisdiction in the Board of Natural Resources.

Subsection (a) provides the authority to make inquiries into any matter over which it has jurisdiction.

Subsection (b) provides the jurisdiction of and authority over any matter dealing with the drilling of any well which is drilled to a depth of over one thousand (1,000) feet for any purpose other than the tapping of and drawing from underground freshwater supplies.

Subsection (c) provides the authority to control the drilling patterns and the production of any minerals, excluding water, through a well or a bore hole which does not exceed eighteen (18) inches in diameter.

Subsection (d) provides the authority to assess a tax not to exceed five (5) mills against each barrel of oil produced and to assess a tax not to exceed one-half (1/2) mill against each one thousand (1,000) cubic feet of gas produced.

Subsection (e) provides the authority to issue, deny or revoke permits as provided for in Section 7.

Section 5 authorizes the Board to adopt and promulgate Rules and Regulations, to include, but not limited to, the following:

(a) to require the drilling, casing and plugging of wells to be done in such a manner so as to prevent the escape of oil or gas out of one bed into another bed, and to prevent the pollution of freshwater beds by oil, gas or saltwater.

(b) to require reports showing the location of oil and gas wells and require the filing of logs and drilling records.

(c) to prevent the drowning by water of any reservoir capable of producing oil or gas in commercial quantities and to prevent the premature and irregular encroachment of water in such a way as to reduce the total ultimate recovery of oil or gas from any pool.

(d) to require the operation of wells with efficient gas-oil ratios and to fix such ratios.

(e) to prevent "blowouts", "caving" and "seepage".

(f) to prevent fires.

(g) to identify the ownership of all oil or gas properties, both real and personal.

(h) to regulate the perforating and treatment of wells.

(i) to regulate secondary recovery methods.

(j) to limit and prorate the production of oil or gas.

(k) to require certificates of clearance or tenders in connection with the transportation of oil or gas.

(l) to regulate the spacing of wells and to establish drilling units.

(m) to prevent, insofar as is practical, unreasonable drainage of an off-setting unit which is not equalized by counterdrainage.

(n) to establish procedures for the abandonment of wells.

(o) to require that accurate records be kept and reported to the Department within thirty (30) days after the completion or abandonment of a well; such reports shall include such information as the Department may prescribe, including but not limited to information concerning cuttings and subsurface samples, geophysical logs and stratographic interpretation.

(p) to require that geologic information obtained from a well be held in confidence by the Department for a period of at least six (6) months from the time of drilling to total depth; provided, however, that such period may be extended at the discretion of the Department.

(q) to require that proof be provided of the right to explore for or produce any minerals covered under this Act prior to the issuance of any permit for said activities.

(r) to assure that any and all activities covered by the provisions of this Act are in compliance with all other laws and Rules and Regulations which are administered by this Department or any order issued by this Department.

(s) to regulate the issuance of permits to persons who have violated any provision of this Act, any Rule or Regulation or any order issued and to establish the amount of bond for such persons.

(t) to provide for the issuing, denying or revoking of permits pursuant to Section 7.

Section 6 prohibits certain activities. They are as follows:

(a) the waste of oil or gas as defined in this Act.

(b) the sale, purchase, transportation, refining, processing or handling of any illegal oil, gas or products.

(c) the sale, purchase, transportation, refining, processing or handling in any way of any oil, gas or any product without complying with the Rules or Regulations promulgated pursuant to this Act.

(d) the negligently permitting any gas or oil well to get out of control.

(e) the drilling of any well covered by the provisions of this Act without a permit for such drilling.

Section 7 deals with the issuance of permits for the drilling of wells covered by this Act.

Subsection (a) provides that, prior to drilling any well covered by the provisions of this Act, the operator must apply for a permit with the Department and shall pay a fee of Twenty-five Dollars ($25.00) for each well.

Subsection (b) requires that the Department shall, within thirty (30) days after the receipt of the application, either issue or deny such permit.

Subsection (c) requires that, in issuing or denying such a permit, the Department shall consider the extent to which the proposed well complies with the provisions of this Act, all Rules and Regulations promulgated thereunder and any order issued by the Board.

Subsection (d) provides that, in issuing a permit for the drilling of any well, the Department shall specify such terms and conditions as may be necessary.

Section 8 deals with the various methods of enforcement of the provisions of the Act.

Subsection (a) provides for the issuance of administrative orders. There are two (2) types of administrative orders provided for in the Act: regular and emergency.

> Paragraph (1) authorizes the Department to issue an administrative order whenever the Department believes that a person is violating the provisions of the Act or the Rules or Regulations promulgated thereunder. The order must identify the violation and state the corrective measures to be taken. Unless a hearing on the matter is requested, the order becomes final and effective in thirty (30) days.
>
> Paragraph (2) authorizes the Department to issue an emergency administrative order whenever the Department believes that a person is violating the provisions of the Act or the Rules and Regulations promulgated thereunder in such a way as to create an emergency. Such an order becomes effective immediately but the person to whom the order is directed may, upon request, have a hearing within ten (10) days.

Subsection (b) provides for injunctive relief for the Department in the appropriate superior court for violations or the threat of violations of the Act or Rules and Regulations promulgated thereunder.

Subsection (c) provides for a penalty not to exceed One Thousand Dollars ($1,000.00) per day for each day of any violation of the Act or any Rule or Regulation promulgated thereunder to be recovered in the appropriate superior court.

Subsection (d) provides that all illegal oil, gas or products shall be contraband and shall be seized and sold by a procedure set out in that subsection.

Section 9 provides for an administrative review by an aggrieved person for any action or order of the Department.

Section 10 provides the subpoena powers necessary to conduct such administrative reviews and provides punishment for persons who fail or refuse to comply with such a subpoena.

Section 11 sets out the bonding requirements under the Act.

Subsection (a) provides that prior to the issuance of a permit to drill any well covered by the provisions of this Act, the operator must furnish a bond in an amount set by the Board, executed by a bonding, surety or insurance company in this State, to insure the faithful performance of the provisions of this Act, any Rules or Regulations adopted pursuant thereto or any condition of a permit granted.

Subsection (b) provides that the bond shall be released two (2) years from the date of receipt by the Department of all geologic information required under the Act or any Rule or Regulation adopted pursuant thereto; provided the Department has examined and approved the completion or abandonment of the well for which the bond was furnished.

Subsection (c) provides that no bond shall exceed Fifty Thousand Dollars ($50,000.00).

Section 12 provides for severability in the event that any part of the Act is unconstitutional.

Section 13 establishes the effective date of the Act, which is when the Act is approved by the Governor.

Section 14 provides for the specific repeal of the 1945 Act.

Section 15 is a general repealer provision.

Conclusion

It should be understood that this Act is not yet law and is still subject to revisions and amendments.

Georgia needs to update her oil and gas laws and this Act, although not perfect, is a good start.

Reward in Georgia for First Commercial Production

In recent years, there has been considerable comment as to the desirability of Georgia's reward of Two Hundred Fifty Thousand Dollars ($250,000.00) for the first producing well. As this provision of law was established by a constitutional amendment, it was not considered in the drafting of the new Oil and Gas Act, although experience may indicate that the reward has not had the effect desired.

PETROLEUM POTENTIAL OF GEORGIA

Sam M. Pickering, Jr.
Earth and Water Division
Georgia Department of Natural Resources

Approximately 70 percent of Georgia's 60,000 square miles is underlain by sedimentary rocks, which have been little explored for petroleum. Although our agency has just completed an extensive surface geologic mapping program, the subsurface aspect of these sediments is very poorly known.

The southern two-thirds of Georgia, the largest state east of the Mississippi, is underlain by Gulf and Atlantic Coastal Plain sediments. Beneath the southern and southwestern portion of this area is an unknown thickness of middle and lower Paleozoic shales and sandstones, which have been encountered by less than a dozen exploration holes. The northwestern 10 percent of Georgia ia an area of highly folded and thrust-faulted shales, limestones, and sandstones. The remainder of the state is igneous and high-grade metamorphic rocks.

Although we have records of approximately 148 oil test holes drilled in Georgia, less than 50 have been drilled to significant depth and subject to serious logging and completion methods. Thus, we have an average of less than one serious oil test for each 800 square miles of exposed sedimentary rocks.

Supposed oil seeps were reported from a number of areas in Georgia in the late 1800's and early 1900's. Our first exploration drilling was done in 1903, when two cable tool tests were made in northwest Georgia. The first rotary-rig hole was drilled in 1938 in the coastal plain. In all, 8 tests have been drilled in Paleozoic sediments of northwest Georgia, 125 in the coastal plain, and an inexplicable three in the granitic rocks of our crystalline piedmont. Occurrences of petroleum and gas have been encountered from several coastal plain drill holes, and from northwest Georgia, but no commercial production has been obtained to date. Our Information Circular 38 (Marsalis, 1970) summarizes available drilling data, logs, samples, and stratigraphic information on wells drilled since that date. Copies of available logs and other information may be obtained by contacting our office. Samples may be examined in our sample library.

Since 1945, when Georgia's oil and gas exploration law was passed, operators have been required to obtain a permit to drill, and are required to submit samples and logs to our office. Thus we have more date for oil tests drilled since that time. Five exploratory wells were drilled from 1900-1910, seven from 1910-1920, six from 1920-1930, 15 from 1930-1940, 40 from 1940-1950, 50 from 1950-1960, 19 from 1960=1970, and 19 from 1970 to the present. In this decade, three were drilled in 1970, one in 1971, two in 1972, eight in 1973, and five to date in 1974. One permit is presently valid, to be initiated in November of 1974.

So far, no commercial production of petroleum or natural gas has been reported from Georgia, although numerous interesting shows have been reported. Rather few of the exploration holes drilled have penetrated to basement, and we feel that our state has by no means been thoroughly explored. General areas considered to be of potential interest are: 1) marine Cretaceous shales, sands, and limestones of southwest Georgia and the Southeast Georgia Embayment; 2) middle to lower Paleozoic black shales and sandstones of south-central and southwest Georgia; 3) lower Paleozoic dolomites, shales and limestones of the northwest corner of the state, on anticlinal structures which are well mapped from surface exposures; 4) Grabens filled with 4-6000 feet of shales and sandstones in various areas beneath the coastal plain; 5) the offshore extent of the Southeast Georgia Embayment; and 6) an apparent domal structure in southern Wayne County, described elsewhere in this symposium proceedings.

Although possibly of doubtful value in attracting serious exploration, our state has shown its interest in developing potential production by voting a $250,000 bonus for the first substantial producing well.

A new exploration regulation law, described in detail elsewhere in this symposium, will be proposed for passage by the 1975 Georgia General Assembly. Objectives will be: 1) protection of fresh water aquifers; 2) reduction of complexity of procedures for permit application; 3) assurance of the state's acquisition of complete geologic information, samples, and geophysical logs from all test holes drilled, assurance of a legally defined period of confidentiality of information; 4) reliable, rapid dissemination of pertinent information to industry after the tight period has lapsed; and 5) updating of equipment and casing requirement.

Our agency will be happy to assist any company or individual in obtaining information on the oil or gas potential of Georgia.

Permit forms, publications, copies of logs of existing wells, and a summary of our present exploration law are available on request. We invite you to visit our Atlanta office to discuss petroleum, natural gas, or any other mineral or geologic problem at any time.

THE GEORGIA GEOLOGICAL SURVEY SAMPLE LIBRARY

by

Lynda P. Stafford

ABSTRACT

The Georgia Geological Survey subsurface sample library now contains cutting samples from more than two thousand water and oil test wells in the coastal plain and valley and ridge. Cores from an additional one hundred holes are also available for study.

Electric, gamma ray, caliper, and other logs are on file for most oil tests, along with plugging records. This information is placed in open files six months after an oil test is completed, and is then available for study at the Survey office. Published reports, including lithologic logs and structure contour and isopach maps, may also be obtained from the Survey.

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Since 1940 the Georgia Geological Survey, in conjunction with the U. S. Geological Survey, has maintained a collection of cuttings and data from most of the oil tests that have been drilled in the state. Much of this material has been summarized in several Survey publications—two well-log bulletins, an information circular on subsurface stratigraphy, a comprehensive information circular listing all oil tests, and various county and area reports. However, we realize that a complete understanding of subsurface stratigraphy can be obtained only from direct examination of samples, logs and other pertinent data. Consequently, it has been our practice to make these records and cuttings available to interested individuals on request.

In order to drill an exploratory hole in this state, it is necessary to obtain a permit from the Department of Natural Resources. Permits to drill become public information as soon as they are approved by the Commissioner and the State Geologist. The permit requires the name and permanent address of the operator; name of the lease; description of well location by land lot and land district; (the State of Georgia does not use the township and range grid system); ground elevation of the test site; proposed depth of the hole; and an accurate map of the lease and location of the test hole.

When a hole is completed or abandoned, we receive a plugging report, samples, and geophysical and stratigraphic logs. This information is held in a closed file for a minimum of six months. At the end of that time, if the operator is drilling additional holes in the area, or if he is ready to begin another test, the period of confidentiality can be extended at the discretion of the Department. After that time, the data, though unpublished, becomes public record.

In the past, our receipt of samples has been a rather haphazard matter. We intend now, with the renewed interest in oil exploration in our state, to do this in a more effective manner. Of the 150-odd oil test holes which have been drilled, we have samples from about 75. These samples are available for inspection in our office, but they cannot be removed. Because of the limited quantity of each sample, we can't offer you splits, and we ask that you confine your testing to non-destructive methods.

Most of our sets of samples begin at about 1000 feet. If your companies send us samples, however, we would like to have cuttings from the upper portion also. There are several reasons for this: 1) That is the interval in which you will penetrate the principal artesian aquifer. 2) The top 1000 feet have the most direct influence on local environment. 3) Those samples can supplement the Survey's stratigraphic research program.

In addition to samples we have electric logs, drilling-time logs, and in some cases lithologic logs on the recent holes. Correspondence, construction data, plugging records—all become part of the open files.

Our geologic library is open for reference, but not for circulation. Copies of our publications and U.S.G.S. topographic maps are on sale at the Survey office.

If you decide to use our facilities, please give us a little advance notice. This will assure that there is a place for you to work, and that someone will be in the office to help locate what you need. For your own convenience, I make the following recommendations:

1. Bring your own microscope, light source, dishes, brushes, and other equipment you normally use.
2. Office supplies such as colored pencils, grid paper, etc., are not conveniently available. You will probably save time by bringing what you are accustomed to using.
3. Any typing needed during your stay must be done by you. We do not have a large enough staff to offer this service.
4. Long distance phone calls from our office must be charged to your credit card, not our phone number. And because of the State's bookkeeping system, you cannot charge calls to us and reimburse us later.

We are anxious to encourage exploration for Georgia's natural resources, and we will cooperate with you in every way we can.

A REVIEW OF OIL AND GAS DEVELOPMENTS IN ALABAMA AND GEORGIA

Donald B. Moore, Geological Survey of Alabama

ABSTRACT

Alabama became an oil-producing state in 1944 with the discovery of the Gilbertown oil field in Choctaw County. The South Carlton field was found in 1950 in Clarke County, and in 1952 the Pollard field was discovered in Escambia County.

In 1955 the excitement of oil and gas exploration in Alabama reached a new peak with the discovery of the Citronelle field. To date, 413 producing wells have been drilled in the Citronelle field and more than 105 million barrels of oil have been produced.

After the excitement of the Citronelle boom died down, it was 10 years before a new oil field, the Tensaw Lake field, was located. Then significant finds were made at Toxey, Choctaw Ridge, Okatuppa Creek, Turkey Creek, Womack Hill, Barrytown and North Choctaw Ridge in Choctaw County; and at Flomaton, Little Escambia Creek, Big Escambia Creek and Fanny Church in Escambia County. These new oil fields were especially important because they were developed in deep formations not known to be productive in Alabama before 1967 and because most wells produced larger quantities of oil and gas than previously developed areas. The discovery of the Flomaton gas field moved the easternmost limits of Jurassic production approximately 80 miles southeast of previous production, thus leaving prospective acres between it and previous Jurassic discoveries in Choctaw County.

These recent discoveries come at a time when a demand for natural gas is at an all time high and reserves are rapidly being depleted. It is anticipated that the quantity of crude oil and natural gas produced in Alabama will double within the next few years, especially in view of recent finds in southwest Alabama.

Since January 1, 1970, there have been approximately 10 oil and gas exploratory wells drilled in the State of Georgia, most of which were in the extreme southwest part. Hunt Petroleum Company is engaged in an oil test-drilling program in Lowndes County. Generally there are four areas of Georgia which appear to have fair to good potential for hydrocarbon production. These areas are the southwest, southeast, and northwest corner of the state plus the offshore zone. Greater incentives for increasing domestic oil and gas activities are developing and the anticipated thrust of oil and gas exploration will involve practically all areas that have potential for hydrocarbon production.

PALEOZOIC GEOLOGY UNDERLYING THE SOUTHEASTERN COASTAL PLAIN

Robert E. McLaughlin, University of Tennessee

ABSTRACT

In terms of stratigraphic units and their implied relationships, a broad outline of the post-Jurassic geologic history of the coastal plain in Georgia and adjacent states has been established for several years. Until recently, however, little was known concerning the deeper rocks beyond the recognition that problematical Paleozoic and Mesozoic sediments did occur in a number of test bores and wells along with crystalline rocks of uncertain age. It is now possible through a survey and analysis of paleontologic and other evidence, collected over a broad area of the southeast and to the limited extent of penetration of the subsurface, to provide new insights into the developmental history of this segment of present-day North America. Use of such information in any attempt to unravel the complicated history of the region, however, must take into account new concepts emerging from the recent revolution in plate tectonics which has introduced frames of reference unavailable to past interpreters. Toward this end, a chronologically developed conceptual model of the composite lithosome, combining paleontologic, sedimentologic, paleogeographic, and tectonic data, is proposed with special emphasis given to the Paleozoic events involved.

Dating of events in this account is based on (1) interpretation of an older faunal record known for some time from scattered subsurface reports, (2) recently determined radiogenic ages, and (3) a compilation of palynological evidence extracted from studies of acid-resistant organic residues. In addition to plate movement, global events of consequence directly or indirectly related to the model presented are inferred from paleomagnetic data and from present understanding of significant episodes in (1) the evolutionary history and spatial distribution of land plants and selected marine megafauna, and (2) the chronological development of marine phytoplankton and assorted micropaleontologic problematica. From the derived model, several lines of evidence point to the development or involvement of the exposed south-eastern coastal plain and the underlying rocks in a sequence of ten phases from Cambrian to Recent. Seven of these phases related to the consequences of plate assembly, separation, and reassembly span the Paleozoic.

ISOPACH AND LITHOFACIES ANALYSES OF THE CRETACEOUS AND CENOZOIC ROCKS OF THE COASTAL PLAIN OF GEORGIA

Howard Ross Cramer

Emory University

Atlanta, Georgia

ABSTRACT

Volumes of sedimentary rocks, computed from isopach-contour configurations are, in cubic miles: Lower Cretaceous (3,392), Upper Cretaceous (9,071), Paleocene (1,369), Lower Eocene (2,409), Middle Eocene (2,850), Upper Eocene (1,359), Oligocene (429), Miocene (and Pliocene ?) (998), and Pliocene to Holocene (111).

Lithofacies maps show the predominantly clastic Lower Cretaceous rocks as having invaded the Georgia Coastal Plain from the southwest, with overlap into and through the Upper Cretaceous. Paleocene overlap, followed by movement on the Central Georgia Uplift, regression, and Eocene transgression are also evident. The Oligocene carbonate-dominated rocks are also transgressive, and also reveal uplift to the south and to the north followed by erosion. Miocene and Pliocene clastic-dominated regression rocks lie on top of the Oligocene rocks unconformably. They, and the thin veneer of clastic-dominated Pleistocene and Holocene rocks which overlies them, thicken southeastward.

The most likely petroleum sources would be the deep, thick, downdip Cretaceous rocks which show strandline fluctuations and which are effected by post-Cretaceous tectonism. Also the thick Eocene and Miocene rocks offshore in the Atlantic may contain some petroleum potential, but these rocks have not yet been adequately investigated.

INTRODUCTION

> .....There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact.
> ...Mark Twain.

Data for this work are gleaned almost entirely from published reports, primarily those of Applin and Applin (1944, 1967), Babcock (1969), Chen (1965), Hurst (1960), and Marsalis (1970). Especially valuable are those of Applin and Applin (1964), Herrick (1961), and the Southeastern Geological Society, Mesozoic Committee (1949).

Data from 405 wells are utilized, almost all from the onshore portion of the Georgia Coastal Plain, but also included are data from a few wells in adjacent Alabama, Florida, and South Carolina. The emergent Georgia Coastal Plain comprises about 33,000 square miles, resulting in a well density of one for a bit less than 100 square miles. The interpretations are, accordingly, very generalized when compared with those of some of the more intensely drilled areas such as Louisiana and Texas. The data also allow for considerable latitude in interpretation, such as that which gave Mark Twain so much great pleasure. In view of the possible interpretive diversity, a bias of northeast-southwest orientation of trends was deliberately imparted. This bias is based upon the presence of known northeast-southwest oriented trends in some of the other aspects of the regional geology. Some of these are: (1) the general trend of the Appalachian Mountains; (2) structural trends in the Piedmont of Georgia and Alabama, such as the Goat Rock and Towaliga Faults, the Brevard Zone, and the Little River Series; (3) known or suspected structures in the Georgia Coastal Plain (Cramer, 1969); (4) geophysical trends, such as (a) magnetic (Drake and others, 1957; Taylor, 1974 sympos.), (b) seismic (Woollard and others, 1957), (c) gravity (Taylor, 1974 sympos.; Long and others, 1972), and (5) facies-pattern trends known from the Tertiary rocks of Alabama (Joiner and Moore, 1966).

The index map, Figure 1, shows the area of the Georgia Coastal Plain, the names of the numerous counties, and some of the major tectonic features to which reference is made in the text.

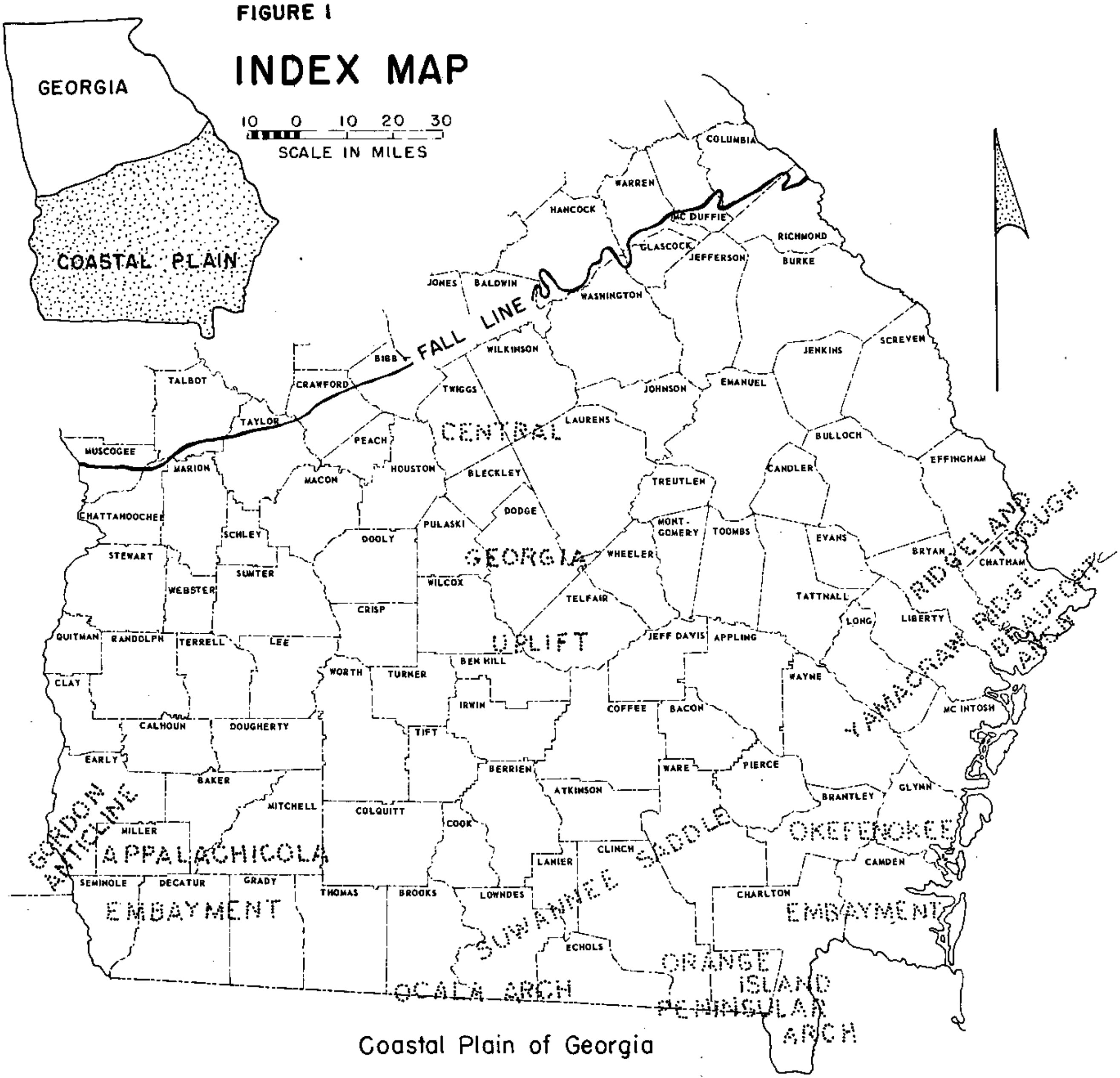
PREVIOUS WORK

Some lithofacies studies have been published about part of the rocks of part of the Georgia Coastal Plain, but none of all of the rocks nor of all of the Coastal Plain. Forgotson (1958, 1963), in describing the Lower Cretaceous of the Gulf Coastal area, included small-scale maps of Georgia, as did Applin and Applin (1965) in discussing the same rocks of Florida. Babcock (1969) describes and discusses the Upper Cretaceous rocks of northern Florida and southern Georgia, as do Applin and Applin (1967), who also include a complete isopach and lithofacies study of the Upper Cretaceous rocks of northern Florida and much of the Georgia Coastal Plain. The work of Chen (1965) on the Paleocene and Eocene rocks of Florida, includes these same rocks in a small portion of adjacent southern Georgia, as does also the work of Goodell and Yon (1966) on the post-Eocene rocks of Florida.

Isopach maps of the various units of the Georgia Coastal Plain have been devised by Herrick and Vorhis (1963), by Applin and Applin (1944), and by Rainwater (1961), but on a small scale. Babcock (1969) includes part of southern Georgia in his isopach maps of the Upper Cretaceous rocks of northern Florida. Other small-scale isopach maps

FIGURE I

INDEX MAP



Coastal Plain of Georgia

of Cretaceous units are given by Applin (1952), of Tertiary units by Toulmin (1952), and of Pleistocene rocks by Herrick (1965).

The isopach and lithofacies maps prepared for this report are necessarily very generalized and are designed to prepare a background matrix as a springboard for more detailed work as more data are unearthed.

BASEMENT CONFIGURATION

Figure 2, a map of the basement configuration of the Georgia Coastal Plain, is constructed largely from the results of the seismic surveys published by Woollard and others (1957), but altered to accommodate new well-data obtained after the seismic map was prepared.

The map clearly shows the spine of the Georgia Coastal Plain--the Central Georgia Uplift--with its two depocenters, one on either side; these are the Appalachicola and Okefenokee Embayments. These and other tectonic features are discussed by Cramer (1969) and by Patterson and Herrick (1971). Herrick and Vorhis (1963) also discuss the basement configuration of the Georgia Coastal Plain as well as other structural features in the overlying rocks.

The nature and distribution of the basement rocks has been a subject of considerable interest and debate (Milton and Hurst, 1965) to which this report contributes no new information nor interpretations. The rocks are variable, being metamorphic, igneous, and sedimentary; Precambrian, Paleozoic, and Mesozoic; and highly-, slightly-, or undeformed.

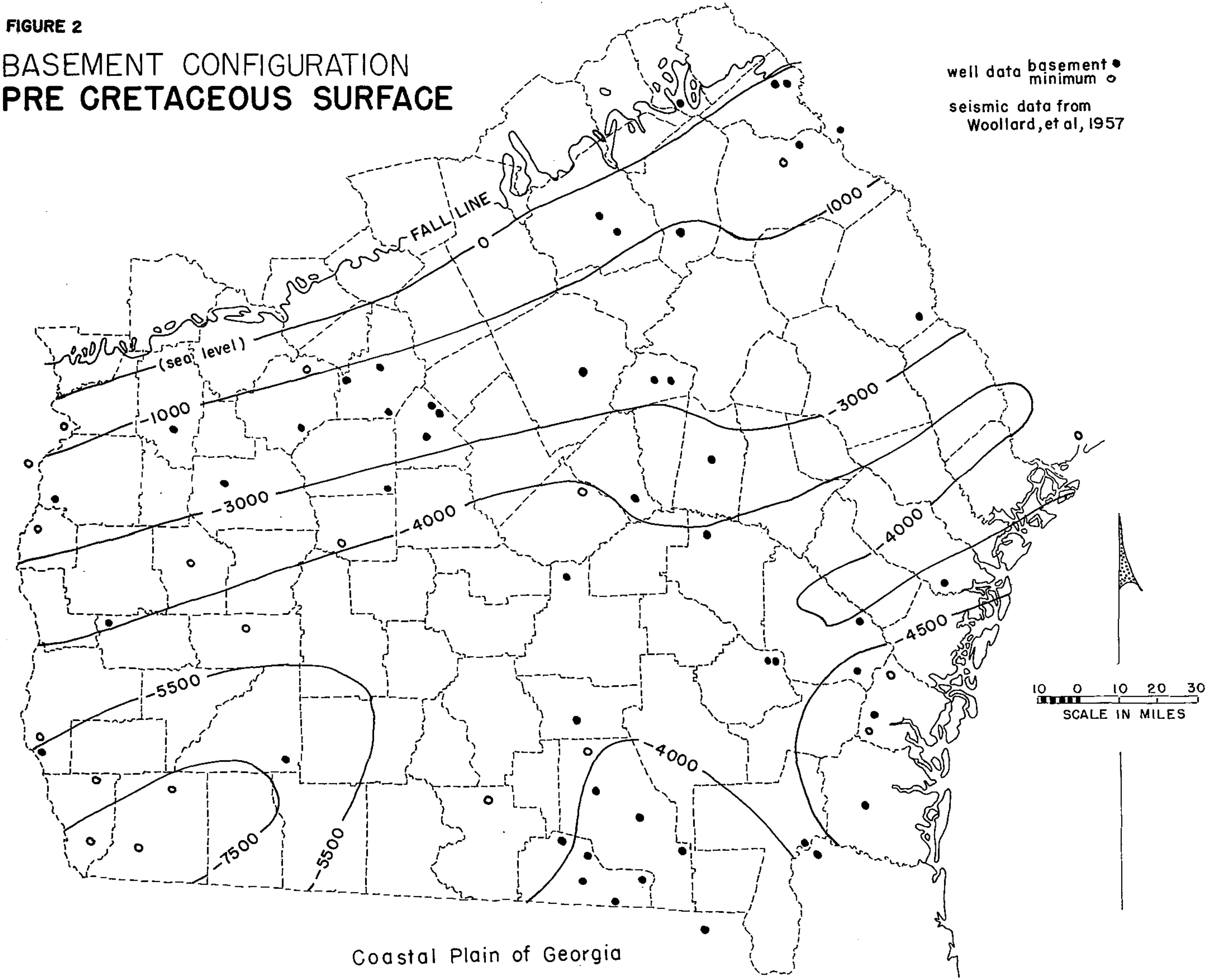
ISOPACH AND LITHOFACIES INTERPRETATIONS

Introduction

The lithofacies maps, shown as figures 3 to 11, were prepared in the manner outlined by Krumbein and Sloss (1963). Isopach contours are superimposed upon the lithofacies patterns. The published well logs of Herrick (1961) and Applin and Applin (1964) are the predominant sources of raw data. Percentages of end members carbonate (which includes limestone and dolostone), shale (which includes clay), and sandstone (which includes siltstone, buhrstone, and conglomerate) were determined for each time-rock unit in each well where the entire unit is present. Arbitrary values were assigned to those lithologic descriptions which were volumetrically indefinite, i.e., sandy shale would be considered as if it were one-fourth sand and three-fourths shale. In those wells which were logged by both Herrick and the Applins, if significant differences were present (and there were not many), averages were struck, or that interpretation selected which best fit the developing facies patterns.

FIGURE 2

BASEMENT CONFIGURATION
PRE CRETACEOUS SURFACE



Coastal Plain of Georgia

A splendid opportunity exists here for the regional stratigrapher inasmuch as the wells were logged by only two persons, and predominantly by one (Herrick), insuring that any operator bias would be more or less consistent.

Isopach contours were determined from three different types of data: (1) some wells penetrate the entire thickness of a unit, thus providing a complete isopach number (as well as complete lithofacies data); (2) some wells penetrate only a portion of a unit, thus providing only a minimal isopach value (and no lithofacies data); and (3) some of the sources include only isopach values, such as those which provide the elevations of the tops of units.

Contours were devised to best explain the distribution of the thickness values obtained, and the previously-mentioned bias was employed if necessary. Structure contour maps were prepared (but are not included in this work) and in some cases were used to assist in some of the isopaching decisions. The reader is referred to Herrick and Vorhis (1963) for published structure-contour maps on some of the various units, and also for some alternative isopach interpretations.

The isopach-contour intervals are not standardized on the maps prepared for this work, as only those were used which were necessary to outline the various patterns. The "0" contour marks the limit of each unit in the subsurface.

The outcrop areas on the maps are taken from numerous published geological maps; for the most part they are approximate. Surface mapping on the Georgia Coastal Plain requires considerable clairvoyance, as exposures are generally very poor, weathering is very intense, and the updip lithologies of most of the units are very similar.

The outcrop areas are not included in the lithofacies mapping (save for the Pliocene to Holocene interval, which is entirely outcrop) because of the boundary problems outlined above and because erosion has been active for an indeterminable length of time, rendering the depositional-facies patterns unintelligible. Rocks buried under erosion surfaces, and now in the subsurface, also show altered depositional-facies patterns, but these are the result of measurable, and relatively short intervals of time so that they are still interpretable except where the rocks are very thin, such as in the updip areas. Furthermore, being in the subsurface, these altered facies-patterns are fixed and are not being further altered.

Isopach contours are included in the outcrop areas because they represent present-day thicknesses, and can show minimal values of the thickness of the unit.

Lower Cretaceous Series

The Lower Cretaceous, or Comanchean Series in Georgia (Fig. 3) do not crop out for certain, although they may extend as far north as the Fall Line. If so, they are indistinguishable from the overlying Upper Cretaceous rocks which are lithologically similar.

Lower Cretaceous rocks in Georgia are entirely clastic. Those toward the east are very thin (less than 100 feet thick) and have been interpreted as being remnants of an older erosion surface, or soil--the "granite wash" of some reports. If so, these rocks would be older than Lower Cretaceous.

Lower Cretaceous deposition began in southwestern Georgia and progressed northeastward, as if flooding onto the continent via a graben-like rift. The amount of overlap onto the continent at this time would depend upon the interpretation of the "granite wash". Rifting is proposed by Long and Lowell (1973) who have created a model of continental deformation based upon an analysis of geophysical anomalies. This possible rifting also follows geophysical-anomaly trends recognized by Taylor (this volume) and others.

Since only 36 published logged wells enter the Lower Cretaceous rocks, of which only 14 pass through to the basement, the data on the distribution of lithofacies in the deep, Mesozoic, sandy rocks are very scant. Babcock (1969) shows possible unconformable relations between the Lower and Upper Cretaceous rocks in Florida and adjacent Georgia, and such relations are also seen in the isopach and lithofacies patterns of the Lower Cretaceous rocks in Clinch and Charlton Counties.

A thick, evaporite-bearing section occurs in the Lower Cretaceous rocks of southern Florida, but no evaporites of this age are known from Georgia.

Upper Cretaceous Series

The Upper Cretaceous Gulf Series in Georgia (Fig. 4) unconformably overlie Lower Cretaceous rocks. Upper Cretaceous rocks extend northward to the Fall Line for the most part, and are overlapped toward the northeast by younger rocks. The overlap of the Upper Cretaceous rocks over the Lower Cretaceous rocks is shown by the increasing amount of carbonate rocks toward the south and by the northward shifting of the various clastic facies.

The deltaic nature of the Upper Cretaceous rocks in the northwestern part of the Georgia Coastal Plain, as suggested by Berry (1917) is evident in the subsurface facies patterns as well as in the outcrops along Chattahoochee River. There is, however, a regional overlap which includes fluctuations of the strandline.

Some of the kaolin-bearing sandstone units toward the north, in the Twiggs County area, are now known to be Middle Eocene in age (Buie

FIGURE 3

ISOPACH-LITHOFACIES MAP

LOWER CRETACEOUS SERIES

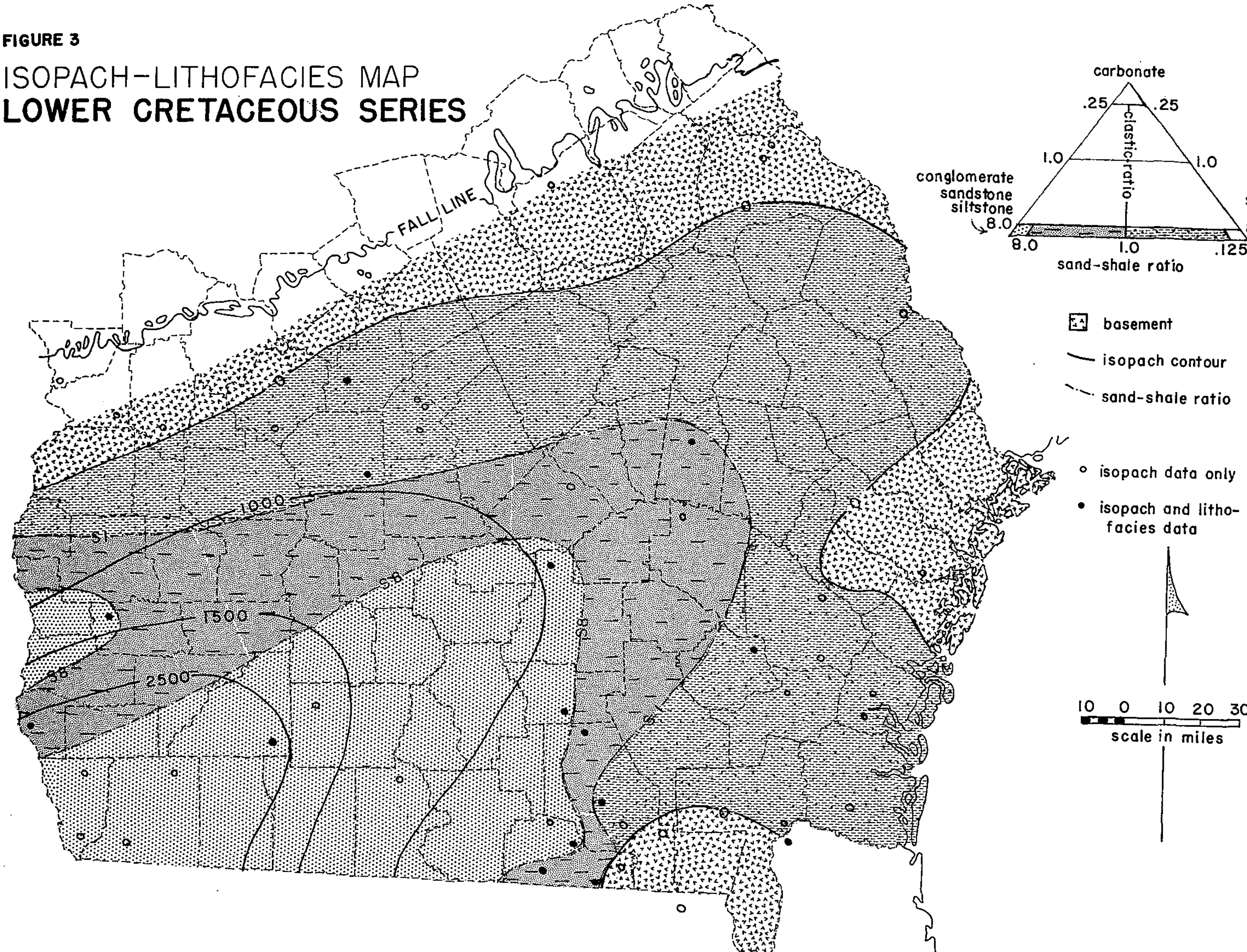


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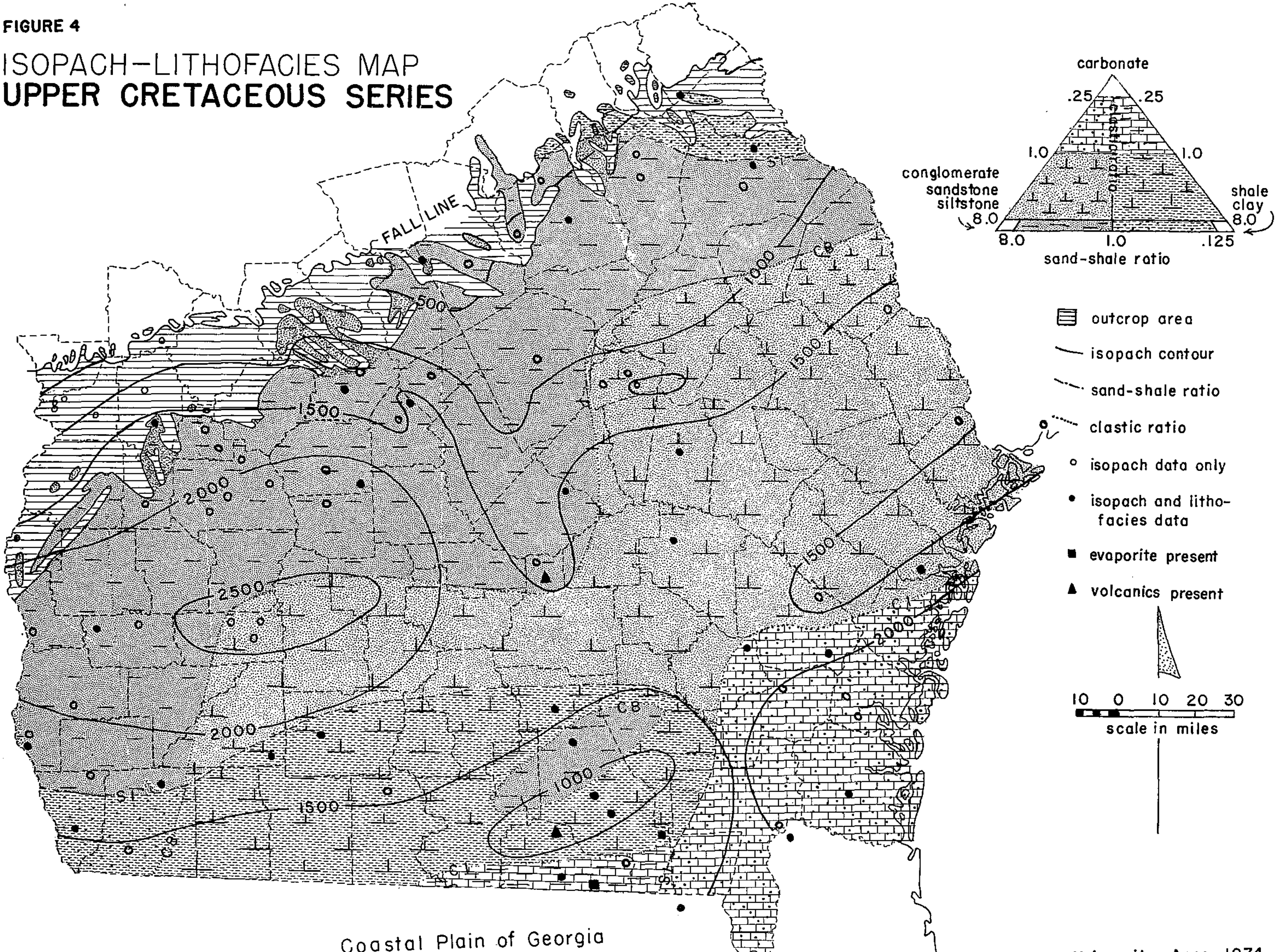
FIGURE 4

ISOPACH–LITHOFACIES MAP
UPPER CRETACEOUS SERIES



Coastal Plain of Georgia

Emory University, Anno 1974

and Fountain, 1968). Lithologic similarities of these units, the Upper Cretaceous and the Middle Eocene, make them easy to confound in the subsurface.

Obsidian from one well in Coffee County could be interpreted as detritus from the erosion of the basement which is known to contain acid volcanic rocks; volcanic ash reported from a well in Echols County could be derived from erosion in the Peninsular Arch area or from Cretaceous volcanism in Cuba.

Note that the Peninsular Arch of Florida (which projects northward into Georgia) has been overlapped by Upper Cretaceous rocks, and the Suwannee Saddle (also called the Suwannee Strait) shows distinctly on the lithofacies map (Fig. 3), and less distinctly but very interpretable from the isopach contours. This is an area of clearly different lithology and thinner rocks. Applin and Applin (1967) give a review of the explanations proposed for this feature, and there is nothing new that can be added from this report. The current explanation is that there was Upper Cretaceous arching, trending northeast-southwest, in what is now the saddle area, which resulted in thinner deposition over the arch, and a different sedimentary regimen established on either side. The arched area later became a relatively low area due to uplift to the north and to the south; the relatively low area then became the Suwannee Strait, or, to avoid an oceanographic inference, the Suwannee Saddle, to provide a structural connotation.

The depocenter, or basin west of the Central Georgia Uplift may be real or apparent. If Cretaceous rocks have been removed from the Central Georgia Uplift due to erosion following post-Cretaceous uplift, what is now an apparent basin may be residual from what was then a trough which trended northeast-southwest.

Evaporites occur in Upper Cretaceous rocks in Florida, but none are reported from Georgia.

There is no way in which the careful, detailed work of Applin and Applin (1967) can be improved upon at this time, and the interested reader is referred to this and other works of these two diligent workers for further details.

Paleocene Series

Where exposed in outcrop, Paleocene Midway rocks appear to rest disconformably upon Upper Cretaceous rocks (Fig. 5). A great paleontological hiatus is described by Rainwater (1960) even though the physical contact does not everywhere show the distinct hiatus. The facies patterns of the Paleocene, in relation to those of the underlying Upper Cretaceous, indicate a continued overlap in the updip region, whether or not preceded by an erosion interval.

Deltaic sedimentation can be deduced from the lithofacies patterns toward the southwest, whereas the numerous and variable facies patterns toward the northwest are probably the result of the alteration of the origianl sedimentary patterns by post-Paleocene erosion.

The variation in the lithofacies pattern in the Suwannee Saddle area shows that the same feature continues to be present; the isopach contours indicate that the rocks are thicker, as if filling in an erosional channel (the original interpretation of the Suwannee Strait), but a structural low would produce the same isopach pattern also.

Evaporites occur in Paleocene rocks of northern Florida, but none are reported from Georgia.

Late- or post-Paleocene uplift in the Central Georgia Uplift area is suggested by the absence of Paleocene rocks in the area, by the thinning of the Upper Cretaceous rocks in the same area (Fig. 4), and by the widespread unconformity which occurs between the Paleocene and overlying Lower Eocene rocks (Rainwater, 1964).

Lower Eocene Stage

The Lower Eocene, Sabine-Stage regression is well documented in the Gulf Coastal Plain, and it is evident in the Georgia Coastal Plain from the nature of the terrestrial deposits resting upon karst topography developed upon Paleocene limestone where exposed along Chattahoochee River. Following the regression, overlap commenced, as Figure 6 indicates. Lower Eocene rocks are largely clastic toward the southwest, suggesting the updip edges of the great regressive delta complex which is centered farther to the southwest from Alabama to Texas. Open marine conditions prevailed elsewhere throughout Georgia and in Florida at this time.

The Suwannee Saddle, whatever its origin, is still evident in the lithofacies patterns.

Overlap onto the Central Georgia Uplift is evident also, suggesting that the initial tectonism which raised it was during the late Paleocene or very early Eocene.

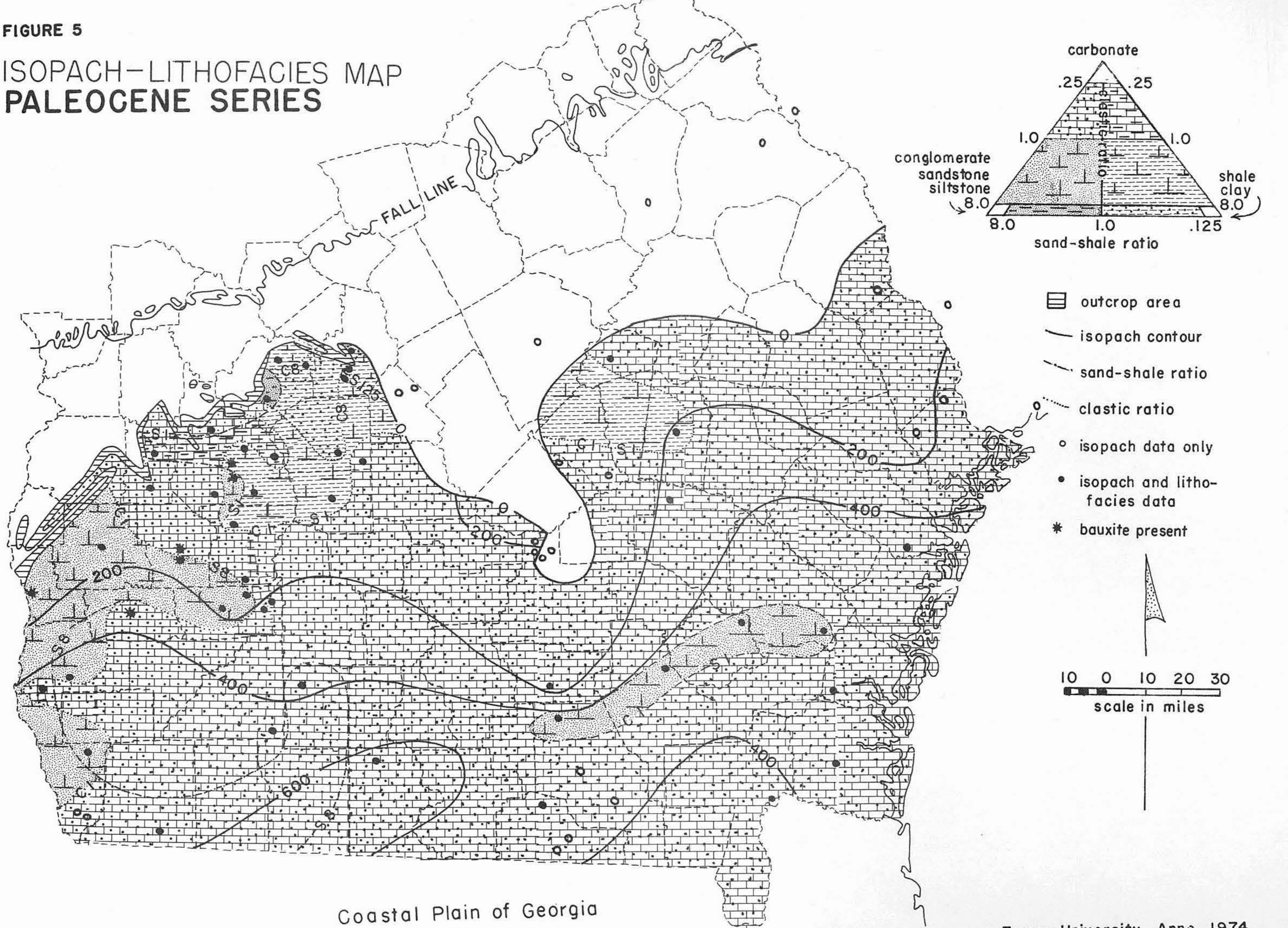
No evaporites are known from Georgia, but they are very extensive in northern Florida.

Middle Eocene Stage

The Middle Eocene, or Claiborne-Stage (Fig. 7) map shows continued overlap of Middle Eocene rocks upon the Lower Eocene rocks. The strandline fluctuations are very evident in the sedimentary deposits in the outcrop, but the general trend was toward overlap with the strandline shifting northward. Some of the kaolin-bearing sandstones in Twiggs County are now known to be Middle Eocene rather than Upper Cretaceous (Buie and Fountain, 1968).

FIGURE 5

ISOPACH-LITHOFACIES MAP
PALEOCENE SERIES



Coastal Plain of Georgia

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FIGURE 6

ISOPACH—LITHOFACIES MAP
LOWER EOCENE STAGE

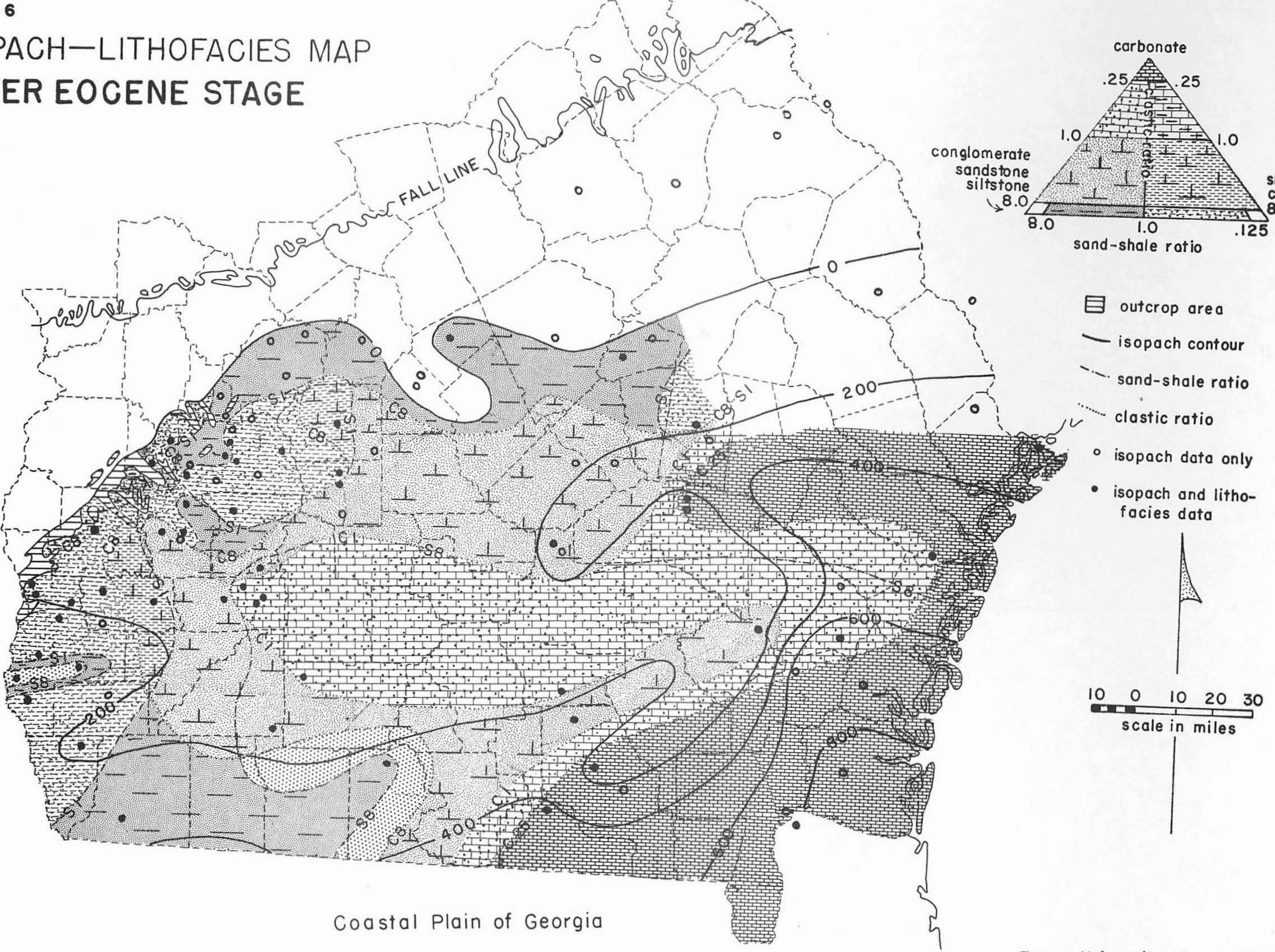

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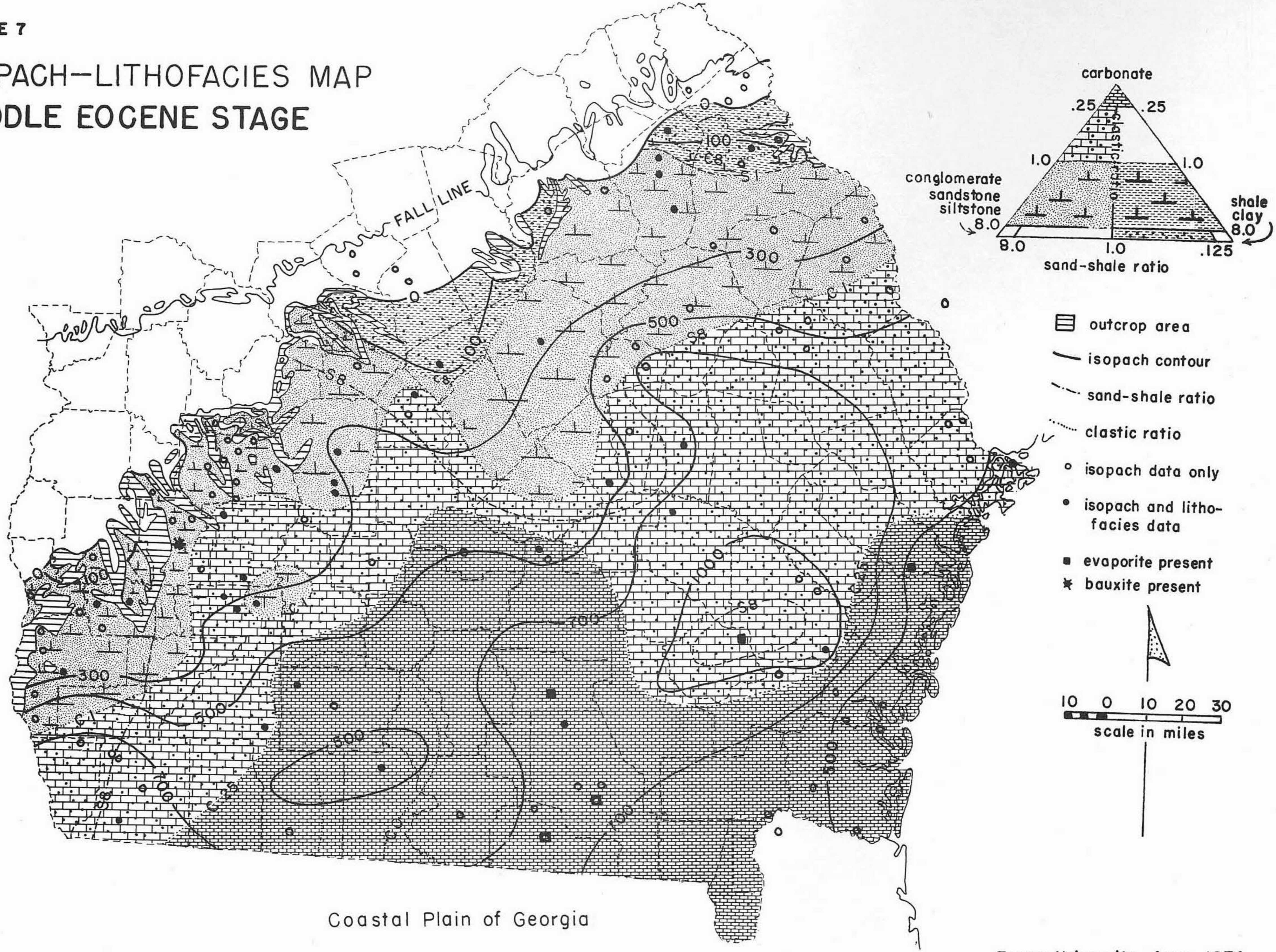
FIGURE 7

ISOPACH—LITHOFACIES MAP
MIDDLE EOCENE STAGE



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The Lower Eocene rocks on the Central Georgia Uplift have been completely overlapped by the Middle Eocene deposits, and the Suwannee Saddle is still evident as an area of sedimentation different from that of the surrounding areas.

Much evaporite occurs in northern Florida, and small amounts are reported from wells in Atkinson, Clinch, Echols, Liberty, and Pierce Counties. All of the evaporite in Georgia is gypsum and all of it is associated with limestone or dolomitic limestone.

Upper Eocene Stage

The map of the Upper Eocene, or Jackson Stage (Fig. 8) shows that overlap continued, and that this may have been the time of the greatest invasion of the Coastal Plain of the Tertiary. Upper Eocene rocks are almost entirely carbonate, and most of the rocks are completely free of any terrigenous material. The Upper Eocene Stage in Georgia is very thin, as it is everywhere in the Gulf Coast region. Fluctuations of the strandline have been shown by the presence of interdigitated diatomaceous claystones (Wise, this volume) and by the presence of interbedded clastic formations updip. Carver (1965) would have the updip clastic rocks (the Barnwell and Twiggs Formations) regressive, and overriding the carbonate units, whereas Herrick and Furlow (1972) consider the updip clastic rocks to be Oligocene in age.

The nature of the contact between the Middle and Upper Eocene rocks is distinct. Carbonate sedimentation predominated during both intervals of time, and the facies maps show that Upper Eocene rocks clearly overlap those of Medial Eocene age. Herrick (1972) suggests that the Clinchfield Sand, below the carbonate sequence in Houston County and vicinity, belongs to the Upper Eocene Stage rather than in the Middle Eocene Stage as generally considered; this would imply an unconformity. The contact of the Upper Eocene Stage with the overlying Oligocene Series is also anomalous. In many places the Oligocene rocks are carbonates (Fig. 9) and overlap or stability is implied, as the various sedimentary environments were continuous (carbonate on carbonate), yet both Herrick (1968) and Furlow (1969) report karst in and between the two units. If there were post-Upper-Eocene uplift and erosion, followed by a reinvasion of the sea during Oligocene time, the lack of clastic material in the unconformity is remarkable. The lack of clastic terrigenous material suggests a provenance of very low relief, and lends support to the hypothesis of the presence of the Schooley Peneplain surface toward the north.

Evaporite, as gypsum, occurs in northern Florida and in scattered wells in Decatur, Thomas, Lowndes, and Glynn Counties; all of the gypsum in Georgia occurs in carbonate areas and is associated with dolomitic limestone.

The facies data from the Oligocene Series (Fig. 9) are the most difficult to resolve into meaningful patterns of all of the Georgia Coastal Plain Tertiary rocks. Oligocene rocks overlie Upper Eocene rocks with a facies conformity (carbonate on carbonate), yet the contact may be disconformable; karst topography between the Oligocene and Upper Eocene is reported from several places.

Late Oligocene tectonism resulted in the uplift of the Peninsular Arch area (Orange Island), resulting in the removal of Oligocene rocks in the extreme southern part of Georgia. Clastic material coming from the uplift area has been infused northward into the marine carbonate sediments. At the same time, uplift in the north has resulted in clastic material being added to the marine carbonate environment from the north. Furthermore, the northeast-southwest trends of the isopach variations can be interpreted as being the results of deformation.

The anomalously thick section centering in Coffee County could be: (1) perfectly normal, the surrounding rocks having been thinned due to post-Oligocene exposure and erosion; such lowered solution plains are not unknown elsewhere; (2) a sink hole in the Upper Eocene rocks which has been filled with Oligocene rocks and into which the drill hole coincidentally passed; (3) misidentification of the Oligocene-Eocene or the Oligocene-Miocene boundary, due possibly to caving; (4) misinterpretation of index fossils; or (5) some sort of structural complexity which has not yet been detected. In view of the isopach-pattern trends which may reflect tectonism, some combination of (1) and (5) seems the most plausible.

The Ocala Uplift in peninsular Florida, which may have influenced sedimentation and topography in the southern Georgia area, occurred during Late Oligocene or Early Miocene time (Vernon, 1951), as the Oligocene rocks in Georgia are unconformably overlain by the Miocene rocks.

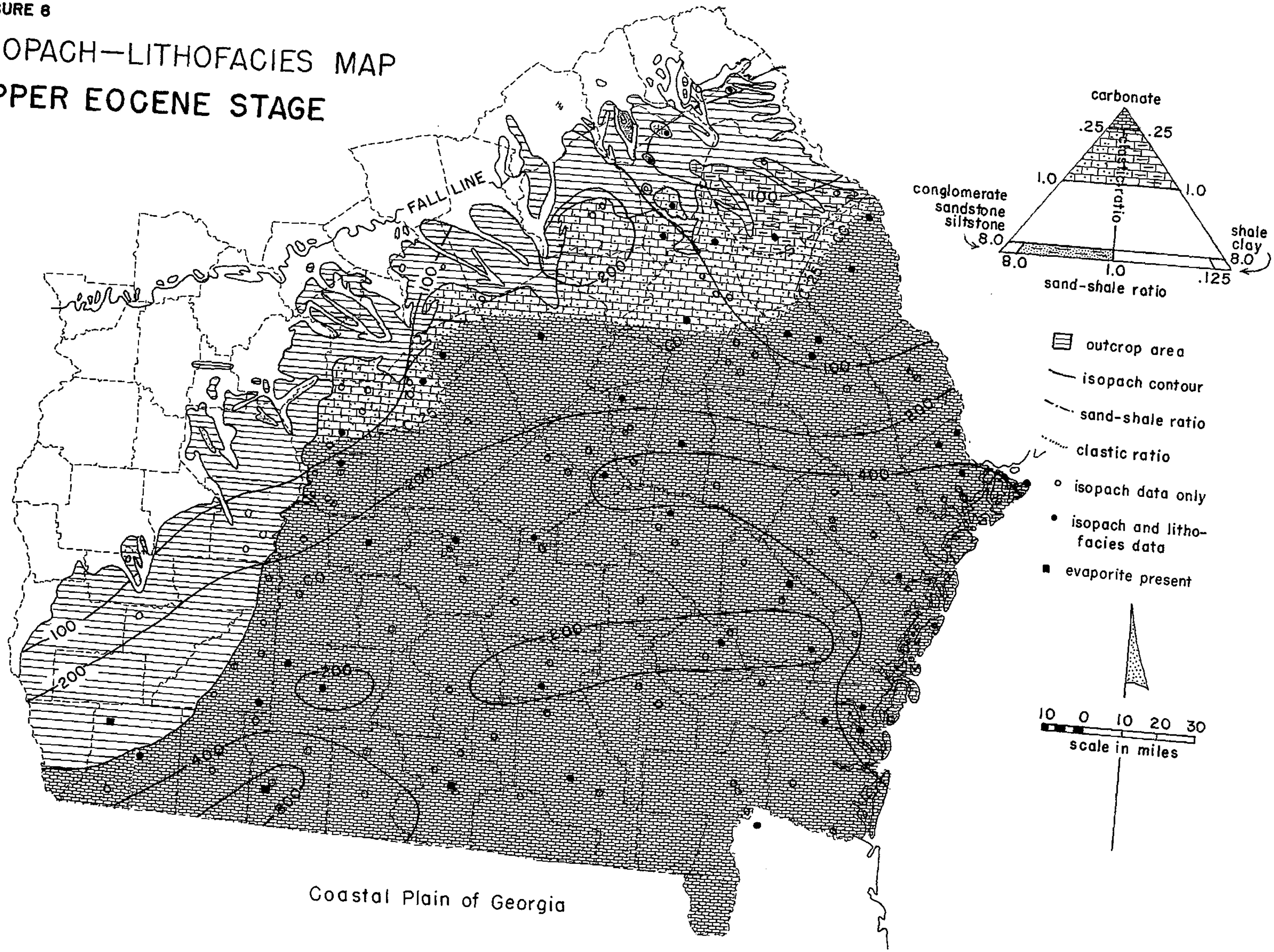
Miocene (and Pliocene?) and Series

Current paleontological work (M. Hunter and P. Huddlestun, personal communication) suggests that some of the reported Upper Miocene rocks of Georgia and elsewhere are more likely Pliocene. Since these are not distinguished in most of the well logs, the map (Fig. 10) includes the possibility and probability that some of the logged Miocene rocks are Pliocene. The Duplin Marl, for instance, considered to be Upper Miocene in most reports, unconformably overlies older Miocene rocks along the Savannah River (Counts and Donsky, 1963), and is considered to be Pliocene. Other rocks in southwestern Georgia, largely in the outcrop area, have been considered Upper Miocene in the past, but are included in the Pliocene.

FIGURE 8

ISOPACH—LITHOFACIES MAP

UPPER EOCENE STAGE



Coastal Plain of Georgia

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FIGURE 9

ISOPACH—LITHOFACIES MAP
OLIGOCENE SERIES

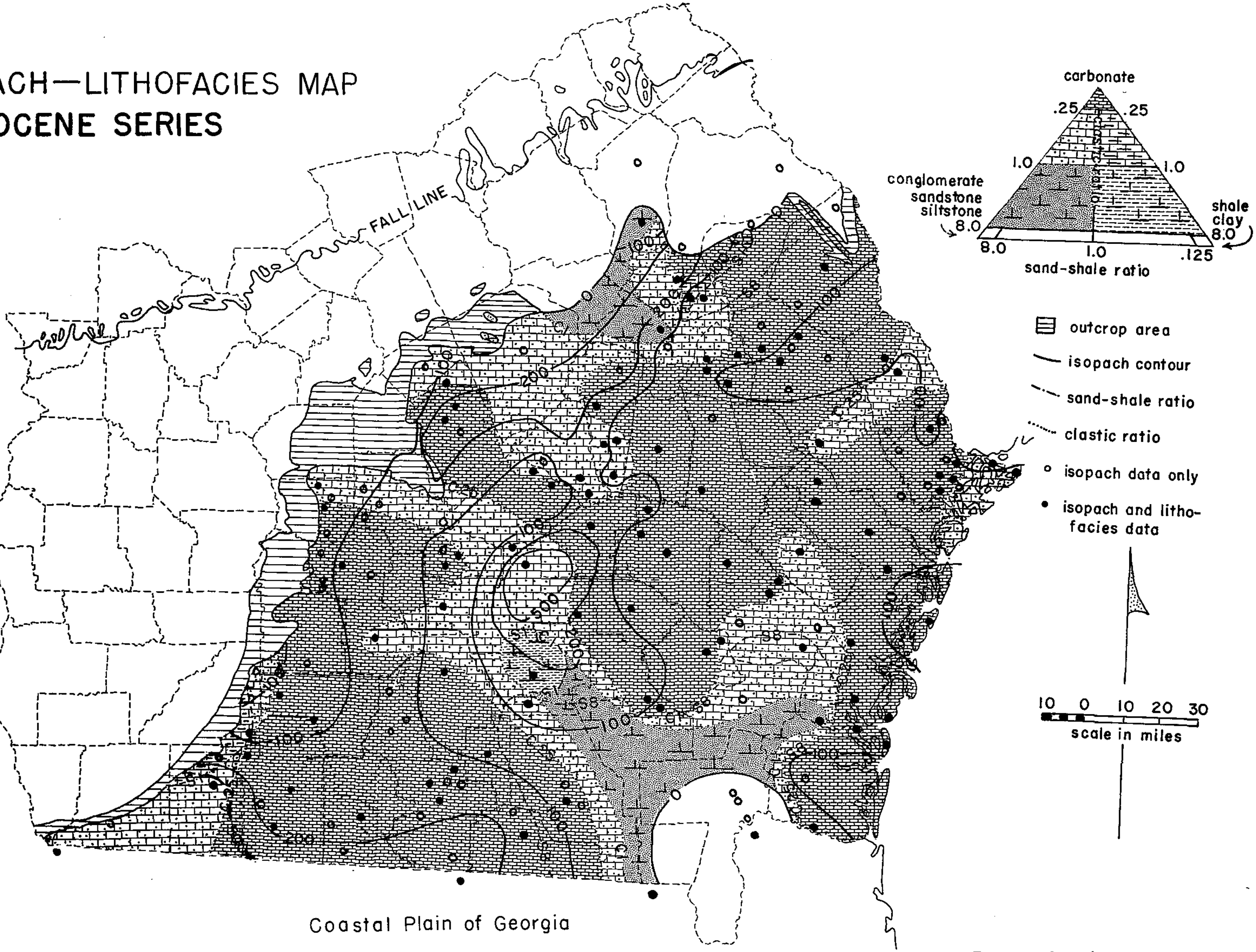

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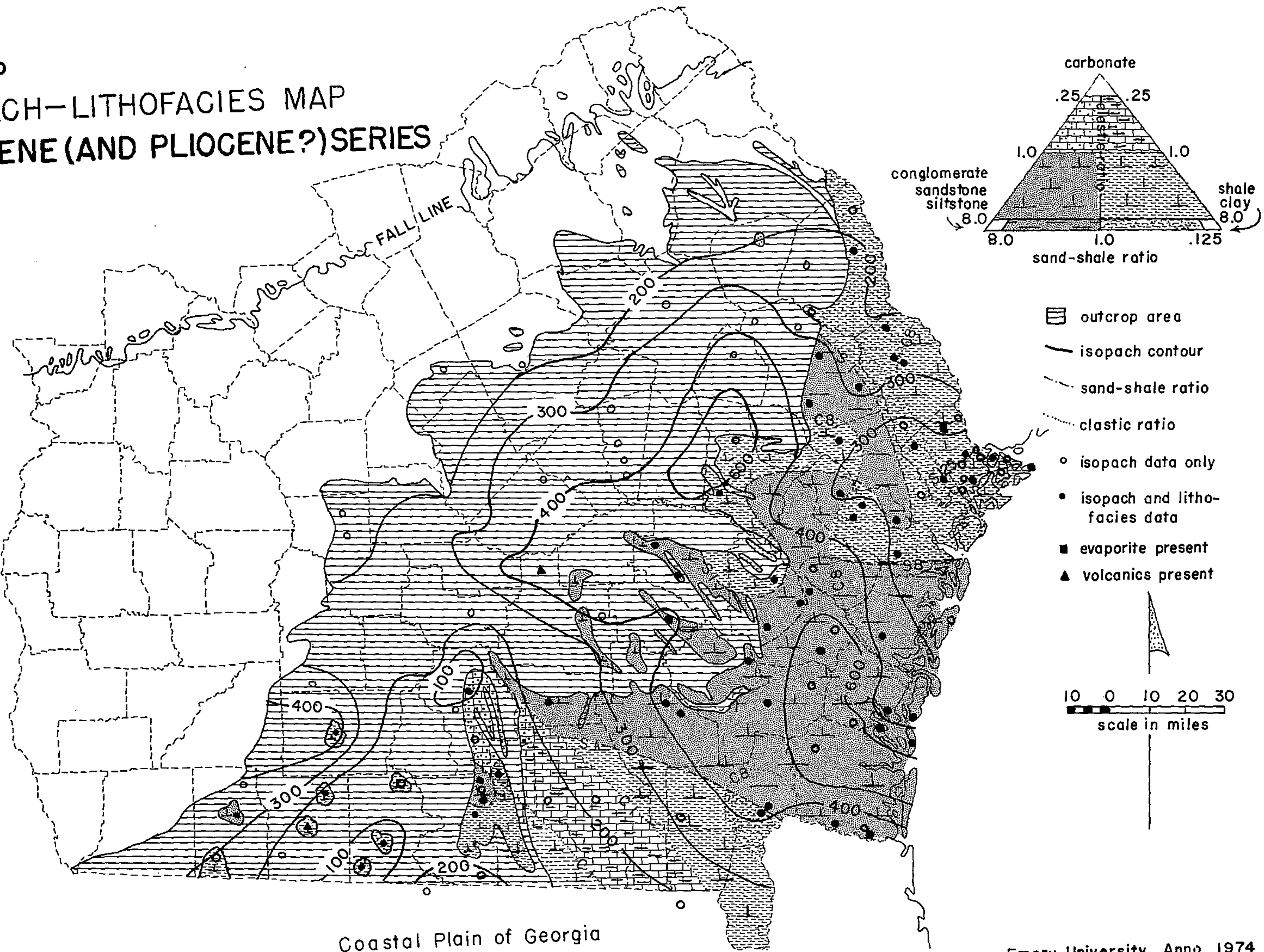
FIGURE 10

ISOPACH-LITHOFACIES MAP
MIOCENE (AND PLIOCENE?) SERIES



Coastal Plain of Georgia

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Miocene (and Pliocene?) rocks appear to be a regressive sequence of predominantly clastic rocks which increase in thickness seaward. The uplift of the Schooley Peneplain to the north during the Late Oligocene and/or Early Miocene poured sediments southward and deposited them in a regressing sea.

Note that Orange Island, exposed by post-Oligocene uplift, has been covered by Miocene sediments.

Considerable post-Miocene erosion has taken place before the return of the Pleistocene sea, and in some places erosion may have continued from the Miocene to the present. The erosion has altered the original sedimentary patterns, making the resulting lithofacies extremely difficult to interpret. It is clear, however, that the bulk of the sediments are clastic, with the carbonate content increasing seaward; the carbonate-rich portions may be the Pliocene rocks.

Bentonite, as tuff, is reported from one well only, that in Coffee County. Its origin is unclear from the isolated and limited data available.

Miocene deformation has also conspired with post-Miocene erosion to produce and then alter isopach and lithofacies patterns. Uplift (folding and/or faulting) in the Savannah area, called the Burton High by Siple (1967), the Beaufort High by Heron and Johnson (1966), the Beaufort Arch by Colquhoun and others (1969), and that part in Georgia the Tybee High by Furlow (1969) is reported. The rocks are thinner across the top of the feature. The arching may be in part responsible for the restriction of the marine waters which resulted in the deposition of the evaporite reported from one well in Chatham County. If the Duplin Marl, which unconformably overlies the Miocene Hawthorn Formation in the Savannah area, is Pliocene, this would make the arch a Miocene feature and the evaporite Pliocene. The area to the north and west of the Beaufort Arch is called the Ridgland Trough by Heron and Johnson (1966).

The isopach and lithofacies patterns of the Miocene (and Pliocene?) rocks suggest that the greatest accumulation of sediments took place in the paleo-Altamaha River terrain; this region may have been topographically and structurally low during the Miocene (and Pliocene?) and so attracted the sediments into it. Later, northeast-southwest-trending warping and subsequent (to and including the Holocene) erosion has reduced the thickness in the trend of the arching. If the Beaufort Arch extended southwestward to the Altamaha River region, it could have resulted in the arching and erosional thinning of the Miocene (and Pliocene?) rocks in Wayne and Long Counties, across the paleo-Altamaha River drainage trend. Structure contours on a Miocene unit by Prettyman and Cave (1923) do not so indicate, however. Here, the Beaufort Arch appears to extend only a short way southwest from Savannah. On the other hand, if the Miocene unit plotted by Prettyman and Cave were Pliocene, then the Miocene flexure below the Pliocene layer would not be evident in their interpretation. Not enough data are available to make a positive decision.

Pliocene to Holocene Series

Little more can be added about the Pliocene, Pleistocene, or Holocene (Fig. 11) than has already been given by Herrick (1965) and Herrick and Vorhis (1963). Marine and littoral Pliocene rocks occur in the southeastern part of the state and appear to represent a slight transgression on an otherwise predominantly regressive pattern which was established during the Miocene. Clastic rocks dominate the Pleistocene and Holocene Epochs, and represent a fluctuating strandline over the Pliocene marine deposits; the present Holocene transgression is the most current event.

The Pleistocene units, while physiographically distinct, cannot be distinguished in the subsurface, and so are mapped together as one unit.

In the southeast, the Pliocene to Holocene rocks appear to be the thickest just to the south of the present-day Alatamaha-River mouth area, as are those also of the Miocene (and Pliocene?) Epochs. This allows for the suggestion that the low area which attracted sediments since at least the Miocene, continued to do so to the present time. Spencer (1912) noted a Pleistocene submarine canyon offshore from the Altamaha River (and also the Savannah River), and the channel of the Altamaha persists as a submarine topographic feature still (Pilkey and Giles, 1965).

Isolated patches of Pliocene to Holocene rocks occur inland from the main outcrop area. Some are remnants of former sea stands, some are river terraces resulting from sea-level changes, and some may be remnants of former fluviatile lithosomes (Voorheis, 1970).

VOLUME INTERPRETATIONS

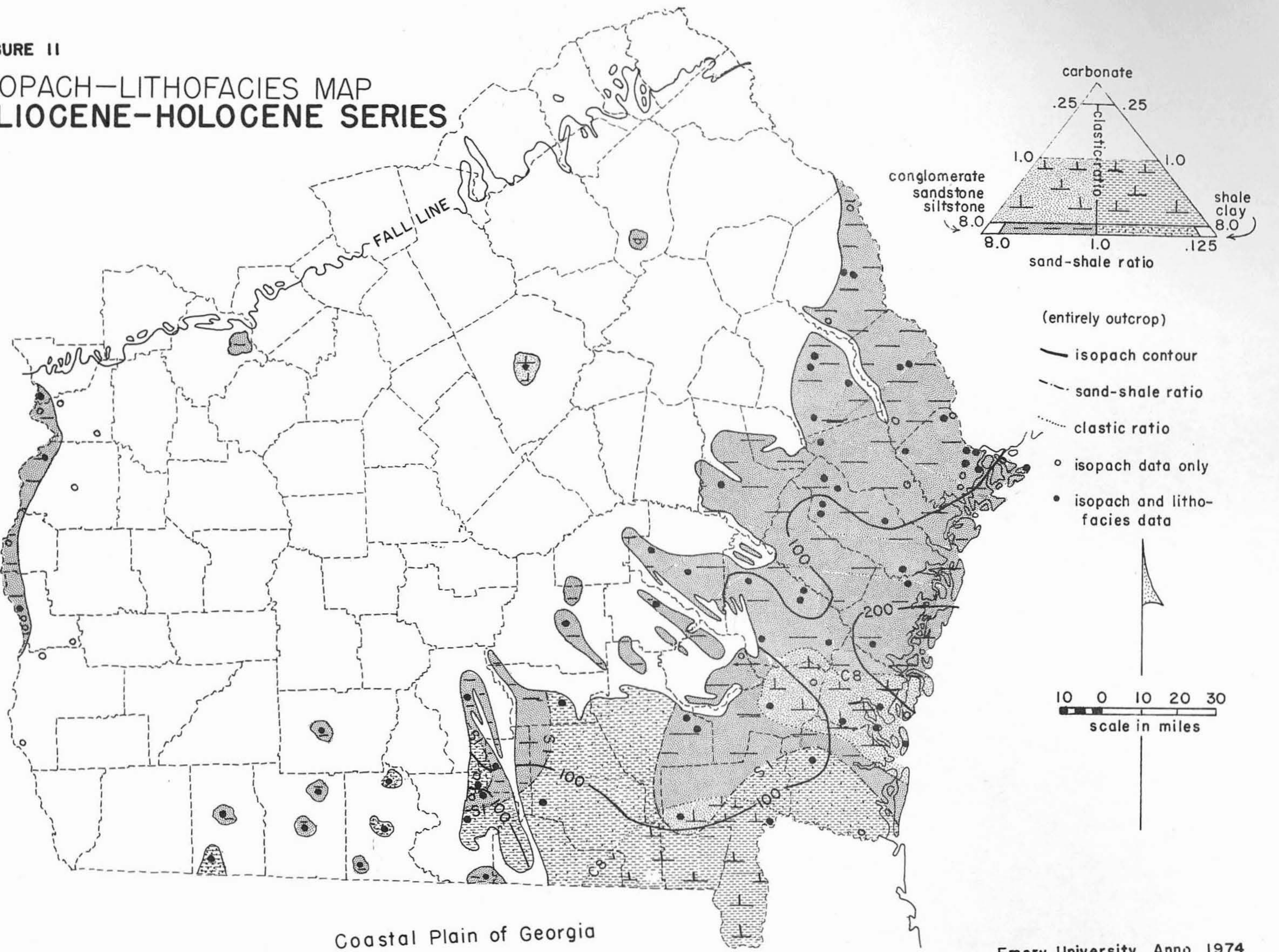
Areas between the contour lines were determined, and were multiplied by the average thickness of the rocks between the contours. The resulting volumes were added together to determine the volume for each of the time-rock units. The results, including the areas in outcrop are, in cubic miles:

Lower Cretaceous	3,392
Upper Cretaceous	9,071
Paleocene	1,369
Lower Eocene	2,409
Middle Eocene	2,850
Upper Eocene	1,359
Oligocene	429
Miocene (and Pliocene?)	998
Pliocene to Holocene	111

The total volume of Cretaceous rocks is 12,463 cubic miles; the total volume of Cenozoic rocks is 9,525 cubic miles, and the total volume of sedimentary rocks on the onshore portion of the Georgia Coastal Plain is 21,988 cubic miles.

FIGURE 11

ISOPACH—LITHOFACIES MAP
PLIOCENE-HOLOCENE SERIES



Coastal Plain of Georgia

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Other volumetric studies have been published. For instance, Applin (1952) determined the volume of Cretaceous rocks in Florida and Georgia to be 50-60,000 cubic miles, but he did not distinguish the volume of rocks in Georgia from those in Florida. His maps indicate, however, that the amount in Georgia is considerably less than the amount in Florida.

Toulmin (1952) determined the volume of Cenozoic rocks on the Georgia Coastal Plain to be 9,100-9,850 cubic miles, substantially the same as the volumes determined in this report.

Spivak and Shelburne (1971) computed the volume of the onshore sedimentary rocks of the Georgia Coastal Plain, below a depth of 1,500 feet, to be 17,000 cubic miles.

In order to place the volume of sedimentary rocks of the Georgia Coastal Plain in a different perspective, Table I shows some volumes determined for other areas of the United States, some of which are very petroliferous. From this table, one can see that Georgia is not particularly well endowed with sedimentary rock in terms of volumetric potential for petroleum, but, on the other hand, there are some regions where, by the petroleum geologist, Georgia may be envied. Weeks (1958b) cautions geologists about making direct volume-reserve ratio estimates, as numerous examples of reverse ratios are known, but volume studies do allow for comparisons of ultimate potential maxima.

SUMMARY AND GEOLOGICAL GENERALIZATIONS

The Georgia Coastal Plain falls into the Class V basin category in Halbouty's classification system (1970)-a stable coastal basin, or coastal graben-fault basin, the end phase of cratonic rift basins. They often include down-to-the-sea faults, and have Tertiary or Mesozoic brackish and marine sediments draped over fault-block structures. Most of these basins have offshore ridges which appear to be basement uplift that act as dams to contain shore-derived detritus. Evaporites form in many of the basins.

The Cretaceous uplift which resulted in the Suwannee Saddle structure could be such an offshore uplift, and possibly the Yamacraw Ridge is a reflection of this type of uplift also. Emery and Zarudzki (1967) in their seismic interpretation from JOIDES cores from nearby offshore, allow for such structures in the deep subsurface below the continental shelf. The Central Georgia Uplift might also be one of these types of anticipated basinal uplifts, as might also be the Ocala Uplift and Peninsular Arch (which produced Orange Island) in Florida.

This continental corner of North America, while containing some of the Class V basin characteristics, also tended toward being a high area, relative to the adjacent areas, perhaps responding to the forces

TABLE I. SOME REPRESENTATIVE SEDIMENTARY VOLUMES IN THE UNITED STATES --IN CUBIC MILES.

Alaska--Cook Inlet		13,000 (Ball)
California		
Northern Coastal Range		525 (Ball)
Sacramento Valley		54,000 (Ball)
San Joaquin Valley		32,000 (Ball)
Ventura Basin		17,000 (Ball)
Los Angeles Basins		2,250 (Ball)
Dakotas		115,000 (Ball)
Mid-continent region		324,000 (Cram)
Nebraska		35,000 (Ball)
Salina Basin		23,000 (Ball)
Forest City Basin		7,100 (Ball)
Oklahoma-Arkansas		55,000 (Ball)
Anadarko Basin		9,500 (Ball)
Texas		
Palo Duro Basin		48,000 (Ball)
Trans-Pecos area		80,000 (Ball)
Fort Worth Basin area		17,000 (Ball)
Illinois Basin	108,000 (Cram)	90,000 (Ball)
Michigan Basin		108,000 (Cram)
Appalachian Basin	305,000 (Cram)	500,000 (Ball)
Pennsylvania		90,000 (Cram)
Western Gulf Coast region		245,000 (Murray)
Central Gulf Coast region		200,325 (Murray)
Atlantic Coastal Plain		
offshore	124,000 (Cram)	110,000 (Ball)
onshore	30,000 (Cram)	15,500 (Ball)
New Jersey	1,000 (Cram)	3,200 (Ball)
Delaware		900 (Cram)
Maryland		2,000 (Cram)
Virginia	2,200 (Cram)	5,000 (Ball)
North Carolina		5,400 (Cram)
South Carolina		2,200 (Cram)
Georgia	17,000 (Cram)	21,980 (Murray)
Florida	315,000 (Cram)*	89,520 (Murray)

Ball, M. W., and others, 1951.
Cram, I. H., editor, 1971.
Murray, G. E., editor, 1952.

*includes offshore

proposed by Long and Lowell (1973). The spine at the continent corner, the Central Georgia Uplift (Pressler, 1947), has been actively uplifted at least once during the history of the Georgia Coastal Plain since Cretaceous sedimentation began, and perhaps even more, as demanded by the Applin and Applin theory of Suwannee-Saddle formation (1967).

Coastal-Plain-forming seas invaded Georgia from the southwest during the Lower Cretaceous or possibly earlier, perhaps into a graben or other structural depression oriented northeast-southwest. The Lower Cretaceous rocks were deformed by the uplift of the Peninsular Arch and vicinity in southern Georgia, possibly by the Central Georgia Uplift, and possibly by the Yamacraw Ridge. Upper Cretaceous seas overlapped the deformed Lower Cretaceous rocks and came on the continent to at least the Fall Line.

The overlap continued to at least the Oligocene, with fluctuations in the strandline being common, and with at least one interval of tectonism on the Central Georgia Uplift, which was followed by a regression before overlap continued during the Eocene. Such uplift is predicted by the theory of Long and Lowell (1973) and is required by the model of Applin and Applin (1967) for the origin of the Suwannee Saddle. The Eocene and Oligocene rocks are largely carbonate, suggesting extensive overlap onto the continent, as much of the shoreward clastic-facies rocks are not present. Whether they were removed by erosion or were never deposited cannot be determined. The low, flat Schooley Peneplain would have allowed such an overlap to develop.

During Late- or post-Oligocene time, uplift occurred again, to the north of the Coastal Plain, and to the south, in Florida, as the Peninsular Arch and as the Ocala Uplift. Oligocene rocks were removed from Orange Island and the Ocala Uplift area (the latter entirely in Florida).

Erosion proceeded on the Oligocene rocks after the uplift, and upon this erosion surface, enormous volumes of clastic material were poured southward from the north, resulting in the Miocene-aged regressive deposit.

The Okefenokee Embayment, attracting the paleo-Altamaha River drainage, was an especially active sediment trap during this time, resulting in the thick Miocene (and Pliocene?) deposits in that area. This river and embayment continue to serve as an attraction and conduit for sediments from the land to the sea even today.

The present Fall Line is not the original depositional edge of the marine invasions, as the isopach and lithofacies patterns suggest that the shoreward, clastic facies were once farther inland; considerable erosion has taken place updip.

The sediments deposited on the Georgia Coastal Plain are not clearly derived from the Rocky Mountain area, as postulated by MacNeil (1966), inasmuch as the Georgia area was relatively high when compared with the Gulf Coast basins to the west. These lower areas would likely deflect the eastward moving sediment and draw it downward before it arrived in Georgia. Further, the deltaic nature of many of the Cretaceous and Cenozoic rocks indicates that a northerly source was likely.

Late Miocene deformation resulted in the formation of the Beaufort Arch and the gypsum-bearing Ridgland Trough north of Savannah. The evaporite may be in Pliocene beds.

Pleistocene sea-level fluctuations followed, resulting in physiographically recognizable terraces at the higher stands; currently a Holocene transgression is underway.

PETROLEUM POTENTIAL

From the estimations based upon volume-reserve ratios from elsewhere, Spivak and Shelburne (1971) estimate that the ultimate hydrocarbon reserve of the Georgia Coastal Plain will be 250 million barrels of oil, 1.7 trillion cubic feet of gas, and 0.05 billion barrels of natural-gas liquids. Where is this?

Sedimentation controls

The Cretaceous rocks of the onshore Georgia Coastal Plain are good potential reservoirs, as most of them are clastic, and show considerable wedging and intertonguing due to strandline fluctuations. No tight cap rocks are known, however. Deltaic sedimentation in the Cretaceous has been identified by Berry (1917), especially in Alabama, and some of the lithofacies patterns suggest that the deltaic conditions may have spilled over into Georgia. Deltaic and nearshore deposits are well exposed in outcrop along Chattahoochee River (Poort, this volume). Rainwater (1970a) thinks highly of the Lower Cretaceous in the entire Gulf Coast area as a potential reservoir rock, but he includes Georgia in his non productive zone. He thinks even less of the Upper Cretaceous of Georgia as a potential producing interval (1970b).

In theory, the onshore Cenozoic rocks of the Georgia Coastal Plain should contain good reservoirs, as considerable clastic material is present and porosity is very high, but no extensive cap rocks are presnet. Furthermore, they contain abundant fresh water and are the main aquifers for the region.

Paleocene lithofacies patterns in the southwestern part of Georgia may be deltaic and the rocks may contain interbedded clay and sand. Paleocene rocks are known to be offshore in the Atlantic, but little is known of them save that they are composed of clay, calcilutite, and chert and are known from only one JOIDES core (Charm and others, 1969).

The regressive sequence of Lower Eocene sedimentary rocks toward the southwest may contain interfingered clastic material; these are splendid traps farther downdip to the west and south. Deltaic patterns can be interpreted from the lithofacies maps in southwestern Georgia, but the published information is too limited to make more than very generalized speculations.

The Middle Eocene rocks are the thickest of the offshore Atlantic units (Charm and others, 1969), but little is known of them except that they are calcarenites which are silty and sandy.

The Miocene rocks offshore in the Atlantic, if the onshore regressive sequence continues seaward, could, if structures permit, contain potential petroleum traps.

The younger Cenozoic rocks onshore are too shallow to be seriously considered as potential petroleum reservoirs; all have been extensively drilled and little encouragement has come forth.

Structural controls

The trapping of hydrocarbons potentially increases with an increase in the structural complexity of the rocks. The rocks of the Georgia Coastal Plain are not, as generally thought, in a monotonously seaward-dipping wedge. Some structures are known, others have been speculated upon, and still others may be hidden between the sparsely distributed wells. Many of the structures are described in Cramer (1969), and many are shown to be ficticious by Patterson and Herrick (1971).

The two great depocenters on either side of the Central Georgia Uplift, the Okefenokee and Appalachicola Embayments, naturally attract the attention of the petroleum geologist. They contain great thicknesses of sediments and have undergone varying periods of downwarping.

The Yamacraw Ridge, a part of the basement configuration, may have been active during the Cretaceous, and if so, would have deformed the Cretaceous rocks which are older than the deformation. This may be the basement reflection of the uplift which was required to form the arch which later became the Suwannee Saddle as postulated by the Applins (1967). Babcock (1969) shows that the Peninsular Arch of Florida and southern Georgia was also uplifted during the Cretaceous and if so, would have deformed the adjacent Cretaceous rocks.

Emery and Zarudzki (1967) postulate Cretaceous high, perhaps uplifted areas below Tertiary rocks under the continental shelf.

The Central Georgia Uplift has also been uplifted at least once, and possibly more since it first was formed. Isopach and lithofacies patterns suggest that it was uplifted during the Late Paleocene or Early Eocene and so would have deformed the adjacent rocks.

Uplift of the Peninsular Arch (Orange Island) during the Late Oligocene, as well as the nearby Ocala Arch in Florida would result in deformation of the older rocks in adjacent southern Georgia.

The Gordon Anticline (Hager, 1918) in southeastern Alabama, has some closure in Early County, Georgia; it has been drilled, but with no success.

Small faults, such as the down-to-the-sea growth faults commonly recognized in Gulf Coast basin deposits may be present in some of the embayments deposits, but to date none have been detected.

Folding and/or faulting may be the origin of the Beaufort Arch near Savannah, and this deformation may be the origin of the restriction of the marine water in the Ridgland Trough, resulting in the deposition of gypsum. If this is true then similar small-scale deformation may be the origin of the restrictions which resulted in the deposition of the evaporites during the Eocene in the southern part of the Georgia Coastal Plain.

Regionally, if the North American Plate is drifting northwestward, then tension features would be expected in the southeastern United States, near the trailing edge at one time. Some of the Triassic grabens below the Coastal Plain may be due to this tension. Similar graben-forming tensions may have been the origin of the great rift into which the Lower Cretaceous sea flowed. Why could not such tension forces continue to exist throughout Cenozoic time, deforming the rocks in a similar manner, but which would not be so obvious because the rocks, being less indurated, would not display the results so prominently? Such faulting, the possible reactivation of older faults, has been proposed as the explanation for the changing of the facies patterns of the Tertiary rocks of Alabama (Joiner and Moore, 1966). Such faults are not only providing structural controls but also have an effect on sedimentation patterns.

The Georgia Coastal Plain extends southwestward into Florida and Alabama, where successful petroleum exploration has continued. The Georgia Coastal Plain also extends southeastward into the Atlantic Ocean and passes onto the continental shelf. Here is another frontier which is beyond the scope of this paper.

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SUBSURFACE CORRELATION OF MESOZOIC ROCKS IN GEORGIA

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Abstract

Mesozoic rocks present in the Georgia Coastal Plain are considered to be Comanchean and Gulfian in age. The presence of Coahuilan or Sabinasian deposits in the subsurface has been suspected but not documented. Comanchean rocks attain a maximum thickness in excess of 2,500 feet in the extreme southwest part of Georgia, have a variable thickness of from 100 to 300 feet in the tier of counties that border the Atlantic Ocean and are proportionately thinner or absent in most other segments of the State. Gulfian rocks are proportionately thickest in the central part of the State.

The dominant structures that have shaped and influenced the sedimentary geometry of the Georgia Coastal Plain appear to reflect or to be derived from the relative displacement, both lateral and vertical, of crustal segments juxtaposed along intersecting hinge lines aligned either N.E.-S.W., N.W.-S.E. or N.-S. The structures present in the Georgia Coastal Plain appear to mirror those described previously in the northern part of the Atlantic Coastal Plain.

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Introduction

As part of the U.S. Geological Survey's research program, investigations are underway to describe the external and internal geometry of the sedimentary rock mass that comprises the Atlantic Coastal Plain, New York through Florida. These investigations have two chief purposes: One, to map the spatial distribution of permeability; two, to make a geologic evaluation of the waste-storage potential in that part of the sedimentary rock mass which lies below the zone of fresh-water occurrence.

For the area extending from New York through North Carolina, results of the investigations have been published (Brown, Miller and Swain, 1972) or, pending publication, approved for open-file release (Brown and Reid, 1974). Currently, these results are being incorporated into additional studies of permeability distribution and waste-storage potential in South Carolina, Georgia and Florida, where the chief target is the subsurface Mesozoic section.

Much of the subject matter presented at this "Symposium on the Petroleum Geology of the Georgia Coastal Plain" will deal with stratigraphic components of the sedimentary rock mass, the basis for their separation, and the definition of their depositional environments. In this respect, the petroleum industry and the waste-storage research program have similar geologic interests. Both would like to determine the location and distribution pattern of structural and stratigraphic traps.

The petroleum industry is trying to predict the location of traps having porosity and permeability distribution favorable to petroleum accumulation and which were, or are, connected to permeability zones that accommodated the passage of petroleum into the traps. An objective of the waste-storage program is to try to predict the location of traps having porosity and permeability distribution favorable to receiving and storing liquid waste, and which are connected to permeability zones that will accommodate expulsion of native fluids but will retard the escape of waste.

Correlation of rock units in terms of their lateral continuities and vertical sequences is a prerequisite toward making these predictions.

Previous Work

P. L. and E. R. Applin, together with S. M. Herrick, are chiefly responsible for current ideas about the relative position of rock units in the subsurface of the Georgia Coastal Plain and for positioning these units within a time framework. Their lithostratigraphic and biostratigraphic correlations, presented in a number of publications, chiefly those of the Georgia Geological Survey, constitute the basic "nuts and bolts" geologic work that has become the standard starting point for subsequent work by others in Georgia.

There are numerous publications that discuss the stratigraphy and structure of Georgia's Coastal Plain in a regional context. Recently and in particular, these include important contributions by Murray (1961) and Maher (1965 and 1971).

I will discuss correlation of the subsurface Mesozoic rocks of Georgia in a regional context and consider the manner in which their depositional geometry appears to be consistent with what are judged to be regional structural patterns first recognized in the northern part of the Atlantic Coastal Plain (Brown, Miller and Swain, 1972).

Correlation of Subsurface Mesozoic Rocks

The Mesozoic stratigraphic units commonly recognized in Georgia, together with their time-rock (stage) equivalents recognized in adjacent Gulf Coast and northern Atlantic Coast regions, are listed in Table 1. For practical purposes the Upper Cretaceous-Lower Cretaceous boundary is considered by most geologists to coincide with the Gulfian-Comanchean boundary (Murray, 1961, p. 331).

Following Murray's (1961) utilitarian use of provincial stages, the Comanchean Series is subdivided into three time-rock units - Trinitian, Fredericksburgian and Washitan. The Gulfian Series is subdivided into five such units - Woodbinian, Eaglefordian, Austinian, Tayloran and Navarroan. In the northern Atlantic Coast region, informal letter units, A through I, were used in a time-rock (stage) sense in establishing a correlation framework for Mesozoic rocks in the subsurface (Brown, Miller and Swain, 1972).

In regional correlations, it should be recognized that rock unit boundaries only approximate time planes, even along strike. Also, it should be emphasized that electrical logs are the chief, sometimes only, source of data for interpreting lithologic character, qualitatively, in the subsurface.

With the exception of red beds comprising various mixtures of arkose, sandstone and shale of possible Triassic age (Newark age?) and which have been encountered in several deep wells in Georgia (Maher, 1971), the Mesozoic rocks penetrated in the subsurface have been considered to be Gulfian or Comanchean in age. The presence of Coahuilan or Sabinasian deposits in the subsurface has been suspected but not documented (Murray, 1961).

SYSTEM	SERIES	EUROPEAN STAGE	U.S. GULF COAST (FROM MURRAY, 1961)		U.S. ATLANTIC COAST (FROM BROWN, ET AL, 1972)	GEORGIA (AFTER APPLIN AND APPLIN, 1944, 1947, 1967; HERRICK, 1963; AND MAHER, 1965, 1971)	
			PROVINCIAL SERIES	PROVINCIAL STAGE	STRATIGRAPHIC UNIT	SURFACE	SUBSURFACE
CRETACEOUS	UPPER CRETACEOUS	SENONIAN	GULFIAN	NAVARROAN	UNIT A	PROVIDENCE SAND RIPLEY FM. UPPER PART OF THE CUSSETA SAND	ROCKS OF NAVARRO AGE AND LAWSON LS.
				TAYLORAN	UNIT B	LOWER PART OF THE CUSSETA SAND UPPER PART OF THE BLUFFTOWN FM.	ROCKS OF TAYLOR AGE
				AUSTINIAN	UNIT C	LOWER PART OF THE BLUFFTOWN FM. EUTAW FM.	ROCKS OF AUSTIN AGE
		TURONIAN		EAGLEFORDIAN	UNIT D	TUSCALOOSA FM.	UPPER MEMBER OF THE ATKINSON FM.
		CENOMANIAN		WOODBINIAN	UNIT E		LOWER MEMBER OF THE ATKINSON FM.
	LOWER CRETACEOUS	ALBIAN	? COMANCHEAN	WASHITAN	UNIT F	ABSENT	LOWER CRETACEOUS ROCKS
				FREDERICKS-BURGIAN			
		APTIAN		TRINITIAN	UNIT G		
		NEOCOMIAN	? COAHUILAN	NUEVO LEŌNIAN	UNIT H		LOWER CRETACEOUS (NEOCOMIAN) OR UPPER JURASSIC ROCKS ABSENT
				DURANGOAN			
JURASSIC	UPPER JURASSIC	PORTLANDIAN	? SABINASIAN	LA CASITAN	UNIT I		

Table 1.- GENERALIZED CORRELATION CHART

Comanchean Rocks.-

The oldest Cretaceous rocks recognized in wells in Georgia have been referred to by various investigators as Comanchean undifferentiated, Lower Cretaceous, undifferentiated, or Lower Cretaceous(?). The time-rock subdivisions, Trinitian, Fredericksburgian and Washitan of Murray (1961), generally have not been used in Georgia. The Comanchean rocks consist of gray, brown and tan micaceous shale, changing at depth to more massive red, purple and green micaceous shale. The shale is interlayered with poorly-sorted fine-to-coarse grained sandstone or loosely-consolidated sand.

The first appearance of pink nodular lime and red and green shale, considered to mark the top of the Comanchean section in wells in southeast Alabama (Moore and Joiner, 1969), occurs at depths as great as 500 feet below what we consider to be the top of the Comanchean in some wells in southwest Georgia. Perhaps bladed rosettes of siderite, rather than lime nodules and varicolored shale, are more characteristic of the upper part of the Comanchean section in the Georgia subsurface. Whereas siderite nodules occur commonly in basal Gulfian and upper Comanchean deposits in Georgia, the occurrence of siderite in the form of rosettes appears to be confined to the upper part of the Comanchean. Similar appearing siderite rosettes are characteristic of and appear to be confined to the upper part of Unit F in wells in the northern part of the Atlantic Coastal Plain.

As identified and described by most workers, Comanchean deposits in the Georgia subsurface have been considered non-fossiliferous marginal clastics. However, our preliminary work suggests that fossiliferous beds, now included in the lower member of the Atkinson Formation of Gulfian age, may, at least in part, represent a brackish-water facies of Comanchean age. Elements of the arenaceous foraminiferal assemblage, characteristic of the lower member of the Atkinson Formation in wells in Georgia, together with the ostracode Fossocytheridea lenoirensis Swain and Brown, occurs in Unit F of Comanchean age in wells in the northern part of the Atlantic Coastal Plain and in equivalents of Unit F in wells in south Florida, chiefly in Palm Beach County.

As suggested by Applin and Applin (1967) it is probable that Comanchean rocks crop out along the inner margin of the Georgia plain and are included with rocks now mapped as the Tuscaloosa Formation. According to maps prepared by Herrick and Vorhis (1963) the Comanchean is best developed in central and southwest Georgia, attains a maximum thickness in excess of 2,500 feet in Decatur, Mitchell and Seminole Counties, has a variable thickness of from less than 100 to about 300 feet in the tier of counties that borders the Atlantic Ocean, and is absent along the northern and northeast margins of the Georgia Coastal Plain. In the northern part of the Atlantic Coastal Plain, Unit F, Unit G, and the upper part of Unit H are considered Comanchean in age.

Gulfian Rocks.-

Throughout the Georgia Coastal Plain, Gulfian rocks overlie Comanchean or older rocks. Lithologically and faunally they are best developed in the subsurface. They comprise Woodbinian, Eaglefordian, Austinian, Tayloran and Navarroan time-rock units of Murray (1961).

Commonly, Woodbinian and Eaglefordian sedimentary rocks have been designated Atkinson Formation (Applin and Applin, 1967) or Tuscaloosa Formation (Herrick, 1961) in subsurface correlation in Georgia. The name Atkinson Formation was proposed (Applin and Applin, 1947) for subsurface sediments encountered between the base of overlying Austinian strata and the top of underlying Comanchean strata in Alabama, Georgia, and north Florida. Three formational members were recognized. To facilitate correlation, E. R. Applin (1955) redefined the Atkinson Formation to include two rather than three members; a lower member of Woodbinian age and a upper member of Eaglefordian age. The designated type section, 805 feet thick, is in Sun Oil Company's No. 1 Doster-Ladson well, Atkinson County, Ga., between the depths of 3,135 and 3,940 feet (Applin and Applin, 1947).

In general practice, both the Atkinson Formation and the Tuscaloosa Formation have been used interchangeably by different authors to refer to the same rocks in a time-rock sense. This has led to confusion in terminology, particularly when the source material from several authors must be combined, without standardization, in one publication (see Marsailis, 1970). In the northern part of the Atlantic Coastal Plain, Unit E is considered a Woodbinian equivalent and Unit D an Eaglefordian equivalent (Brown, Miller and Swain, 1972).

The lithology of the Atkinson Formation is variable. According to Applin and Applin (1967) fossiliferous marine shale, siltstone, sandstone and unconsolidated soft sand are the principal lithologic constituents of the lower member. Carbonaceous material, mica, pyrite, glauconite and siderite are common accessories. The principal lithologic constituents of the upper member are shale, sandstone, siltstone and a few lenses of bioclastic limestone. The limestone lenses decrease in number and in areal distribution from southern Georgia toward central Georgia.

Although absent in some wells on the crest of the Peninsular arch in southeast Georgia (Applin and Applin, 1967, pl. 3) the Atkinson

Formation maintains a rather even thickness of about 150 to 300 feet across the southern part of the Georgia Coastal Plain from whence it thickens towards the northwest, attains a maximum thickness of about 500 feet in central Georgia, and thins again toward the inner margin of the Coastal Plain. Thus, in Georgia, the Atkinson Formation appears to have a dominant axis of thickening that trends N.E.-S.W. through the central part of the State.

Austinian sediments in the Georgia subsurface commonly have been referred to as rocks of Austin age, Austin undifferentiated, Eutaw Formation, Eutaw Formation (restricted), and Blufftown or lower part of the Blufftown Formation. They are considered correlative with the upper part of the Eutaw Formation or Eutaw (restricted), the Mooreville Chalk, and the Arcola Limestone of Alabama (Murray, 1961, p. 352-353). In the northern part of the Atlantic Coastal Plain, Unit C is considered an Austinian equivalent (Brown, Miller and Swain, 1972). The characteristic lithology of Austinian sediments consists of a gray shale or shaly marl that may grade laterally and vertically into shaly chalk locally. The shale and marl are intercalated with well-to-poorly-consolidated sand. Commonly, and at the base of the Austinian section in a number of wells, a transgressive conglomerate is present. Across the southern part of the Georgia Coastal Plain, Austinian sediments maintain an average thickness of from 400 to 500 feet. As is the case with underlying sediments of the Atkinson Formation, sediments of Austin age thicken toward the northwest, attain a maximum thickness of 600 to 700 feet in central Georgia along an axis that trends N.E.-S.W., and thin in the direction of the inner margin of the Coastal Plain.

In the subsurface, Tayloran sediments overlie Austinian sediments from which they are distinguished chiefly by differences in their microfaunas. Generally, Tayloran sediments contain a greater proportion of sand than

Austinian sediments, otherwise there appears to be little difference in their lithologic character. According to Murray (1961, p. 357) Tayloran correlatives at the outcrop in Georgia appear to occur principally in the upper part of the Blufftown Formation and in the lower part of the Cusseta Sand. In the northern part of the Atlantic Coastal Plain, Unit B is considered a Tayloran equivalent (Brown, Miller and Swain, 1972). Across southern Georgia Tayloran strata maintain an average thickness of from 200 to 300 feet, but may attain a somewhat greater thickness locally. In the tier of counties bordering the Atlantic Ocean the average thickness of Tayloran strata appears to be about 450 to 500 feet. Like underlying time-rock units of the Gulfian Series, Tayloran strata thicken from the southern part of the State toward central Georgia and then thin toward the inner margin of the Coastal Plain.

In parts of south Georgia where overlying Navarroan strata are absent in the section, Tayloran sediments are immediately overlain by strata of Midway age.

In the subsurface, Navarroan strata overlie Tayloran strata throughout much of the Georgia Coastal Plain. Navarroan equivalents at the surface have been mapped as the upper part of the Cusseta Sand, Ripley Formation and Providence Sand (Murray, 1961, p. 360). While these names have been applied to Navarroan equivalents in the subsurface by some authors, more commonly, the equivalents have been designated beds, or rocks, of Navarro age and Lawson Limestone. In the northern part of the Atlantic Coastal Plain, Unit A is considered a Navarroan equivalent.

According to Applin and Applin (1967, p. G23 and pl. 6A), Navarroan strata occur in two distinct facies that occupy two different geographic areas and which are separated by an area where Navarroan strata are absent in the section. A clastic facies that consists chiefly of gray or brown marly shale and fine-to-medium grained sand is dominant in the northwestern, central, and south central parts of the Coastal Plain. A carbonate facies, named the Lawson Limestone (Applin and Applin, 1944, p. 1708), which consists chiefly of chalk and algal limestone, is present in the section in a few counties in the extreme southeast corner of Georgia (see Applin and Applin, 1967, pl. 5).

Applin and Applin (1967, p. G31) postulate that a N.E.-S.W. trending positive element separated the areas of clastic and carbonate deposition during Navarro time. Northwest of this postulated barrier Navarroan strata thicken toward central Georgia where they attain a maximum thickness of 600 to 800 feet, and then decrease in thickness toward the inner margin of the Coastal Plain. On the southeast side of the postulated barrier the Lawson Limestone thickens toward central Florida.

Structural Elements

A discussion of sedimentary geometry cannot be separated from a discussion of structure because of the dependence of the one upon the other. Five principal structures, known by various names, appear to have exerted a dominant influence in shaping the subsurface sedimentary geometry of the Georgia Coastal Plain. They are the Ocala (Peninsular) arch, whose extension into Georgia sometimes is referred to as the central Georgia uplift, the Chattahoochee arch, the Apalachicola (Southwest Georgia) embayment, the Savannah (Southeast Georgia) embayment, and the Suwannee saddle.

According to interpretation by various authors of patterns of time-rock discordances within the sediment mass, these structures appear to have been active intermittently, in either a up or down sense, during Mesozoic and Cenozoic time. Among others, Murray (1961), Maher (1965 and 1971), and Applin and Applin (1967) discuss the manner in which these structures have influenced regional sediment distribution patterns and provide maps showing their general location.

When evaluating geologic parameters that influence waste-storage potential in the subsurface, it often is helpful to synthesize a preliminary structural model using available data. Such a model is not fully deterministic in the early stages of an investigation. However, it is useful in developing a graphic summary of regional geology, in making a preliminary evaluation of trap potential for waste-storage purposes, and in locating potential drill sites. During the course of the investigation and as new data become available, the preliminary model undergoes refinement and modification. This process continues until such time as further change is no longer required in order for the model to satisfy, in a geometric sense, the recognized and mappable discordances, both directional and compositional, within the sediment mass being studied.

Following our initial study and correlation of Mesozoic time-rock units occurring in representative wells in Georgia and contiguous areas, a preliminary structural model for the region was synthesized (Figure 1). As our investigations proceed, this model will be refined and modified. At present, it appears to be consistent with published interpretation and also with our preliminary interpretation of sediment distribution patterns in the Mesozoic section of the Georgia subsurface. Also, it is consistent with our interpretation of the regional geophysical data available to us.

As shown by Figure 1, we suggest that the sedimentary geometry of the Georgia Coastal Plain is controlled by the relative displacement of adjacent crustal blocks along segments of a system of intersecting hinge zones which have one of three alignments, N.E.-S.W., N.W.-S.E. and N.-S. The five

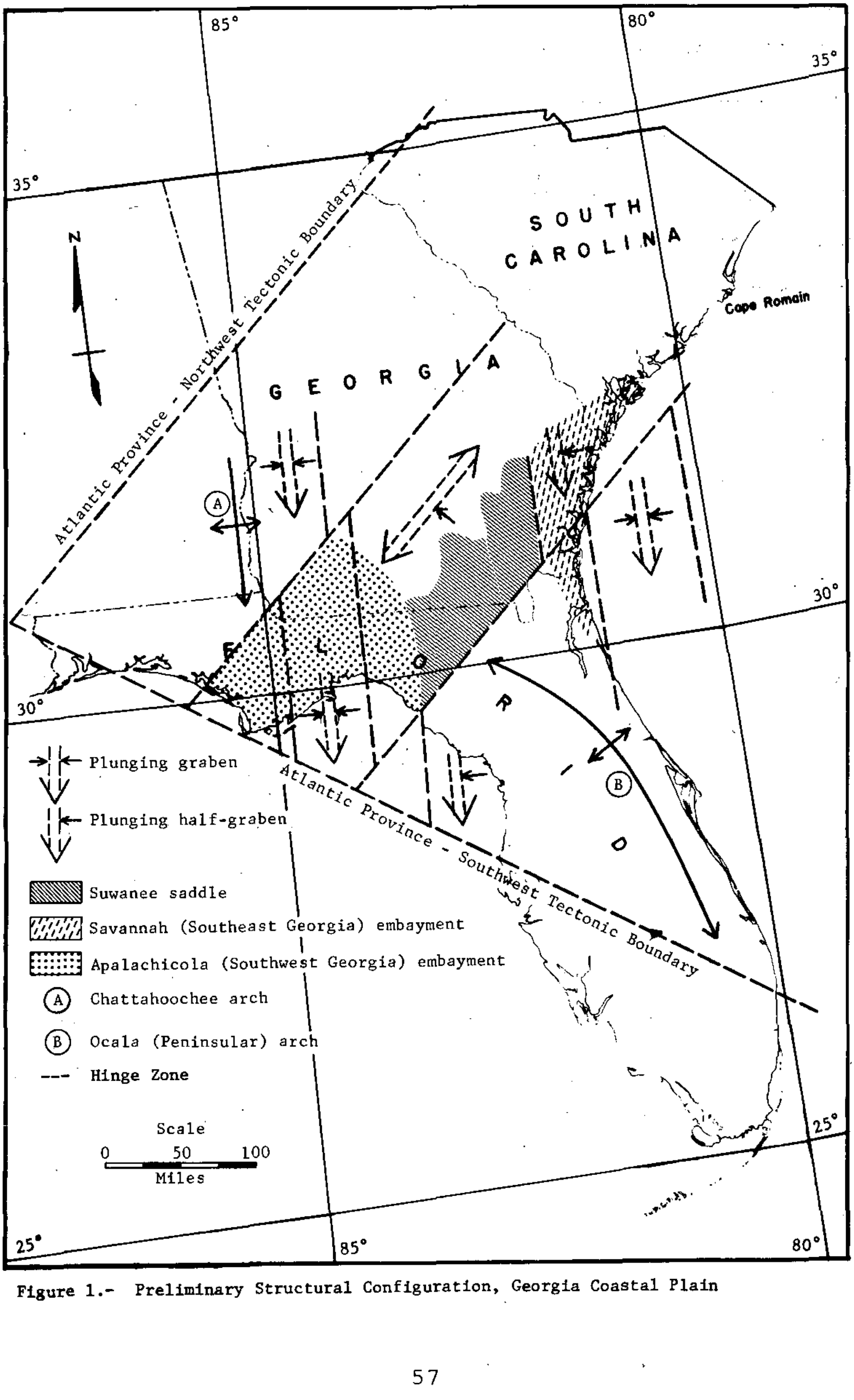

Figure 1.- Preliminary Structural Configuration, Georgia Coastal Plain

principal structures present in the area, and their relative positive or negative expression at any one time, appear to reflect or to be derived from, the relative displacement both lateral and vertical of crustal segments juxtaposed along these intersecting hinge zones. Previously, Brown, Miller and Swain (1972) recognized and described this type of structural system in the northern part of the Atlantic Coastal Plain. They concluded that the relative displacement of crustal segments is associated predominantly with the action of lateral compressive forces, and that vertical forces operative in the system are chiefly the resultants of compressional stress.

The dominant structural form characteristic of this type of system is that of full or half graben whose segments may be offset along hinge zones that intersect and lie athwart the graben. The structural patterns inferred from preliminary study of the sedimentary geometry of the Georgia Coastal Plain (Figure 1) appear to mirror the structural patterns recognized in the northern part of the Atlantic Coastal Plain.

For a structural-sedimentary system such as that postulated for the Georgia Coastal Plain, trap potential would depend upon the relation between structure and sediment thickness. Ideally, trap potential would be greatest in those areas where a considerable thickness of sediments is present, where alternate beds of sand and clay are present to provide the reservoir and reservoir-seal relationship, and where stratigraphic pinch outs would occur most commonly. Inasmuch as these parameters are related to structural mobility and hinge zones appear to be locales for the principal mobility in this type of structural-sedimentary system, our investigations of waste-storage trap potential will be concentrated in those areas where hinge zones are thought to be present (Figure 1).

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GENERALIZED STRATIGRAPHY OF SOUTHEASTERN ALABAMA[1]

By Charles W. Copeland[2]

ABSTRACT

Coastal Plain sediments in southeastern Alabama attain a maximum thickness of about 8,650 feet between their overlap of metamorphic rocks of the Piedmont province in east-central Alabama and Geneva County in southeastern Alabama. These sediments overlie a basement complex consisting of buried igneous and metamorphic rocks of the Piedmont province and essentially unmetamorphosed Early Ordovician shale and sandstone. Rhyolite porphyry of possible volcanic origin was penetrated in a deep test in Geneva County. A red bed sequence of arkosic sandstone and micaceous shale as much as 1,500 feet thick believed to be Triassic in age overlies the basement rocks. These beds are overlapped by younger sediments updip. The probable Triassic red beds are overlain by about 4,000 feet of Early Cretaceous red gravelly sand and shale that contain traces of varicolored nodular limestone. These sand and shale units, like the underlying red beds, are overlapped in the subsurface by younger sediments.

The Late Cretaceous units are better known. Near the Alabama-Georgia boundary, deposits of Late Cretaceous age are about 2,000 feet thick and, in ascending order, are represented by the Tuscaloosa Group (undifferentiated), the Eutaw, Blufftown, and Ripley Formations, and the Providence Sand. The dip is southward about 40 feet per mile. In the area of outcrop in eastern Alabama, chalk formations of the Selma Group merge laterally into equivalent formations consisting of sand and clay.

The Tertiary units in eastern Alabama, in ascending order, are the Clayton Formation (Paleocene), the Nanafalia Formation, Tuscahoma Sand, and Hatchetigbee Formation (lower Eocene), the Tallahatta and Lisbon Formations (middle Eocene), and the Moodys Branch Formation and Ocala Limestone (upper Eocene). Limestone of late Eocene and Oligocene age and clastic Miocene sediments have been severely weathered and affected by leaching, solution, and collapse in southeasternmost Alabama. The weathering processes have resulted in the formation of deposits of residuum as much as 100 feet thick. Normal sections of the affected units occur in the stream valleys, but mapping in the interfluves has not been possible. The Tertiary units in the outcrop are about 900 feet thick and thicken downdip to about 1,700 feet in southern Houston and Geneva Counties. The dip of these units toward the south generally ranges from 10 to 30 feet per mile.

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INTRODUCTION

Southeastern Alabama lies within the East Gulf Coastal Plain section of the Coastal Plain province. The area is underlain by rocks of the Piedmont province and pre-Coastal Plain basement complex and marine and nonmarine Mesozoic and Cenozoic sedimentary rocks. The Coastal Plain strata range in age from probable Triassic to Holocene and the succession in southeastern Alabama ranges in thickness from about 7,500 feet in Houston County to 8,650 feet in Geneva County.

The report is a brief summary of the stratigraphy of the counties near the Alabama-Georgia boundary. The information presented has been summarized from published reports and geologic maps and descriptions of oil test wells in the open files of the Geological Survey of Alabama. The Alabama Coastal Plain has been studied by paleontologists and stratigraphers for over a hundred years and the more comprehensive of these works have been utilized in the preparation of this report.

MESOZOIC UNITS IN THE SUBSURFACE

Coastal Plain sediments in southeastern Alabama attain a maximum thickness of about 8,650 feet, between their overlap of metamorphic rocks of the Piedmont province to the north and Geneva County to the south (fig. 1). These sediments overlie a basement complex consisting of buried igneous and metamorphic rocks of the Piedmont province and essentially unmetamorphosed Early Ordovician black micaceous shale and medium gray quartzitic sandstone (King, 1961). Rhyolite porphyry of possible volcanic orgin was penetrated in an oil test well in Geneva County. The various rock types penetrated by oil test wells beneath the Coastal Plain are shown in figure 2 and the well data is included in table 1.

A red bed sequence of arkosic sandstone and micaceous shale as much as 1,500 feet thick believed to be Triassic in age overlies the basement rocks (McKee and others, 1959). The sedimentary beds in three wells in southeastern Alabama were cut by igneous dikes or diabase sills (fig. 3 and table 1). The arkosic nature of the sediments and the similarity of the diabase to that found in Triassic basins to the north have prompted Applin (1951), McKee and others (1959), Maher and Applin (1968), and others to suggest a possible correlation of this red bed sequence with the Newark Group of Late Triassic age in the Atlantic coastal plain. Maher and E. R. Applin (1968) described the probable Triassic beds as being composed of hard, dark-red and greenish-gray mottled, micaceous shale interbedded with partly conglomeratic and arkosic sandstone with poorly sorted, angular grains.

Jurassic rocks have not been reported in Alabama east of Crenshaw and Covington Counties in the middle of the State, However,

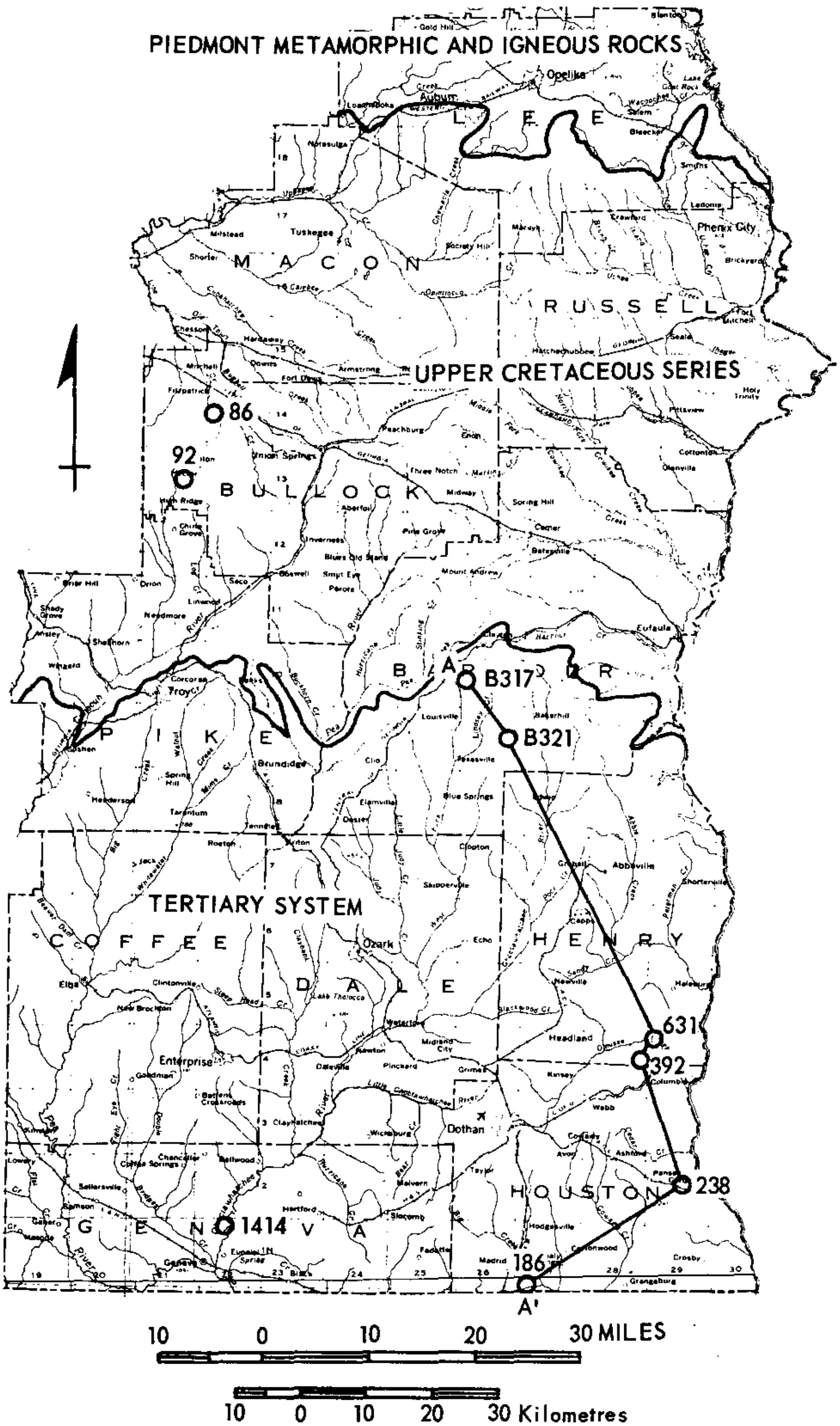

Figure 1.–Map of southeastern Alabama showing locations of selected oil and gas test wells listed in Table 1 and line of cross section A-A' shown on figure 5.

TABLE 1.-----DATA FOR SELECTED OIL AND GAS TEST WELLS

State Oil and Gas Board permit number	County	Name and location of well	Date of completion	Surface elevation	Total depth (feet)	Remarks
B317	Barbour	H. A. Stebinger *et al* Mrs. Alice Robertson #1, Sec. 19, T.10N.,R.26E	3-14-39	554	5,215	Well cut by diabase dikes or sills of Triassic (?) age at 4,135-4,152 feet, 4,202-4,208 feet, and 4,273-4,274 feet (King, 1961). Overlain by Triassic (?).
B321	Barbour	W. B. Hinton Creel #1, Sec. 14, T.9N.,R.26E.	10-24-39	504	5,546	Well cut by diabase dikes or sills of Triassic (?) age at 5,342-5,372 feet and 5,491-5,522 feet. Overlain by Triassic (?).
86	Bullock	Capital Oil and Gas Company Mrs. Ethel B. Gholston #1, Sec. 18,T.14N., R.22E.	5-20-45	270	1,714.5	Granite gneiss at 1,712 feet. Overlain by Lower Cretaceous.
92	Bullock	Capital Oil and Gas Company Fred Pickett #1 Sec. 22,T.13N., R.21E.	6-13-45	430	2,523	Diorite at 2,502 feet. Overlain by Lower Cretaceous.
1414	Geneva	George S. Engle S.P. and B.F. Thompson #1,Sec. 4, T.1N.,R.22E.	6-5-67	146	8,792	Rhyolite porphyry at 8,655 feet. Overlain by Triassic (?).

Table 1 continued

State Oil and Gas Board permit number	County	Name and location of well	Date of completion	Surface elevation	Total depth (feet)	Remarks
392	Henry	Southeastern Operators Committee Mrs. Beatrice and O.A. Gamble #1 Sec. 13,T.4N.,R.28E.	12-3-52	302	6,392	Quartz diorite at 6,355 feet. Overlain by Lower Cretaceous (?) Core at 6,391-6,394 identified by Charles Milton (1952) as granophyre in King (1961).
631	Henry	Renwar Oil Corporation H. V. Granberry #1 Sec. 6,T.4N.,R.29E.	3-2-56	192	6,610	Well cut by diabase dike or sill of Triassic (?) age at 6,488-6,492 feet. Overlain by Triassic (?).
186	Houston	Union Producing Company E.P. Kirkland #1 Sec. 20,T.7N.,R.11W.	7-16-49	140	8,100	Quartzitic gray sandstone and black micaceous shale of Early Ordovician age at 7,556 feet (King, 1961). Overlain by Triassic (?).
238	Houston	John S. Neilson A. L. Snell #1 Sec. 10,T.2N.,R.29E.	11-21-50	217	4,012	Well in clastic sediments of Early Cretaceous age at total depth.

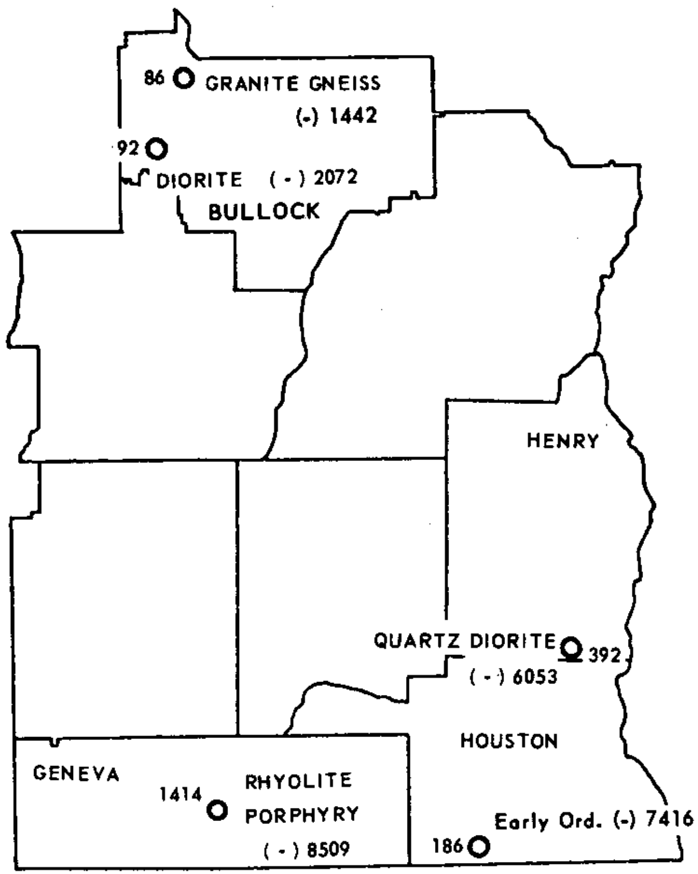

Figure 2.–Wells penetrating pre-Coastal Plain rocks.

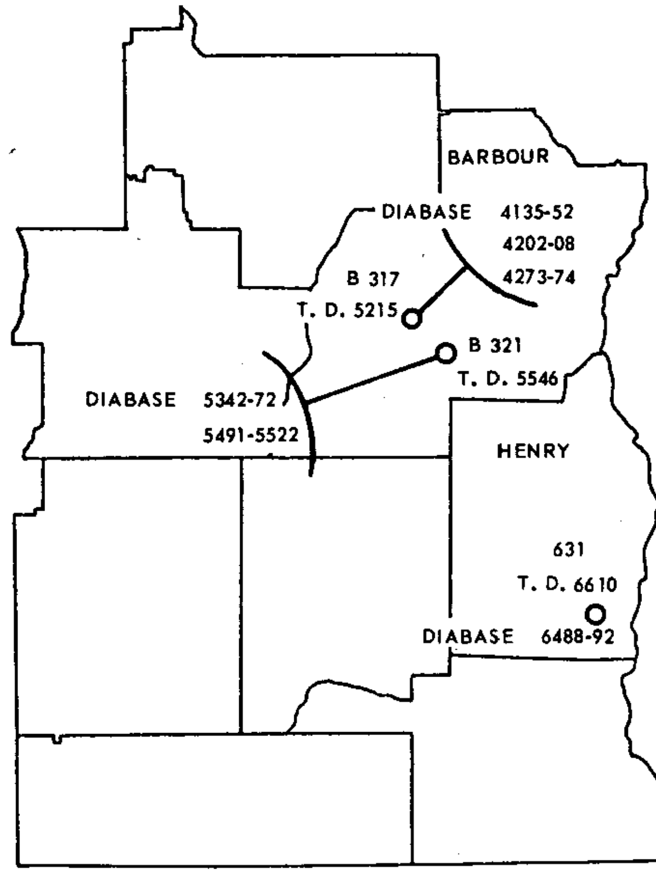

Figure 3.–Wells cut by diabase dikes or sills of Triassic (?) age.

Maher and E. R. Applin (1968) thought that at least a part of a well in Jackson County, Florida (Humble Oil and Refining Company-No. 1 C. W. Tindel, sec. 8, T. 5 N., R. 11W.), immediately south of Houston County, Alabama, probably contained rocks of Jurassic age.

The probable Triassic red beds are overlain by as much as 4,000 feet of probable Early Cretaceous red gravelly sand and shale that contains minor amounts of varicolored soft limestone. Insufficient studies have been made at this time to make it possible to differentiate the Triassic (?) sequence in southeast Alabama from the overlying red beds of the Lower Cretaceous. The Triassic (?) and Lower Cretaceous clastic sequences are overlapped in the subsurface by younger sediments.

Applin and Applin (1967) and Maher and Applin (1968) have separated the Lower Cretaceous from the overlying Upper Cretaceous on the basis of electric log correlations and differences in lithology. Sediments identified as Lower Cretaceous in southeastern Alabama generally consist of dusky-red, grayish-green, and grayish-purple micaceous sandy clay, gravel, and medium- to coarse-grained subangular micaceous sand and sandstone. Weathered feldspar crystals occur in these coarse clastics as well as moderate-pink and light-gray pieces of limestone. Quartz grains composing the sands and sandstones are often light-red and grayish-yellow in color.

The Mesozoic subsurface stratigraphic units presently used in the Alabama Coastal Plain are shown in figure 4. The units shown for southwest Alabama are the tops being picked and used by the oil industry. The subdivisions of the Lower Cretaceous are mainly applicable to the Citronelle Field in Mobile County and are dependent to a large extent on the distribution of the Ferry Lake Anhydrite--a key electric log marker. Most of the names used in the Lower Cretaceous have their origins much farther west but these correlations have been established by the oil industry and each name should properly be followed by the word equivalent.

The subdivisions of the Cretaceous in the subsurface in east Alabama follow the usage of Applin and Applin (1967) and Maher and E. R. Applin (1968). In general, the top of the Atkinson of the Applin's coincides with the Eutaw top as picked by the Survey and Miss Winnie McGlamery in her many descriptions of Alabama oil test wells. The top of the lower Atkinson generally coincides with the marine shale of the Tuscaloosa Group in the subsurface and the "Lower Tuscaloosa" or massive sand of the Tuscaloosa Group would also be included in the lower member of the Atkinson. Electrical characteristics typical of the marine and Lower Tuscaloosa are somewhat vague in southeastern Alabama and so in this brief summary, the terms proposed by the Applins are used.

The lower member of the Atkinson Formation is composed of subangular fine- to medium-grained quartzose sandstone that usually is glauconitic, fossiliferous medium-gray shale, and greenish-gray to dark-gray shale. Carbonaceous material and pyrite are commonly

	S. W. Ala.	S. E. Ala.
UPPER CRETACEOUS	Selma Group	Navarro, Taylor and Austin
	Eutaw Fm.	U. Atkinson
	"Upper Tuscaloosa"	
	"Marine Shale"	L. Atkinson
	"Lower Tuscaloosa"	
LOWER CRETACEOUS	Wash.-Fred. undiff.	Lower Cretaceous undifferentiated
	Paluxy Fm.	
	Mooringsport Fm.	
	Ferry Lake Anh.	
	Rodessa Fm.	
	Pine Island Fm.	
	Sligo Fm.	
	Hosston Fm.	?
UPPER JURASSIC	Cotton Valley Group	Jurassic absent?
	Haynesville Fm.	
	Smackover Fm.	
MIDDLE JURASSIC	Norphlet Fm.	
	Louann Salt	?
TR?	Werner Anhydrite	Triassic ?
	Eagle Mills Fm.	

Figure 4.–Subsurface Mesozoic formations in south Alabama.

present in the shale; glauconite is present in some lenses and mica also is a common constituent.

The upper member of the Atkinson overlies the relatively thick marine shale of the lower member and consists of greenish-gray calcareous micaceous fossiliferous shale, medium-gray carbonaceous shale, and fine- to coarse-grained glauconitic quartz sandstone, sand, and fossiliferous sandstone. Fragments of oysters are found in the cutting samples as well as foraminifers and ostracodes. The foraminiferal faunas enabled the Applins (1967) to correlate the upper member of the Atkinson with the Eagle Ford of Texas. The entire formation ranges in thickness from 940 feet in southern Barbour County to 730 feet in Houston County. The thinning is most drastic in the upper member.

The Atkinson Formation was deposited in shallow marine conditions. The Eutaw Formation in the outcrop, the updip equivalent of the upper part of the Atkinson was also apparently deposited in shallow marine waters. The Tuscaloosa Group in the outcrop, which is the updip equivalent of the remainder of the Atkinson, is quite different in composition and is a fluvial deltaic complex.

Selma Group correlatives in the subsurface are subdivided by the Applins (1967) into beds of Austin, Taylor, and Navarro ages on the basis of the contained microfaunas. In Barbour County, these units consist mainly of sand; sandy fossiliferous, glauconitic, micaceous marl; fine-grained micaceous, glauconitic, fossiliferous sandstone and carbonaceous shale. Southward the units become increasingly chalky and less sandy. The various units of the outcrop area have not yet been carried into the subsurface.

A cross-section from Barbour County to Houston County shows the various subsurface units studied by the Applins (fig. 5). The beds of Late Cretaceous age or the Gulf Series thin from 2,120 feet in Barbour County to 1,730 feet in southern Houston County. The greatest thinning occurs within Houston County. The total thickness of the Gulf Series in well 238 is 1,940 feet and in well 186 is 1,730 feet.

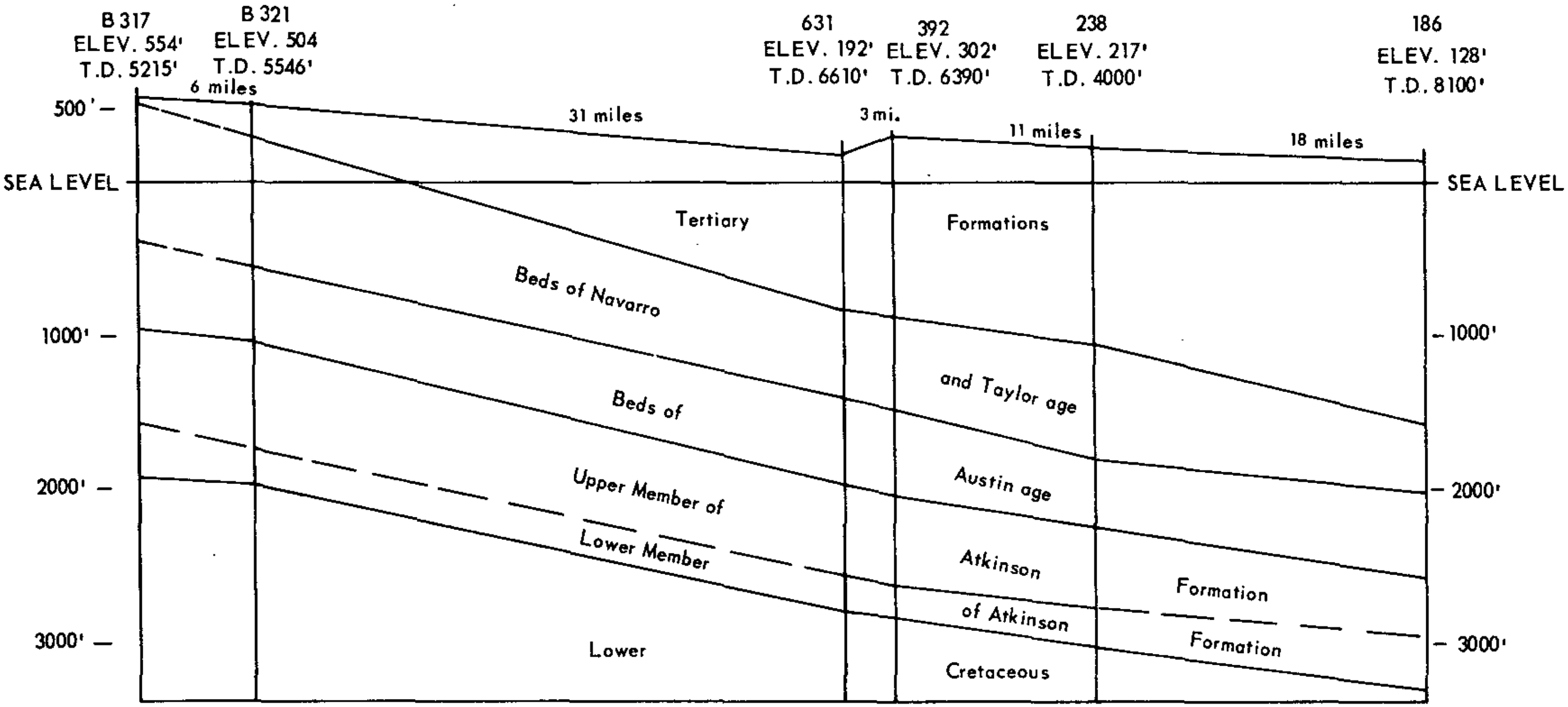

Figure 5.--Subsurface cross section of Late Cretaceous formations extending from Barbour County to Houston County.
(Well data from Applin and Applin, 1967, and files of Geolgical Survey of Alabama)

EXPOSED FORMATIONS OF LATE CRETACEOUS AGE

In western Alabama, deposits of Late Cretaceous age are assigned in ascending order to the Tuscaloosa Group which includes the Coker and Gordo Formations; the Eutaw Formation; and the Selma Group which includes the Mooreville and Demopolis Chalks, the Ripley Formation, and the Prairie Bluff Chalk (fig. 6). In eastern Alabama the chalk formations of the Selma Group merge laterally into formations consisting chiefly of sand and clay (fig. 7). In the outcrop in easternmost Alabama, deposits of Late Cretaceous age, in ascending order, are represented by the Tuscaloosa Group (undifferentiated), the Eutaw Formation, the Blufftown and Ripley Formations, and the Providence Sand (fig. 8). Near the Alabama-Georgia boundary the Cretaceous formations strike slightly north of due east and dip to the southeast about 40 feet per mile.

Tuscaloosa Group

The Tuscaloosa Group is not formally subdivided in the outcrop east of Elmore County. The Group in Lee County overlaps crystalline rocks of the Piedmont province that consist chiefly of schist and gneiss and narrow belts of quartzite and marble. Tuscaloosa sediments rest unconformably on buried Piedmont rocks in the updip areas and on sediments of probably Early Cretaceous age in the subsurface in the southern part of Bullock County and northern Barbour County. The Tuscaloosa ranges in thickness from 0 at the pinchout in southern Lee County to about 400 feet at the contact with the overlying Eutaw Formation. The unit generally consists of white, yellowish-orange, and very light gray sand and gravel interbedded with brightly-colored and light-gray clay that contains some thin beds of sandstone (Scott, 1960, 1962).

Eutaw Formation

The Eutaw Formation unconformably overlies the Tuscaloosa Group and in the outcrop in Macon and Russell Counties is about 150 feet thick. Downdip, the formation is about 300 feet thick. The formation consists of greenish-gray fine-grained calcareous fossiliferous clayey sand and sandy clay with thin interbeds of indurated fossiliferous sandstone and limestone. Most of the formation contains abundant *Ostrea cretacea* Morton and the accumulations of fossils are numerous enough to be referred to locally as "shell reefs" or "oyster banks." According to Stephenson (1956), the Eutaw in eastern Alabama was deposited in relatively shallow offshore marine waters. The *O. cretacea* zone of Stephenson at the base of Eutaw is about 130 feet thick in Macon and Russell Counties. Stephenson (1956) was of the opinion that the *O. cretacea* zone in east-central Alabama is approximately synchronous with the Tombigbee Sand Member at the top of the Formation of central and western Alabama. The upper part of the Eutaw in eastern Alabama is mainly greenish-

<table>
<tr><th>Eastern Texas</th><th colspan="2">West Alabama</th><th>East Alabama</th></tr>
<tr><td rowspan="2">Navarro Group</td><td colspan="2">Prairie Bluff Chalk</td><td>Providence Sand</td></tr>
<tr><td colspan="2">Ripley Formation</td><td>Ripley Formation</td></tr>
<tr><td>Taylor Marl</td><td colspan="2">Demopolis Chalk</td><td>Cusseta Sand Member</td></tr>
<tr><td rowspan="2">Austin Chalk</td><td colspan="2">Mooreville Chalk</td><td>Blufftown Formation</td></tr>
<tr><td colspan="2">Eutaw Formation</td><td rowspan="2">Eutaw Formation</td></tr>
<tr><td rowspan="2">Eagle Ford Shale</td><td colspan="2">McShan Formation</td></tr>
<tr><td rowspan="2">Tuscaloosa Group</td><td>Gordo Formation</td><td rowspan="2">Tuscaloosa Group</td></tr>
<tr><td>Woodbine Formation</td><td>Coker Formation</td></tr>
</table>

Figure 6.–Exposed Upper Cretaceous formations in south Alabama.

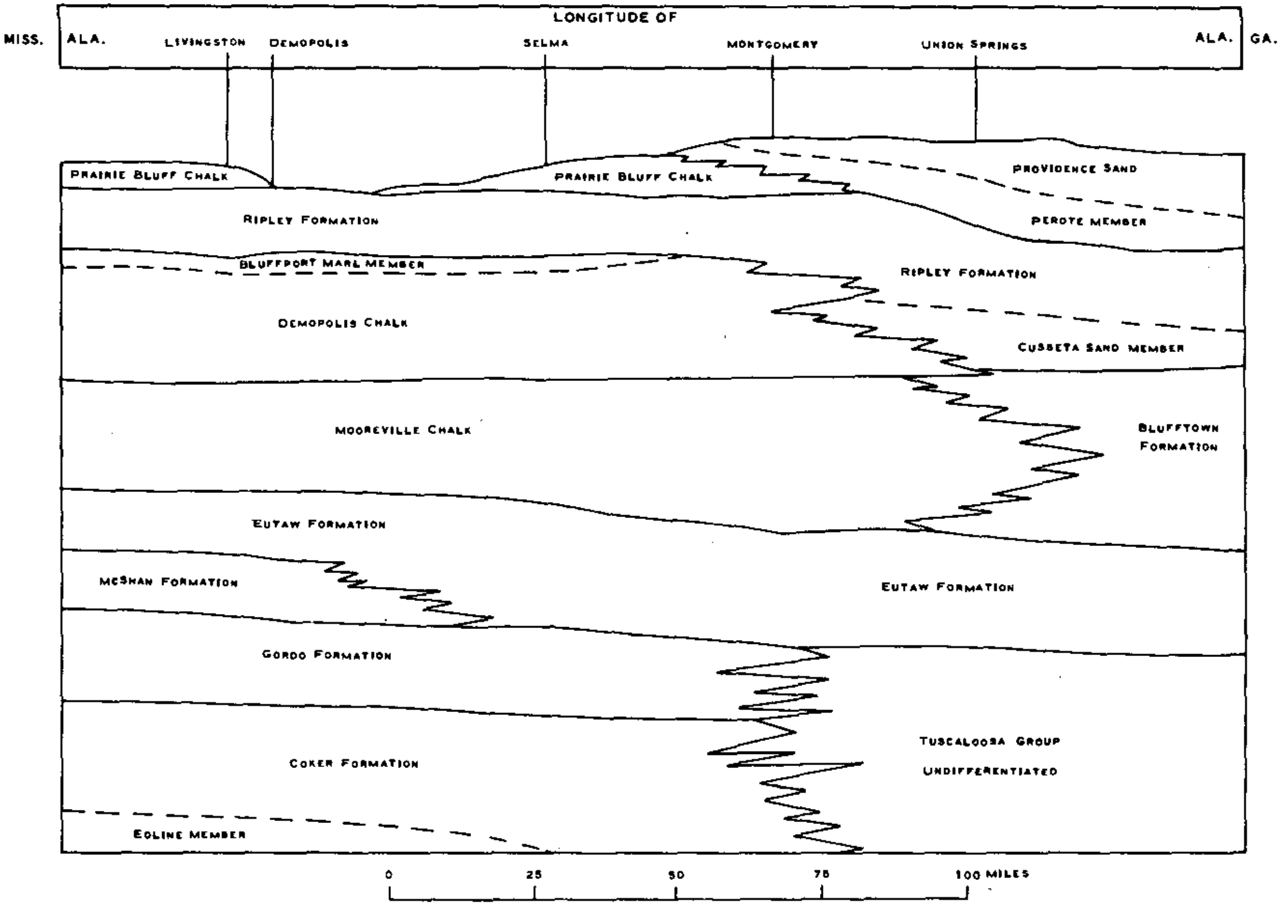

Figure 7.—Generalized diagram showing stratigraphic relations of Upper Cretaceous formations.

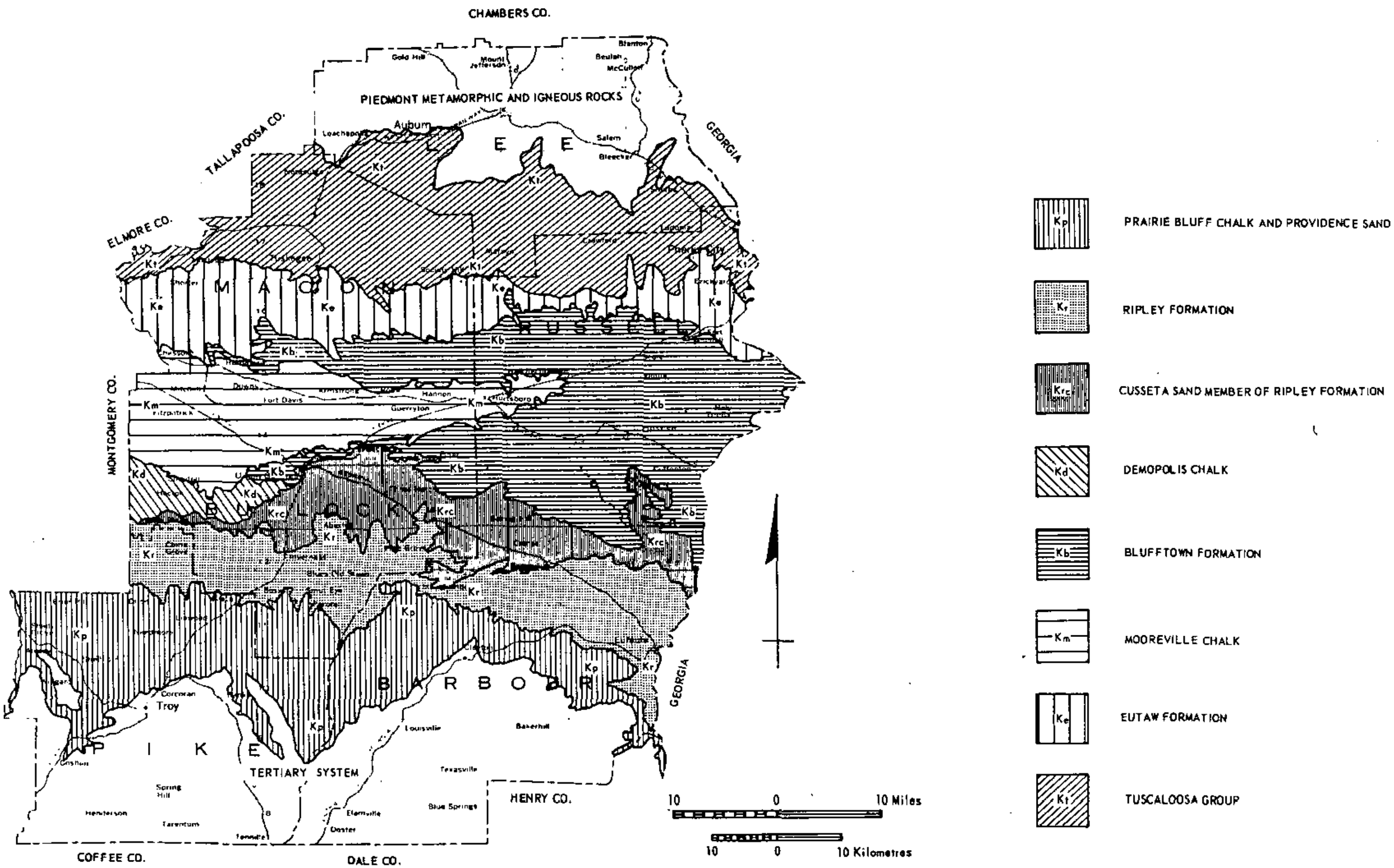

Figure 8.–Generalized geologic map of the Upper Cretaceous formations in southeastern Alabama (modified from Monroe, 1941, and Eargle, 1950).

gray somewhat laminated clay containing some sand. Stephenson felt that the clay in the upper part of the Eutaw, above the O. cretacea zone was possibly stratigraphically higher and a little younger than the main body of the Tombigbee Sand Member to the west.

Mooreville Chalk

The Mooreville Chalk is about 500 feet thick in western Bullock County, thins rapidly eastward, and pinches out in western Russell County. The Mooreville typically consists of compact, very calcareous locally glauconitic clay or marl and clayey chalk. The contact of the Mooreville with the underlying Eutaw is unconformable in eastern Alabama according to Monroe (1941), and Eargle (1950). The Mooreville was formed in warm shallow seas and foraminifers, ostracodes, and other microfossils (chiefly coccoliths) comprise a large percentage of the chalk. Mollusks occur rarely in the formation and the zone fossil Exogyra ponderosa Roemer occurs most abundantly in the central part of Alabama.

The Mooreville Chalk extends into eastern Alabama as far as Macon County with little change in lithologic character. There the basal part merges laterally into chalky sand and a little farther east the chalky sand merges into gravelly sand, the basal conglomerate of the Blufftown Formation (Monroe, 1947). The Mooreville thins to 100 feet in southern Macon County as clayey chalk typical of the formation grades into sand in the lower part of the Blufftown Formation. Overlying the basal sandy beds of the Blufftown is a long tongue of chalk that extends eastward as far as west-central Russell County, where it grades into sandy clay of the Blufftown (fig. 8).

Blufftown Formation

The Blufftown Formation crops out along the Chattahoochee River south of the outcrop of the Eutaw Formation from about the middle of Russell County to the northeastern corner of Barbour County and is about 550 feet thick (Eargle, 1950). In central Russell County the Blufftown Formation is divided into two westward-extending tongues by an eastward-extending tongue of the Mooreville Chalk (Monroe,1941). The "lower tongue" of the formation can be traced westward through the southern part of Macon County to within 5 miles of the Macon-Montgomery County boundary where it merges with the lower part of the Mooreville Chalk. The "upper tongue" of the Blufftown can be traced westward through northern Bullock County to an area about 7 miles west of Union Springs where it merges with the upper part of the Mooreville Chalk.

The "lower tongue" of the Blufftown Formation in southern Macon County ranges in thickness from about 30 feet where it merges with the lower part of the overlying Mooreville Chalk to about 150 feet in the eastern part (Scott, 1960). It overlies the Eutaw Formation and consists of light-gray to yellowish-orange glauconitic sand, calcareous clay, and sandy clay of deltaic and marine origin.

The "upper tongue" of the Blufftown Formation in Bullock County consists of yellowish-orange to dark-gray sandy calcareous clay and fine-grained micaceous silty sand with thin layers of limestone and sandstone. It was deposited in shallow marine conditions and is fossiliferous in part. The "upper tongue" ranges in thickness from 30 feet west of Union Springs to 200 feet near the Bullock-Russell County boundary (Scott, 1962a).

In eastern Russell County and east of all the chalk facies, the lower part of the formation consists of about 200 feet of light-gray fine- to coarse-grained sand and sandy clay and the upper part consists of 200 to 300 feet of greenish-gray calcareous sandy clay containing some thin beds of sand and calcareous sandstone.

Demopolis Chalk

The Demopolis Chalk, about 420 feet thick in western Montgomery County, is split into two eastward-extending tongues by a westward-extending tongue of the Cusseta Sand Member of the Ripley Formation The "lower tongue" of the Demopolis is about 225 feet thick in Montgomery County. It unconformably overlies the Mooreville and consists of pale-olive to yellowish-gray silty to finely sandy micaceous fossiliferous chalk. The "lower tongue" extends eastward to near Union Springs in central Bullock County and is less than 100 feet thick at its eastward extent where it merges with the Cusseta Sand Member of the Ripley Formation. The "lower tongue" overlies the Mooreville Chalk in the western part of Bullock County and the Blufftown Formation in central Bullock County.

The "upper tongue" of the Demopolis is about 80 feet thick in south-central Montgomery County and is more argillaceous than the "lower tongue" and contains abundant mica and very fine-grained sand. The "upper tongue" grades eastward into calcareous bentonitic clay that merges with the upper unnamed member of the Ripley Formation.

Cusseta Sand Member of the Ripley Formation

East of mid-Bullock County, the Cusseta Sand Member at the base of the Ripley overlies the Blufftown Formation and is overlain by the upper unnamed member of the Ripley Formation. The top of the Cusseta Sand Member becomes progressively higher stratigraphically eastward and thickens as the Demopolis thins.

The unit is as much as 200 feet thick in Bullock County where it consists mainly of light-gray and yellowish-orange sand, clay and chalk interbedded with thin layers of limestone and fine gravel. Exposures of the Cusseta in Russell and Barbour Counties range in thickness from 70 to 125 feet. The lower part of the Cusseta in Barbour and Russell Counties generally consists of 10 to 20 feet of medium- to coarse-grained sand that locally contains clay pebbles and is glauconitic, gravelly, and fossiliferous. The basal sand grades upward into clayey, fine-grained micaceous sand and dark-gray silty micaceous carbonaceous fossiliferous clay.

Upper Unnamed Member of the Ripley Formation

In Barbour County the upper member of the Ripley is about 250 feet thick. The basal beds of the upper member are generally characterized by fine- to coarse-grained sand that is gravelly in some exposures (Newton, 1965). The basal sands are overlain by clayey very fine- to fine-grained sands containing ledges of calcareous sandstone and abundant fossils, including *Exogyra costata* Say. Overlying beds consist cheifly of fine- grained clayey micaceous carbonaceous fossiliferous sand containing a few thin layers of sandy fossiliferous limestone, calcareous sandstone, and carbonaceous clay. Fossil species occurring in the upper member in western Alabama also occur abundantly in eastern Alabama.

Providence Sand

The Providence Sand extends eastward from central Alabama into Georgia and ranges in thickness from 0 to 300 feet. The Perote Member of the Providence, in the lower part of the formation, intertongues with the upper part of the Prairie Bluff Chalk (of western Alabama) in central Alabama. The Perote Member thickens to the east as the Prairie Bluff thins and finally pinches out in north-central Pike County. From north-central Pike County eastward, the Perote Member overlies the upper unnamed member of the Ripley Formation.

The Perote Member was named by Eargle (1950) for exposures along U. S. Highway 29 in the vicinity of Perote in southern Bullock County, Alabama. These exposures have now all been grassed over, but the member is still relatively well exposed along secondary roads in the Perote vicinity. The Perote Member reaches a maximum thickness of 150 feet in southern Bullock County and ranges in thickness from 60 to 100 feet in Barbour County.

Conglomeratic sandstone about 2 to 3 feet thick containing numerous waterworn pebbles, shells and phosphatic nodules occurs at the base of the Perote Member. The remainder of the Perote consists mainly of dark-gray laminated to thin-bedded silty clay and very fine- to fine-grained sand that is abundantly micaceous and carbonaceous. The member is fossiliferous and fresh exposures contain pelecypods, principally Exogyra costata Say, Anomia argentaria Morton, and Crenella serica Conrad and several species of gastropods, chiefly Turritella sp. Weathered outcrops are characterized by thin resistant limonitic beds of sandstone and abundant ironstone concretions.

The upper unnamed member of the Providence rests conformably on the Perote Member and is about 100 to 150 feet thick. The upper member consists of crossbedded fine to coarse sand and white, black, and very dusky purple mottled clay. Eargle (1950) felt that the sand with steep and long foreset beds was apparently deposited in deltas. The clays are variable in texture, color, and composition. Lignite, sand, and kaolin are common constituents in the clays.

The unnamed member in the western part of the area consists of interbedded lenses and beds of fine and coarse sand with calcareous ledges containing Exogyra costata, Cardium sp., and other fossils. Eastward the member is coarser in texture and much less fossiliferous except in downdip areas as in the Chattahoochee River Valley where coarsely sandy limestone contains abundant well preserved specimens of echinoids and shells of various mollusks.

EXPOSED FORMATIONS OF TERTIARY AGE

The Tertiary formations in the outcrop in southeastern Alabama, in ascending order, are the Clayton Formation (Paleocene), the Nanfalia Formation, Tuscahoma Sand, and Hatchetigbee Formation (lower Eocene), the Tallahatta and Lisbon Formations (middle Eocene), and the Moodys Branch Formation and Ocala Limestone (upper Eocene) (fig. 9). Late Eocene and Oligocene limestone units and the overlying Miocene clastics have been severely weathered and are mainly mapped as deposits of residuum (fig. 10). The formations strike east-west in Houston County and slightly north of due east in Henry and Barbour Counties. The units dip toward the south and southeast from 10 to 30 feet per mile. The Tertiary units in the outcrop are about 900 feet thick and thicken downdip to about 1,700 feet in southern Houston and Geneva Counties.

Clayton Formation

At the type locality of the Clayton Formation in eastern Alabama, at a cut on the Central of Georgia Railroad 1 mile east of Clayton (near northeast corner of sec. 4 and northwest corner of sec. 3, T. 10N., R. 26 E.), C. Wythe Cooke (1926) measured a section consisting at the base of coarse-grained moderate yellow sand resting on the eroded surface of the Providence Sand of Cretaceous age. The strata become more calcareous and irregularly indurated upward and grade into hard fossiliferous limestone. The lower sand and limestone are 35 feet thick and these beds are overlain by 15 feet of dark-gray laminated to hackly fine silty, finely micaceous fossiliferous calcareous clay (exposed at southeast corner of sec. 33, T. 11 N., R. 26 E.). The limestone contains the characteristic guide fossil *Ostrea crenulimarginata* Gabb.

The formation is generally deeply weathered throughout most of the outcrop in eastern Alabama and is from 70 to 125 feet thick most everywhere except at the type locality where only 50 feet are exposed. Fresh nearly complete sections of the Clayton were measured along the Chattahoochee River by Toulmin and LaMoreaux (1963). The section along the Chattahoochee is about 150 feet thick, or less depending upon the amount of pre-Eocene and Holocene erosion and solution of the upper surface. The lower 40 feet is grayish-yellow sandy limestone, sand and light-gray calcareous silt containing abundant mollusks. The middle part, about 40 feet thick, is sandy fossiliferous massive limestone containing abundant shells of *Ostrea crenulimarginata* Gabb and the nautiloid *Hercoglossa ulrichi* (White). The upper part, from 50 to 70 feet thick, is white massive limestone containing poorly preserved assorted invertebrate remains. Weathered residual accumulations of the Clayton are intermittent sources of iron ore. Relief on the upper surface of the Clayton is locally often 50 feet or greater due to solution activity (Newton, 1965).

Series	Group	Western Alabama	Central and Eastern Alabama
Holocene and Pleistocene		Terrace deposits	Terrace deposits
Pliocene		Citronelle Formation	
Miocene		Undifferentiated upper Miocene Catahoula Sandstone Paynes Hammock Sand	Miocene Undifferentiated
Oligocene	Vicksburg	Chickasawhay Limestone	Chickasawhay Limestone
		Byram Formation: Bucatunna Clay Member, Marl facies, Glendon Limestone Member	Byram Formation: Bucatunna Clay Member, Marl facies, Glendon Limestone Member
		Forest Hill Sand; Marianna Limestone	Marianna Limestone
		Red Bluff Clay	"Bumpnose Limestone"
Eocene	Jackson	Yazoo Clay: Shubuta Member, Pachuta Marl Member, Cocoa Sand Member, North Twistwood Creek Clay Member	Ocala Limestone or Crystal River Formation
		Moodys Branch Formation	Moodys Branch Formation
	Claiborne	Gosport Sand	
		Lisbon Formation	Lisbon Formation
		Tallahatta Formation: Claystone	Tallahatta Formation: Sand
	Wilcox	Hatchetigbee Formation	Hatchetigbee Formation
		Bashi Marl Member	Bashi Marl Member
		Tuscahoma Sand: Bells Landing Marl Member, Greggs Landing Marl Member	Tuscahoma Sand: Greggs Landing Marl Member
		Nanafalia Formation: Grampian Hills Member, "*Ostrea thirsae* beds", Gravel Creek Sand Member	Nanafalia Formation
Paleocene	Midway	Naheola Formation: Coal Bluff Marl Member, Oak Hill Member	Absent
		Porters Creek Formation: Matthews Landing Marl Member	Absent
		Clayton Formation: McBryde Limestone Member, Pine Barren Member	Clayton Formation

Figure 9.–Outcropping Tertiary formations of south Alabama.

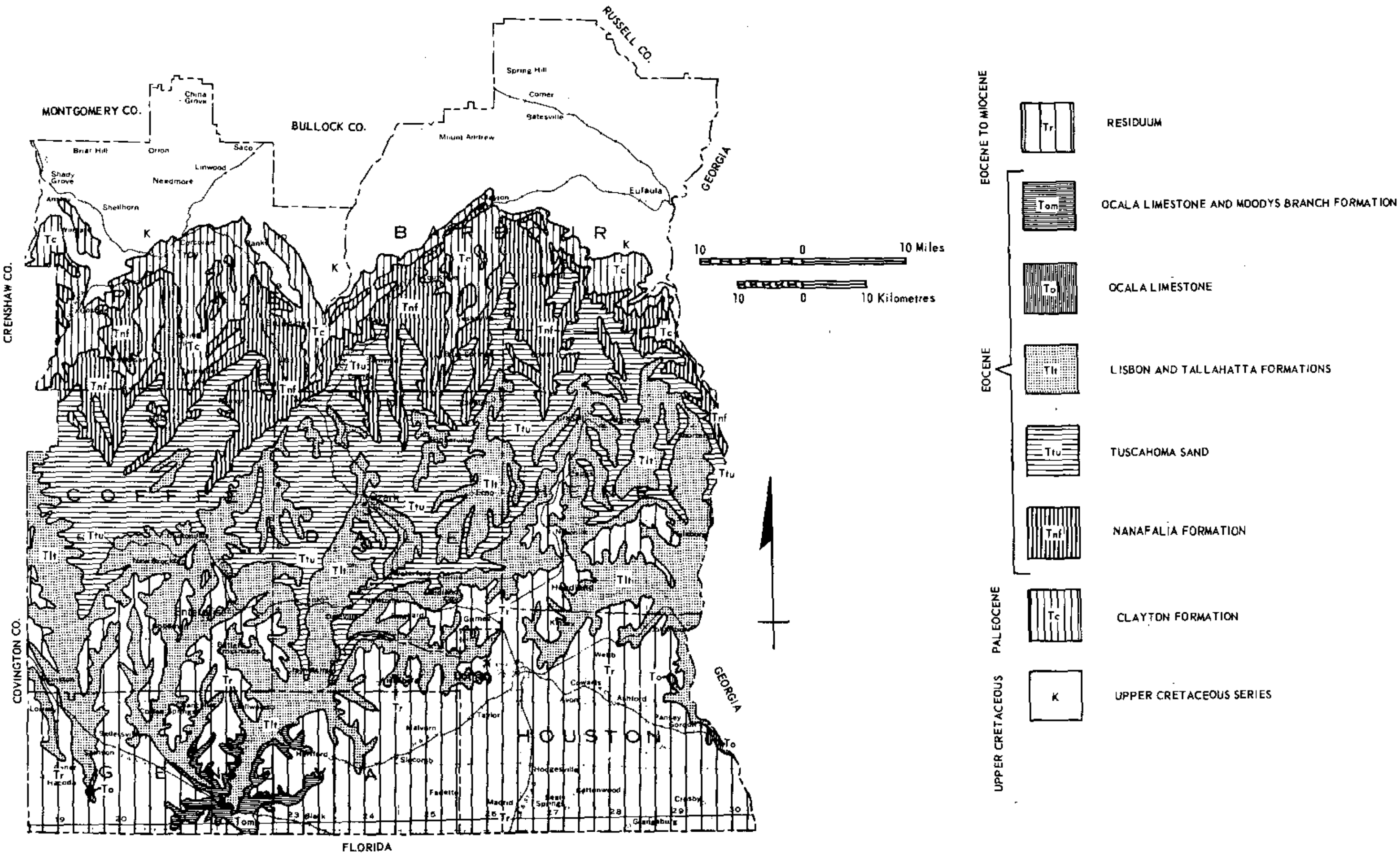

Figure 10.–Generalized geologic map of the Tertiary formations in southeastern Alabama (modified from MacNeil, 1946).

Nanafalia Formation

The Nanafalia Formation in southeastern Alabama unconformably overlies the Clayton Formation and ranges in thickness from 75 feet along the Chattahoochee River to about 110 feet in Barbour and Henry Counties. The Nanafalia is distinctly nonmarine updip and marine downdip (Newton, 1968b). In the area of outcrop, the sequence of beds is often obscured by weathering and the collapse of beds into sinkholes resulting from the solution of limestone in the underlying Clayton Formation. Updip, the nonmarine facies corresponds roughly to the Gravel Creek Member of west Alabama and consists of a basal sand overlain by alternating beds of light-gray and white clay, white and grayish-yellow fine- to coarse-grained sand, lenses of lignite and carbonaceous clay and lenses of bauxitic and kaolinitic clay. Bauxite and kaolinitic clay are mined from the lower part of the Nanafalia in southern Barbour and northern Henry Counties. Sand in the lower part of the formation commonly is crossbedded, gravelly, and contains numerous clay pebbles (Newton, 1968b).

Downdip, the basal sand is overlain by beds of olive-gray to yellowish-gray very fine- to coarse-grained glauconitic, micaceous, calcareous, fossiliferous, sand and clayey sand containing abundant _Odontogryphaea thirsae_ (Gabb) = _Ostrea thirsae_ (Gabb). The "_Ostrea thirsae_ beds" are overlain by light-gray irregularly indurated clay, claystone, and sandy clay containing molluscan shells and prints. The clays, often referred to as "pseudobuhrstone" are typical of the Grampian Hills Member of the formation in west Alabama of LaMoreaux and Toulmin (1959). The Nanafalia thickens in the subsurface and is composed mainly of fossiliferous limestone and coarse sand.

Tuscahoma Sand

The Tuscahoma Sand overlies the Nanafalia Formation and is about 175 feet thick. The lower 10 to 25 feet of the formation consists of greenish-gray fine- to coarse-grained glauconitic sand containing some gravel and clay pebbles. Just above the basal sand is a glauconitic abundantly fossiliferous sandstone containing the guide fossil _Chlamys greggi_ Harris and the large shells of _Ostrea sinuosa_ Rogers and Rogers, formerly known as _O. compressirostra_ Say. The sandstone bed as interpreted from Toulmin (1969) is probably correlative with the Greggs Landing Marl Member of the formation on the Alabama River. The Bells Landing Marl Member is not readily recognizable in southeastern Alabama. The basal sand and sandstone are overlain by laminated and thin-bedded carbonaceous micaceous silty clay and very fine-grained sand. The laminated and thin beds are the most distinguishing characteristics of the formation. Spheroidal, calcareous, fossiliferous, siltstone and sandstone concretions are formed locally as a result of the weathering of the upper beds of the Tuscahoma.

Hatchetigbee Formation

The Hatchetigbee Formation in southeastern Alabama is represented by about 30 to 35 feet of beds. The Bashi Marl Member at the base of the formation generally consists of 3 to 10 feet of greenish-gray fine-grained abundantly glauconitic fossiliferous sand that weathers white, sandstone and chertlike fragments, and concretions (Newton, 1968a). Well-preserved foraminifers, ostracodes, and molluscans can be collected from the Bashi Member. The glauconitic sand is overlain by 20 to 25 feet of light- to dark-gray laminated to massive clay and fine-grained micaceous carbonaceous sand. In the channel of the Chattahoochee River, Toulmin and LaMoureaux (1963) described 35 feet of glauconitic fossiliferous sand and thin beds of sandstone concretions.

Tallahatta Formation

The Tallahatta Formation in eastern Alabama is about 70 feet thick and consists chiefly of massive sand and several beds of medium-gray laminated clay. Massive beds of siliceous claystone or buhrstone typical of the formation in western Alabama are generally not present in southeastern Alabama. Thin beds of buhrstone are present in Coffee, Dale, and Henry Counties, but in general the formation is composed mainly of sand. The sand generally is deeply weathered, fine- to coarse-grained and gravelly in some exposures. The base of the Tallahatta has been mapped in downdip areas at the base of a 5-foot thick, glauconitic, calcareous, fossiliferous gravel bed. Along the Chattahoochee River, Toulmin and LaMoreaux (1963) described 15 feet of light-gray, sandy, hard, fossiliferous limestone at the base of the formation. When they can be found, *Cubitostrea perplicata* (Dall) and *Alectryonia johnsoni* (Aldrich) are excellent guide fossils that are restricted to the Tallahatta.

Lisbon Formation

On the Alabama River, at Lisbon and Claiborne Bluffs, type localities of the formation, Oman (1965) and Toulmin (1974, in preparation) have divided the Lisbon Formation into three parts based on faunal assemblages and general lithologic characteristics. The lower Lisbon, about 16 feet thick, is exposed at Lisbon Bluff and consists of coarse-grained glauconitic sand and many species of mollusks including the diagnostic species *Cubitostrea lisbonensis* (Harris). The middle part of the Lisbon is 19 feet thick and is chiefly carbonaceous sand and carbonaceous silty clay. The upper Lisbon is 75 feet thick at Claiborne Bluff and consists of beds of greenish-gray calcareous glauconitic sand, dark-greenish-gray sandy clay, and yellowish-gray calcareous sand. The beds are abundantly fossilferous, diverse in composition, and the large oyster, *Cubitostrea sellaeformis* (Conrad) is the guide fossil.

According to Oman (1965), the entire formation thins to 75 feet on the Conecuh River. The lower C. lisbonensis zone is 20 feet thick, the middle part is 40 feet thick, and the upper part, the O. sellaeformis zone, is 12 feet thick. The lower and middle Lisbon have not been identified east of Conecuh County. The section in southeastern Alabama is all termed upper Lisbon by Oman (1965) and Toulmin (1969) and is reported to be about 115 feet thick in the Chattahoochee River section. The beds along the Chattahoochee are more calcareous than in western Alabama. Cubitostrea sellaeformis occurs in all but the uppermost beds and the zone has been traced by Toulmin (1969) eastward into Georgia.

Where fresh in southeastern Alabama, the Lisbon consists of greenish-gray fine- to very coarse-grained glauconitic silty sand, yellowish-gray glauconitic sandy limestone, greenish-gray calcareous sandy clay, and laminated to thin-bedded sandy siltstone. In most exposures, the formation is very deeply weathered and consists of moderate-red to moderate-reddish-orange well-sorted sand. Generally gravelly sand occurs in the lower part of the formation.

Moodys Branch Formation

The Moodys Branch Formation in southeastern Alabama is generally highly weathered and fresh exposures are confined to stream valleys. Along the Choctawhatchee River in Geneva County, according to Huddlestun (1965), the Moodys Branch is about 21 feet thick and consists of 3 feet of greenish-gray fossiliferous calcareous glauconitic sand overlain by 18 feet of sandy glauconitic argillaceous limestone. The lower sand bed contains the diagnostic fossils Periarchus lyelli (Conrad) and Chlamys deshayesii Lea.

Residuum

The upper Eocene and Oligocene limestone units in southeastern Alabama including areas in Coffee, Dale, Henry, Geneva, and Houston Counties have been deeply weathered and affected by leaching, solution, and collapse. As a result, deposits in excess of 100 feet in thickness consisting of white to yellowish-orange medium- to coarse-grained gravelly sand, white to light-gray sandy clay, fossiliferous chert and limestone boulders, and limonitic sandstone occur over broad areas between stream valleys. Disarranged beds of the overlying Miocene Series are also included in the deposits of residuum. Normal sections of the Moodys Branch and the lower few feet of the overlying Crystal River occur in some of the stream valleys but mapping in the interfluves is difficult because of the residuum. The Moodys Branch Formation is the base of the residuum in most of southeastern Alabama but locally limestone beds in the upper part of the Lisbon Formation have also been severely weathered.

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SOME STRUCTURAL PATTERNS IN SEDIMENTS OF THE GEORGIA COASTAL PLAIN

By

Robert C. Vorhis

ABSTRACT

Structural attitudes on the top of the Tertiary and Cretaceous formations in Sumter, Crisp, and Wilcox Counties, Georgia, change with time. Strikes rotate about 28° counterclockwise from the top of the lower Cretaceous to the top of the Ocala Limestone (upper Eocene); with a corresponding decrease in dip from about 60 to 12 feet per mile (18 to 4 m).

Sediments of more than 1,000 feet (300 m) were deposited in the southwest Georgia embayment during Early Cretaceous, in the Suwannee strait during Late Cretaceous, and in part of the southeast Georgia embayment during middle Eocene. This sequence suggests an eastward migration of the depositional basins.

INTRODUCTION

The strikes of Cretaceous and Tertiary formations in Sumter, Crisp, and Wilcox Counties, Georgia, rotate consistently counterclockwise with time from N 65° E to N 37° E. The purpose of this paper is to document the counterclockwise rotation of strikes, the decrease in dips with time, and ascertain the rates at which these changes occurred. The data available are limited, but it is hoped that they will encourage both the acquisition of more data and a more precise interpretation.

METHOD OF ANALYSIS

On structure-contour maps of each geologic unit (Vorhis, 1972), one contour line that was most firmly controlled by data points was selected and its "strike" measured by a protractor. Dips were measured generally by dividing the vertical distance between the highest and lowest contours by the horizontal distance between the two contours.

Ideally, all data points for a study of this kind should be stacked vertically. This was not possible, so the next best solution was to select data points on a relatively short line of section in Sumter, Crisp, and Wilcox Counties, Georgia (figure 1).

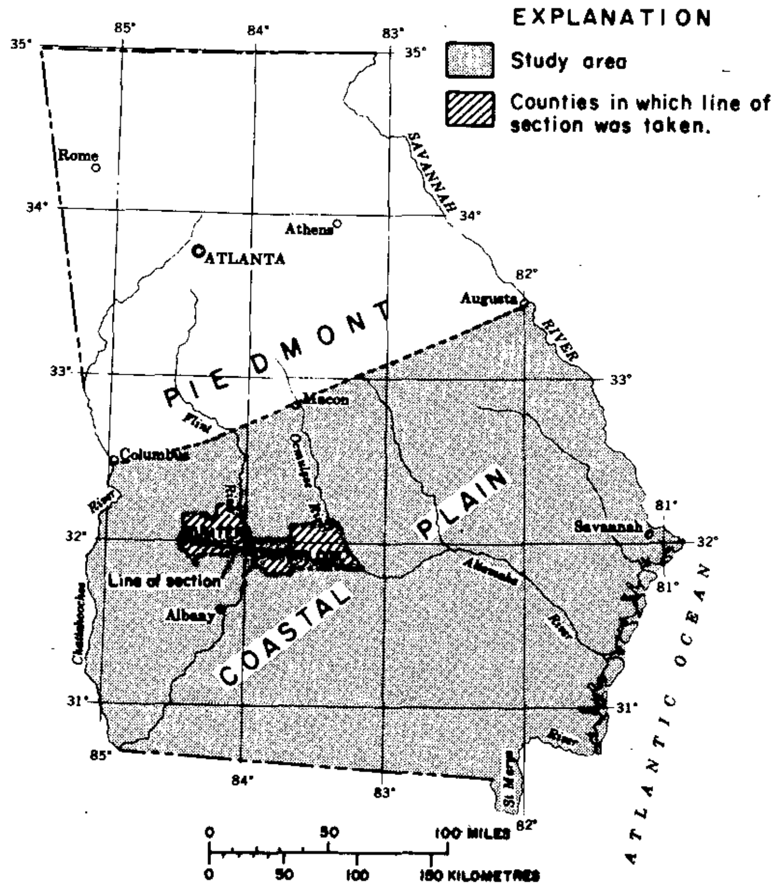

Figure 1.—Location of study area and line where strike and dips were measured on structure contour maps.

RESULTS

The strikes of formational tops on the line of section (table 1) rotate counterclockwise from Cretaceous (N 65° E) to Eocene (N 37° E). Furthermore, when they are plotted against geologic time, they delineate two lines (figure 2). From slopes of these lines, the average rate of strike rotation was about -0.28° per million years from the start of Cretaceous until the end of early Eocene time and about -0.87° per million years from then until the end of Eocene time. These figures, if valid, indicate that rotation of strikes was more than twice as rapid in post-Tuscahoma than in pre-Tuscahoma time.

When plotting strike against dip, the points delineate two lines (figure 3) with the break in slope again at the top of the Tuscahoma Formation, at the end of early Eocene time. This figure shows that the distinct break in slope of the two lines is not related to errors in measuring the duration of geologic time.

Table 1.--Strike and dip of geologic formations, Sumter, Crisp, and Wilcox Counties, Georgia (measured along line shown in figure 1).

Series	Formation	Age of top (million yrs. before present)	Strike	Dip (ft/mi)	Dip (m/km)
Oligocene	Suwannee Limestone	25 1/	6/	10	1.8
Eocene, upper	Ocala Limestone	36 1/	N37°E	12	2.2
	Clinchfield Sand	41 2/	N43°E	16	3.0
, middle	Lisbon Formation	43 2/	N44°E	17	3.3
	Tallahatta Sand	47 2/	N47°E	18	3.4
, lower	Tuscahoma Formation	51 2/	N50°E	21	4.0
	Nanafalia Formation	55 2/	N51°E	23	4.4
Paleocene	Clayton Formation	58 1/	N52°E	25	4.7
Upper Cretaceous	Providence Sand	63 1/	N53°E	27	5.2
	Ripley Formation	65 3/	5/	5/	
	Cusseta Sand	68 3/	5/	30	5.6
	Blufftown Formation	70 3/	5/	31	5.8
	Eutaw Formation	84 4/	N59°E	45	8.6
	Tuscaloosa Formation (marine shale member)	96 4/	5/	5/	
Lower Cretaceous		105 4/	N65°E	5/	
Pre-Cretaceous surface		135 1/	N74°E	60	11.4

1/ Wetherhill, G. W., 1966, Geol. Soc. America Mem. 97, p. 518.
2/ Interpolated.
3/ Owens, J. P., and Sohl, N. F., 1973, Geol. Soc. America Bull., v. 84, no. 9, p. 2814.
4/ Best guess that fits data.
5/ Map not yet ready for data to be picked.
6/ Contours too variable to justify a strike reading.

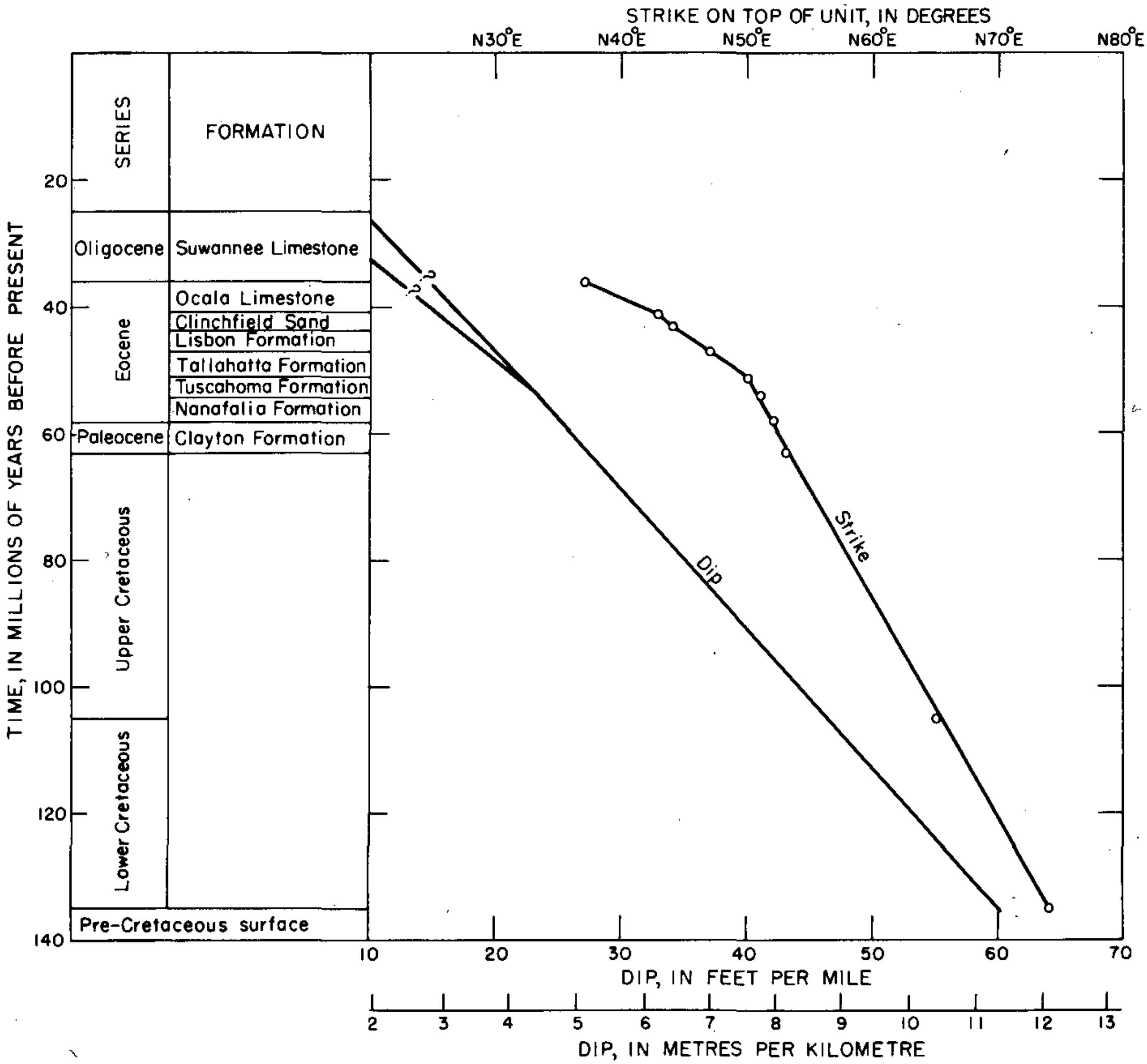

Figure 2.—Strike and dip versus geologic time. Ages from Wetherill (1966, p.518) and Owens and Sohl (1973).

In the Georgia Coastal Plain, geologic units thicker than 1,000 feet (300 m) occur in three different areas that overlap only in part. The oldest and thickest of Early Cretaceous age fills the southwest Georgia embayment. Figure 4 shows the surface on which this thick unit was deposited and its area in Georgia. The next thickest unit is the post-Tuscaloosa Cretaceous, of which the Blufftown Formation is a major unit, having a thickness of more than 1,000 feet (300 m) in west Georgia (figure 5). This was deposited in the oldest of several successive Suwannee straits that extend east-west across Georgia. It presumably was formed by downwarping and filled during Austin-Taylor time (Senonian). The middle Eocene is the only other geologic unit in the Coastal Plain which is known to exceed 1,000 feet (300 m) in thickness (found only in three wells in Pierce and Wayne Counties). Data to support the primary elliptical basin shown in figure 6 are so sparse that the basin as mapped should be considered a suggested interpretation until more data are available. The relation of these deposits to those with lesser thickness suggests post-depositional structural changes.

The three sedimentary basins are delineated in figure 7 by showing only those areas within which deposits exceed a thickness of 1,000 feet (300 m). These three features are markedly different both in shape and location.

The history of the above mentioned structures suggests that centers of deposition migrated from southwest Georgia during Early Cretaceous, eastward across Georgia during Late Cretaceous, to southeast Georgia during Tertiary time. This eastward migration of deposition may have some relation to the counterclockwise rotation of strike and dip with time in the tri-county area. However, more study is needed to see if rotation of strikes is a widespread phenomenon. Additional detailed mapping of formational tops should prove whether this is more than a chance occurrence.

In New Jersey, Minard and Owens (1960) reported strikes that rotated clockwise with time. This is opposite in direction to what is reported herein for Georgia, but is still compatible with the idea of a mobile depocenter. Moreover, Owens (written commun., 1974) has come to favor a mobile depocenter model as the cause of strike rotation in New Jersey. Such may prove to be the explanation for strike rotation in Georgia. Further study is needed in the Georgia Coastal Plain to prove that the analysis of strikes measured in one relatively small area can be interpreted as outlined. At least, this is an hypothesis to be tested as more geologic data becomes available.

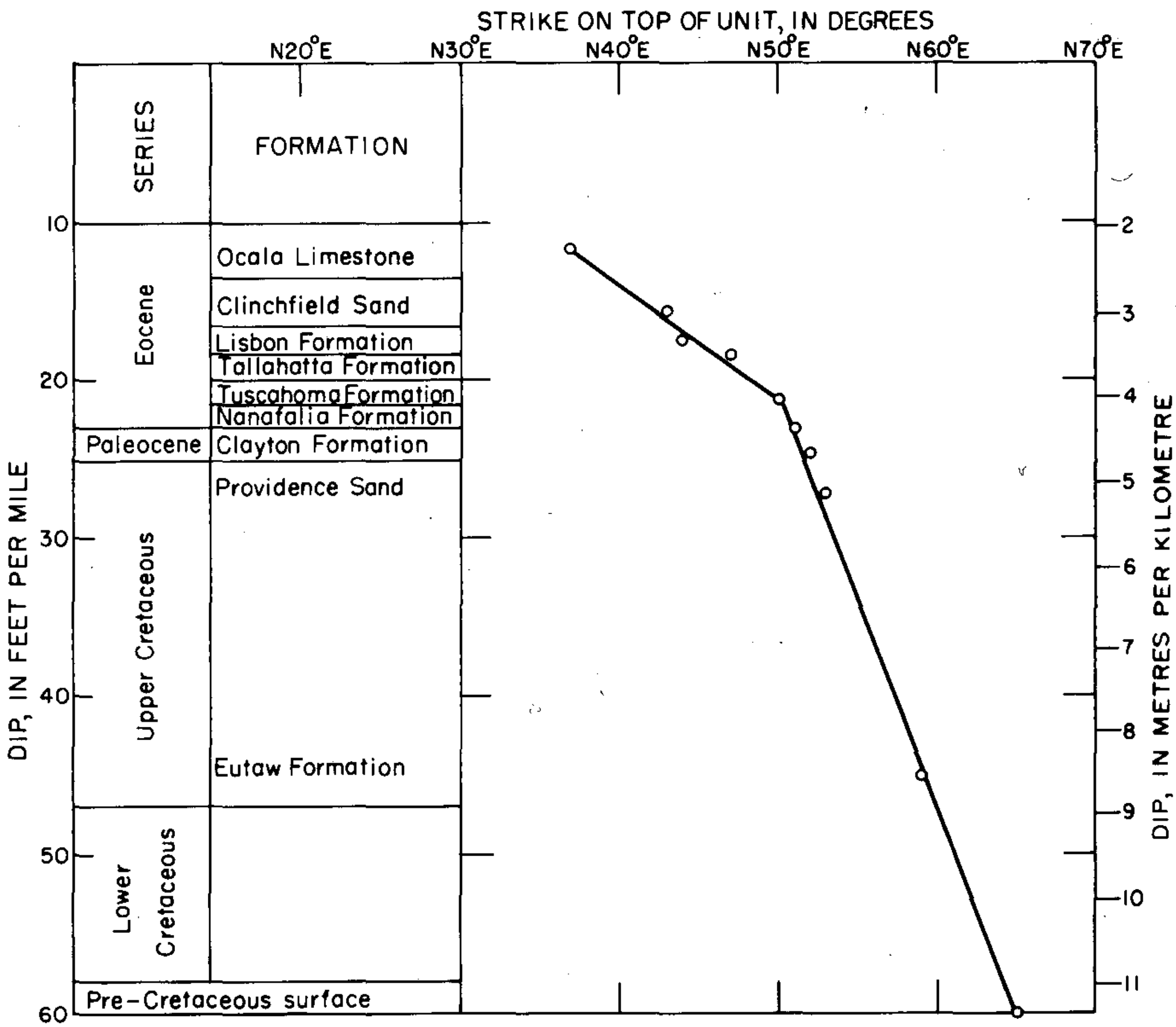

Figure 3.—Strike versus dip.

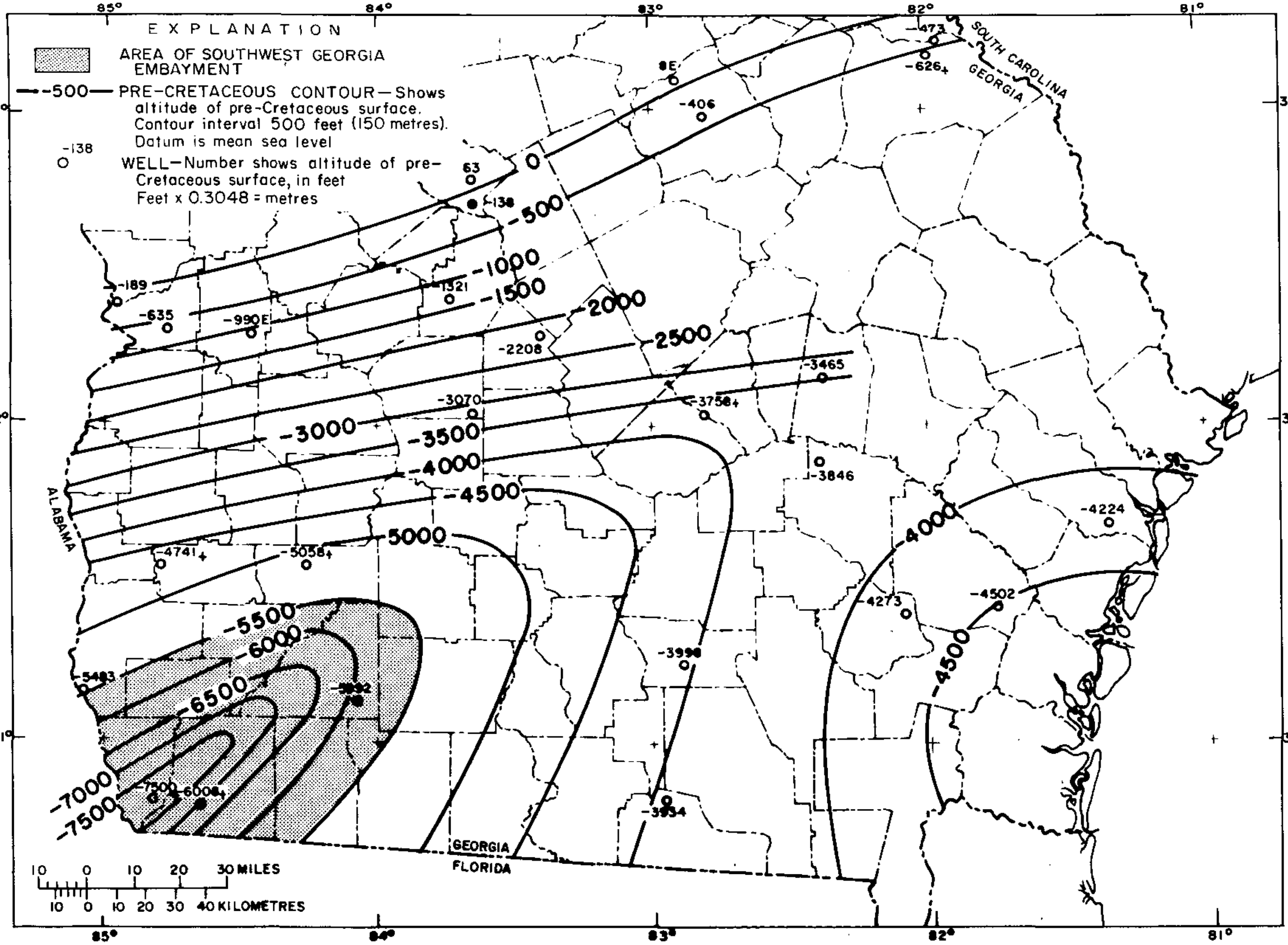

Figure 4.—Structure—contour map of the pre-Cretaceous surface. After Herrick and Vorhis 1963, fig. 20.

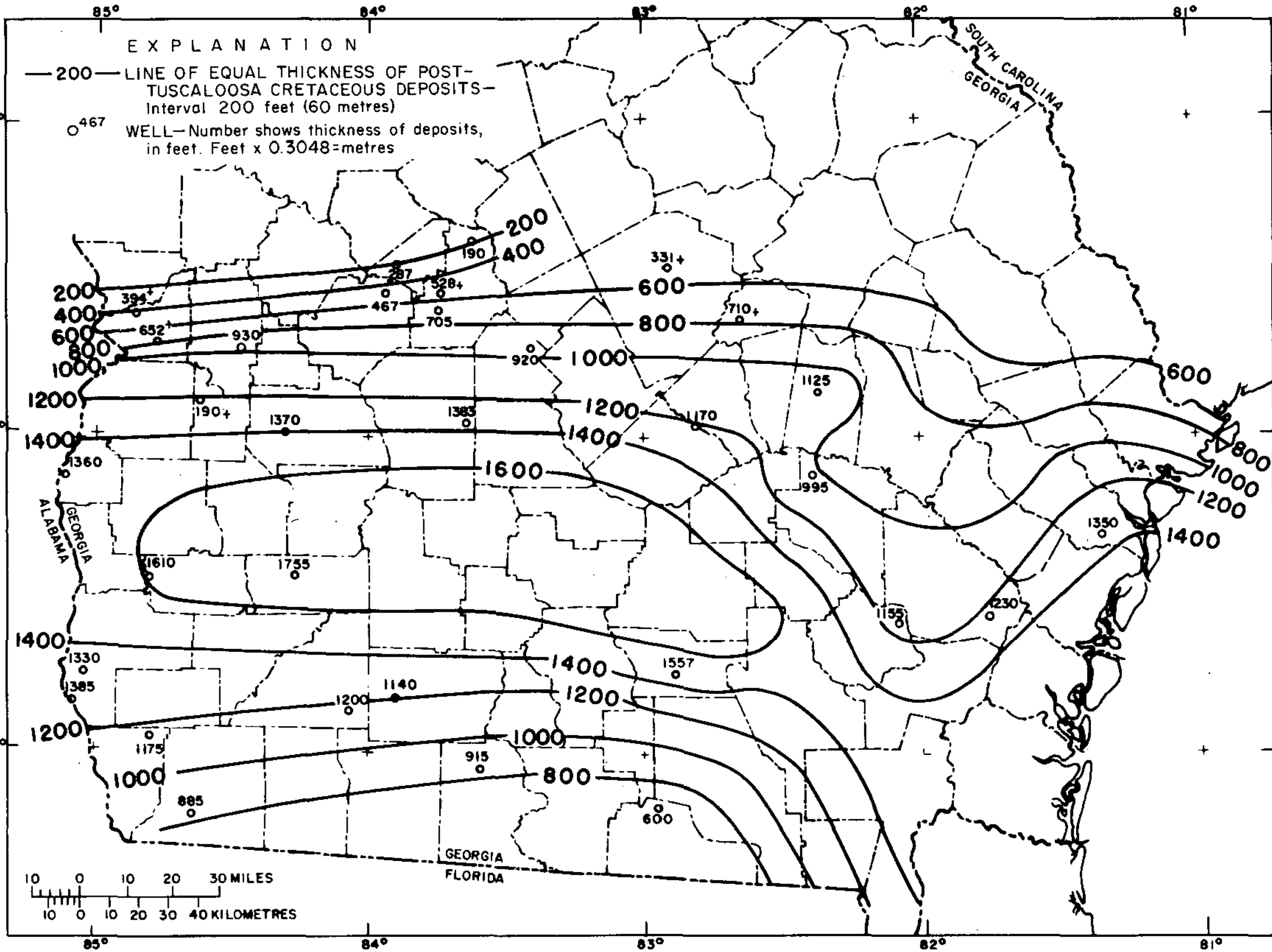

Figure 5.—Thickness-distribution map of post-Tuscaloosa Cretaceous deposits. After Herrick and Vorhis 1963, fig. 15.

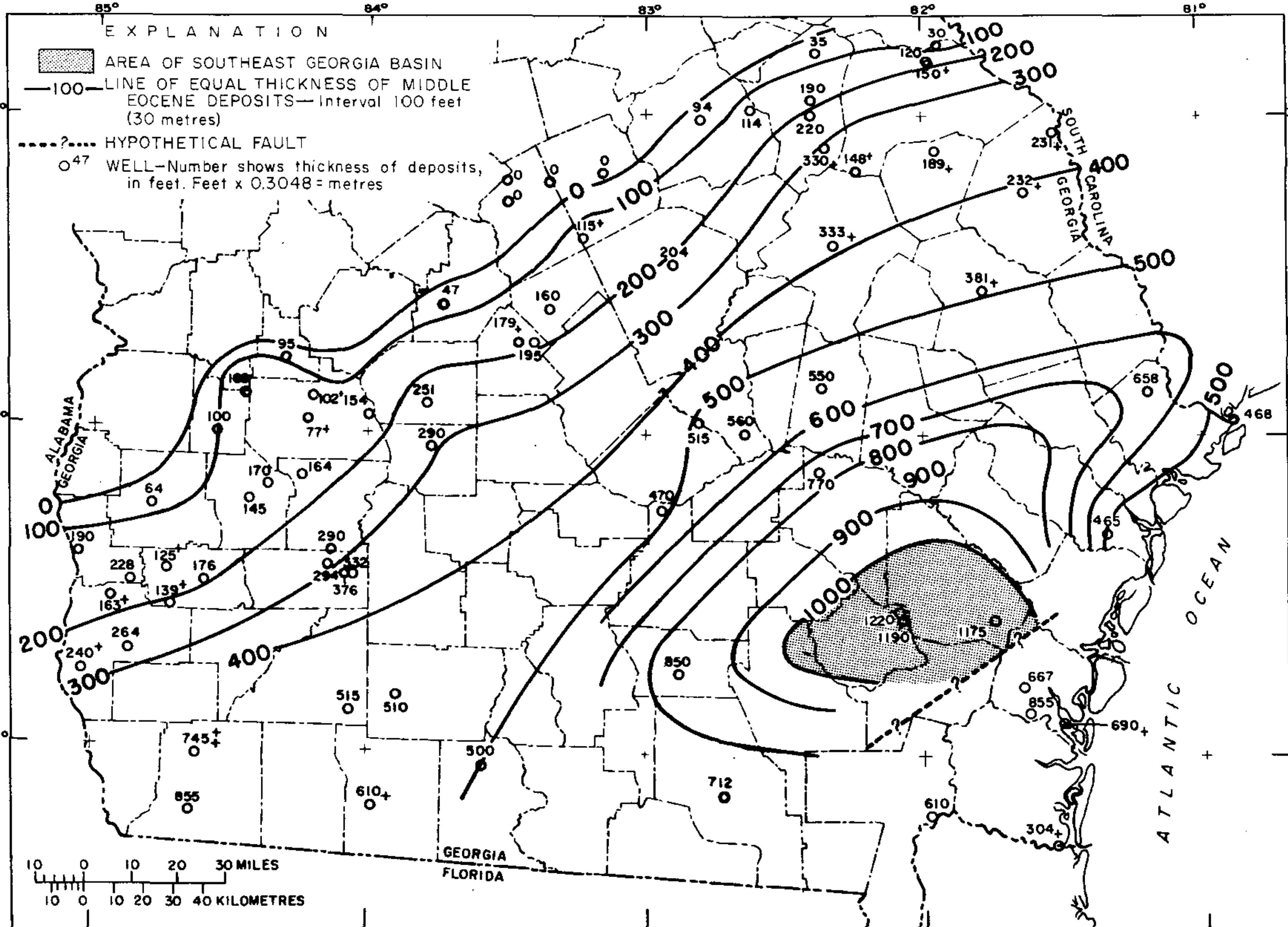

Figure 6—Thickness—distribution map of middle Eocene deposits. Revision of Herrick and Vorhis 1963, fig. 9.

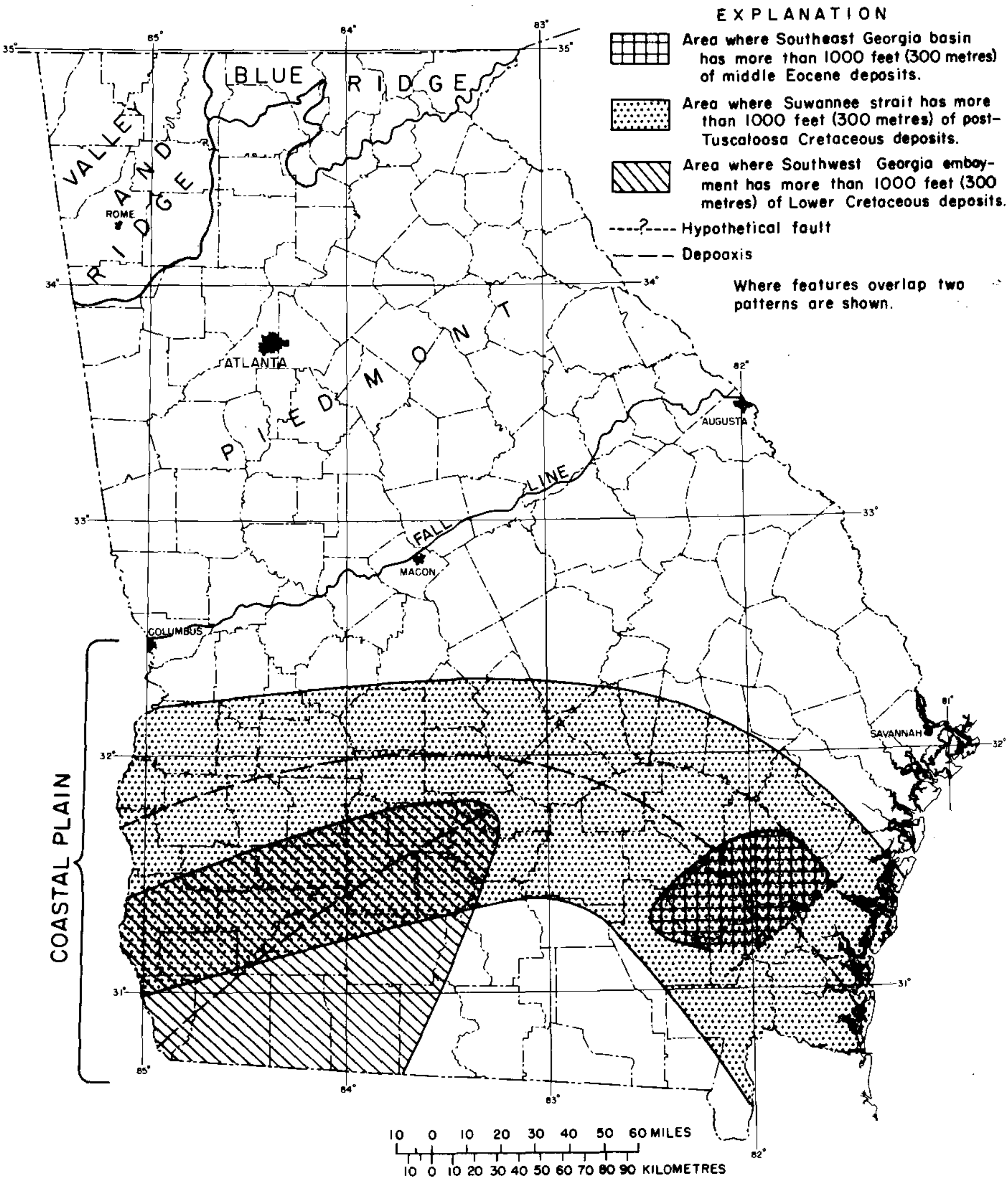

Figure 7.—Major depositional structures in the Georgia Coastal Plain.

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MOLLUSCAN BIOSTRATIGRAPHY OF THE UPPER CRETACEOUS ROCKS OF GEORGIA

Norman F. Sohl, U. S. Geological Survey

ABSTRACT

Upper Cretaceous rocks of western Georgia provide a strategic reference section that forms a correlation link between Gulf Coast sections and those of the Atlantic Coastal Plain. Most previous attempts at correlation of Upper Cretaceous units in these areas were based upon contained molluscan taxa. Early in the century Stephenson recognized the widespread occurrence and limited stratigraphic range of certain oysters and a few other molluscan species. Subsequent additions have been made to his original zones but the existing scheme is keyed to his broad concept of range zones of certain mollusc "index species". As presently understood, these range zones are stratigraphically wider if compared to ammonite zones proposed by such workers as Cobban for the contemporaneous strata of the Western Interior region. Some biostratigraphic units, (such as the Exogyra costata zone) range almost through a complete stage whereas other zones are narrowly confined, (such as the Diploschiza cretacea zone). The widely dispersed Exogyra zones may be traced over several thousand miles, but as is the common failing with zones based upon "index species." others can be only sporadically recognized because of environmental control over species distribution.

The diverse molluscan assemblages of the Upper Cretaceous Coastal Plains hold the potential for a more refined zonation than now exists. Study of generic evolution of common taxa (Trigonia, Flemingostrea, Turritella, etc.) may permit subdivision of sections into a system of lineage zones (= phylozones). A second approach to finer zonation may be through formulation of assemblage zones constructed from the diverse association of taxa. Both methods increase the possibility of zonal integrity that transcends facies changes and thus gives greater potential to wider geographic applicability.

EFFECTS OF WALTER F. GEORGE RESERVOIR ON THE CRETACEOUS OUTCROPS ALONG THE CHATTAHOOCHEE RIVER

by

Jon M. Poort
West Georgia College

Introduction

The Cretaceous strata exposed along the banks of the Chattahoochee River have been one of the focal points of stratigraphers and paleontologists working in the coastal plain for over eighty years. Now, however, access to the Cretaceous outcrops has been severely limited by the building of the Walter F. George Dam near Fort Gaines, Georgia in 1962 with the consequent flooding of the river valley by the impounded reservoir.

Many geologists in the past have either completely traversed or studied portions of the Upper Cretaceous stratigraphy exposed along the Chattahoochee River banks. One of the earliest visitors to the Cretaceous outcrops along the river was Charles Lyell in 1842. Most of the fundamental Cretaceous stratigraphic relationships and basic paleontologic collections were compiled around the turn of the century by a number of geologists, the most prominent of whom were Stanton, Veatch, and Stephenson. The Cretaceous stratigraphy of Georgia was later summarized by Eargle in 1955 which represents the last published resume prior to the completion of the Walter F. George Reservoir. However, Dr. Norman Sohl of the United States Geological Survey made extensive paleontologic collections, photographs, and compilations of stratigraphic data just prior to the dam's completion. Much of the data in this report is derived from Dr. Sohl's unpublished data and is used in conjunction with recent field observations.

Chattahoochee River

The headwaters of the Chattahoochee River are in the mountainous portion of north central Georgia. The very noticeable southwesterly flow of the river across most of the Piedmont (Figure 1) is primarily due to its course direction being controlled by the Brevard Fault Zone and the overall strike of the Piedmont metasediments. At about the state line between Alabama and Georgia, the river turns and flows in a southerly direction across the balance of the Piedmont and across all of the Coastal Plain. The Chattahoochee River is known as the Appalachicola River as it flows across Florida into the Gulf of Mexico.

Of primary interest in this brief report is the portion of the river channel and valley where it flows through sediments of Cretaceous age. The Cretaceous outcrop belt transects the river for a nearly eighty mile stretch from Columbus south to Fort Gaines, Georgia. At Columbus, the Upper Cretaceous sediments rest nonconformably on the metasediments of the Piedmont and because of differential erosion rates, the characteristic waterfalls and rapids are presently marking the Fall Line. South of the Fall Line at Columbus, the river flows across the gently south-dipping unconsolidated sediments of the Cretaceous until the contact with the lithologically-similar Tertiary age sediments is reached just north of Fort Gaines, Georgia. The river in this stretch is classified as being in a mature erosional stage as it crosses the Cretaceous strata, since it meanders from bank to bank across the floodplain. Therefore, the Cretaceous outcrops in the river channel are all covered with a varying thickness of Pleistocene terrace or floodplain gravels and sands. The largest exposures of Cretaceous strata were therefore located in the river bluffs. Because of the

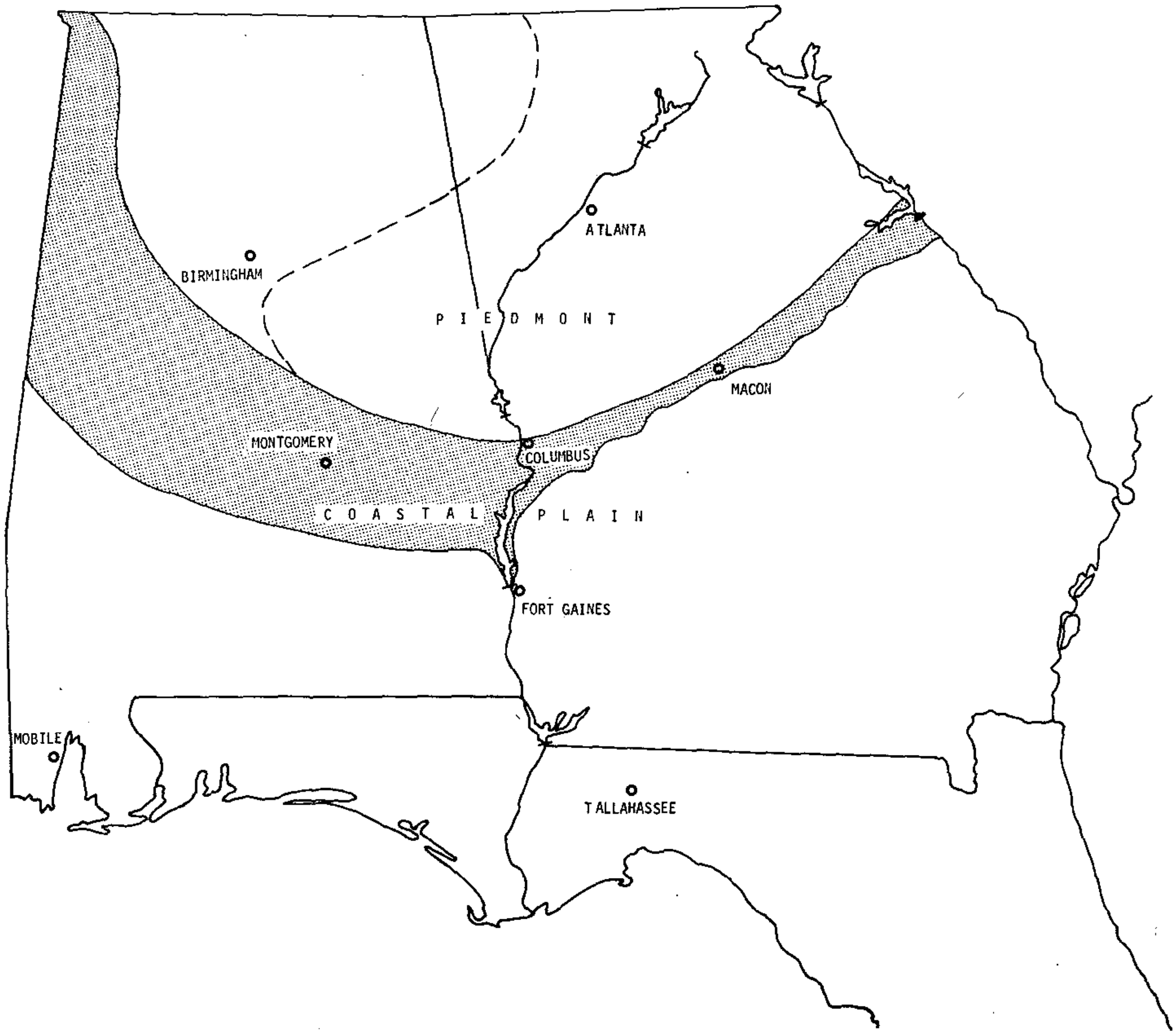

Figure 1. Generalized map of Cretaceous outcrops (stippled) in Georgia and Alabama.

gentle south dip of the Cretaceous strata, a complete composite stratigraphic section could be compiled by using the nearly continuous outcrops in the river channel.

Walter F. George Dam

It was this nearly eighty miles of continuous outcrop of Upper Cretaceous sediments in the Coastal Plain along the Chattahoochee River that was geologically significant and made the river the focal point of many stratigraphic and paleontologic studies. Now, however, things have changed. In the early 1960's, the Corps of Engineers built a large dam, now known as the Walter F. George Dam and Reservoir, across the Chattahoochee River Valley at nearly the Cretaceous-Tertiary contact about a mile north of Fort Gaines, Georgia. At this point, the river bluffs were narrow and a dam was built which would impound about 90 feet of water. The mean river level at that point was about 100 feet above sea level and the top of the dam and lock system was built to 214 feet above sea level. This allowed a designed pool level of 190 feet above sea level. This 190-foot pool level was required to allow the effective reservoir pooling to reach Columbus. Columbus was to be a port city and the Chattahoochee River was to be a navigable river with a minimum depth of no less than nine feet.

Effects on Outcrops

In Figure 2, the Walter F. George Dam is just to the left (south) of measured section number 113. As can be readily seen in Figure 2, all of the outcrops are buried under many feet of water for sixteen miles up to the famous Eufaula Bluff site at Eufaula, Alabama. Figure 3 shows how much of the Cretaceous

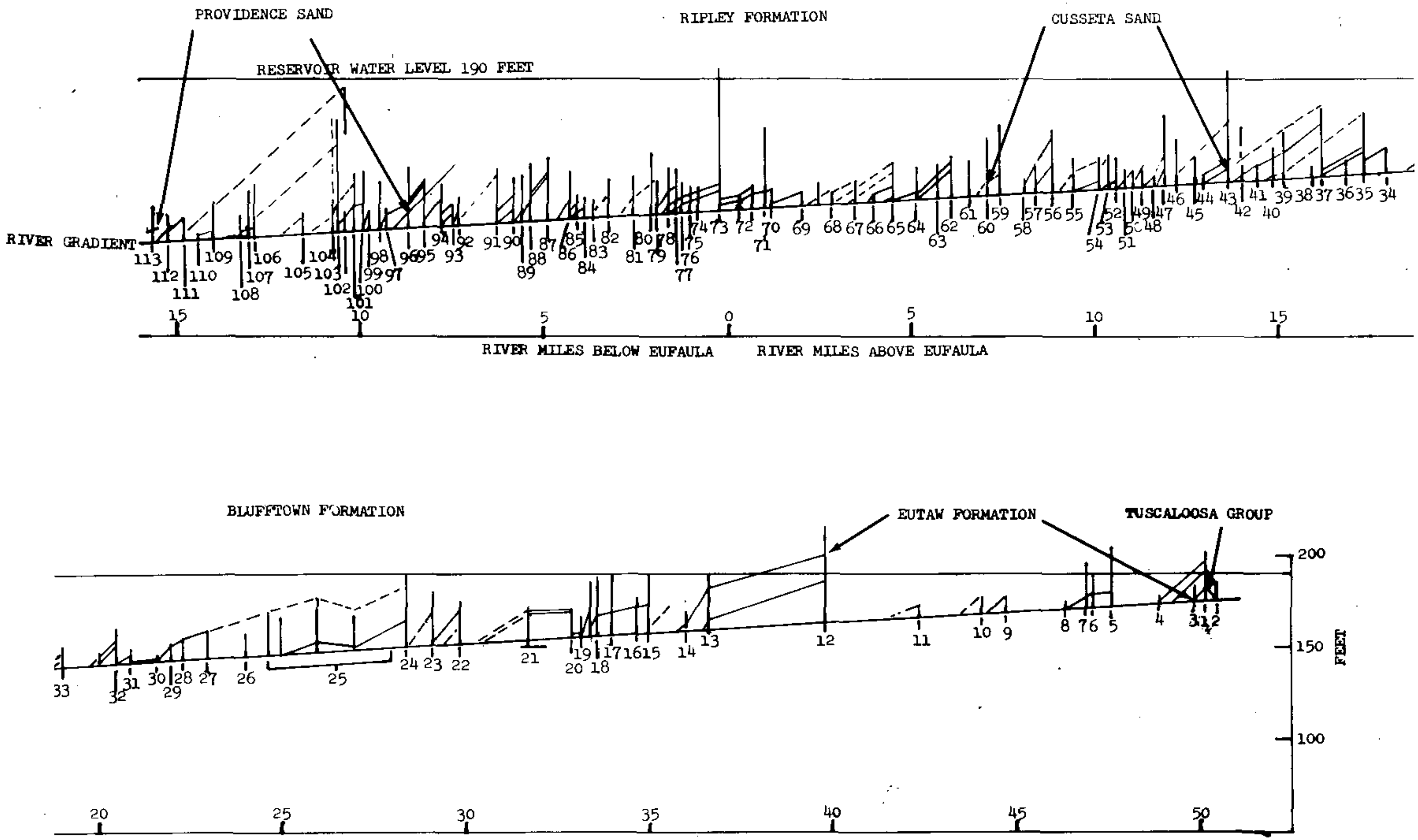

Figure 2. Relationship between measured outcrops and reservoir pool level of 190 feet above sea level.

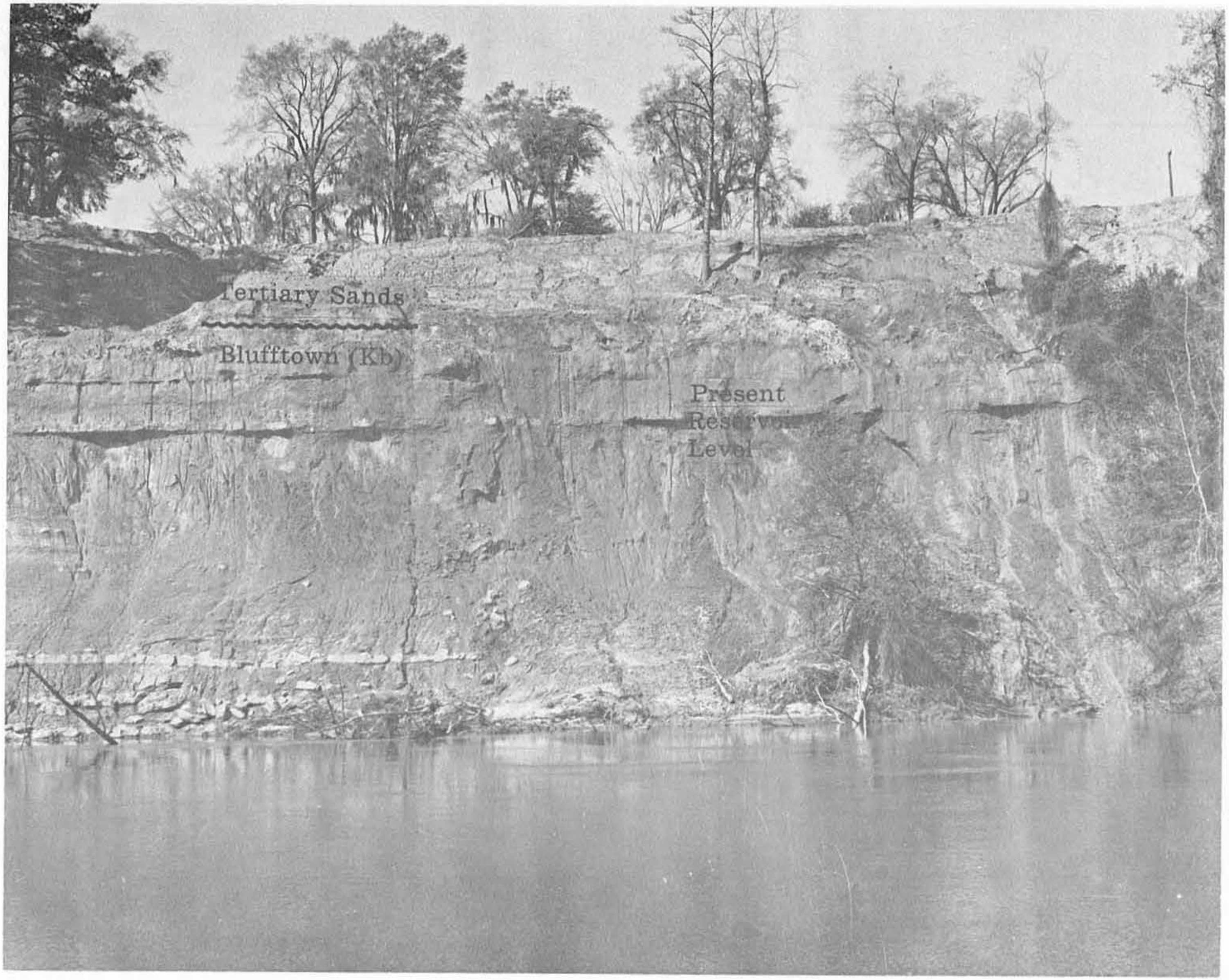

Figure 3. Present reservoir level on Eufaula Bluff, Eufaula, Alabama (pre-reservoir photograph taken by Dr. Norman Sohl).

section is below water level. Of all the now lost outcrops of the Providence Formation and the upper portion of the Ripley Formation, one of the particularly rich fossil localities was along Pataula Creek. Figure 4 is a pre-reservoir photograph of paleontologic collections being obtained at the then famous site "the Narrows". From Eufaula Bluff locality north toward Columbus, the effect of the flooding becomes progressively less. Unfortunately, the most continuous outcrops remaining exposed at present along the river banks in the Columbus-Fort Benning region are the very sparsely fossiliferous basal Upper Cretaceous Tuscaloosa Formation. Figure 5 shows a now covered river bank outcrop containing about the middle two-thirds of the Cusseta Formation (Figure 2, section number 47). Finally, Figure 6 indicates the water level at the famous Blufftown section. In Figure 2, the outcrops of the Tuscaloosa extend for some ten miles further up river toward Columbus. The Piedmont-Cretaceous contact which Stephenson could barely see at low water stage at Columbus is now covered; however, this contact can be seen at several localities in the Columbus area.

Conclusions

The river valley of the Chattahoochee, which for so long was looked to by geologists as a means of studying a nearly continuous cross-section of Upper Cretaceous strata in the Coastal Plain, is now flooded and its geological utility is now lost. There are still some good paleontologic collecting localities and measurable outcrops far up the tributaries or along reservoir flanking roads for the Providence, Ripley, Cusseta, and Blufftown, but they are scattered and not uniformly accessible. The Eutaw and Tuscaloosa can still be partially seen in river outcrops, but better outcrops are available in areas adjacent to the river.

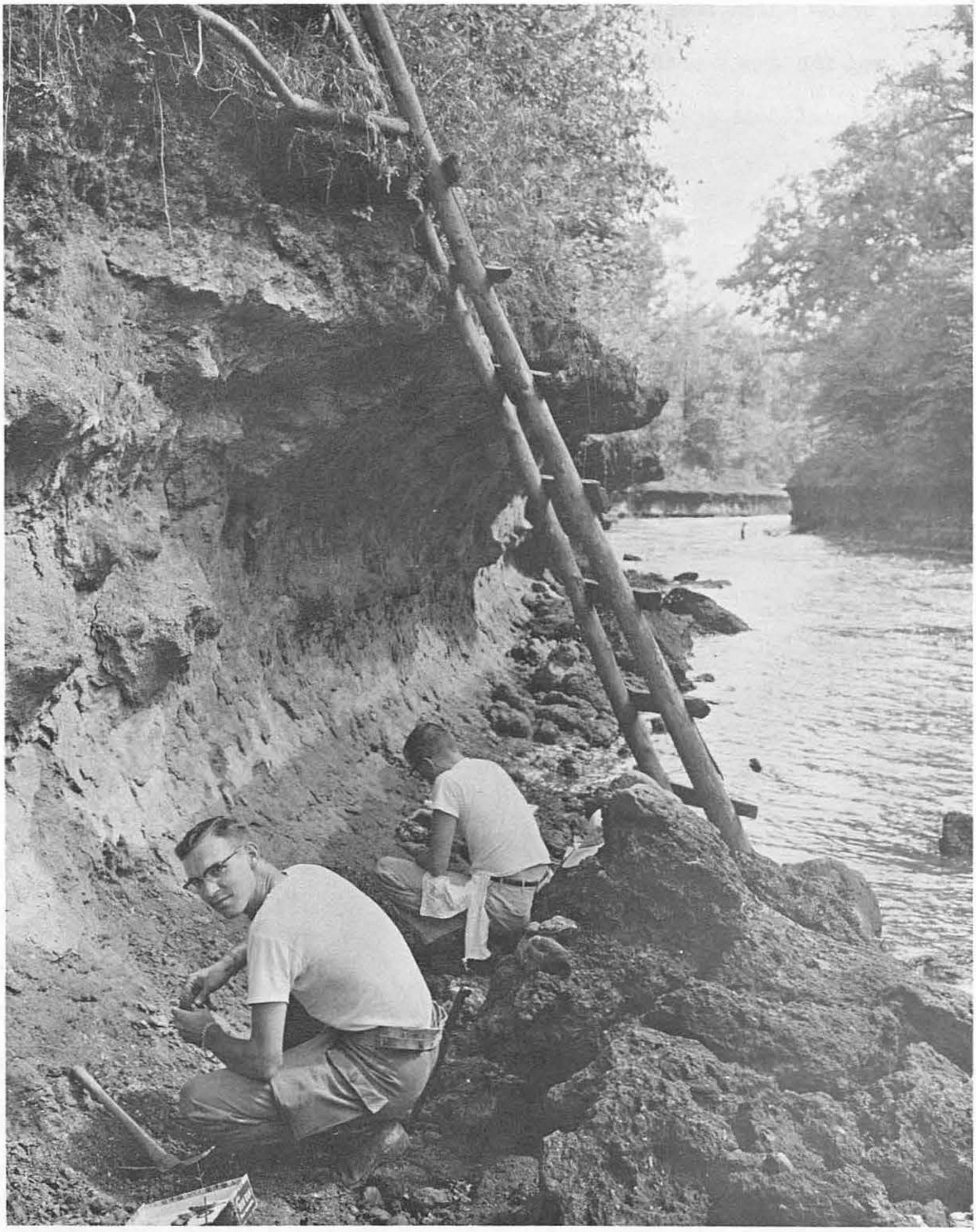

Figure 4. Providence Sand at "the Narrows" of Pataula Creek with S. C. Crosby and Porter Kier. The outcrop is covered by approximately 35-40 feet of water(per-reservoir photograph taken by Dr. Norman Sohl).

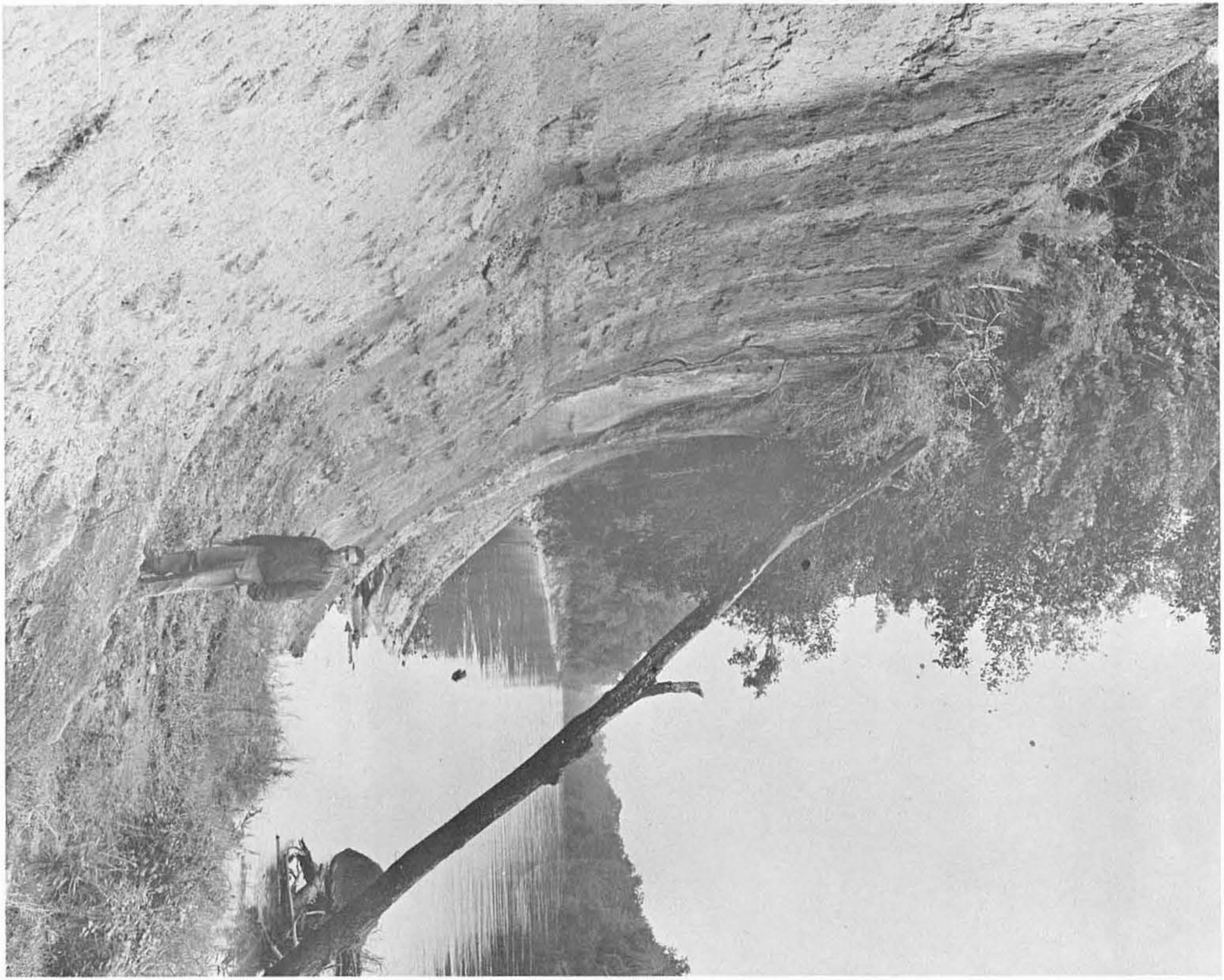

Figure 5. Cusseta Sand in bluffs on left bank of Chattahoochee River twelve miles north of Eufaula, Alabama, Stewart County, Georgia. Water now covers outcrop (pre-reservoir photograph by Dr. Norman Sohl).

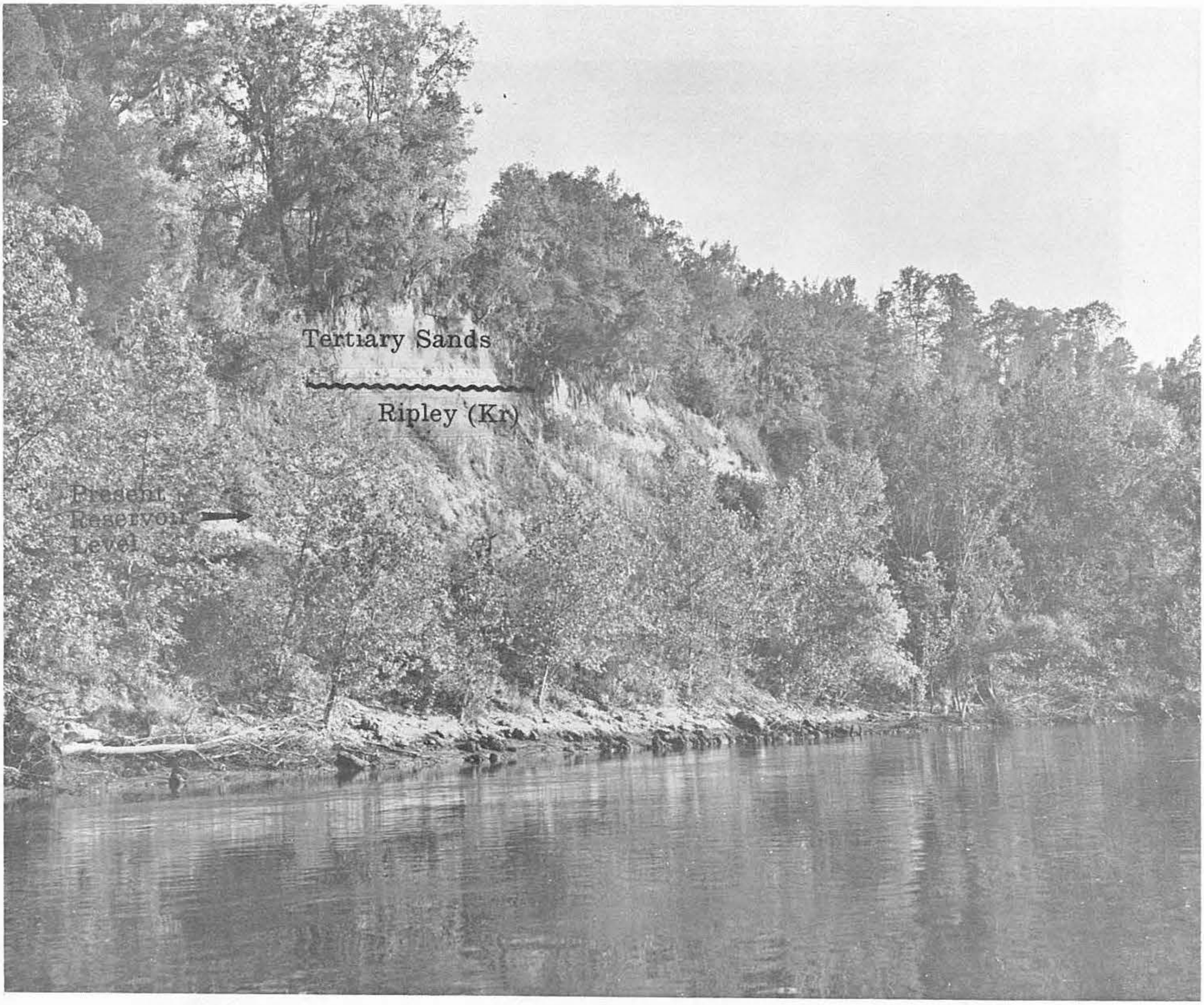

Figure 6. Present reservoir level on Blufftown Bluff, Blufftown, Georgia (pre-reservoir photograph by Dr. Norman Sohl).

A GEOPHYSICAL PROFILE IN THE SUWANNEE BASIN, NORTHWESTERN FLORIDA

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Abstract

Deep drilling in the southeastern states has revealed a buried terrain of lower Paleozoic and possibly older rocks which was folded in Mesozoic time to form the Suwannee Basin. The axis of this broad basin extends northeasterly from Apalachicola, Florida, into southwestern Georgia.

Geophysical Service Inc. has completed a survey over the basin consisting of reflection seismic profiles with accompanying gravity and magnetic data along selected intervals. The section described here was used as the type profile for the area. Seismic records provided migrated time and depth sections based on detailed velocity analyses. Models of gravity and magnetic fields were generated by computer programs which, by a series of consecutive refinements, resulted in an interpretation that corresponds closely to observed values.

The interpretation described here was based on the geophysical data plus regional geological information, including a well completed in 1972 that was located on the section line. The Tertiary and Cretaceous sediments are well displayed by the seismic profile. In the northern half of the line, Lower Cretaceous beds of probable Trinity age lie upon Paleozoic and Triassic rocks above a remarkably smooth unconformity. In the southern portion, clastic strata up to 365 m thick occur between the recognized Cretaceous and the older rocks. The lower contact of the clastics is somewhat irregular, whereas the upper surface is very smooth, suggesting that the upper contact may be conformable and that these clastic rocks are Coahuila (Lower Cretaceous) age. A post-Triassic unconformity is well defined and slopes upward from a depth of about 3600 m at the southern end of the profile to 2560 m at the northern end. Below the unconformity is a folded and faulted sequence of Triassic and Paleozoic rocks. The Paleozoic rocks are believed to consist of Cambrian volcanics in fault contact with Ordovician quartzite. This is overlain by Silurian and Lower Devonian sandstone and shale, up to 2440 m thick. Triassic continental sediments and basaltic flows or sills fill a faulted syncline located in the northern half of the profile.

INTRODUCTION

Geophysical data were collected along a profile in northwestern Florida (Fig. 1) by a Geophysical Service Incorporated (GSI) field party. The line is 42 mi long and approximately parallels the regional dip. The objective of the study was to gather geophysical data to support a geologic interpretation of the western flank of the Suwannee Basin.

The present interpretation resulted from integrating several lines of evidence to achieve a picture that was consistent with each. Drilling information furnished control points to date the upper part of the section and to identify horizons that could be traced on the seismic profile. Closely spaced interval velocities were

Fig. 1

INDEX MAP

used to convert reflection times to true depths and provide clues to general lithologies. Gravity and magnetic measurements were used to test hypotheses relating to the pre-Cretaceous section where drilling information is incomplete.

ANALYSIS METHODS

The basic framework of interpretation was the seismic section (Fig. 2). This was processed for optimum horizon display and migrated in time to remove dip distortion. Selected portions of the seismic section were subjected to velocity analysis (Fig. 3). The intervals selected were between recognizable seismic horizons within which the velocity was generally uniform. It was usually possible to select a series of intervals that represented significant differences in physical characteristics of the strata and therefore corresponded to lithologic boundaries. Along the Suwannee Basin section velocity analyses were made at approximately one-mile intervals, with about 14 individual determinations at each point, thus providing nearly 600 separate velocity samples along the section. After interval velocities were determined, average velocities to the various reflecting horizons could be computed, along with interval thicknesses and depths. These computations permitted conversion of the section in depth as well as time.

Gravity and magnetic data are especially valuable for testing hypotheses about rock unit composition where they have not been penetrated by drilling. In the Suwannee Basin this includes most of the pre-Cretaceous section. Figure 4 shows the observed gravity and magnetic section in relation to the digitized interpreted section. Interpretation was accomplished by comparing a synthetic model of the gravity or magnetic field with the observed field. This is illustrated in Figure 4. If the trace of the synthetic model field is subtracted from the observed, there will be perfect cancellation only if the two traces are identical. In most cases, however, such coincidence will not occur and there will be points of nonconformity resulting in unresolved residuals. The shape, sign, and magnitude of residuals will suggest how the synthetic model may be improved, and subsequent models will result in fewer and smaller residuals until the parameters of the synthetic model accurately reflect the shape of the observed field.

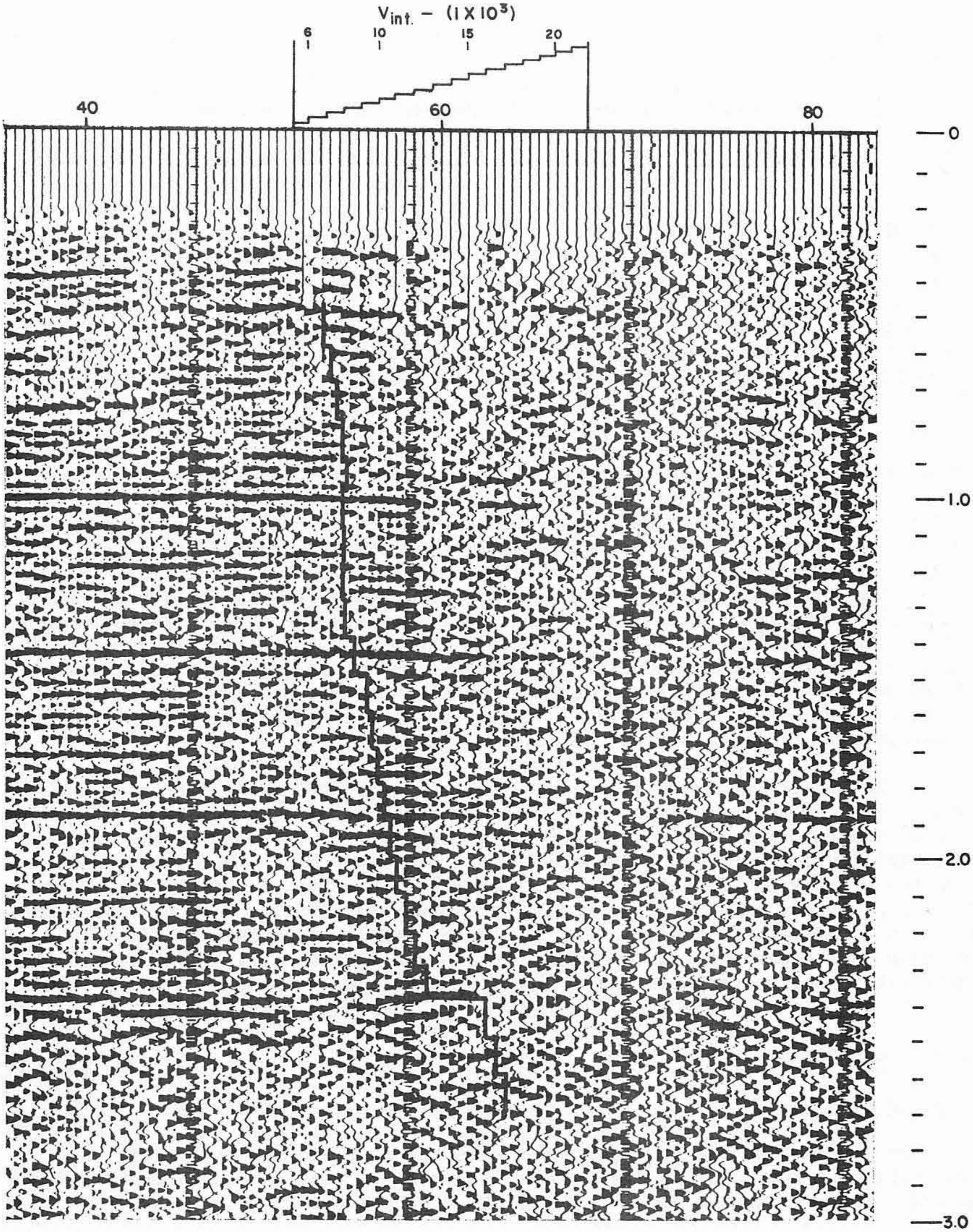
In the present study we made a preliminary geologic interpretation of the migrated seismic depth section using velocity data, well sections, and published regional geologic information. Employing an estimate of the density and magnetic susceptibility for each major lithologic unit displayed on the section, computer-generated gravity and magnetic synthetic models were computed and the resulting profiles prepared. These were compared with observed profiles and the discrepancies were used to adjust the geologic interpretation until a satisfactory fit of the synthetic and observed fields was obtained. Geologic information provided realistic limits within which synthetic fields could be modified to conform to observed fields.

REGIONAL GEOLOGY

Paleozoic rocks

Deep drilling in the southeastern states has revealed a buried terrain of Lower Paleozoic and possibly older rocks that seem to have no counterpart in North America. These rocks are discussed by R. E. McLaughlin in this volume.

Fig. 3 Velocity Analysis. Vicinity of Mosbacher First National Bank #1 Well.



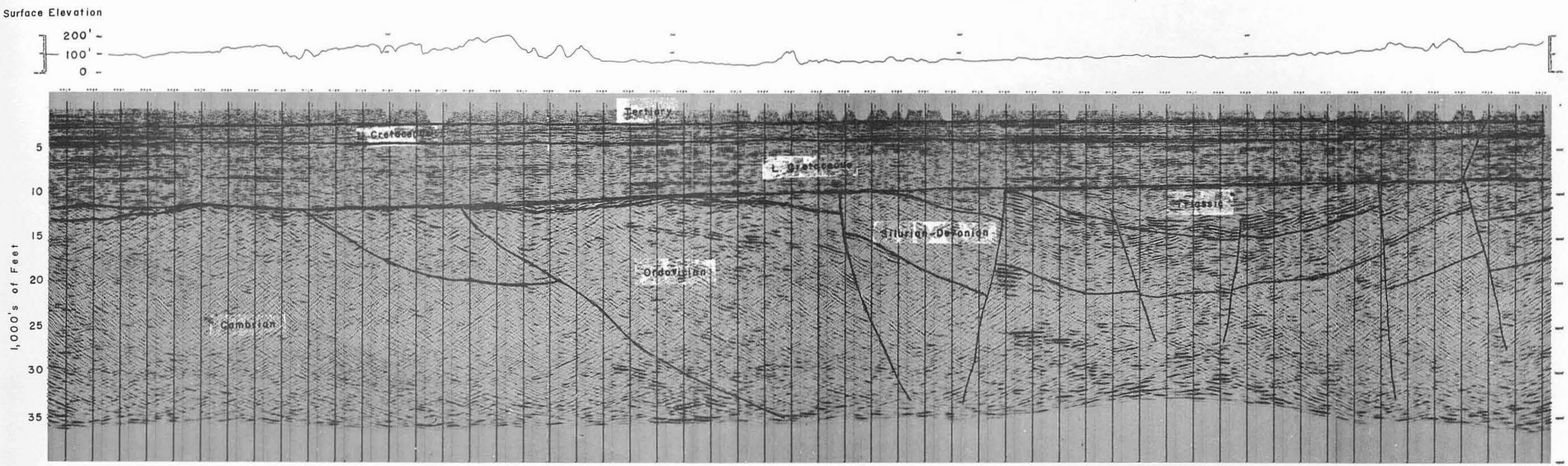


Fig. 2 REFERENCE SEISMIC SECTION – DEPTH CONVERSION

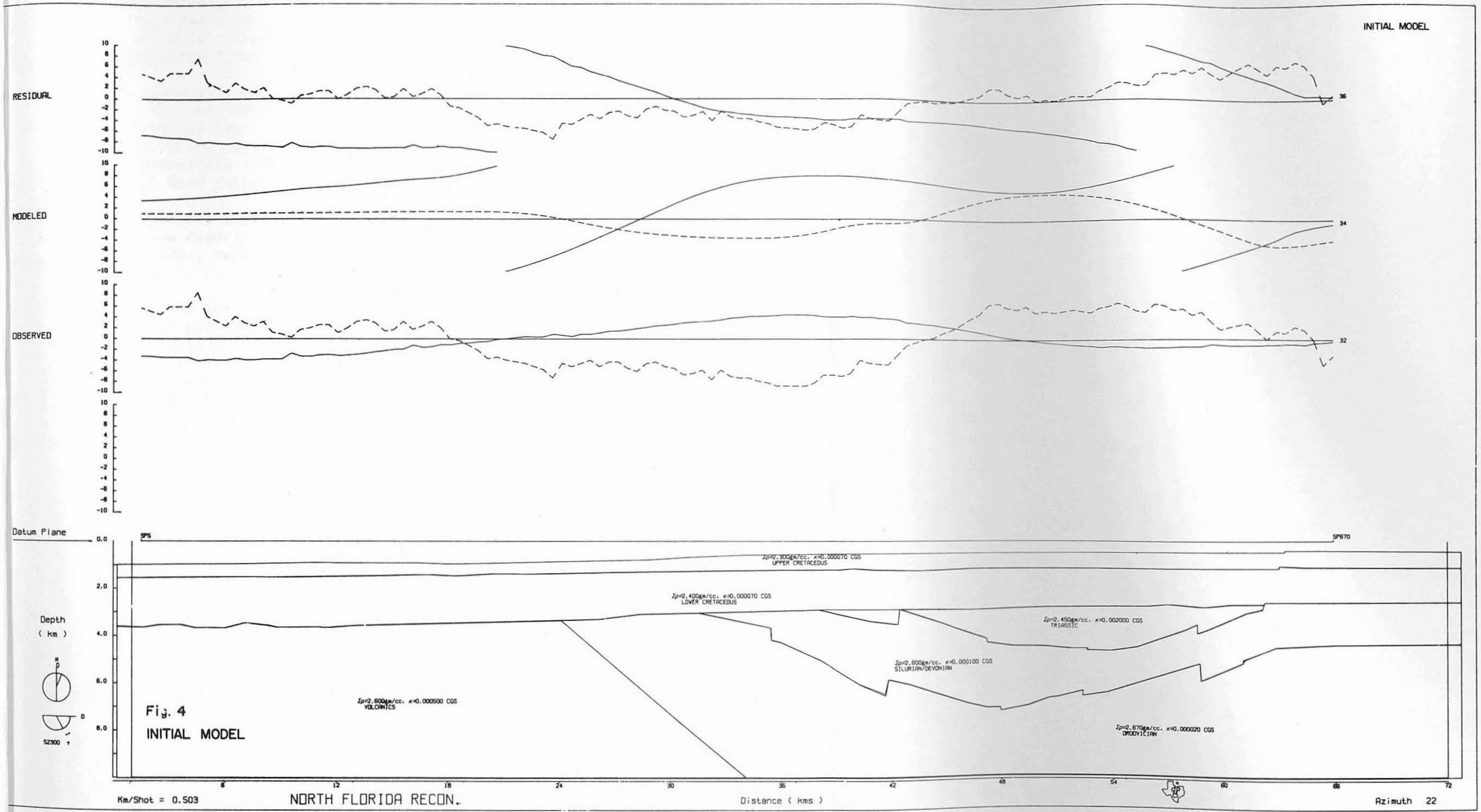


Fig. 4
INITIAL MODEL

In northern Florida and southern Georgia a number of wells have terminated in relatively unmetamorphosed sediments containing fossils of Lower Ordovician to Middle Devonian age. Thickness estimates of 6000 ft or more have been made for the sequence (e.g., King, 1961, p. 90), but these estimates have not been based on any substantial evidence. The deeper portion of the section examined in the present study has been interpreted as Paleozoic sediments and volcanics. If the interpretation is correct, there could be as much as 20,000 ft of Paleozoic rocks beneath the Coastal Plain cover.

The Paleozoic rocks underlie a remarkably uniform surface which, prior to Jurassic time, was deformed into a broad basin whose axis extends northeasterly from Apalachicola into southwestern Georgia (Fig. 5). This surface is probably 13,000 ft below sea level at the Florida coast. It was named "Suwannee River Basin" by Braunstein (1957), later shortened to Suwannee Basin by King (1961), and has also been called Apalachicola Embayment and Southwest Georgia Embayment.

The Paleozoic rocks and the igneous rocks associated with the lower Mesozoic beds have been described by a number of workers (Applin, 1951; Bridge and Berdan, 1952; King, 1961; Carroll, 1963; Milton and Hurst, 1965; Bass, 1969; Milton and Grasty, 1969).

No Cambrian sediments have been identified, although various rhyolitic volcanic rocks have been called Cambrian or Late Precambrian on the basis of a few radiometric dates of bottom-hole samples of similar lithology from deep wells in southeastern Georgia and central Florida. In some wells there is an orthoquartzite identified as Lower Ordovician in age, followed by a sequence of dark-colored shale with sandstone interbeds which contains fossils ranging in age from Lower Ordovician to Lower Devonian. The youngest Paleozoic strata recognized in the Suwannee Basin are Middle Devonian rocks of probable continental origin from the Humble No. 1 C. W. Tindel well in Jackson County, Florida, where red, brown, and gray, cross-bedded sandstone and shale has yielded plant fragments and spores.

Some Paleozoic fossils from Florida (Cramer, 1971) appear to have closer affinity with strata from western Africa than with the Appalachian area. It is suggested as a working hypothesis that the crust underlying the Suwannee Basin may have been attached to Africa, and that in Devonian time the ocean basin closed, resulting in plate collision and a subduction zone represented by the Brevard fault trend. Similar ideas have been suggested by other workers (e.g., Wilson, 1966; Watkins, 1970) and will not be pursued further in this study. Much more evidence will be needed before an acceptable historical synthesis of Paleozoic history can be presented.

Lower Paleozoic section

The early depositional history of the Gulf of Mexico was characterized by closed-basin conditions, resulting in terrestrial red beds and marine sediments that included evaporites. It appears that these conditions of restricted circulation lasted from Upper Triassic through Middle Jurassic time. The strata deposited during this interval are not exposed at the surface in the U. S. Gulf Coast region.

In the Suwannee Basin a sequence of terrestrial clastics associated with mafic igneous flows and thin intrusions has been encountered in a number of wells beneath Upper Jurassic or Cretaceous beds. We have no knowledge of fossils from

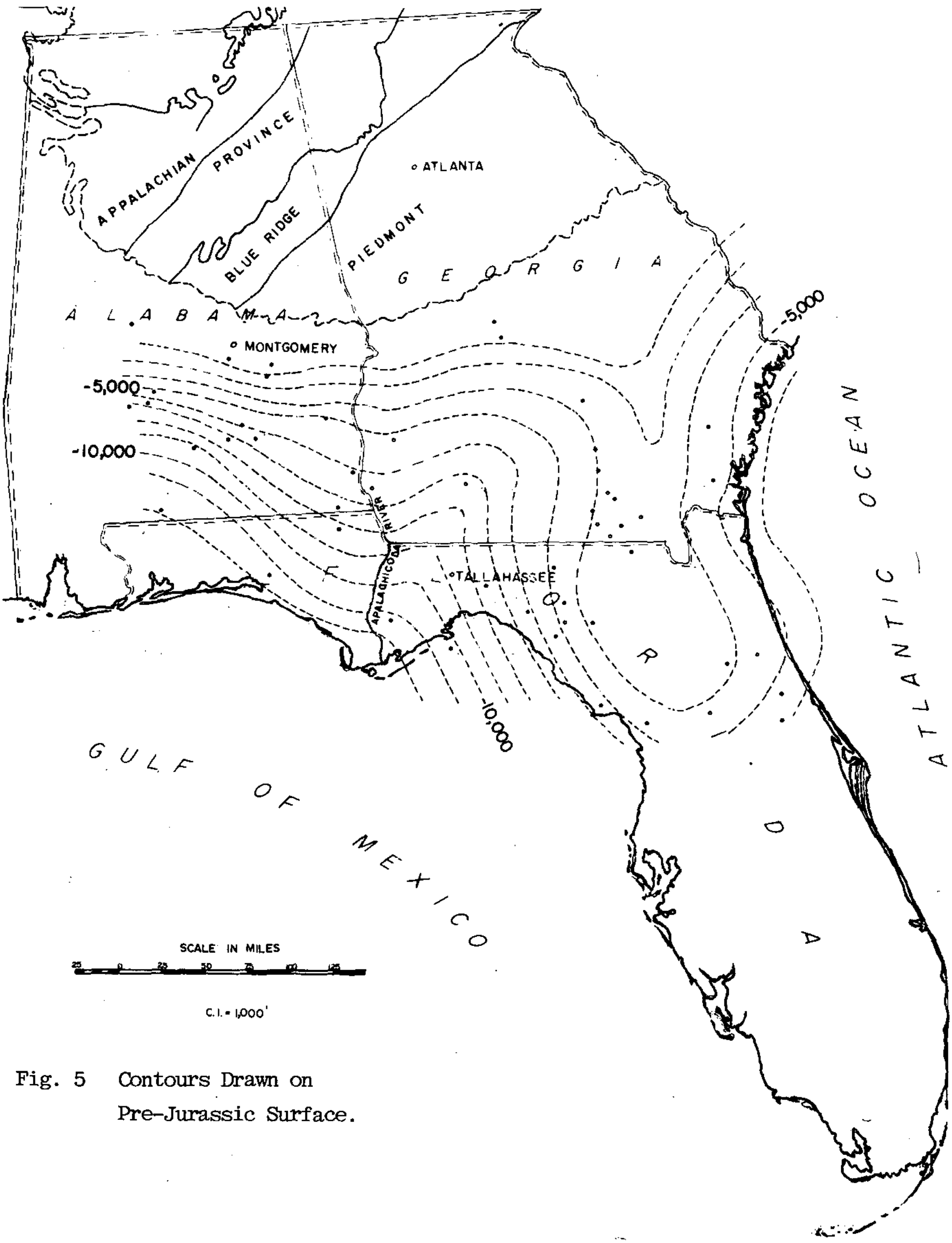


Fig. 5 Contours Drawn on Pre-Jurassic Surface.

enclosing sediments, but diabase samples from wells in Mitchell and Echols Counties, Georgia, have been dated radiometrically by Milton and Grasty (1969) at 182 m.y. and 191 m.y., thus indicating an Upper Triassic age for the igneous rocks.

In the Gulf of Mexico region south of the Ouachita structural belt, a red-bed sequence is present also in the subsurface (Eagle Mills Formation). On the basis of stratigraphic position and identified plant fossils (Scott, et al, 1961), this formation is correlated with the Newark Series of Upper Triassic age. Diabase intrusions are also associated with Eagle Mills sediments. Great differences in thickness of Eagle Mills beds occur over relatively short distances, which suggests deposition in grabens and half-grabens in a tectonic framework comparable with the Newark occurrences. A similar tectonic situation appears to characterize the Suwannee Basin, and is most clearly demonstrated on the northern half of the profile.

Overlying the Eagle Mills unconformably is the Werner Formation, which is composed of a lower red-bed member and an upper anhydrite member. The Werner Formation grades upward into the Louann Salt, and both are truncated by the Norphlet Formation. The Louann Salt has no recognized up-dip equivalent along the northern Gulf Coast and is limited by the Mexia-Talco and Pickens-Gilbertown fault trend. Thus, the salt appears unlikely to occur east of Okaloosa County, Florida.

Whereas the lower member of the Werner Formation could occur in the Suwannee Basin and not be recognized because of similarity with Mesozoic red beds, there is no evidence that this is the case. Beds similar to the upper anhydrite-bearing member have not been reported. It seems likely that Lower or Middle Jurassic sediments are absent in the Suwannee Basin.

Upper Jurassic and Lower Cretaceous

Beneath beds of Upper Cretaceous Woodbine age there is a sequence in the Suwannee Basin that reaches a thickness near Apalachicola of about 6000 ft and is known only from wells. It is marine in origin near the coast, dominated by clastic sediments, but containing some carbonate layers. Up dip the carbonates are rare; marine and terrestrial beds alternate, and the entire sequence becomes thinner and more continental in appearance towards the flanks of the basin.

Some of the section is unfossiliferous and no internal biostratigraphic zonation has been made. Near the base of the sequence Jurassic spores have been reported from two wells in Florida, one sample of which was from a coal bed in Franklin County.

At the top of the sequence some fossils of Washita age have been found, and the base of the Washita has been located in a few wells. It has not been customary, however, to carry this horizon throughout the region. In the Georgia wells Lower Cretaceous beds are generally referred to as "rocks of Comanche age", inasmuch as Coahuila and Jurassic rocks have not been recognized. No finer zonation has been made in the Georgia studies.

Upper Cretaceous and Tertiary

Beds of Upper Cretaceous age mark the maximum advance of the sea in the Suwannee Basin. Except for some terrestrial clastics near the outcrop belt, sediments of the Gulf Series are marine in origin. Although calcareous shale is common, lithologies range from dark, waxy shale, containing lignite and other carbonaceous matter, to chalky organic limestone composed almost entirely of microorganism tests. Glauconitic sands commonly occur throughout the section.

Tertiary sediments reach a maximum thickness of about 3500 ft near the present coast. There is no marked unconformity between Upper Cretaceous and Paleocene, nor is there always a distinct change in lithology. Even though log correlations near the age boundary are generally possible, the actual demarcation may not be determinable without close paleontologic control.

INTERPRETATION OF SEISMIC SECTION

In the examination of the Suwannee Basin profile we have taken into account all data, from regional geology to interval velocities. Alternative interpretations could probably be made in the pre-Cretaceous portion of the section, especially for lithologic and age designations, but the one outlined here will fit the data, and lacking new drilling information, this interpretation is not likely to be greatly altered (Fig. 6).

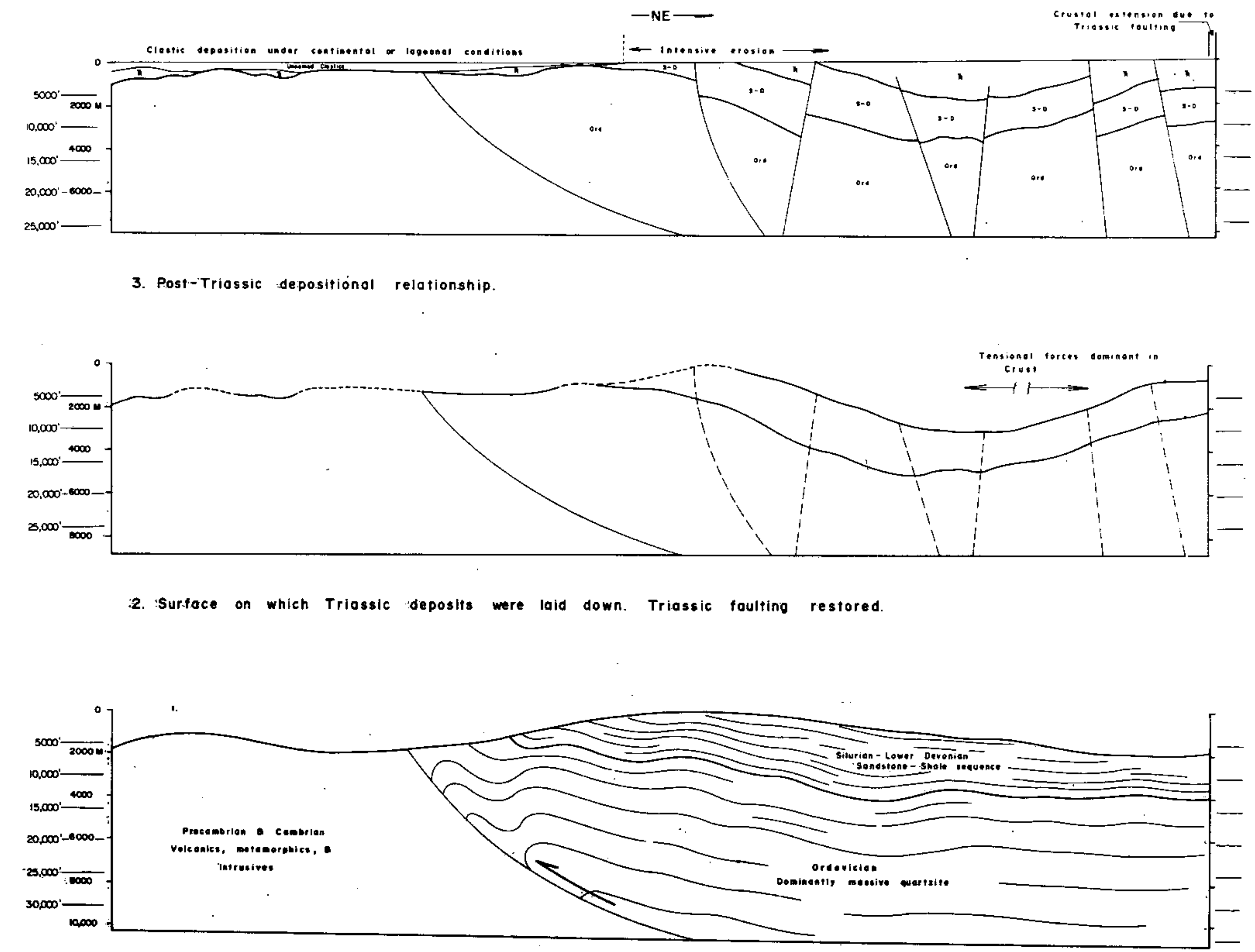
Paleozoic rocks

It was mentioned in the previous section that numerous Coastal Plain wells in the southeastern United States terminated in Paleozoic sediments of crystalline rocks. Exclusive of obviously younger volcanics or intrusives, the crystalline rocks have been frequently described as "metamorphics" or as "volcanics" which are commonly rhyolitic. Radiometric dates from some samples indicate a Cambrian age. From their regional distribution and their occurence beneath presumed Ordovician quartzite in one well, they are tentatively considered to be Cambrian or older. These old rocks are likely to be effective basement for oil exploration in the Suwannee Basin. Rhyolite was reported as the bottom formation in the Mosbacher et al No. 1 First National Bank well drilled in 1972 near the southern end of the section, thus substantiating the interpretation of volcanics in this area. Cambrian sediments may exist but have not been identified.

North of the volcanics the seismic section indicates a thick basal sedimentary sequence. The gravity profile requires a relatively dense material and the magnetic data indicate an unusually low susceptibility. Ordovician quartzite would meet these criteria and could reasonably be expected to occur here. Alternatively, dolomite would also meet the requirements, but there are well records of quartzite at this stratigraphic position, and dolomite has not been reported. The contact with the volcanics appears to be a thrust fault which may be related to Middle or Late Paleozoic compressive forces. The data suggest some shale intercalations in the upper part of the Ordovician sequence, with a very clean, massive quartzite below. It is interesting to note that this would also describe the Ordovician section of western Africa, particularly the Bani Quartzite and succeeding Ordovician beds of the western Sahara region.

Overlying the Ordovician strata in apparent conformity is a Silurian-to-Middle Devonian clastic section consisting of alternating sandstone and shale. Paleozoic rocks younger than Middle Devonian have not been encountered beneath the southeastern Coastal Plain, and we have no basis for predicting their occurrence. The seismic section indicates a deeply weathered zone as much as 1000 ft thick at the top of the Paleozoic. Velocities in this zone are often 10 to 15 percent below velocities in the formation immediately overlying it. This condition occurs along the unconformable surface truncating all three Paleozoic units.

Fig. 6 Significant events in the history of Suwannee Basin Section



1. Late Paleozoic, subsequent to orogenic episode.

Triassic rocks

In contrast to the compressive forces that folded and faulted the Paleozoic rocks, crustal tension was dominant in eastern North America in Upper Triassic time, and the effects of this situation can be seen quite clearly on the section. The Triassic topography was generally rugged, and in the northern half of the section crustal downwarp increased the difference in relief. At first the tensional forces resulted in a structural depression which must have received a heterogeneous assortment of clastics. Typically, the Triassic deposits of eastern North America are in narrow troughs, sometimes up to 20,000 ft thick, with red coloring and other signs of having been derived from the rapid erosion of a lateritic soil. In this section the Triassic beds reach a maximum thickness of 6000 ft in a graben near the northern end. Magnetic susceptibilities indicate a relatively high magnetite content, a situation commonly found in similar Triassic deposits elsewhere. It seems likely that a band of high seismic velocity in the lower 2000 ft of the Triassic beds results from basalt (or diabase) flows or sills. Existence of mafic igneous sheets would also be compatible with the gravity and magnetic readings.

Subsequent to the development of the downwarp, continued crustal tension resulted in high-angle normal faults, and a series of block faults appeared, into which Triassic deposits were transported. Thinner beds of this age are postulated to have been laid down elsewhere in topographically low areas and may be preserved along the section at its southern end.

Post Triassic clastic unit

From the southern end of the section to near the mid-point is a thin wedge of sediments overlying both Triassic and Paleozoic rocks. These beds read a maximum thickness of about 1600 ft at the southern end and thin northward to a feather edge. Similar clastics are known from the terrigneous fringe of basins of nearly every age in the Gulf Coast, and without fossils or correlation with dated sections, we can place them only as post-Triasic to pre-Fredericksburg. Because of the conformable contact with overlying beds of Comanche age, it is likely that they are lowermost Cretaceous clastics of Coahuila age, possibly correlating with the Hosston Formation.

It is interesting to compare the post-Triassic surface north and south of Shot Point 320 (near the middle of the section). To the south, beneath the clastic unit, the surface is somewhat irregular, emphasizing that deposition probably began rather suddenly over the area. The region not covered by the clastic unit (the portion to the north of Shot Point 320 on the section) was undergoing erosion, and during the time the clastics were being deposited the exposed surface was planed smooth. Thus, above the Triassic and Paleozoic beds in the northern portion of the section a smooth surface with a slope of about 70 ft/mi was developed. The surface of deposition on top of the clastic unit slopes about 30 ft/mi.

Lower Cretaceous

Correlations from Florida wells to standard Lower Cretaceous Gulf Coast sections have not been reliably established. The top of Lower Cretaceous is taken here to be the top of Washita beds, recognizing that there is no consensus among Gulf Coast geologists as to exactly where the time boundary should be placed. Sediments within the interval considered to be Lower Cretaceous range in thickness from 5600 ft at the south to 4800 ft at the northern end of the section. Lithology is variable both laterally and vertically, as evidenced by variable seismic velocities and non-continuous reflections.

Upper Cretaceous

Upper Cretaceous beds conformably overlie the Lower Cretaceous. They thin slightly but regularly from about 1950 ft at the south end of the line to about 1800 ft at the north. There are several good reflections and it is possible to follow a number of closely-spaced horizons.

Tertiary

The Tertiary beds overlie the Upper Cretaceous conformably and without a remarkable change in character. If good well control was absent there would be little basis for selecting a specific boundary. The highest horizon that can be traced completely across the section is the top of the Wilcox Group. Several strong reflectors occur and the Salt Mountain facies is identified at a depth of about 1700 ft, north of Shot Point 440. Whereas the Midway-Wilcox contact can be identified from comparison with well sections and this horizon can be traced in the seismic section, there is no outstanding reflector marking the contact. A small fault with downward separation on the south cuts Tertiary beds near the northern end of the section. It probably resulted from movement along an underlying Triassic fracture.

CONCLUSIONS

Modern seismic data-collection and processing methods furnish a realistic structural profile that shows dip angles and reflecting horizons in undistorted relationship. When the seismic data are accompanied by gravity and magnetic observations, additional factors are introduced which aid in recognizing rock types as well as refining the structural interpretation. Hypotheses can be tested by comparing computer-generated gravity and magnetic models with observed fields. Adjustments of lithologic boundaries, densities, and magnetic susceptibilities can be made until the synthetic model corresponds to the observed.

The method was successfully tested in the Suwannee Basin, where seismic reflections were recorded to a depth of 35,000 ft. The section was interpreted as a normal sequence of southward-dipping Tertiary and Cretaceous beds lying unconformably upon folded and faulted Triassic and Paleozoic rocks. A well drilled near the southern end of the geophysical profile terminated in volcanic rock of probable Cambrian age and provided stratigraphic control for the post-Paleozoic beds. Nearby wells and regional geologic studies were also used to support the interpretation.

A lower Paleozoic sequence with west African faunal and lithologic affinities is believed to be present. Triassic sediments and volcanics filled a tensional sag and were fractured by normal faults. The Paleozoic and Triassic rocks were smoothly eroded prior to deposition of Cretaceous strata, and the unconformity is clearly visible on the seismic section. Cretaceous and Tertiary horizons can often be followed for varying distances along the section, but can be definitely identified only where they are related to well sections.

ACKNOWLEDGEMENTS

I want to express appreciation to GSI for permission to review the results of the project and to acknowledge the technical support of the Exploration Services staff of GSI. I want especially to cite the contribution of Anthony B. Williams who devised the synthetic gravity and magnetic modeling system.

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OPALINE CLAYSTONES OF THE ALABAMA-GEORGIA-SOUTH CAROLINA COASTAL PLAIN: ENVIRONMENTAL INTERPRETATION

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ABSTRACT

Opaline claystones of Paleogene age in Alabama, Georgia and South Carolina are unusually porous, light-weight siliceous rocks which possess oil clarification properties. Referred to locally as "fuller's earth" or "buhrstone", these inner- and middle-shelf deposits represent an unusual depositional environment for the Southeastern Coastal Plain, but one which has important implications for regional and global paleoenvironmental analysis. However, the origin of these deposits is still a matter of dispute. Because they lack easily identified microfauna or flora, many of the claystones have been regarded as nonfossiliferous, and have been classified as bentonites or altered rhyolitic ashes. A common association with montmorillonitic clays and in some areas, zeolites, has provided support for such interpretation.

Scanning electron microscope examination, however, has revealed molds of siliceous microfossils in most samples which include several forms of radiolaria, sponge spicules and diatoms. The latter are especially abundant in the Twiggs Clay (Barnwell Formation) of Georgia, and include large and small centrics, pennates, and forms that resemble Triceratium and Actinoptychus. Diatom frustules represent the principal source of silica for most of the deposits, although siliceous sponge spicules may be locally important. The matrix of the claystones formed by postdepositional *in situ* dissolution of biogenous opal with subsequent reprecipitation of silica as disordered alpha cristobalite.

The microfauna and flora indicate that the claystones were deposited primarily as a normal marine near-shore and shelf facies of transgressive sequences. Characteristically they are underlain by transgressive basal sands, overlain by regressive sands, and grade seaward into outer-shelf marls and carbonates. Lower and Middle Eocene opaline units in Alabama and South Carolina are time equivalents of extensive deep-sea radiolarian cherts discovered by deep sea drilling in the Caribbean and Northeast Atlantic ocean basins. These opaline rocks probably formed as a result of favorable ocean-current patterns which provided abundant nutrients to plankton in deep-sea and near-shore areas. Offshore drilling along the eastern and Gulf continental shelves of the U. S. should provide important information for correlation between these two oceanographic provinces.

GEOLOGY OF COASTAL GEORGIA

William R. Mann

This paper presents a brief summary of research on the coastal geology of Georgia, rather than a discussion of specific features. Early interpretations of the lower Georgia Coastal Plain were based on regional morphology (Fig. 1). A series of marine "terraces" and "scarps" was described. These features were thought to be cut by wave action at succeedingly lower still-stands of the sea (Veatch and Stephenson, 1911; Cooke, 1930, 1943). Later investigators have recognized constructional coastline features and also have made regional correlations (MacNeill, 1950; Doering, 1960). Further studies of these features by Hoyt and Hails (1967) showed them to be depositional in origin, thus suggesting the inaccuracy of the terms "terrace" and "scarp".

Below an elevation of approximately 85 to 95 feet, the Atlantic Coastal Plain of Georgia consists of seven former eustatic shorelines, one Holocene, five Pleistocene and one early Pleistocene or late Pliocene. These shorelines are composed of segmented old barrier islands which trend parallel to the modern coast (Fig. 2).

Each barrier sequence is related to the highest level of the sea during several Pleistocene (Pliocene) interglacial episodes and can be subdivided into barrier island and lagoon-salt marsh facies. The barrier island facies include dune, littoral, and shallow neritic deposits. The lagoon-salt marsh facies include salt marsh and tidal channel deposits. The sediments associated with the barrier island facies are generally well-sorted, fine- to coarse-grained quartz sands. The lagoon-salt marsh facies contain larger amounts of silt and clay sized particles; however, sands are abundant in this environment also. Because each barrier complex can be mapped separately, Hails and Hoyt (1967) suggested that formational status be given these features. There has been some disagreement on this because lithologic units have not been successfully recognized in the subsurface (Logan, 1968). The question about these features and their formational status has not been answered yet.

Several machanisms for the evolution of barrier islands have been proposed. DeBeaumont (1845) believed that the barriers formed from locally derived sediment. Waves erode the sea floor outside the breaker zone and redeposit the material on the inside of the breaker to form a barrier (Fig. 3). Gilbert (1885) associated the formation of barriers to the growth of spits by longshore drift (Fig. 4). The spit would be converted into barrier islands by subsequent breaching. Shepard (1960) suggested that both processes are probably important although the problem of local versus longshore drift has not been resolved. Hoyt (1967) proposed that the barrier island is initiated by the building of beach ridges immediately landward of the shoreline (Fig. 5). Slow submergence causes flooding of the area landward of the ridge forming a barrier and a lagoon. Once formed, the island may migrate parallel or perpendicular to the coast, or it may remain stationary, depending on sediment supply, local hydrodynamic conditions, and land-sea stability. The width of the lagoon depends on the slope of the mainland surface, amount of submergence, sediment infilling, and erosion (Fig. 6). Slow submergence or negligible sedimentation is necessary to maintain the lagoon. Emergence in excess of lagoonal depth terminates the barrier complex (Henry, Giles and Woolsey, 1973).

Along the Georgia coast, the trace fossil *Ophiomorpha* is used as an indicator of former sea levels. *Ophiomorpha* is closely comparable to the burrow of the marine decapod *Callianassa major* (Weimer and Hoyt, 1964). *C. major* is restricted to present beaches, above the low tide line. The fossil burrows, therefore, are considered an approximate indicator of former mean sea levels. The upper limits of ancient lagoon-salt marsh sediments which accumulated landward of barriers afford corroborative evidence of previous sea levels.

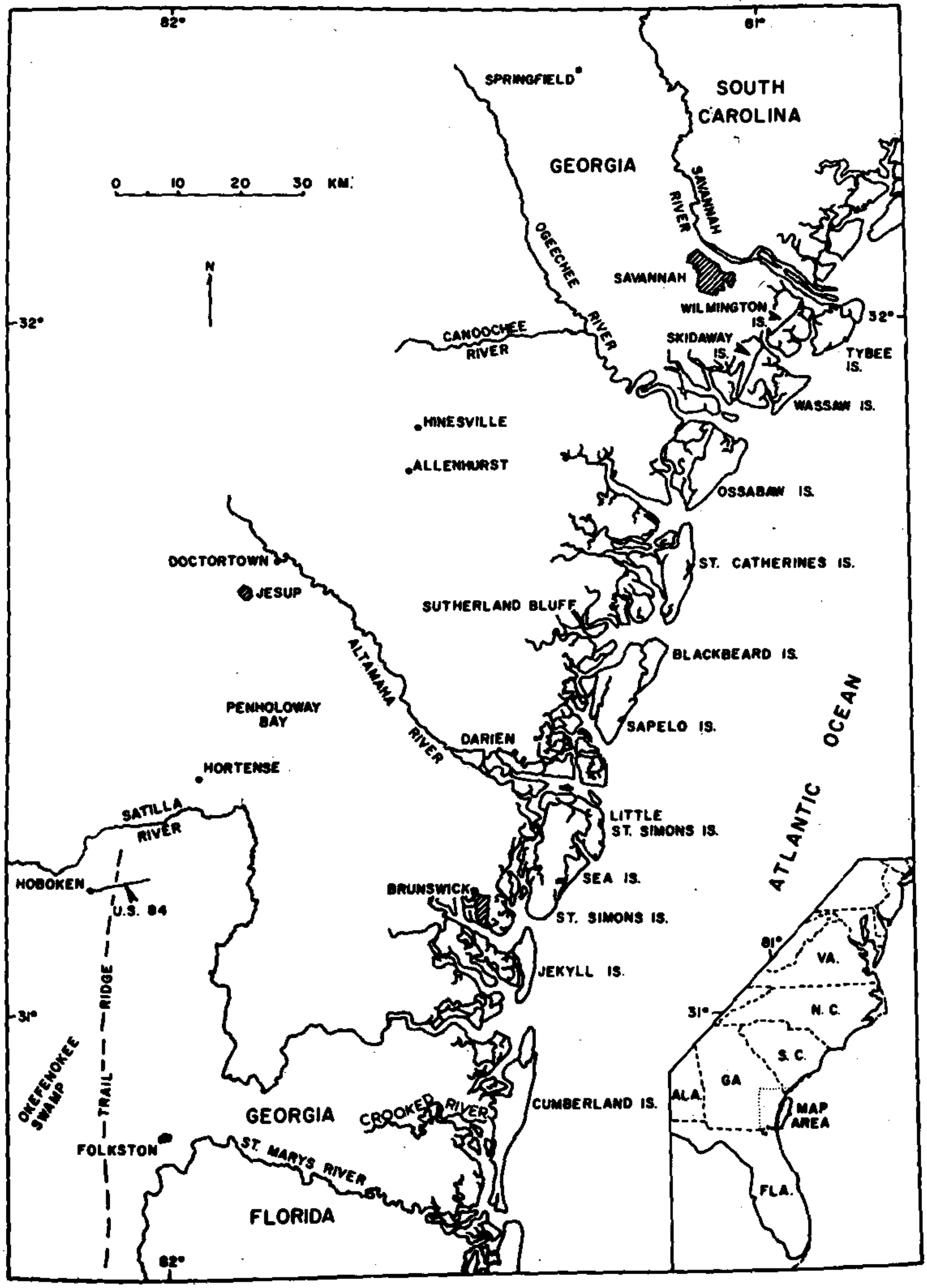

Figure 1. Location map of the lower Atlantic Coastal Plain of Georgia (Hails and Hoyt, 1969)

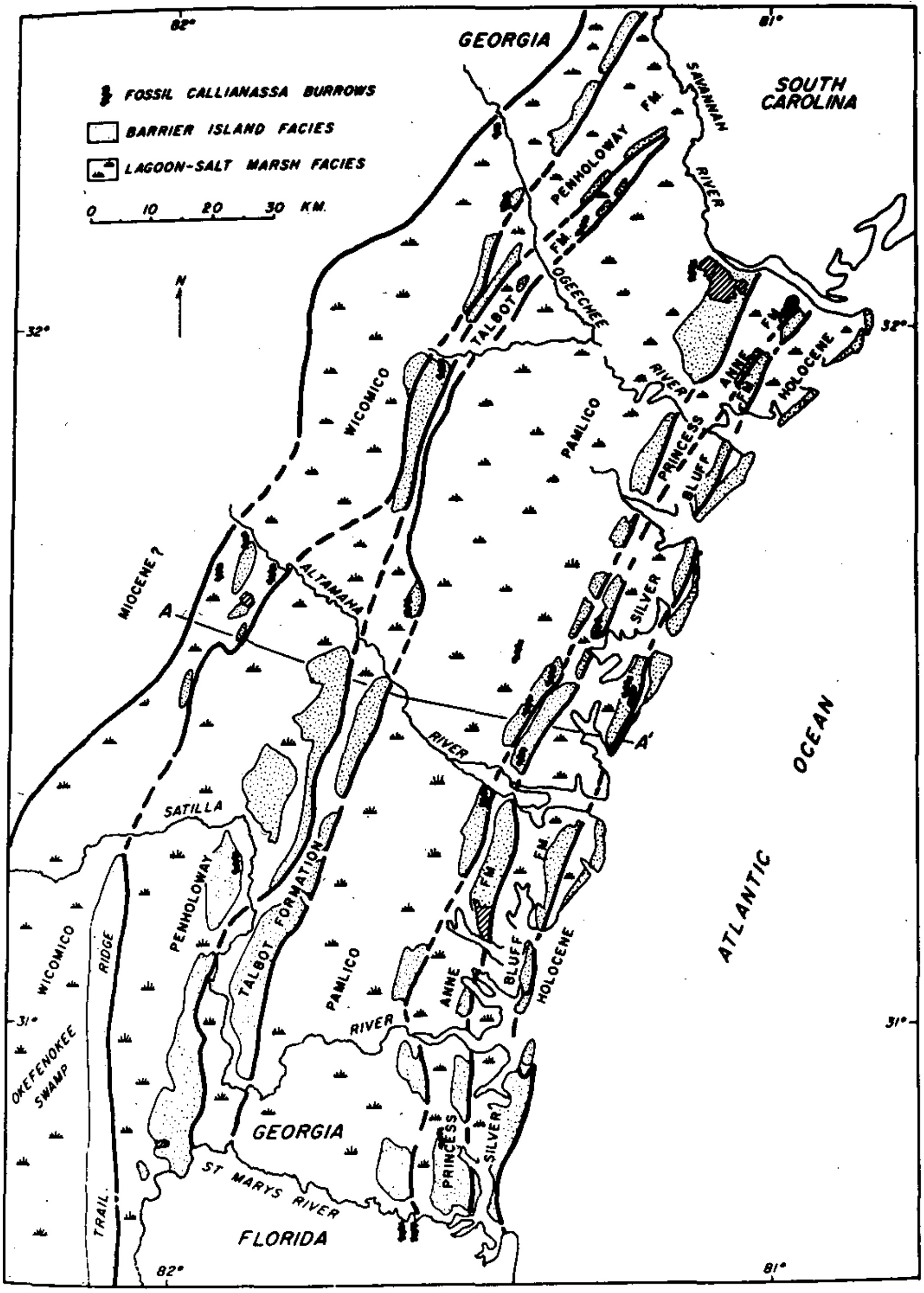

Figure 2. Map of the Georgia Coastal plain showing the six Pleistocene coastlines and the Holocene coast. Barrier island and lagoon-salt marsh facies are indicated for each coastaline. Lagoon-salt marsh facies include salt marsh and tidal channel deposits. Barrier island facies include dune, littoral and shallow neritic deposits (Hails and Hoyt, 1969)

There appears to have been very little compaction of the sediments. This condition, coupled with coastal stability (Hoyt, 1969), accounts for the widespread uniformity of elevation of these sediments along the Georgia coast. Because some former lagoon areas are more than 20 miles wide earlier workers considered them terraces. However, they are dissected by numerous small streams, some of which flow in relict tidal channels.

Although shore and beach features such as dunes and ridges may accrete well above sea-level, sediments accumulate in the salt marsh only until the altitude of the surface approaches the high spring tide level. Initially, the salt marsh is drained by channels of all sizes which accommodate the twice-daily flooding and ebbing of the tides. At slack water a part of the sediment load carried by the waters settles out and is not picked up again as the water flows in the opposite direction. In this way, an increment is added to the marsh surface and to the floors of the channels, gradually filling the marsh. If this process continues for a long time, the channels will completely fill, except for minor drainages necessary to facilitate the removal of rain water. The ancient marsh surfaces can be used, therefore, as an indicator of former sea levels if the assumption is correct that the Pleistocene tidal ranges were similar to those of today.

Although the relative ages of eustatic shoreline deposits in the Georgia Coastal Plain are generally well established using topographic and geomorphic criteria, the absolute ages are as yet unavailable, except for the Holocene and youngest Pleistocene deposits. In the latter case, Carbon-14 dates are finite but are at the extreme end of the confidence limit (Henry et al., 1973). The older complexes have not been dated for lack of suitable material.

The oldest barrier complex of the area is the Wicomico. It is late Pliocene or early Pleistocene in age. The Wicomico is well preserved in southern Georgia where it is known as Trail Ridge. This ridge rises sharply in Florida, especially on the northeastern flank of the Peninsular Arch where slight uplift has taken place (Hoyt, 1969). The Okefenokee Swamp occupies the former Wicomico lagoon west of Trail Ridge. The Wicomico barrier is poorly preserved between the Satilla and Altamaha Rivers. In this area of veneer of reworked barrier sand, in the form of ancient dunes and washover fans overlies Wicomico lagoon-salt marsh facies. The Wicomico barrier is absent between the Altamaha River and Allenhurst although several remnants have been found between Allenhurst and the Savannah River.

Generally, sedimentary structures are very poorly preserved in the ancient barriers and, apart from certain morphological features such as dunes and washovers, it is sometimes impossible to distinguish between sands reworked by wind or wave action. It can only be inferred that processes similar to those along the modern coast were operative during the Pleistocene.

The Penholoway barrier complex in Georgia is fairly intact. Between the Ogeechee and Savannah Rivers, it consists of a series of 3 to 6 feet high parallel dune/beach ridges. These ridges were probably deposited during late Penholoway time when part of the barrier was eroded and reworked, and the lagoon salt-marsh area inundated. The type area, northeast of Hortense to Penholoway Bay (Cooke, 1925, 1932) is a lagoon-salt marsh deposit 8 miles wide.

The Talbot barrier complex is well preserved in a few areas, particularly between the Altamaha and Satilla Rivers, where the barrier is about 10 feet wide. Eolian deposits are more than 2 miles above the lagoon-salt marsh deposits. The barrier is almost entirely absent south of the Satilla River. North of Hinesville the Talbot barrier exists in small remnants overlying lagoon-salt marsh sediments. Sea level was 39 to 45 feet above its present level, as indicated by *Ophiomorpha* and the upper limit of the lagoon-salt marsh deposits. As in the case of the older complexes, weathering and solution have destroyed much of the fossil material and sedimentary structures.

The Pamlico salt marsh lagoon is a broad, distinct depositional feature which trends parallel to the modern coast. It is located between 8 and 12 miles inland and its width ranges from 10 miles to

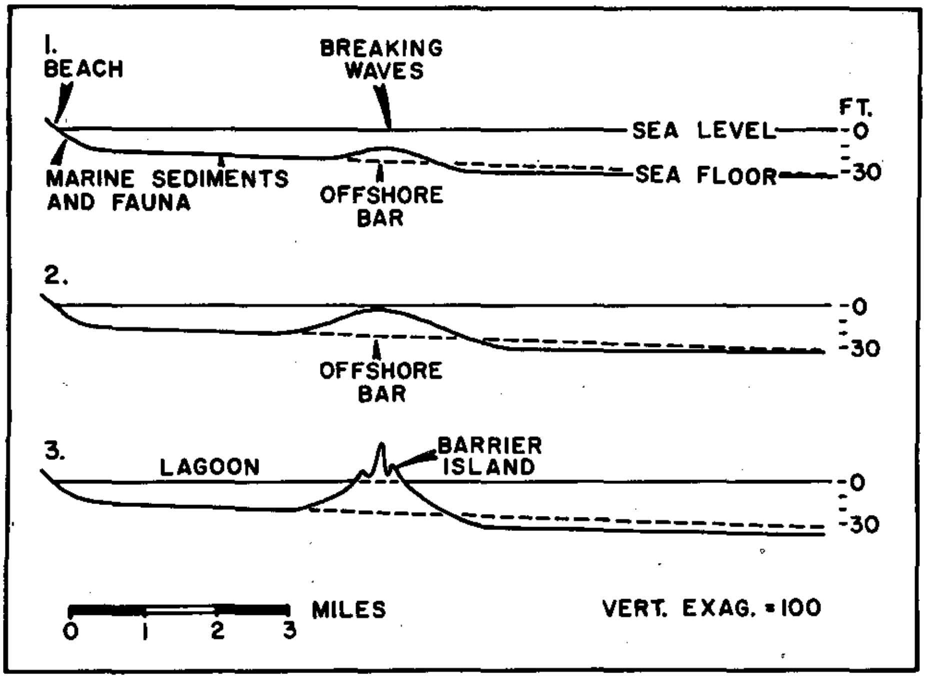

Figure 3. Idealized cross-section showing barrier island formation from an offshore bar. 1) Waves agitate sea floor and deposit sediment to form bar in area of energy loss. 2) Sediment accumulation approaches level. 3) Bar is converted to island with lagoon on landward side (Hoyt, 1967).

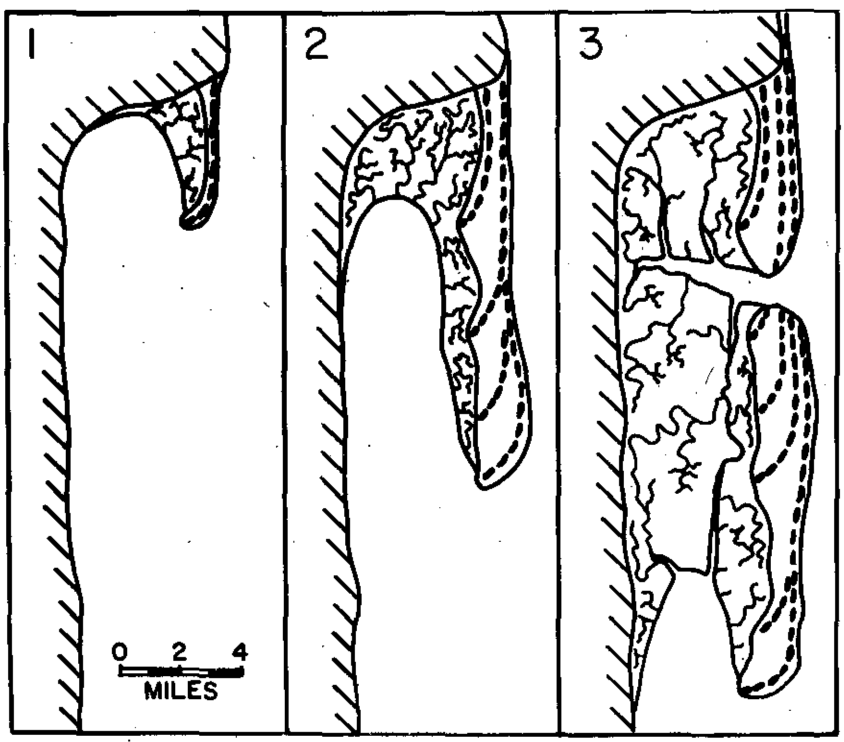

Figure 4. Idealized diagram showing barrier island formation from spit. 1 and 2) Spit develops in direction of longshore sediment transport. 3) Spit breached to form barrier island (Hoyt, 1967).

a maximum of 14 mile east of Hinesville. The Pamlico barriers are mostly small features which stand 6 to 10 feet above the lagoon-salt marsh deposits near Savannah. *Ophiomorpha* and lagoon-salt marsh deposits indicate that sea level stood 22.5 feet higher than at present (Hails and Hoyt, 1969).

The Princess Anne barriers developed a short distance seaward of the Pamlico barriers. Generally, the barriers do not form distinct topographical features, and crest heights seldom exceed 10 feet above lagoonal sediments. Barriers are well developed north of the St. Marys River and near the towns of Brunswick and Darien. Hails and Hoyt (1969) further state that *Ophiomorpha* indicates a former sea level elevation 12 feet higher than at present.

Most of the Georgia Sea Islands bordering the mainland are composed of Silver Bluff and Holocene sediments. The Silver Bluff salt marsh-lagoon area is 4 to 5 miles wide along much of the coast. It has been reoccupied by Holocene marsh landward of the Silver Bluff barriers. The Holocene salt marsh is narrow along the front of most of the Silver Bluff barrier complex. In some areas where it is entirely absent, Holocene and Pleistocene barrier sediments are continuous. The lengths of the Georgia Sea Islands have been determined largely by the position of the Princess Anne barriers, because tidal inlets appear to have maintained similar positions during the Silver Bluff sea level.

Soil profiles are poorly developed in the Holocene barrier sediments. In contrast, the Pleistocene deposits have well-developed A and B horizons, typical of a podzol soil. Humate, a dark brown to black, water-soluble, organic substance is widely distributed in the Plesitocene sediments. According to Swanson and Palacas (1965) humate is derived by leaching from decaying plant material, or humus, on the land surface. Soluble and colloidal organic substances are carried by surface and subsurface waters to the subsurface sand environments, where flocculation or precipitation of humate takes place. This process commonly cements or impregnates barrier or dune sands.

The Wicomico, Penholoway, and Talbot barriers have well-developed bi-sequal soils. Such soils consist of one podzol directly above another. The thickness of the upper podzol is usually less than 6 feet, but the base of the profile is characterized by a layer of humate. The underlying podzol is much thicker, and the cemented sand is generally more than 6 feet thick. The age of the coastlines cannot be determined by the thickness of the individual podzols, because it is impossible to calculate the rate of podzol development. The presence of bi-sequal soils may indicate climatic changes during the Pleistocene.

A comparison of the Holocene and Pleistocene barrier environments provides a comprehensive account of the depositional and erosional history of the Coastal Plain sediments.

On several section of the Atlantic Coastal Plain, Holocene barriers have been partially eroded and driven landward over salt-marsh deposits. Sand, 2.5 to 5 feet thick, overlies marsh sediments on the upper foreshore and backshore of several beaches. Silver Bluff barriers are actively eroding along the modern shoreline at Cumberland, Jekyll and St. Catherines Islands. Dunes are rarely higher than 30 feet above present sea level. In contrast, the dunes of Trail Ridge stand 75 feet above the level of the Wicomico shoreline. This might suggest that more sand was available in the past to build larger dunes.

Several reasons have been suggested to account for the erosion of modern barriers in other parts of the world (Davies, 1957; Bird, 1961; Haild, 1964, 1968). These include a renewed rise of sea level, increased storminess, a diminished supply of material being delivered to the coast, and downwarping of the continental shelves.

Shoreline equilibrium is disturbed when sand is removed from the beach by wind and wave action and is not replaced by material moved either onshore or alongshore. A barrier island can

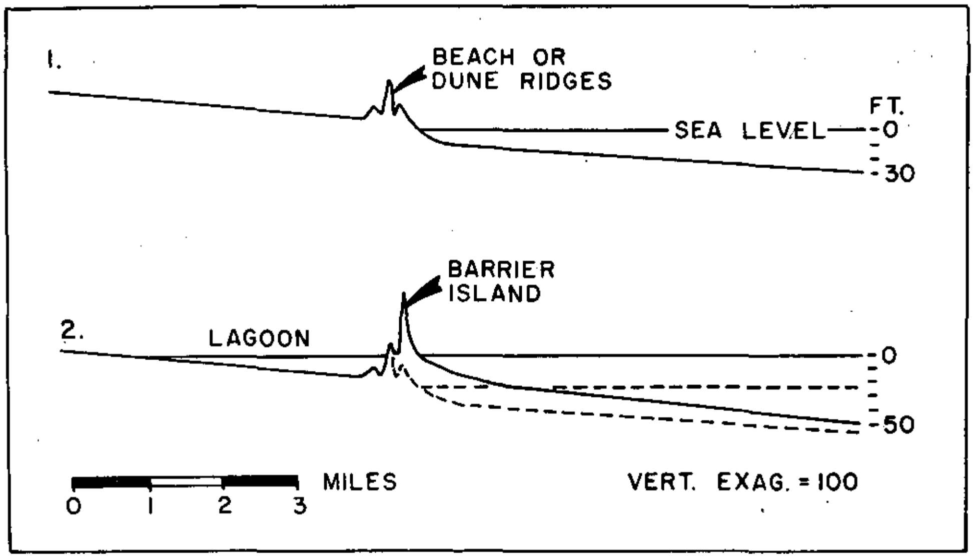

Figure 5. Formation of barrier islands by submergence. 1) Beach or dune ridge forms adjacent to shoreline. 2) Submergence floods area landward of ridge to form barrier island and lagoon (Hoyt, 1967).

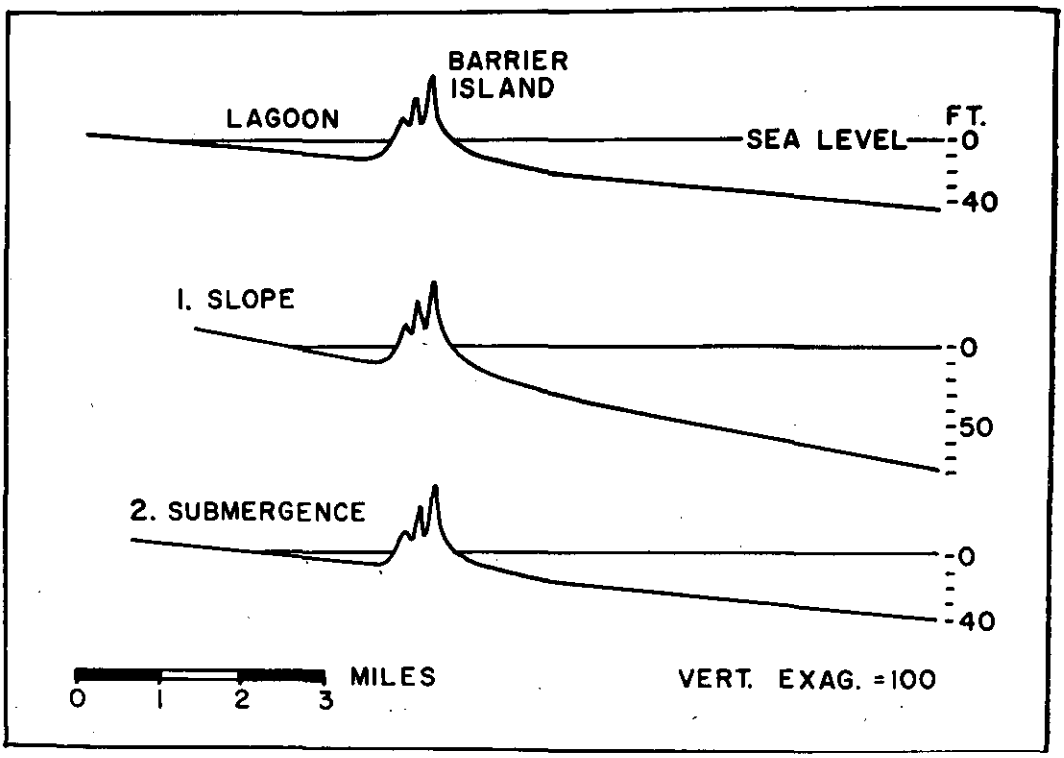

Figure 6. Lagoonal width and depth are functions of 1) slope and 2) submergence. Sediment deposition and erosion modify dimensions of lagoon (Hoyt, 1967).

remain stable or even prograde during a rising sea level, if there is sufficient sediment. A reduction in sediment supply during a rising sea level results in transgression of the sea onto the island. Since sand is trapped in the lower river valleys along the Georgia coast and sea level is rising, the climax of barrier development probably has been reached. The barriers are in various stages of destruction, and there is little evidence to indicate that erosion on one area of the coast is being balanced by deposition on another, except at the extreme nortern and southern ends of the barriers in the form of shoals and bars.

In concluding this summary of the geology of coastal Georgia, several main concepts should be emphasized. The broad, horizontal, parallel areas along the coast are salt marsh-filled lagoons which developed landward of chains of barrier islands. Seven sequences of barrier and salt-marsh lagoonal sediments can be mapped in many places. These range in age from possible Pliocene for the Wicomico barrier complex, to Holocene. The barrier islands form a rim along the seaward edge of the filled lagoons and thus the terms "terrace" and "scarp" are not accurate morphological terms.

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SURFICIAL SEDIMENTS OF THE GEORGIA CONTINENTAL SHELF

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ABSTRACT

Analysis of more than 200 box cores collected from the inner and outer continental shelf of Georgia indicates that considerable variation occurs in texture and in sedimentary structures.

Inner Shelf. In most of the inner shelf study area, sand forms 90 to 98 percent of the substrate. Mud layers are present, but are locally restricted. Deposits formed in less than nine to ten meters water depth have a sediment fraction composed of five to ten percent silt and clay. Below the 10 m bathymetric contour in the inherited sand facies, the fine fraction is consistently less than two percent. Material coarser than sand forms less than one percent at depths less than nine to ten meters water depths, and generally one to two percent in greater water depths.

Grain sizes in the vicinity of shoals are highly variable. In the channels between shoals and the beach, layers of coarse- medium- and fine-grained sand may be intermixed. Megaripples adjacent to the shoals contain coarse-sized sand whereas the intertidal shoal surfaces are commonly composed of fine-grained sand.

From the low tide zone to approximately 5 n. mi. (9 km) offshore, the substrate sand fraction is fine-sized sand. Beyond this is a zone of variable width consisting of medium-fine sand. In the most seaward part of the study area the fraction is composed of medium-grained sand.

Outer Shelf. Textural analysis indicates that the midshelf area is covered by evenly distributed medium- to coarse-grained sand with no north-south linear trends. Areas of fine-sized sand are present on the inner and outer shelf edges and in two distinct lobes extending seaward from the Georgia coast. Parts of the lobes suggest that the finer material forming them was supplied by the Savannah and Altamaha Rivers. Local patches of semi-consolidated mud indicate the location of remnant marsh or estuary deposits.

Biogenic sedimentary structures greatly exceed primary depositional structures. All box cores show some degree of biogenic reworking, and most were more than 60 percent bioturbated.

Physical sedimentary structures include crossbedding, ripple lamination, interbedded sand and mud, wavy bedding, and graded bedding.

Reference to these sediments as remnants is misleading because physical and biogenic reworking of the outer Georgia continental shelf sediments has removed or greatly modified most of their original depositional characteristics.

MAGNETIC AND GRAVITY DATA FROM THE GEORGIA CONTINENTAL SHELF

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and

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ABSTRACT

One of the results from the east coast aeromagnetic survey (Taylor et al., 1968) was delineation of a linear magnetic anomaly that approximately parallels the eastern seaboard of the United States. This anomaly changes trend off the Georgia coastline and crosses the continental margin near the 31st parallel at Brunswick. Several hypotheses have been proposed to account for this anomaly. All available gravity data off the southeast Georgia coastline have been examined to determine if the magnetic anomaly has an accompanying gravity signature.

In the region where the magnetic feature crosses the coastline it is represented by a negative magnetic anomaly (-400) with a poorly developed positive anomaly (+200) to the south. When these gravity and magnetic data are combined the magnetic anomaly divides the freeair gravity field into predominately negative values to the north (-20 mgal) and positive values to the south (+20 mgal). Consequently, the east coast magnetic anomaly results not only from contrast in intensity of magnetization but also from associated density variation. This result appears to eliminate the possibility that the east coast magnetic feature is a "sea-floor spreading" type anomaly produced immediately after the break-up of the continents. Contrast in magnetic intensity plus density could be explained by juxtaposition of differing geologic units or an intrusive igneous body.

Attempts to explain the anomaly as resulting from an "edge effect" between the magnetic oceanic crust and the relatively nonmagnetic continental crust can not account for the morphology of the anomaly. Efforts to trace the anomaly to the west have been inconclusive. Therefore, despite the available potential field data the source of the east coast anomaly remains to be determined.

THE GEORGIA GRAVITY BASE NET

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and

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ABSTRACT

Using the international datum instead of a "floating" or arbitrary datum for local gravity surveys increases the value of the data by making it possible to combine or compare surveys done at different times and areas without further adjustment. To encourage use of the international datum we have established 58 gravity base stations in Georgia. These stations have been tied to the national network, and hence the international network, using multiple gravimeter connections. These stations were included in a simultaneous least squares adjustment of state base networks from Florida to Virginia to achieve the maximum consistency consonant with the observational uncertainty of the individual ties.

BOUGUER GRAVITY ANOMALIES OF GEORGIA

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Introduction

The Simple Bouguer Gravity Map of Georgia shown in Figure 1 (Long, *et al.*,1972) was developed from gravity data accumulated for a study of isostasy and large scale crustal structures. This map is a regional representation of the gravity field based on a mean data separation of seven kilometers. For consistency in representation of the gravity field, details in areas with more dense coverage were not included. Following the publication of this gravity map, efforts at Georgia Tech and other institutions have improved the coverage in a number of interesting and important areas. The distribution of data obtained recently by Georgia Tech and other non-proprietary surveys is summarized in Figure 2. One important contribution is the completion and availability of a Georgia State Base Net (Ziegler and Dorman, 1974), which allows adjustment of all data to the U.S. National Gravity Base Net (Schwimmer and Rice, 1969). The Simple Bouguer Gravity Map of Georgia and all other maps presented in this report are tied into the state base net.

For the numerical analysis of isostasy and the larger geologic units of the crust, a 64 by 64 point grid with an eight kilometer interval was developed from all the data generally available within a quadrangle, defined by latitudes 30 and 36°N and longitudes 80 and 86°W. The object of this paper is to present some conclusions derived from the examination of this grid and to present some of the areas where new data have been obtained. By presenting the gravity data in these various forms, hopefully some of the interpretation problems associated with southeastern gravity data can be illustrated.

Regional Bouguer and free air anomalies

Gravity anomalies are determined uniquely by the relative distribution of densities. The anomalies are computed by systematically removing from observed gravitational attractions the theoretical gravitational attraction of the normal earth and the effects of elevation and mass above sea level. The resulting Bouguer anomalies imply density anomalies relative to a normal stratified earth. Because gravitational attraction is inversely proportional to the square of distance, the density anomalies closest to the observation point will have the strongest influence in determining the observed gravity anomaly. Hence, Bouguer gravity anomalies are determined largely by density contrasts in the geologic structures of the crust. The resolution of gravity anomalies due to shallow structures is limited only by the station separation and precision of the gravity data and the distribution of density contrasts in geologic structures. Unfortunately, however, the inverse problem of finding the distribution of the anomalous density contrasts which can generate any given gravity anomaly is not unique. There always exists an infinite number of structures which can satisfy a set of gravity data. For a unique interpretation, gravity data must always be supplemented by other geophysical data or geological field observations.

In Georgia the density variations of the crustal rocks are most pronounced in the igneous and metasedimentary rocks of the Piedmont and Blue Ridge Provinces. The granitic and many gneissic rocks typically exhibit densities of 2.6 to 2.7 gm/cm^3. The hornblende gneisses, diorites and other basic rocks, however, exhibit densities in the range of 2.7 to 3.0 gm/cm^3 allowing for significant density contrasts near

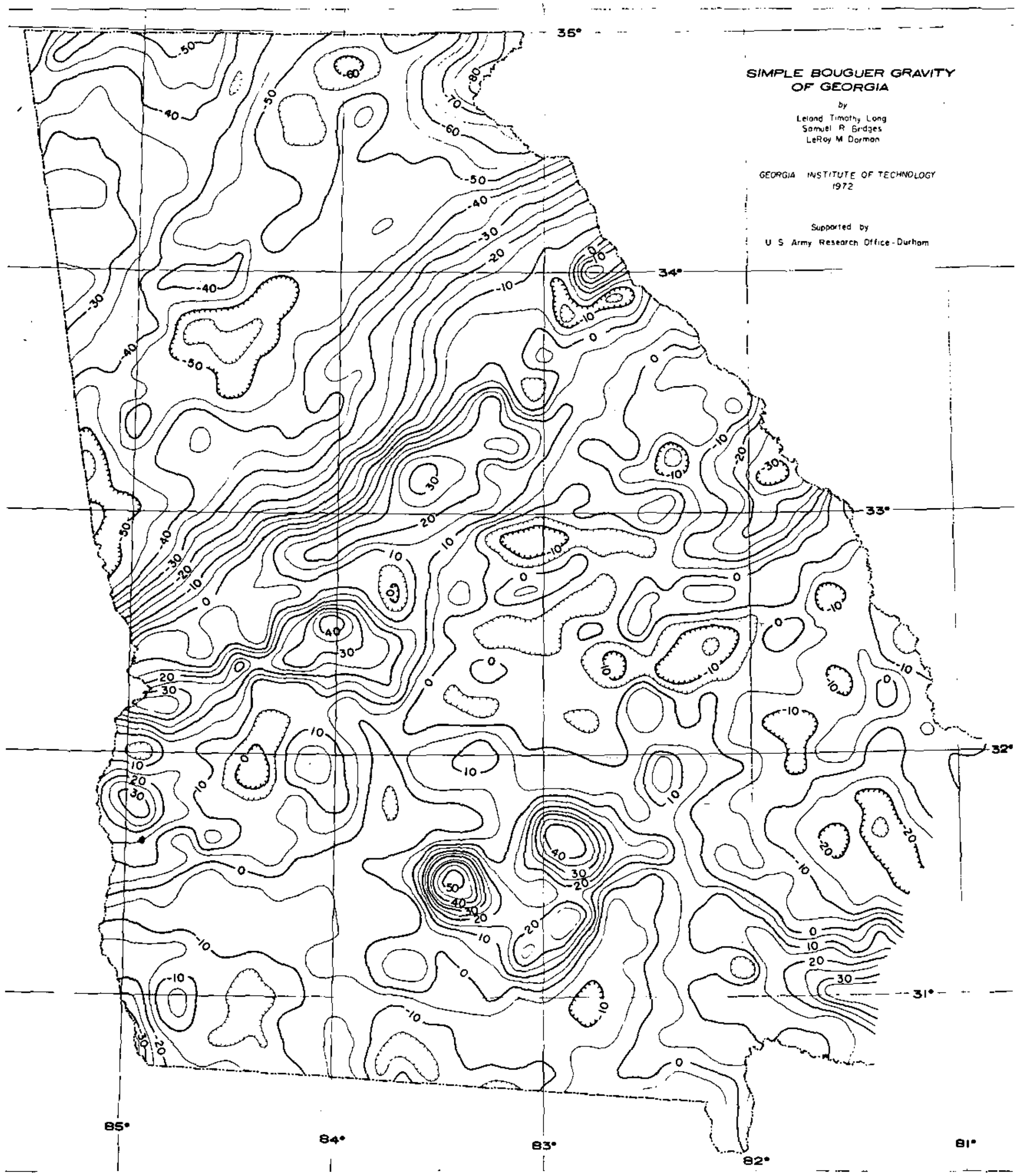


Figure 1. Simple Bouguer gravity map of Georgia.

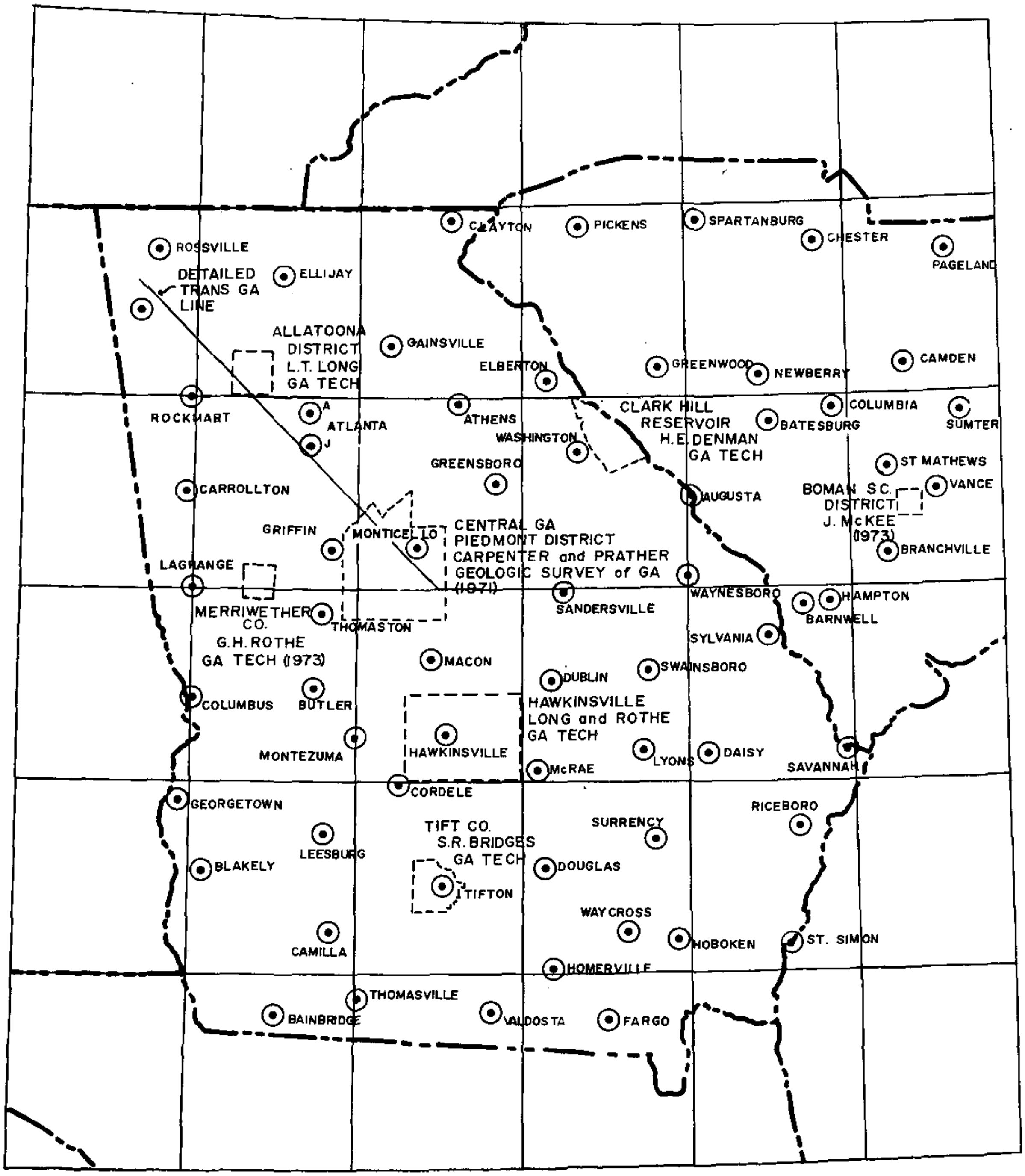


Figure 2. State base station locations and recent gravity surveys in Georgia.

the surface. Consequently, the details of the gravity anomalies in the Crystalline Provinces depend primarily on the structures and distribution of these rock units. Sedimentary near-surface rocks, like those that cover the Coastal Plain, have densities in the range of 1.9 to 2.5 gm/cm^3. The gradual or slight structures in the Coastal Plain sediments of Georgia do not influence the gravity field significantly. Instead, the gravity anomalies of the Coastal Plain indicate variations in the total thickness of the sediments and density contrasts in the basement. Gravity anomalies are also influenced regionally by variations in crustal thickness, since the density contrasts between the upper and lower crust, as well as between the lower crust and upper mantle, are about 0.3 gm/cm^3. While the Bouguer reduction removes, theoretically, a uniform layer of crustal material between the observation point and sea level, the Bouguer reduction neglects increased thicknesses of lower density crustal material required for isostatic compensation. This ommission introduces large negative anomalies in mountainous areas. By smoothing the Bouguer gravity anomalies (Figure 3) the effects of local or shallow structures are suppressed, and the remaining anomalies should correspond, generally, to changes in crustal thickness or composition. The most prominent feature is the low associated with the north Georgia and North Carolina mountains. Seismic evidence (Long and Mathur, 1972) indicates a 40 to 45 km average thickness for the crust in the mountainous areas. The Coastal Plain areas should have a more normal 30 to 35 km thickness of crust on the basis of the gravity anomalies. The positive anomalies of south Georgia indicate a significant intrusion of basic or, perhaps, mantle material into the crust.

The direct comparison between elevation and Bouguer gravity anomalies shown in Figure 4 for all 4096 grid points does not yield a simple linear relation. The expected relation for isostatic equilibrium, about 0.11 mgal/m, fits the total spread of the data if averaged. However, a significant portion of the points from 200 to 400 meters in elevation are more negative than would be predicted for isostatic equilibrium. These anomalies imply over compensation and support the possible existence of tectonic stresses consistent with uplift.

The free air anomaly is often a simple index of isostatic equilibrium since it theoretically removes no mass and is a direct measure of deviations in mass from a normal earth. In the gridded data the free air anomalies were computed with a distance weighted average out to an effective radius of 8 km (Figure 5). This averaging is sufficient for flat areas where the topographic irregularities are minor but is not sufficient for the mountain areas, as indicated by the irregular contours in the north Georgia portion of the map. Negative anomalies imply isostatic inequilibrium consistent with uplift. However, narrow free air anomalies like those in the northeast portion of the map are typical of mountainous areas where the smoothing is not extensive enough to accommodate compensation at the base of the crust. The largest negative zone extends from Atlanta to the northwest and is responsible for the excessively negative Bouguer anomalies at 200 to 400 meter elevation (Figure 4). When compared with probable annual rates of vertical crustal uplift (Meade, 1971) (Figure 6), the negative free air anomalies correspond to the zone of most rapid probable uplift, except north of the Georgia-Tennessee border. The large positive anomalies in the free air data are primarily a consequence of the location of the first order leveling line. The actual regional average free air gravity value between Columbus and the Georgia-Florida border is between 10 and 20 mgals.

A simplified isostatic anomaly map of the United States (Woollard, 1969) is in general agreement with the free air data in Georgia. Woollard's map, however, shows one rather than two paired negative and positive isostatic anomalies extending

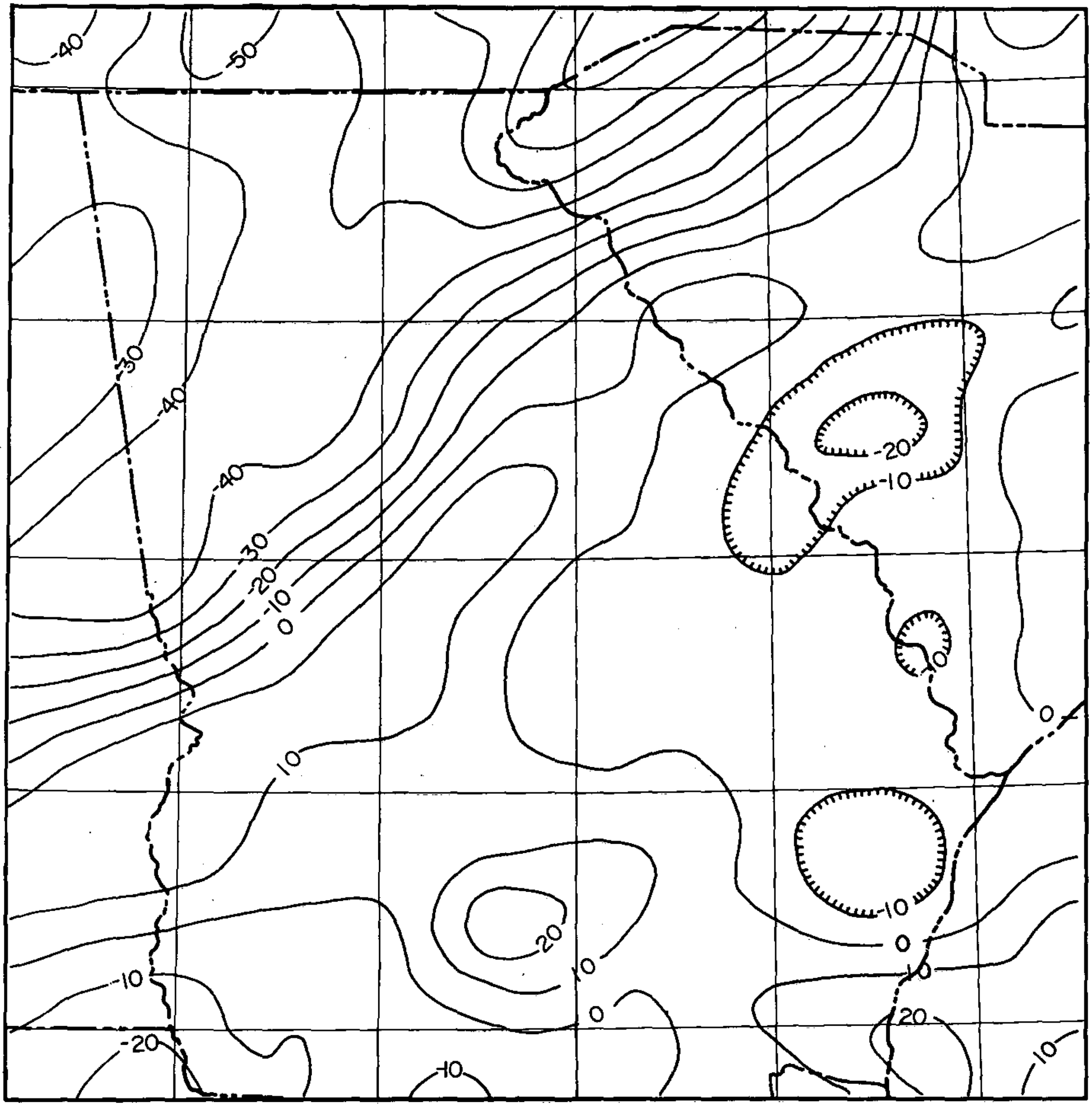


Figure 3. Smoothed Bouguer anomalies contoured at 10 mgal in the 512 km square. The smoothing is over an effective radius of 50 km.

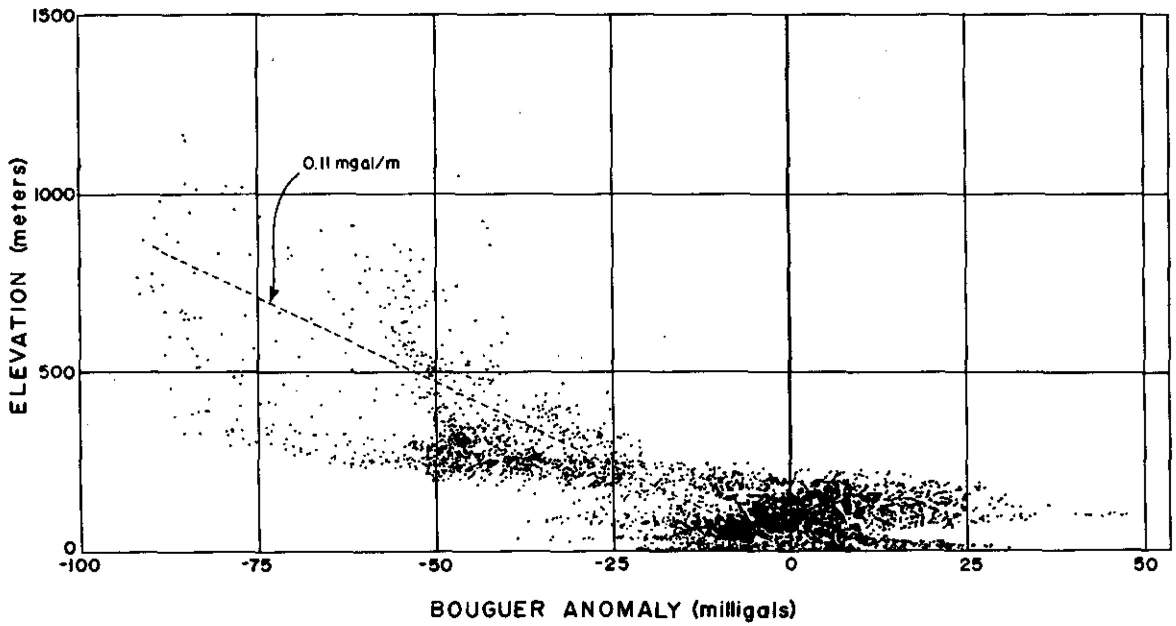


Figure 4. Point plot of elevation versus Bouguer anomaly. The 0.11 mgal/m line would correspond to zero free air anomaly or roughly isostatic equilibrium.

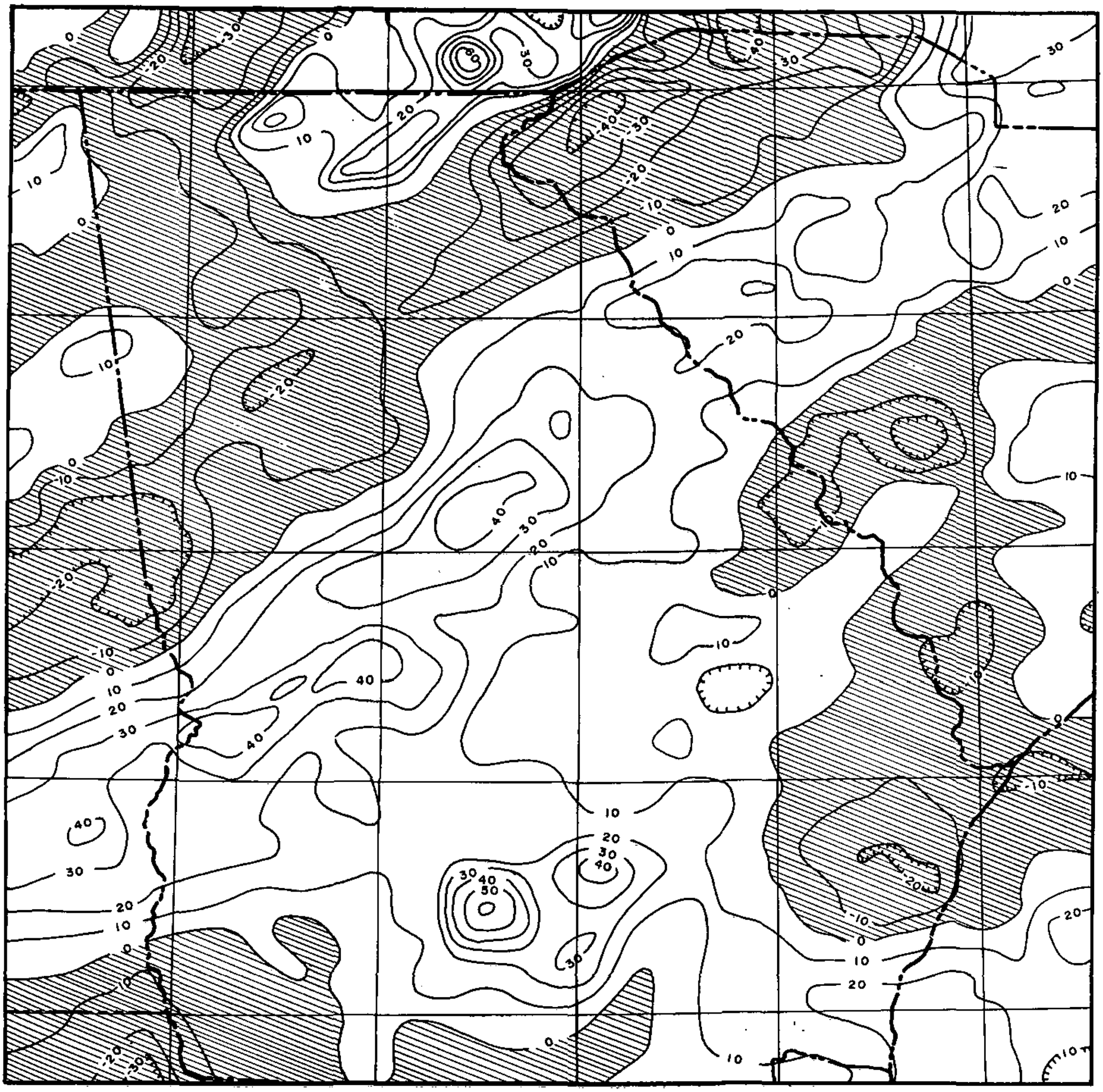


Figure 5. Free air anomalies in the 512 km square grid. The contour interval is 10 mgal and shaded areas are negative.

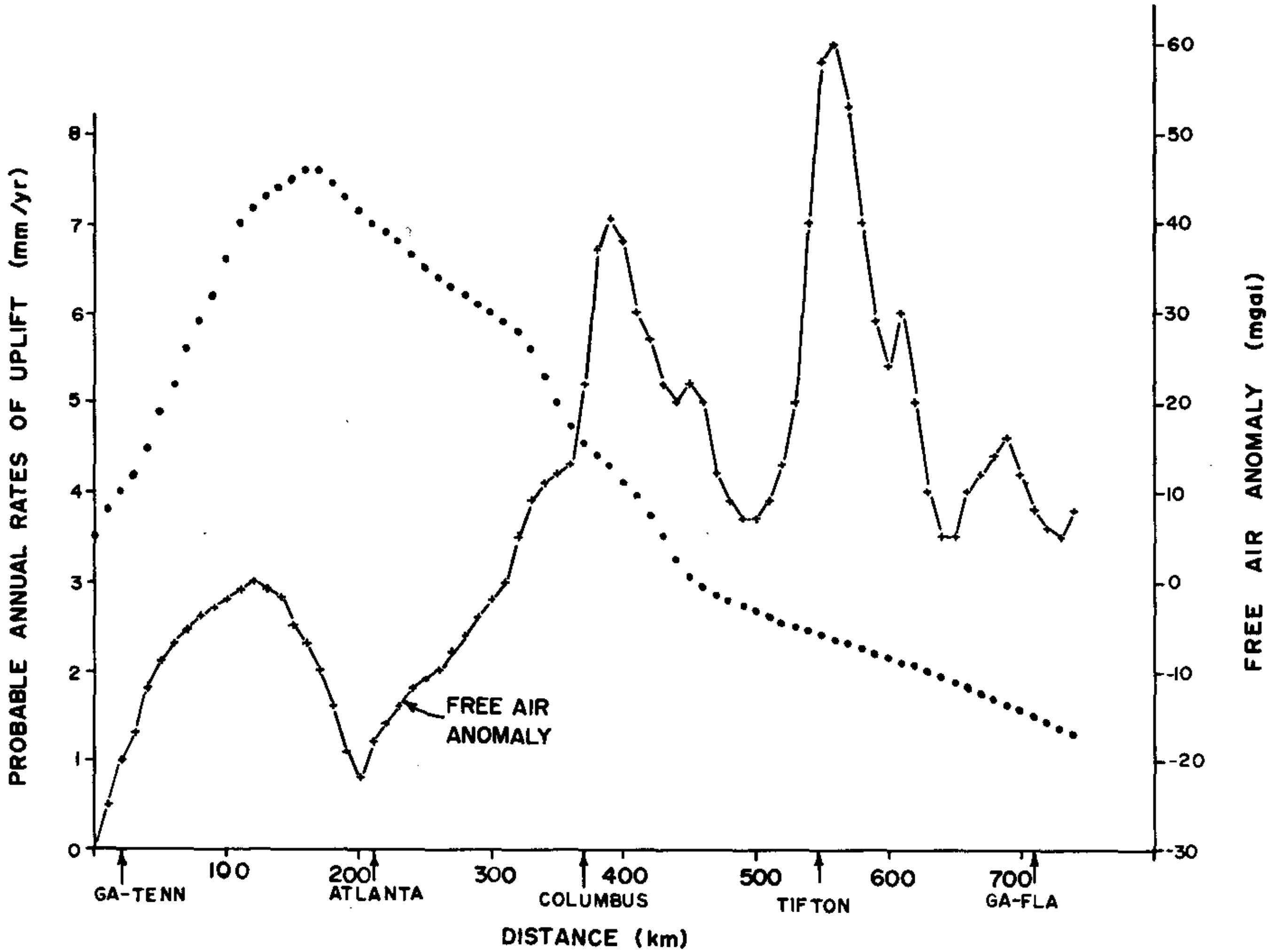


Figure 6. Comparison of probable annual rates of vertical crustal uplift (Meade, 1971) and free air anomalies.

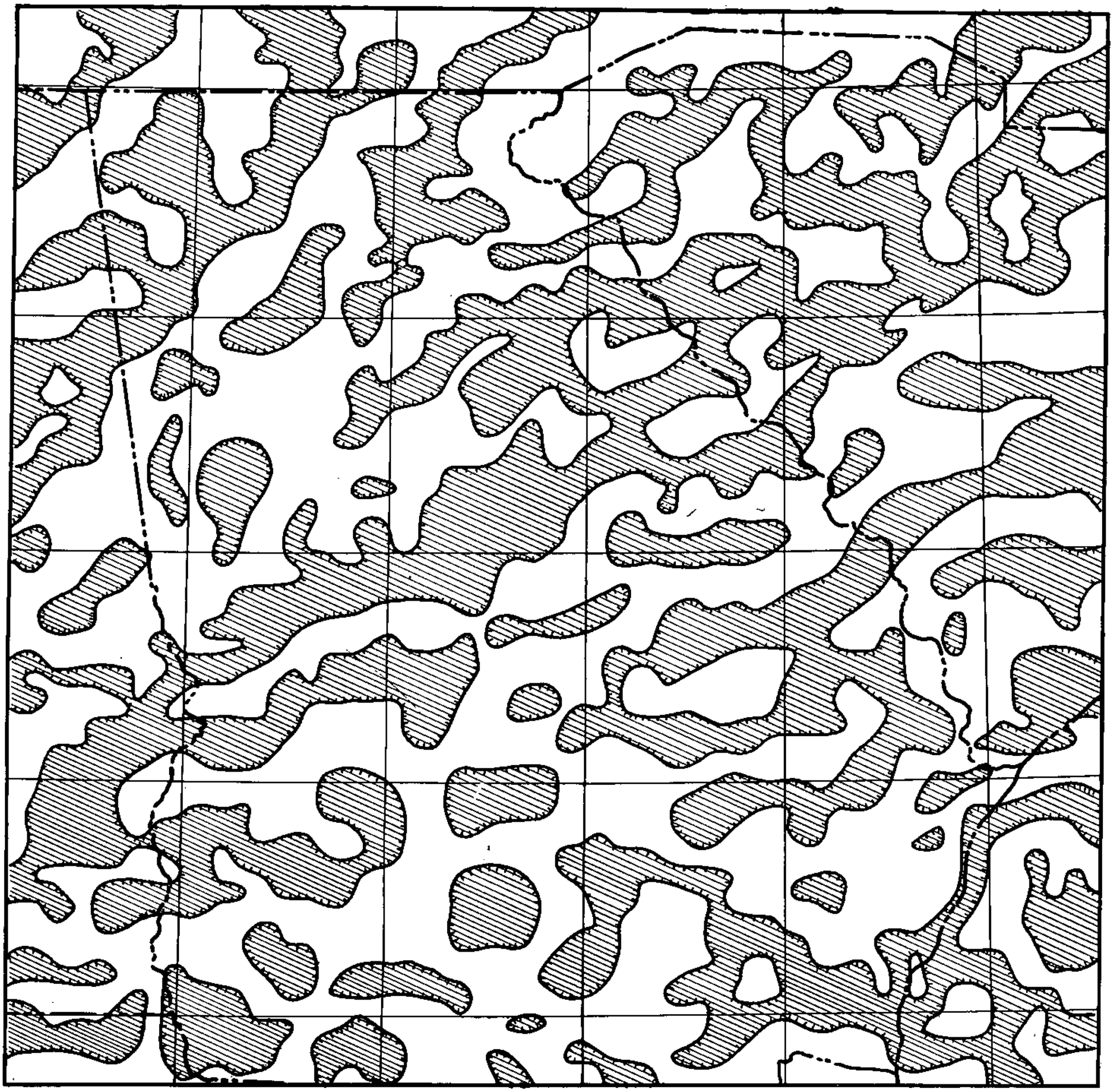


Figure 7. Residual Bouguer anomalies obtained by subtracting the smoothed Bouguer anomalies (Figure 3) from the grid values. Shaded areas are negative and the contour interval is 10 mgal.

northeast parallel to the Appalachian Mountain trend. These isostatic anomalies also appear to be in general agreement with the probable annual rates of vertical crustal uplift (Meade, 1971) if compared only along the leveling lines.

Two additional representations of the gridded Bouguer gravity data were computed. Both the residual anomalies (Figure 7) and the second derivative (Figure 8) are attempts to emphasize local structures and suppress the regional trends. The residual Bouguer map was computed by subtracting the smoothed Bouguer anomalies (Figure 3) from the gridded data. As expected, the details are relatively unchanged. However, because of the coarseness of the grid the details are limited to those that can be resolved with the eight kilometer data separation. Thus, the residual map also emphasizes geologic features of crustal dimensions, on the order of 8 to 32 kilometers. The second derivative map was computed directly from the gridded data by using a finite difference approximation of the second derivative function (Dobrin, 1960, Pg. 246). The second derivative is more sensitive than the residual to sharp changes in the Bouguer anomalies. The patterns revealed by the residual and second derivation maps in the eastern and northern portion of the map are, as expected, parallel to the structural trends. At least two possibly significant exceptions to the pattern are apparent. One is a persistent break or change in the pattern along a narrow zone extending southeast from the northwest corner of Georgia toward Savannah. This zone of change in the NE-SW trends is also apparent in the free air anomalies (Figure 5). The other is a change in the anomaly trends to an east-west strike in the southwest corner of the map. The change in character is also confirmed by the half-height contours of local (64 x 64 kilometer) autocorrelation functions of the residual data (Figure 9). The autocorrelation functions effectively remove any possible contouring bias that may have influenced the residual or derivative maps. The radius of the contour is a measure of the distance the anomalies are correlated in that direction. Hence, structural trends would be indicated by ellipses alligned with the trend. The unusually large positive Bouguer anomalies and the change in trend support a major change in the crust underlying southwest Georgia.

Detailed gravity data

In order to study variations in the crustal structures in north Georgia in more detail, a 200 kilometer line of gravity data was obtained. The line is perpendicular to the main structural trends and extends from the northwest corner of Georgia to southeast of Atlanta (see Figure 2). A hypothetical profile of the Moho was derived by assuming the existence of compensating mass in the form of horizontal prisms, extending below 30 kilometers depth with a 0.3 gm/cm^3 density anomaly (Figure 10). In deriving the hypothetical Moho structure, only gravity anomalies with wavelengths longer than 30 kilometers were considered in a least squares fit of the model to the observed data. The contribution from a hypothetical intermediate layer at 15 kilometers was computed in a similar manner after removal of the gravity expression of the hypothetical Moho from the Bouguer anomalies. The 15 and 30 kilometer depth constraints are relatively arbitrary. However, variations of 5 to 10 kilometers would not significantly affect the interpreted lateral variations. The thickest crustal section is indicated at 10 kilometers southeast of Atlanta. The crust thins toward the Southeast and thins gradually toward the Northwest. The intermediate layer appears to undulate with the topography. The undulation cannot be explained entirely by an inappropriate Bouguer reduction density since the magnitude of the undulation is five times the expected undulation for a 0.3 gm/cm^3 error in reduction density. Regional density anomalies at the depth of the intermediate layer or shallower are needed to explain the Bouguer anomalies. Their correlation with differences in elevation implicate the total crustal section in possible

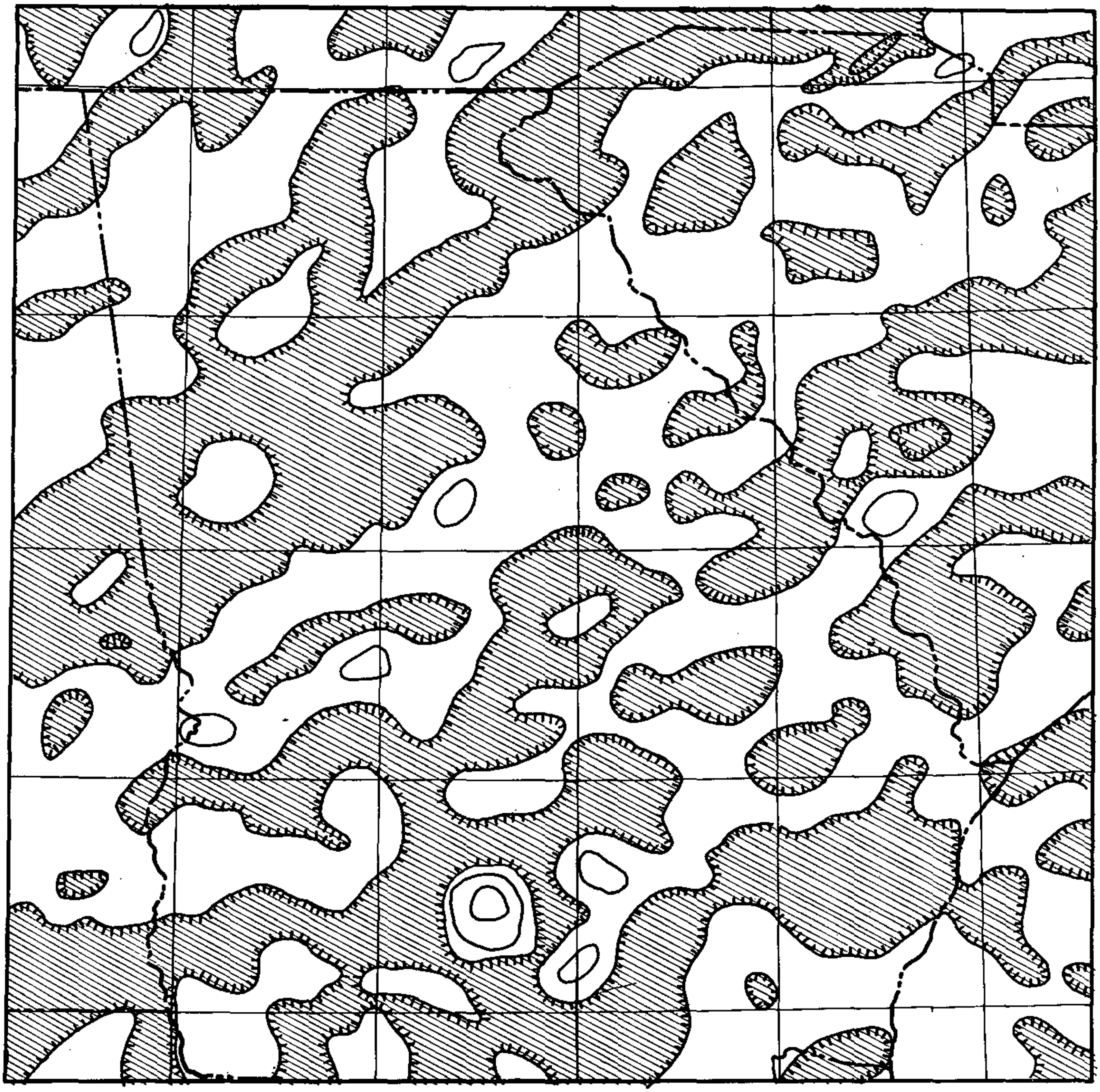


Figure 8. Second derivative map of the Bouguer anomalies in the 512 km square grid. Shaded areas are negative and imply a radius of curvature pointing down.

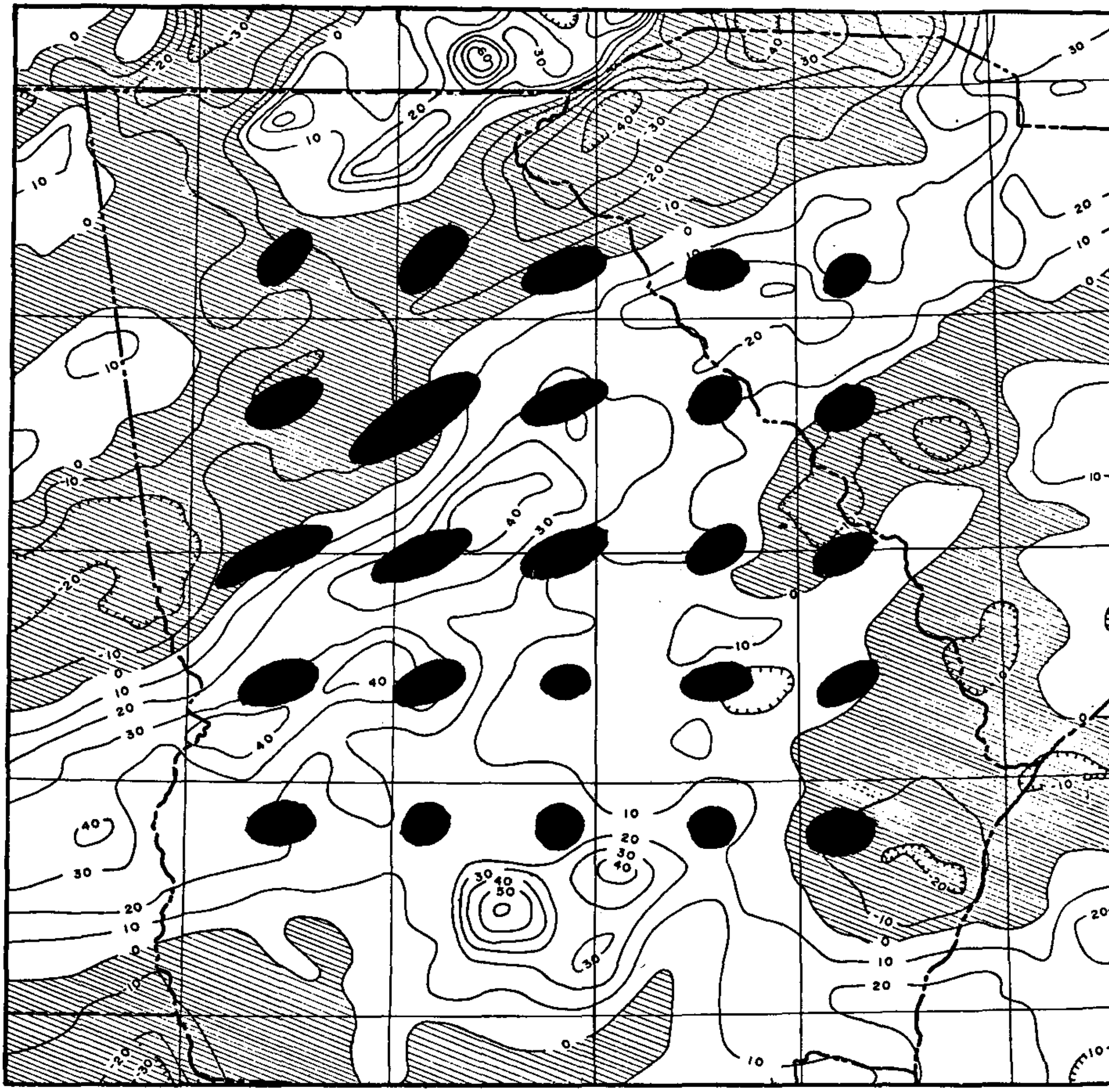
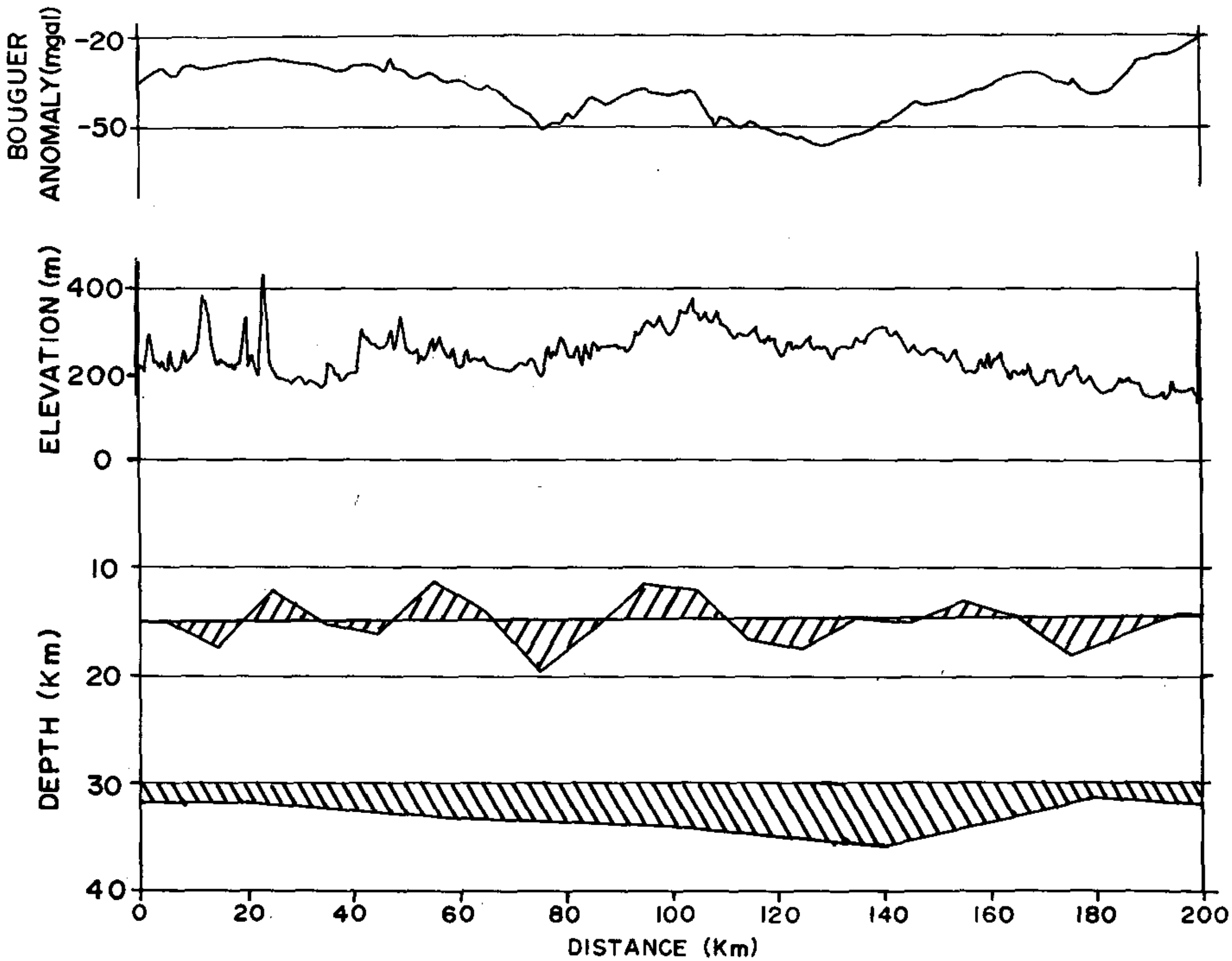


Figure 9. Half height contours of local (64 x 64 km) autocorrelation functions compared with free air anomalies.


BOUGUER ANOMALY (mgal)
-20
-50
ELEVATION (m)
400
200
0
DEPTH (Km)
10
20
30
40
0
20
40
60
80
100
120
140
160
180
200
DISTANCE (Km)

vertical movements.

At about 100 km the profile crosses the Allatoona reservoir area near Cartersville, Georgia. The reservoir area, which includes the Allatoona Dam, Acworth, South Canton and Kennesaw quadrangles, has gravity coverage at an average spacing of one kilometer. The resulting Simple Bouguer anomaly map in Figure 11 shows that the positive linear anomaly 12.0 km southeast of Cartersville corresponds to an outcrop of metagabbro and related rocks. Typically, basic rock units in the Crystalline Provinces of Georgia, such as those designated hornblende gneiss on the 1939 geologic map of Georgia, give 3 to 15 mgal positive anomalies, depending on their thickness. This unit is about 2 km wide and has a 7 mgal positive anomaly. A comparison with more detailed geology (Crawford and Medlin, 1970) and radiation data (Charles Ostrander, personal communication)(Figure 12) shows the correlation among geophysical data. The dip of the structure in Figure 12 to the south is indicated by the smaller gravity gradient to the south as well as by measured dips in the surface geology.

The gravity anomaly associated with a dike in Meriweather County (Rothe, 1973) is similar but proportionately smaller. The dike is expressed in regional data (Figure 13) as 2 mgal pertrubations in the contours. The profiles AA' to DD' are shown in Figure 14 with a regional gradient removed. Comparison of these profiles to theoretical models for a dike (Figure 15) indicate that this dike probably consists of a system or swarm of dikes one or possibly two kilometers thick. As noted in the insert to Figure 15, the sharpness of the dike anomaly is strongly dependent on the depth to the top of the dike or the thickness of the weathering surface. This factor probably explains some of the scatter in the observed profiles of the dike in Figure 14. Magnetic data along the same profiles (Rothe, 1973) also indicates the swarm character of the dike.

Under more than 500 meters of Coastal Plain sediments even a dike system as large as the Meriweather dike would be difficult to detect or distinguish from the other sturctures of the basement rocks. However, larger structures, like the hornblende gneiss in the Allatoona reservoir region have been detected through Coastal Plain sediments. One example (Figure 16) is a dense dike-like structure nearly 6 km wide in the Bowman, South Carolina area (McKee, 1973). This structure generates a 10 mgal positive gravity anomaly, striking northeast-southwest and, if not vertical, dips to the southeast. Seismic velocities obtained from microearthquakes recorded in the vicinity (McKee, 1973) predict a 6.6 km/sec velocity. This would be appropriate for a diorite or large basic intrusive. The magnitudes of the gravity anomaly would indicate a 2.9 gm/cm^3 density which is also appropriate for a diorite. The magnitude of the gravity anomaly would indicate a depth of 15 km or down to the lower crust which has approximately the same density. A gravity line with 0.2 kilometer separations (or less) along the crest of the anomaly (Figure 17) shows a positive anomaly coinciding with a decrease in elevation at 5 kilometers. The sharpness of this anomaly requires that its source be at or above the basement. Since the diorite was assumed uniform along strike, this anomaly was interpreted as a fault in the basement. The fault may also involve some of the overlying sediments. The correlation with an elevation change requires examination of the reduction density, but as seen in Figure 17 the elevation is in the opposite sense to allow a realistic reduction density as an explanation for the anomaly.

Southeast of the Bowman area, a two milligal anomaly shown at the southwest end of the line in Figure 18 is found to also correlate with the topography. In this case, the reduction density required to eliminate the anomaly is a positive 6.0 gm/cm^3 obviously too dense to be realistic. Again, this is interpreted as a fault at or near basement. The correlation of the gravity anomaly with topography

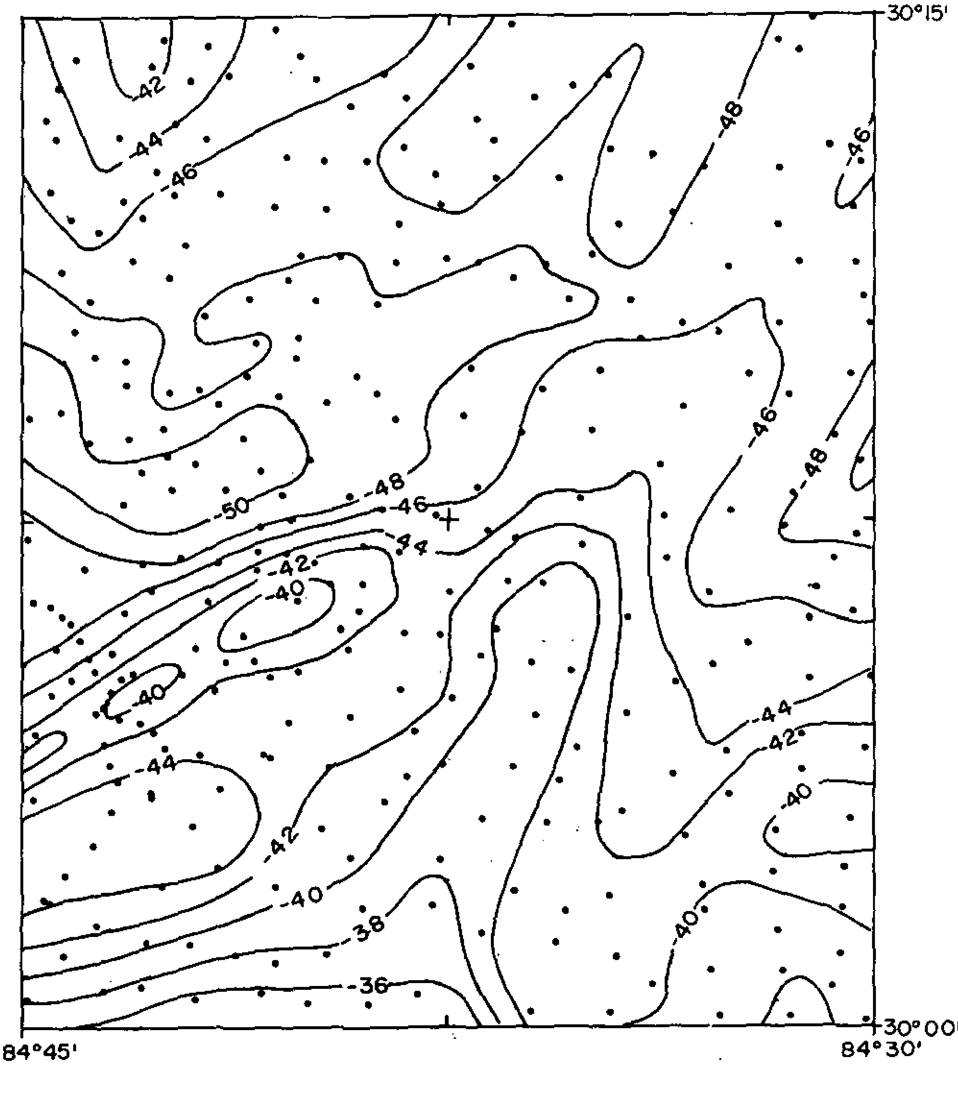


Figure 11. Simple Bouguer gravity anomaly map of the Allatoona reservoir area consisting of the Allatoona Dam, Acworth, South Canton and Kennesaw quadrangles. The contour interval is 2 mgal and average data spacing is one kilometer.

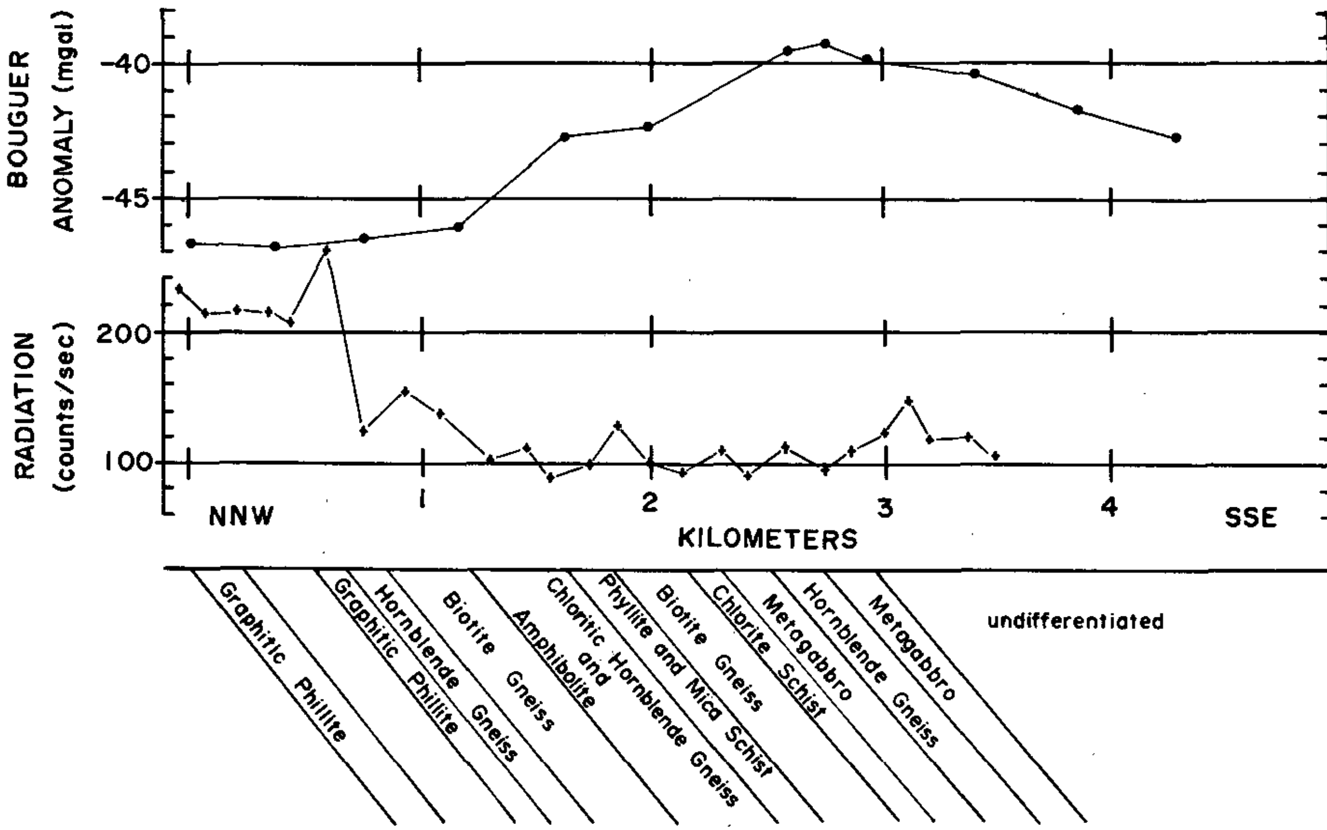


Figure 12. Comparison of a Bouguer anomaly in Allatoona area with radiation data (Charles Ostrander, personal communication) and geologic data (Crawford and Medlin, 1970).

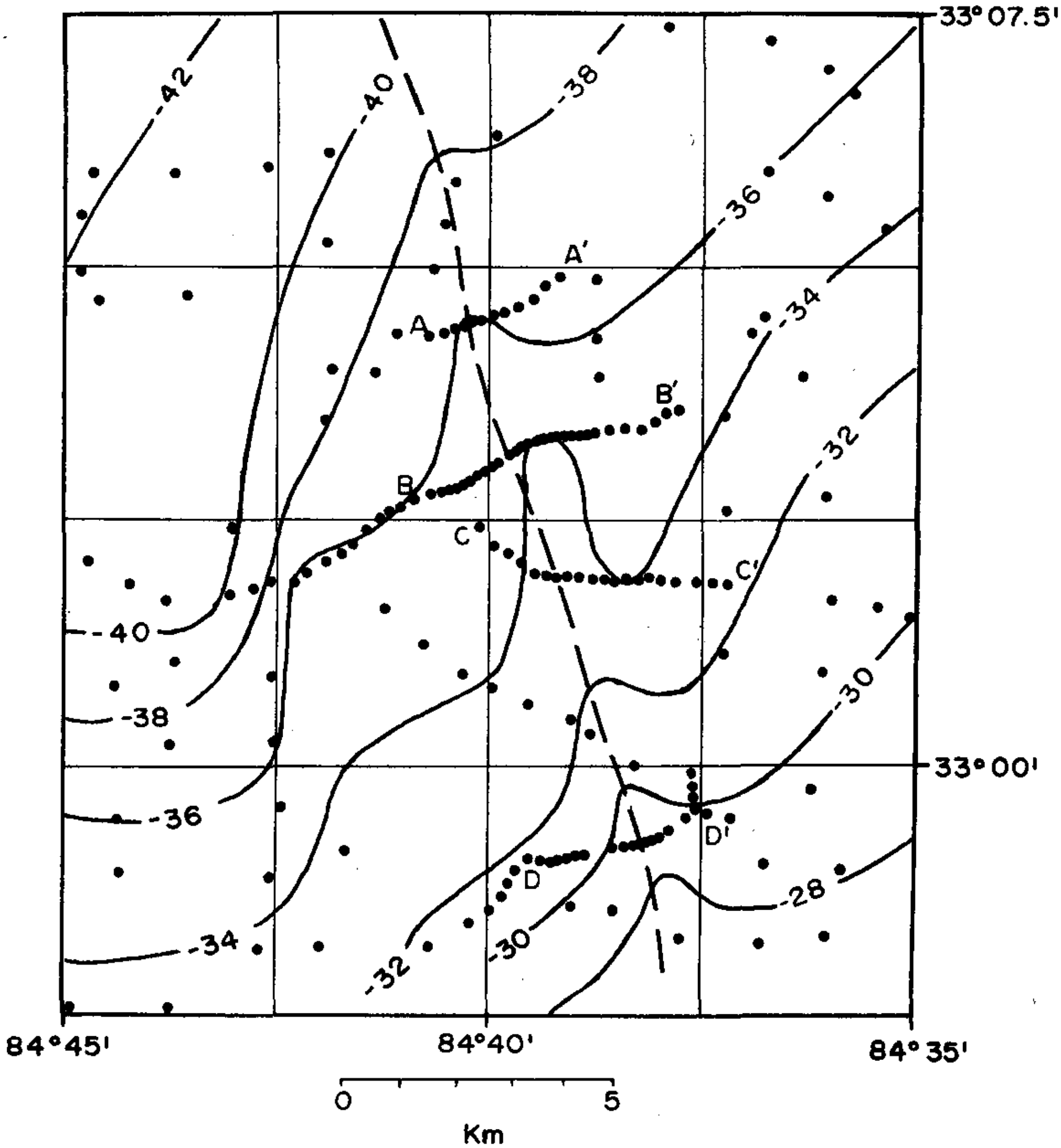


Figure 13. Simple Bouguer anomaly map near diabase dike in Meriwether County (Rothe, 1973). The contour interval is 2 mgal. The dashed line marks the mapped location of the Meriwether dike.

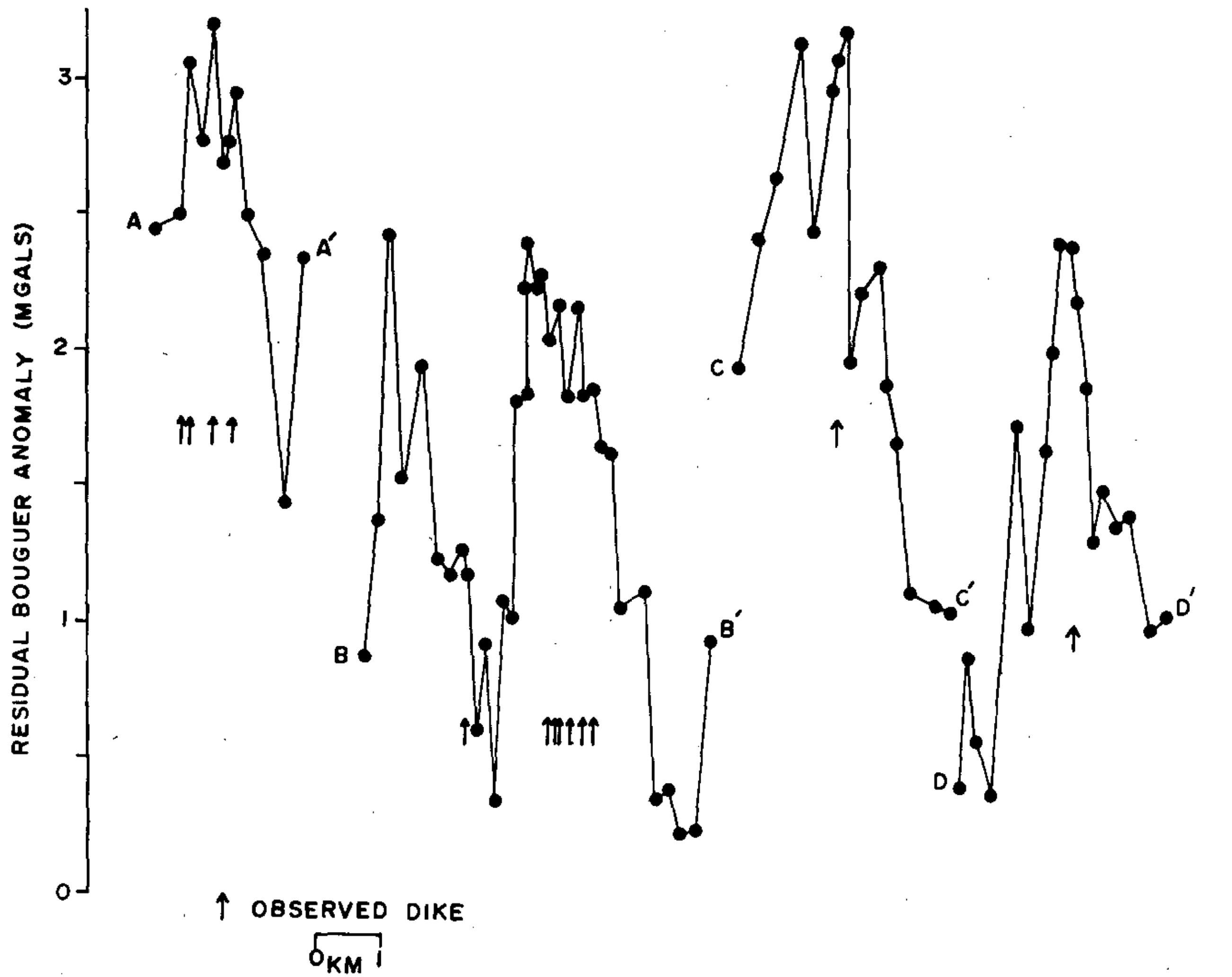


Figure 14. Gravity profiles across the dike complex in Meriwether County, Georgia (See Figure 13 for location). A plane was filled by the method of least squares to the regional data exclusive of the profiles to remove the regional gradient.

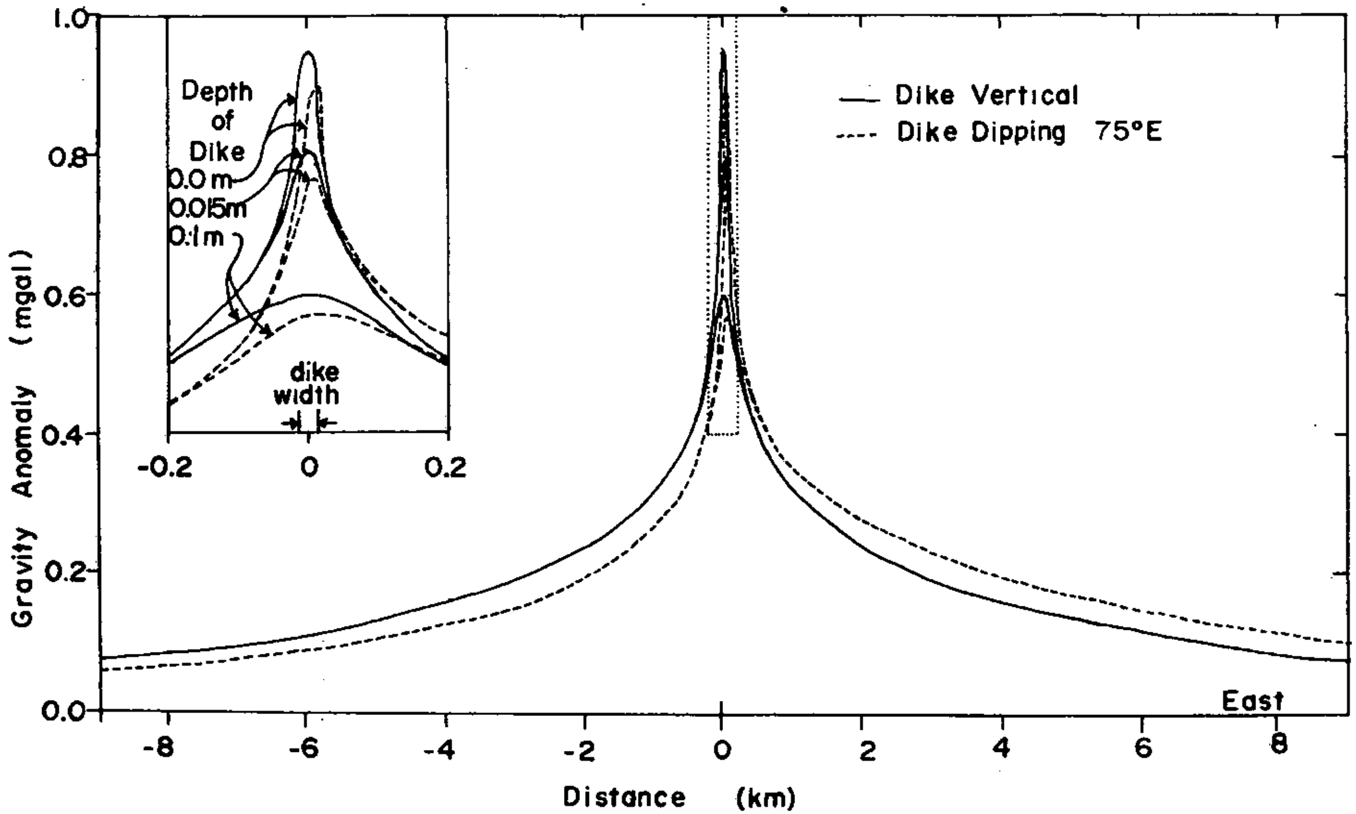


Figure 15. Theoretical gravity profiles across a vertical and 75° dipping dike. Width of the dike is 30 meters. The insert illustrates the effect of depth to the top of the dike.

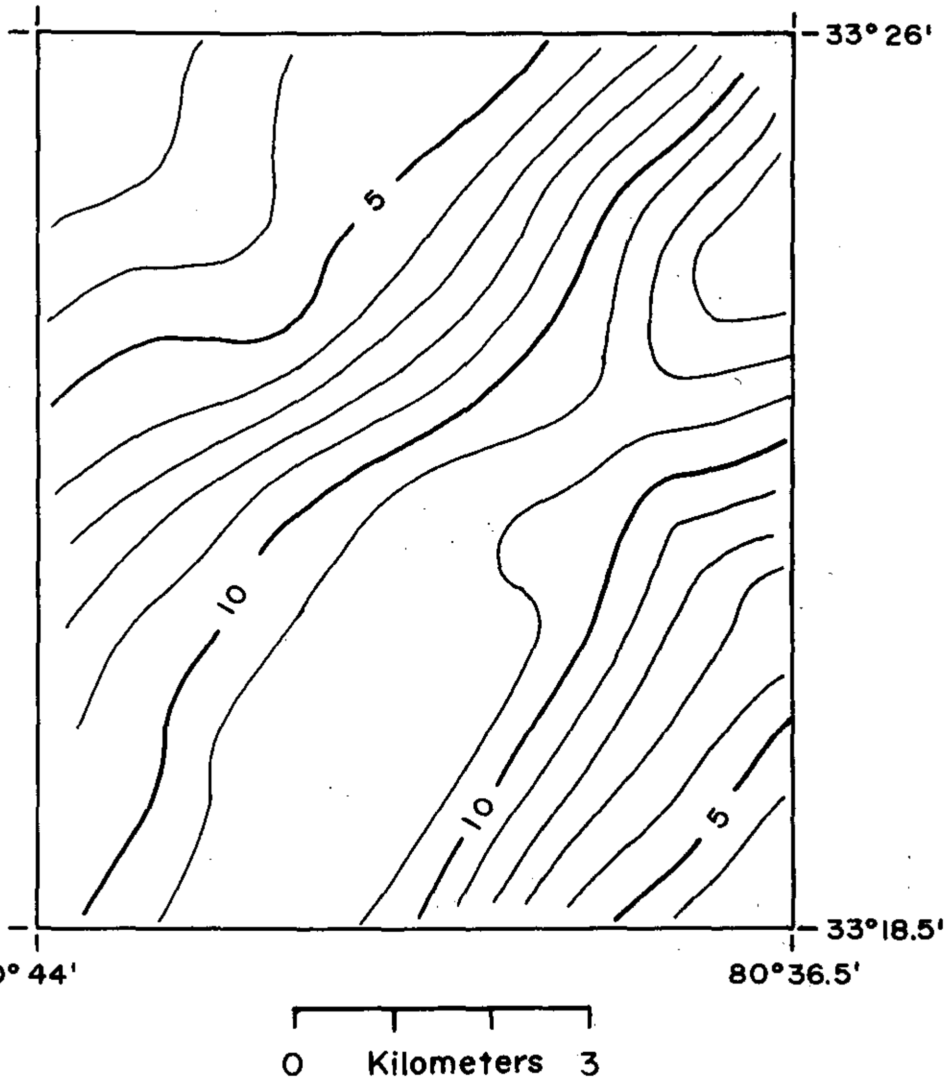


Figure 16. Linear positive Bouguer gravity anomaly near Bowman, South Carolina. The Contour interval is 1 mgal.

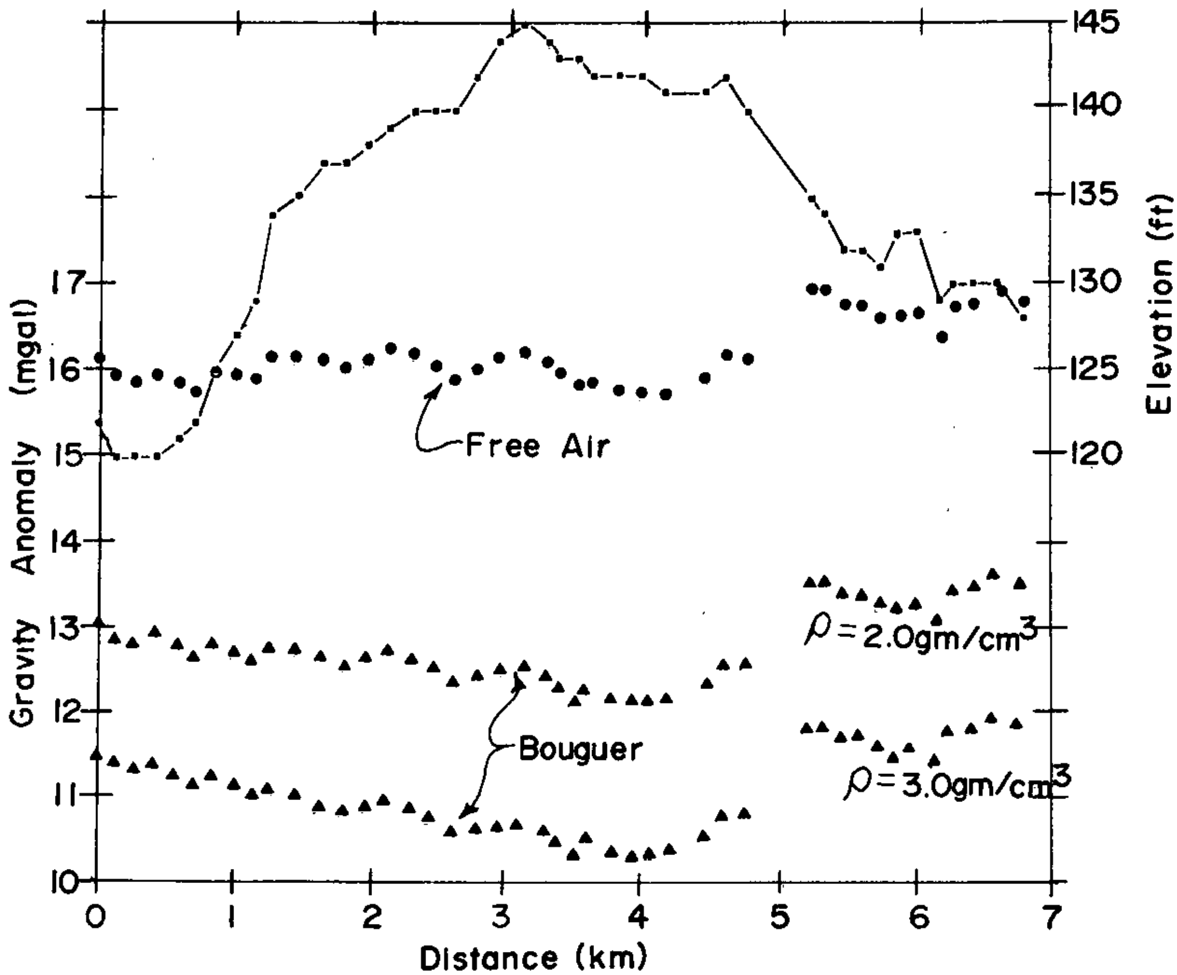


Figure 17. Southwest-northeast (left to right, respectively) profile along crest of the Bouguer gravity positive in Figure 16.

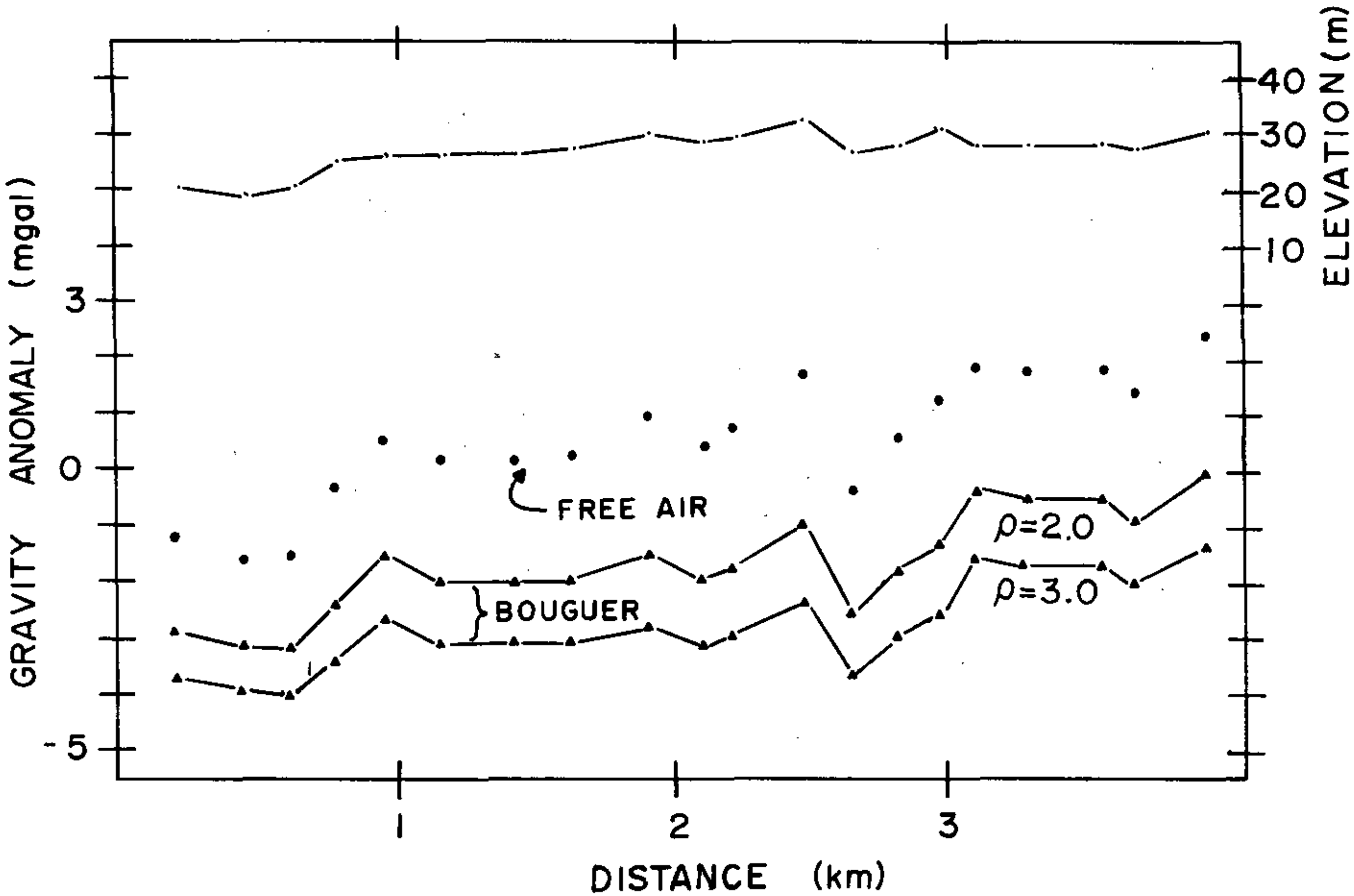


Figure 18. Southwest-northeast gravity profile approximately 30 km southeast of Bowman showing correlation of elevation with gravity anomalies on the southwest end of the line.

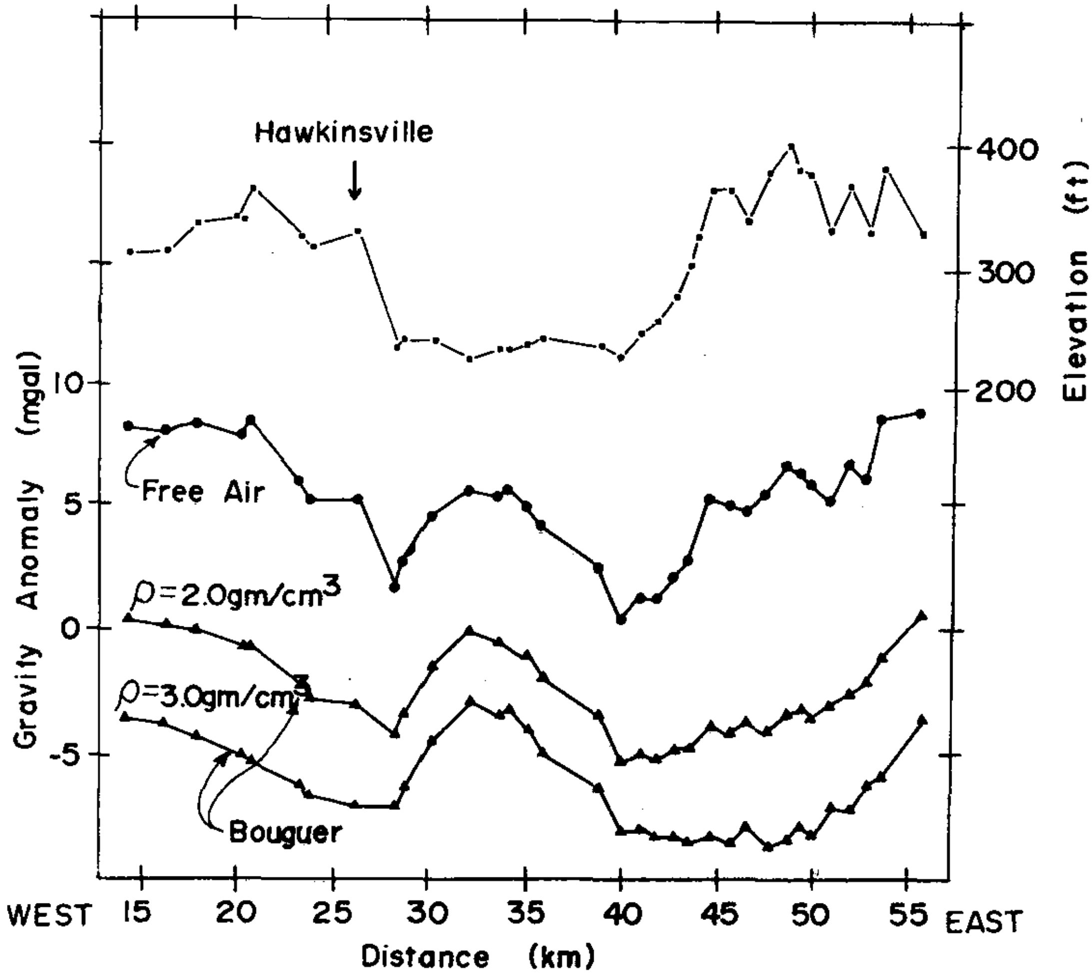


Figure 19. Detailed west to east gravity profile near Hawkinsville, Georgia showing both the anomalous correlation of elevations with Bouguer anomalies and the effect of a correct Bouguer reduction density of 2.0 gm/cm^3 near the 50th kilometer of the line.

implies a post-Cretaceous origin for these features in a zone of known recent seismic activity. However, because interpretations of gravity data are not unique, additional data would be required to rule out an alternate explanation of these features as buried flood plane boundaries.

Similar relations have been observed in the Georgia Coastal Plain. In an east-west line near Hawkinsville, Georgia (Long and Rothe, 1972) the topography correlates with a 1.0 milligal anomaly at 45 kilometers (Figure 19). The anomaly is removed by a 3.0 gm/cm^3 reduction density but this is too dense for surface rocks. A correct Bouguer reduction density at 2.0 gm/cm^3 is shown at about 47th kilometer of the data line (Figure 19) for a small topographic irregularity. The implied vertical displacement is approximately 60 meters and correlates with the surface topographic irregularity. Although the association of Bouguer anomalies with elevation change in Georgia involve smaller anomalies and hence, perhaps, smaller displacements than those on the South Carolina Coastal Plain, the association exhibits characteristics which would be expected as a consequence of post-Cretaceous vertical crustal movement.

The major and dominant gravity anomalies in the Coastal Plain are related to significant geologic units in the crust. As previously noted in the eastern and northern part of the map they are primarily extensions of Piedmont Province rocks under the Coastal Plain sediments. However, in the southwest portion of the map, their character changes. Just southwest of the zone of change in the central Coastal Plain of Georgia there is a 50 mgal circular positive anomaly (Figure 20). This is the largest of a group of three (see Figure 1) which may be part of a westward extension of the east coast magnetic and gravity anomaly which appears to come inland near Brunswick, Georgia. The Tift County anomaly (Bridges, 1973) is of the size and character of the anomaly due to a volcanic plug. Seismic velocities (Woollard, 1955) indicate a high velocity (20,000 ft/sec) structure in the basement. The magnitude and shape of the gravity anomaly requires that it extend at least 15 kilometers into the crust.

Conclusions

Observations of the regional gravity data and detailed lines implicate isostasy and/or differential crustal uplift as significant factors in the contemporary tectonics of the southeast United States. The free air anomalies are regionally consistent with observed uplift and detailed gravity profiles are indicative of post-Cretaceous vertical movements. Undulations of the intermediate layer for a hypothetical crustal model derived from gravity data also correlate with elevation and indicate the existance of long-term vertical crustal movements or perhaps the contemporary adjustment of relic features like subduction zones or collision features as described by the theory of plate tectonics (e.g. see Long and Lowell, 1973). The possibility that collision or separation features exist under the southwestern Georgia Coastal Plain is indicated by the change in character to more symmetrical or east-west anomalies. Finally, the studies of areas where detailed gravity data has been obtained show that gravity data can contribute significantly to the understanding of the geologic structures.

Acknowledgements

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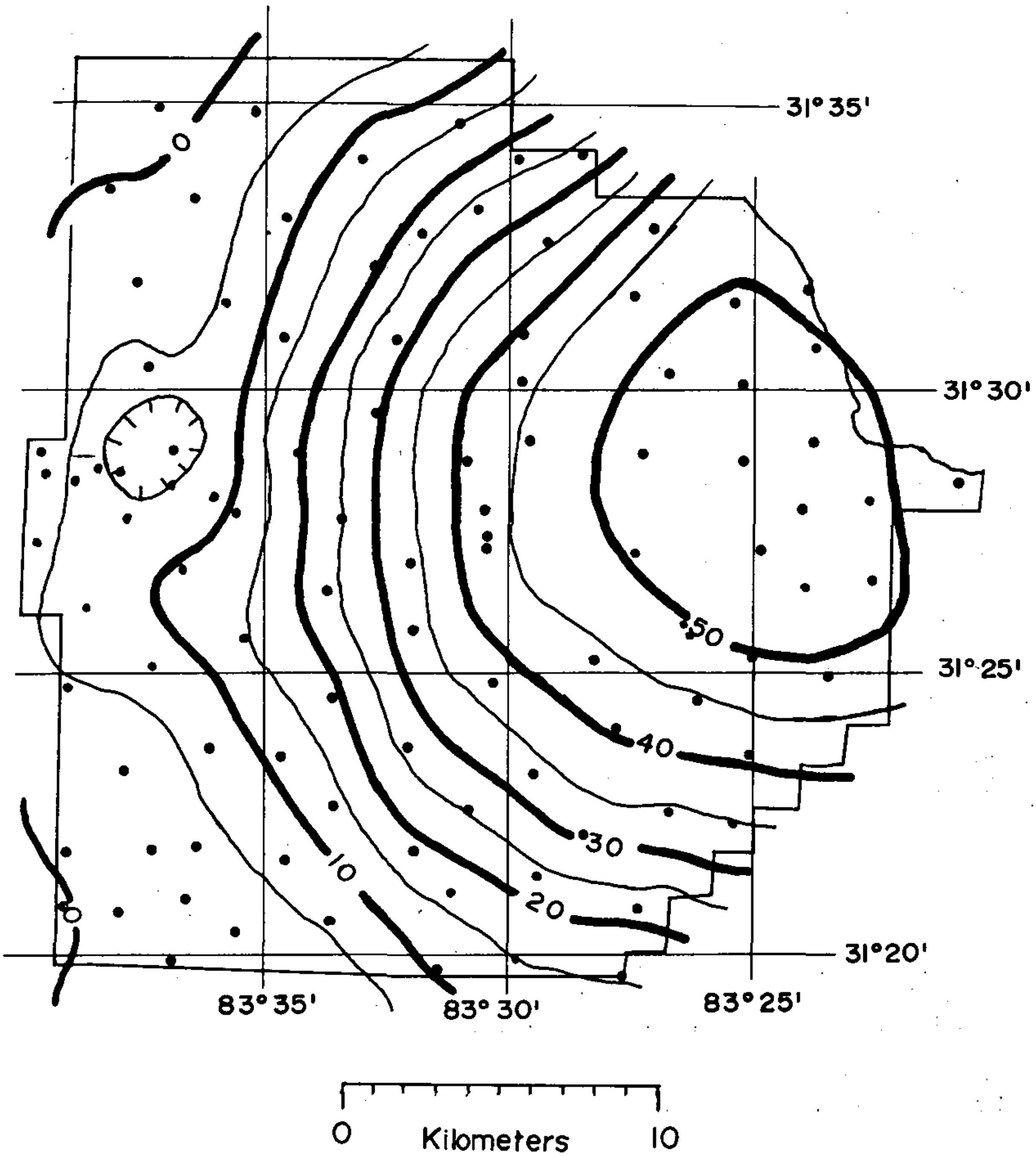

Figure 20. Simple Bouguer anomaly map of Tift County, Georgia (Bridges, 1973).

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SHALLOW, HIGH RESOLUTION SEISMIC INVESTIGATIONS OF THE GEORGIA COAST AND INNER CONTINENTAL SHELF

by

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University of Georgia Marine Institute

INTRODUCTION

Shallow, high resolution seismic investigations of the Georgia coast and inner-continental shelf have revealed a number of interesting stratigraphic and structural features which are of regional significance. This report presents pertinent seismic sections with limited interpretations, preliminary to a more comprehensive work in progress.

Equipment used for the project included:

1) EG&G UNIBOOM, sub-bottom profiler.

2) Truck mounted, rotary drill

3) Boat mounted, jet-airlift drill.

Drill samples were processed and examined for diagnostic planktonic foraminifera and lithologic characteristics which provided data for age assignment and correlation of the various stratigraphic units. Where possible, drill sample data was correlated with key reflector horizons of the seismic records as a means of identification and control. Age assignment (and stratigraphic nomenclature) of the Neogene section in coastal Georgia has been discussed by Giles, Henry, and Woolsey, 1973 and will be considered more fully in the forthcoming comprehensive work.

The seismic profiling and drilling phase of the project was carried out between

January 1971 and June 1973 and was funded by the National Science Foundation (GA 24086) and supported by the facilities of the University of Georgia Marine Institute, Sapelo Island, Georgia and Skidaway Institute of Oceanography, Savannah, Georgia. Gratitude is extended to Mr. Jess Hunt for his help during the seismic and drilling phase and Mr. Paul Huddleston for his assistance in the identification of planktonic foraminifera.

GENERAL GEOLOGY

A. General

The surface and near surface geology of Coastal Georgia consist of a relatively thin sequence of Quaternary sediments composed chiefly of gravels, sands and muds of barrier island/ lagoon and alluvial origin. These deposits overlie a common erosion surface developed on Pliocene and Miocene shallow marine and alluvial sediments dominantly composed of fine,silty sands, gravels and marls (Plate 1).

B. Quaternary Section

The greater part of the Quaternary deposits thin both to west and east, terminating along the eastern flank of the Trail Ridge/ Orangeburg Scarp and the 20 meter shelf contour respectively. Thickness of barrier sequences average 12 to 15 meter with lagoonal counterparts 6 to 9 meter thick. Total Quaternary thickness may approximate 30 meters in sections including burried channels cut into the Tertiary erosion surface. Modern as well as Pleistocene rivers and tidal estuaries commonly cut through the Quaternary sediments and into the underlying Tertiary deposits (Plate 1). Such channels become less common on the near shore shelf (Plate 2) and rare to absent beyond 20 kilometers (Plate 3).

Interesting features in the Quaternary sections revealed by high resolution, sub-bottom profiling include sand waves, both regular (Plate 4) and climbing (Plate 5) and cut and fill structures ranging from small inter-channel features (Plate 6) to major channels (Plates 7 & 8).

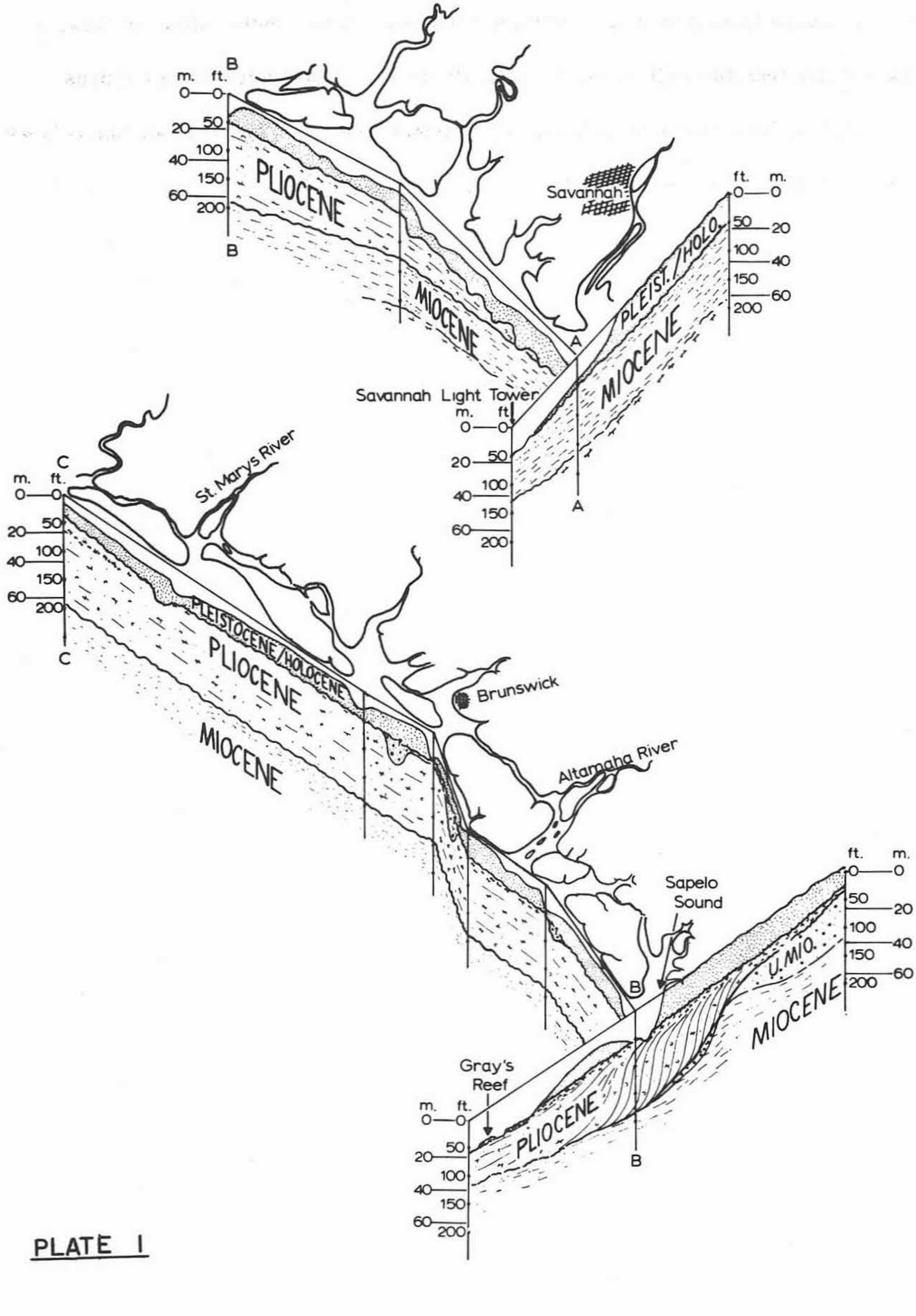
C. Tertiary Section

The uppermost Tertiary sediments in the area are Pliocene. They consist of; 1) a thin, discontinuous blanket of transgressive sands and gravels developed on a Miocene erosion surface, overlain by; 2) regressive deposits of estuarine and deltaic origin consisting of silty sands and gravels. Variable amounts of carbonate occur consisting chiefly of shell parts with secondary concentrations forming local indurated horizons. Carbonate content generally increases to the south. The more sandy facies are typically featureless in the sub-bottom profile records except for a strikingly well developed deltaic sequence of topset, forset and bottomset beds which is traceable from Ossabaw Sound to St. Simons Sound Entrance (Plates 4 & 9). The Pliocene deposits reach their greatest thickness in a wedge located beneath and roughly paralleling the modern shoreline. Thicknesses recorded from drill and seismic data approximate 60 meters in the Brunswick/St. Simons Is. area and at least 30 meters at Amelia Is., Florida. The deposits thin rapidly to the west and typically occur as discontinuous sections of less than 3 meters thick extending as far as Trail Ridge. Seaward, the Pliocene thins gradually to about 15 meters (Plate 10) along the 20 meter curve (approximately 30 kilometers offshore) where local indurated zones of dolomitic calcaranite, less than 1 meter thick, occur as patchy reefs (J. L. Hunt, 1974). This thickness persist at least as far as 65 kilometers offshore to the 60meter curve (Plate 11). To the north the Pliocene thins on the southern flank of a gentle structural rise in the vicinity of Tybee Is.. The section, approximately 20 meters at the Wassaw Sea Buoy (Plate 2), pinches out just south of the Savannah Light (Plate 12). To the south the wedge of Pliocene sediments broadens and thickens along the trend of the South Georgia Embayment. In this region, however, seismic data is limited by restricted penetration in the typically indurated Pliocene surface material.

The deeper Miocene sediments of coastal Georgia are less well known due to depth limitations of high resolution seismic and water-born drill equipment. The upper levels are reasonable well defined, however, particularly in the northern sector. The greater part of the Miocene lithology is a very uniform sequence of locally deformed, alternating beds of fine silty sand, clays and gravel, the latter containing phosphorite of economic interest. The age of this sequence is considered Middle Miocene (Shoal River equivalent, according to Paul Huddleston, personal communication, 1974).

Overlying the Middle Miocene between the Altamaha and Medway Rivers, is a regressive sequence of alluvial sands and gravels. Seismic and drill data suggest the gravels occupy broad fluvial valleys transitional to a deltaic environment. Maximum thicknesses encountered range from 45 to 55 meters in the Riceboro/ Midway area. The age of these gravels has been tentatively assigned to the Upper Miocene as they occur between the marine Middle Miocene deposits and the transgressive Pliocene member (Plate 13 & 14).

A prominent feature apparent in the seismic records is an erosional scarp of some 10 to 15 meter relief extending from Ossabaw to Doboy Sound (Plates 4, 14 & 15). A genetic relationship is suggested for the overlying, Pliocene deltaic, forset sequence which is developed directly on the scarp in the north and superimposed, but separated from it by a structureless sequence in the south. Miocene erosion features are tracable well out on the shelf (Plate 16). Other interesting features revealed on the seismic records include possible diapirs (Plate 13), slumps (Plate 9) faults (Plate 18) and folds (Plate 17).


B
m. ft.
0 0
20 50
100
40
150
60
200
B
PLIOCENE
MIOCENE
Savannah
ft. m.
0 0
50 20
100 40
150
200 60
PLEIST./HOLO.
MIOCENE
A
Savannah Light Tower
m. ft.
0 0
20 50
100
40
150
60
200
A
C
m. ft.
0 0
20 50
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40
150
60
200
C
St. Marys River
PLEISTOCENE/HOLOCENE
PLIOCENE
MIOCENE
Brunswick
Altamaha River
Sapelo
Sound
B
ft. m.
0 0
50 20
100 40
150
200 60
U. MIO.
MIOCENE
Gray's
Reef
m. ft.
0 0
20 50
100
40
150
60
200
PLIOCENE
B

PLATE I

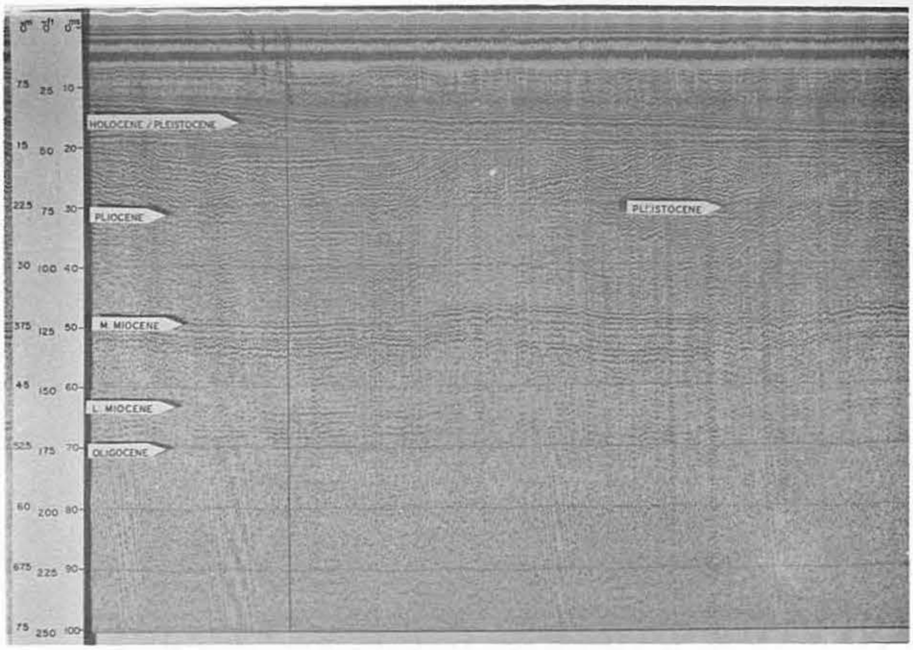


Plate 2

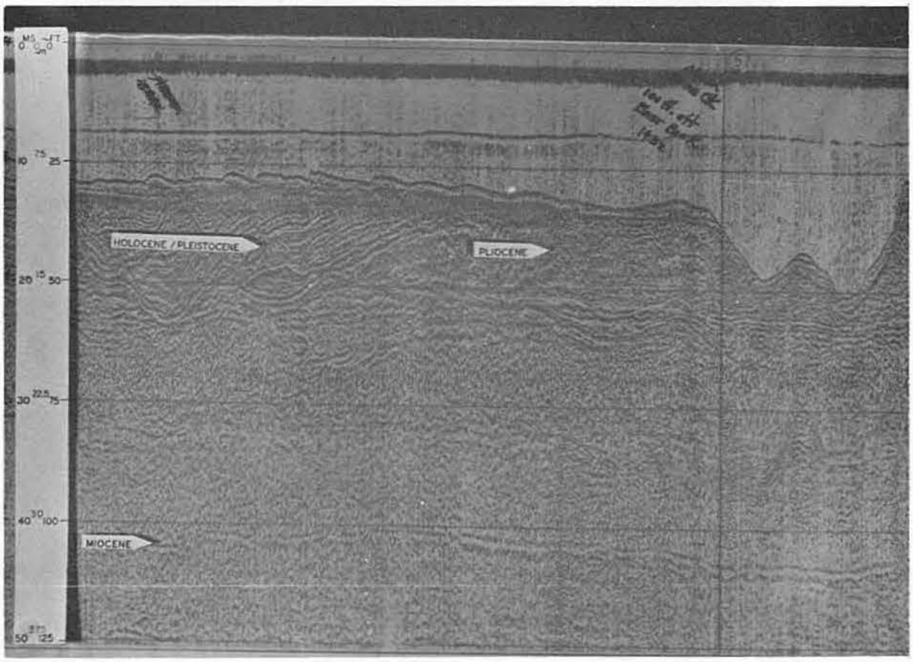


Plate 3

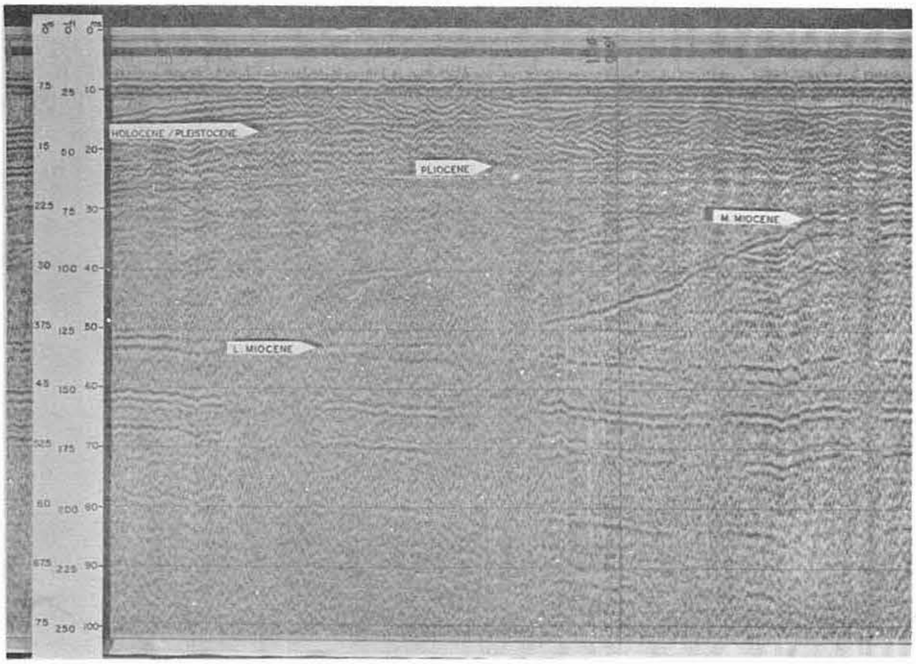


Plate 4

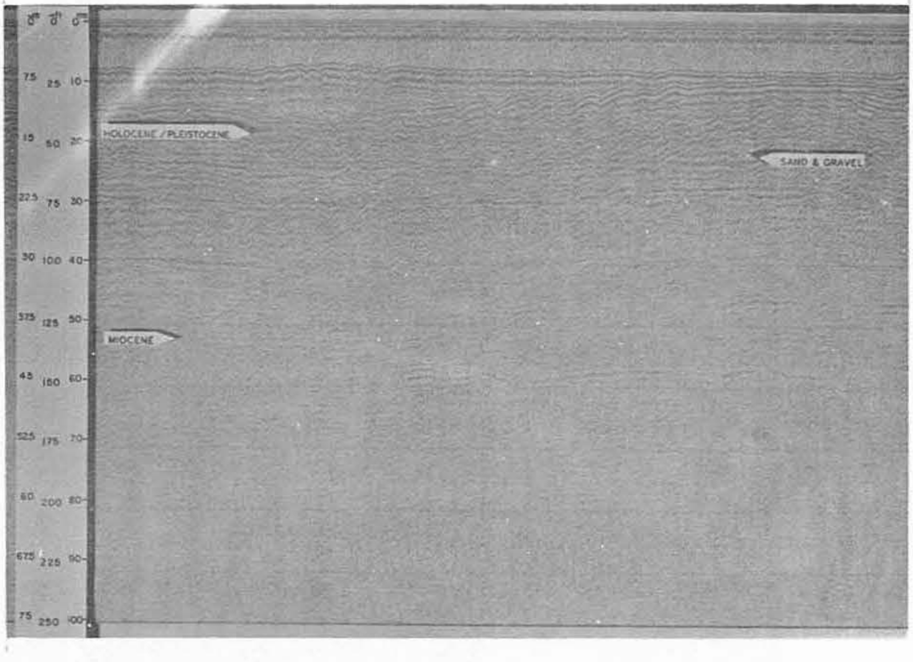


Plate 5

PLATE DESCRIPTION

A. General

Seismic sections cover a horizontal distance of approximately 1 kilometer. The vertical scale reads left to right in meters, feet (approx.) and milliseconds. Locations of the seismic sections are presented on Plate 19.

B. Plates

1) Cross section, (longitudinal and transverse) of the Georgia coast, showing stratigraphic relationships within the Neogene section as interpreted from drill sample and seismic data.

2) Seismic section, approximately 5 kilometers east of Petit Chou Island, extending from S. W. (left) to N. E. (right), showing channel dissection of Pliocene sediments on the Tertiary erosion surface.

3) Seismic section, approximately 20 kilometers east of Wassaw Island, extending from N. W. (left) to S. E. (right), showing channel cut.

4) Seismic section, south of Hells Gate, Ossabaw Sound, extending seaward from W. (right) to E. (left) showing sand waves (megaripples) on bottom surface immediately below the direct arrival trace (parallel traces at 7.5 meters). Pliocene deltaic forset bedding (only slightly evident this section) developed on Miocene erosional scrap which extends southward, roughly paralleling modern coastal zone at least as far as Doboy Sound. Section with deltaic forsets extends further, at least as far as St. Simons Sound entrance.

5) Seismic section, South Altamaha River, large bend, approximately 2 kilometers

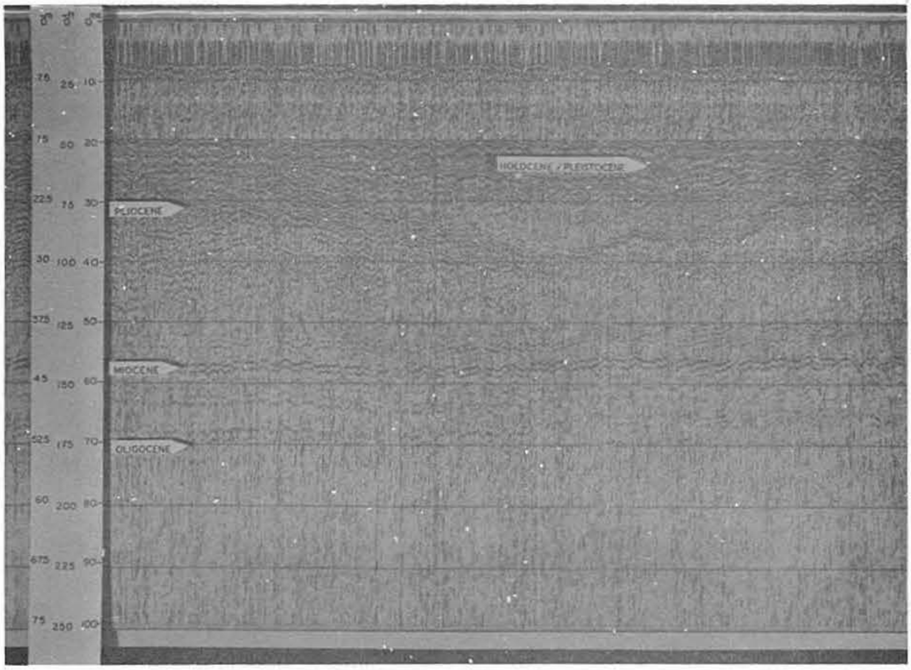
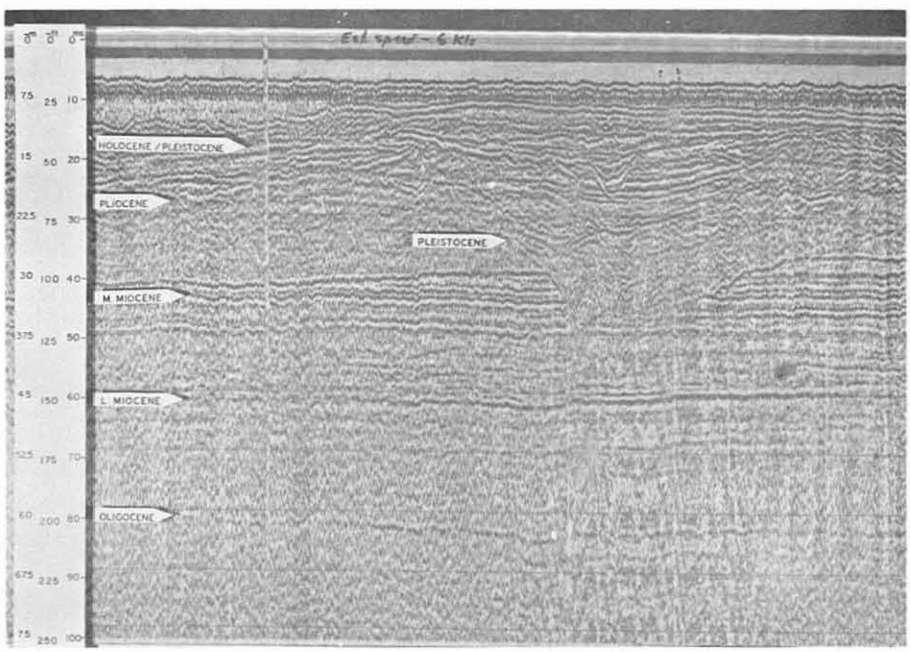


Plate 6



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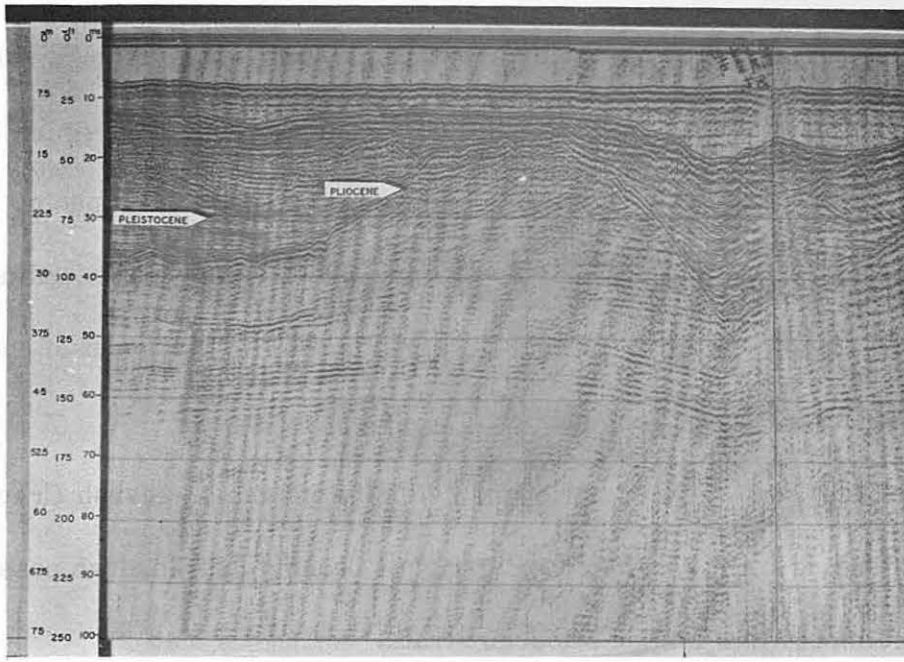


Plate 8

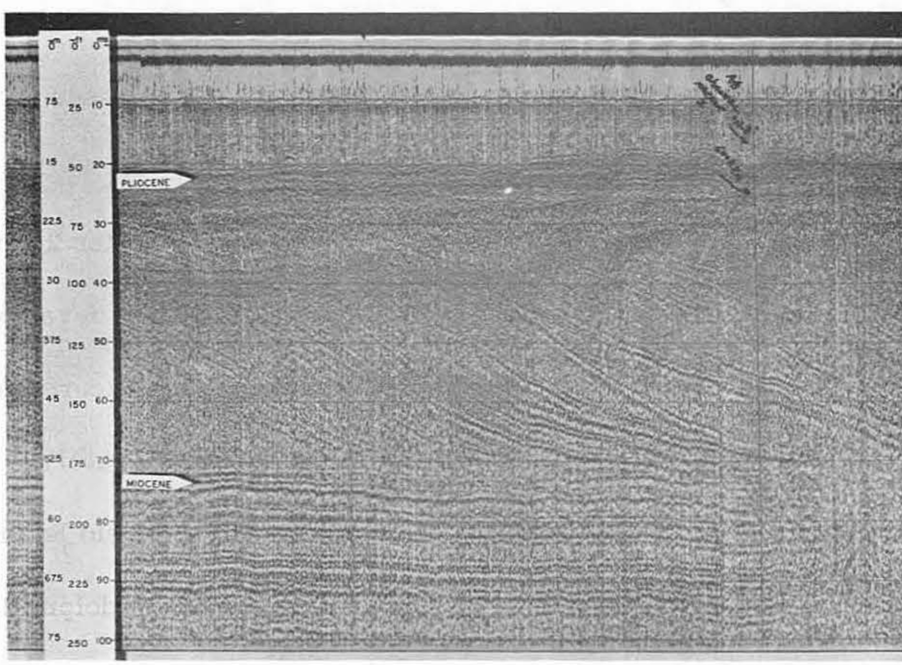


Plate 9

east of the Highway 17 bridge, extending from W. (left) to E. (right). Note climbing ripples developed up slope (down current). Disregard direct arrival trace merging with bottom surface, right side of photo.

6) Seismic section, Duplin River at Barn Creek entrance, extending from S.(left) to N. (right), showing cut and fill structures. Hole at right of photo is scour channel at Barn Creek entrance.

7) Seismic section, Wassaw Sound, vicinity of Romney Marsh Creek entrance, extending from W. (left) to E. (right). Channel cuts through possible Pliocene sediments into Middle Miocene strata.

8) Seismic section, Village Creek, vicinity of large bend abeam St. Simons Island, extending from S. E. (left) to N. W. (right), turning at bend (mark) to N. E. Large channels of probable Pleistocene age cut through Pliocene section with forset bedding. A similar channel on the west side of St. Simons Island, northwest of this section, suggest the channel passes under St. Simons Island (Silver Bluff).

9) Seismic section, Sapelo Sound , vicinity of channel marker 2, extending seaward from W. (left) to E. (right). Deltaic forset bedding developed on Miocene strata, section capped by .5 meter layer of dolomitic calcarenite. Note slump-like feature on lower slope of a forset (right of center).

10) Seismic section, Gray's reef, 30 kilometers east of Sapelo Island, extending from E. (left) to W. (right). Outcrop section consist of dolomitic calcarenite. Disregard multiples at 37.5 and 52.2 meters.

11) Seismic section, Snapper Banks, 65 kilometers east of Sapelo Island, extending from W. (left) to E. (right). Outcrop section consist of dolomitic calcarenite.

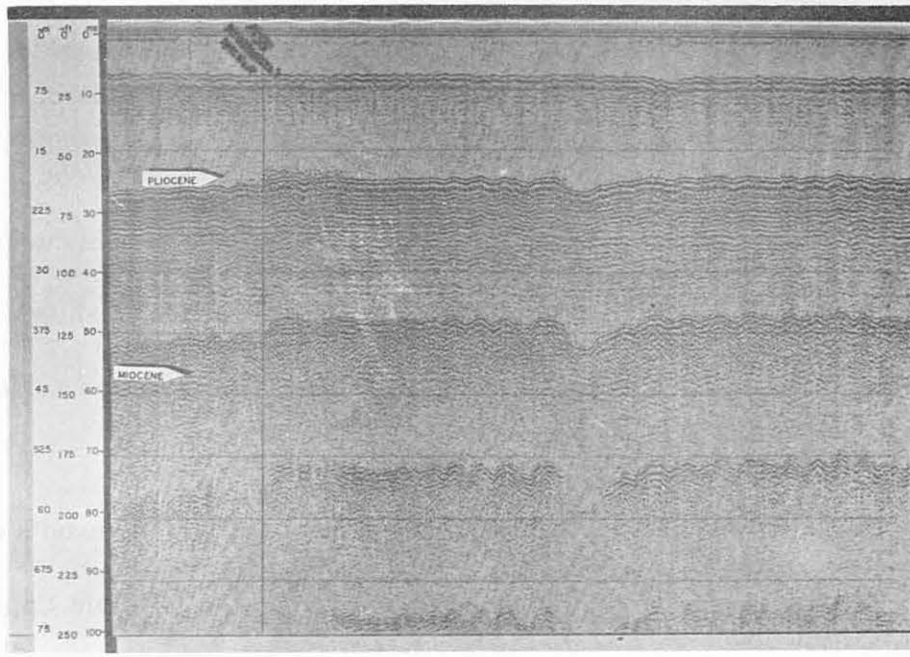


Plate 10

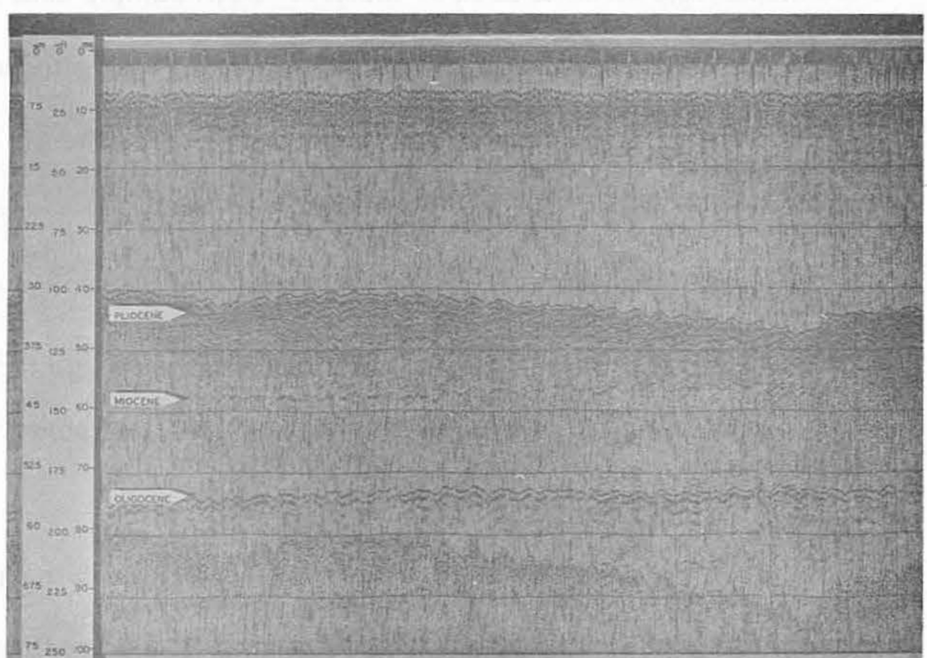


Plate 11

Ripply appearance of traces due to sea effect on transducer raft and hydrophone ell.

12) Seismic section, 3 kilometers southwest of Savannah Light Tower, extending from S.W. (left) to N.E. (right). Pliocene section is shown wedged out on flank of a gentle,regional,structural rise. Note erosion surface with channel dissection of Pliocene sediments.

13) Seismic section, South Newport River, vicinity of Johnson's Cut, extending from W. (left) to E. (right). Alluvial gravels of possible Upper Miocene age overlie Middle Miocene marine deposits both of which are truncated by a common erosion surface.

Immediately overlying the surface are transgressive Pliocene sediments. Note diapir-like structures at 37 meters. Drill sample data suggest that Middle Miocene clays have penetrated overlying Upper Miocene gravels.

14) Seismic section, St. Catherines Sound, vicinity of markers 116 and 114A, extending from W. (left) to E. (right). Possible Pliocene transgressive sequence overlying Miocene erosion surface (scarp), separated from regressive deltaic deposits by strong reflector of possible clay. Record at right side of photo disrupted by non-transmission of energy (possibly due to presence of gaseous surface sediments).

15) Seismic section, Mouth of Doboy Sound, close abeam south tip of Sapelo Island, extending from W. (left) to E. (right). Pliocene sediments overlying Miocene erosion surface. Disregard electrical interference.

16) Seismic section, approximately 10 kilometer west of Snapper Banks, extending

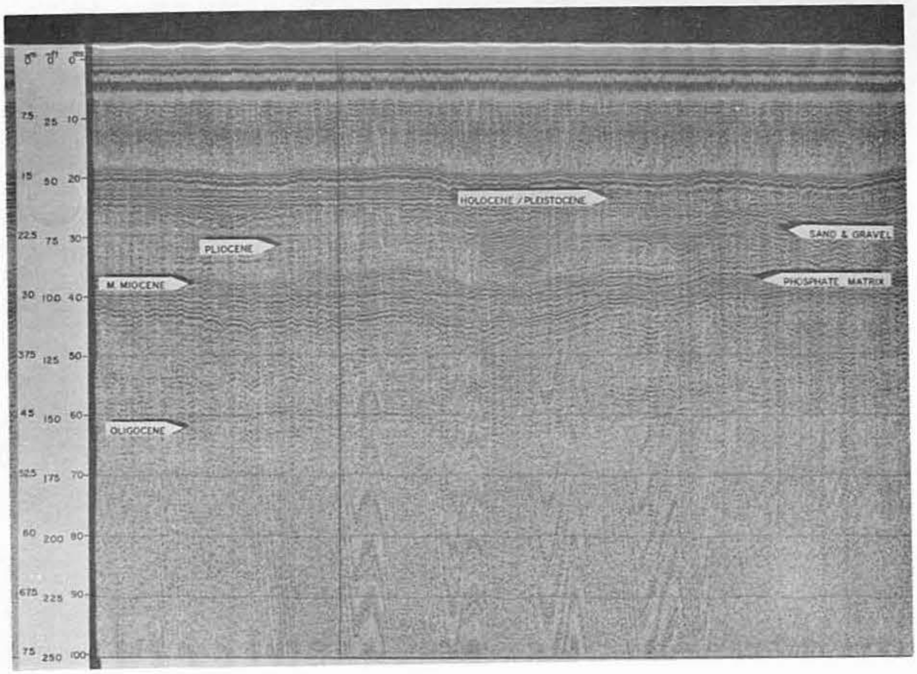


Plate 12

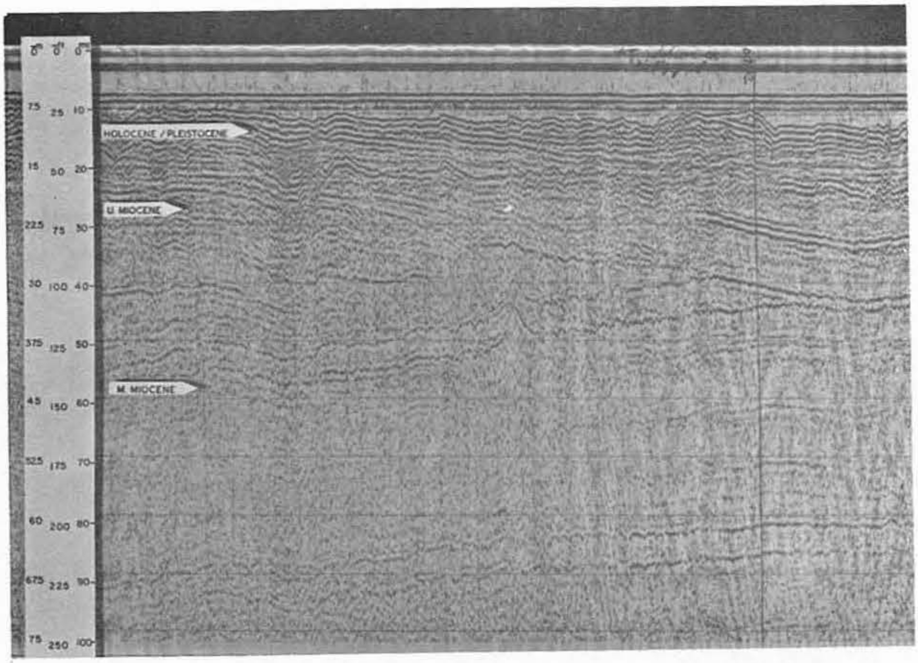


Plate 13

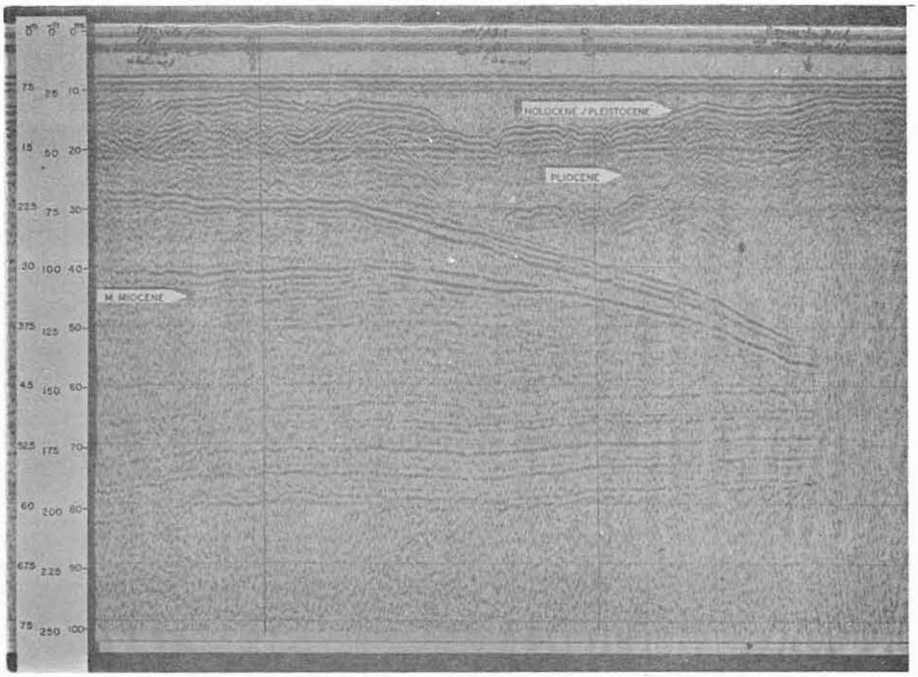


Plate 14

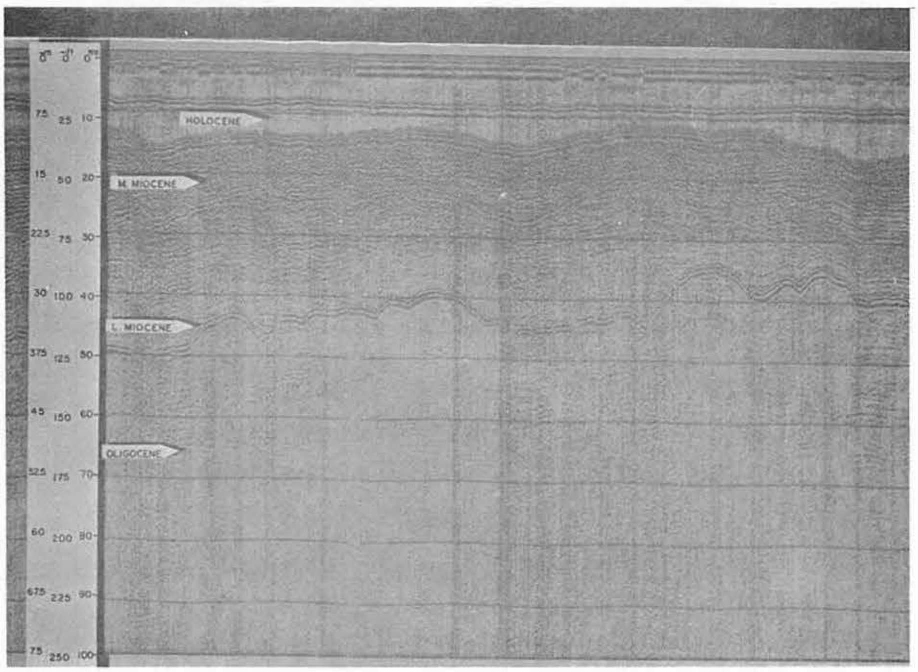


Plate 15

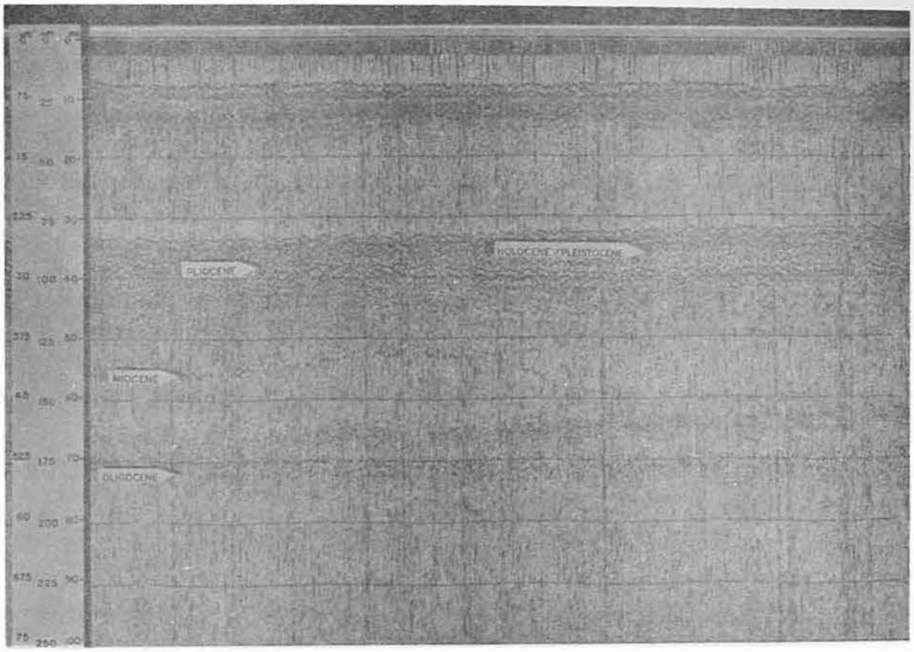


Plate 16

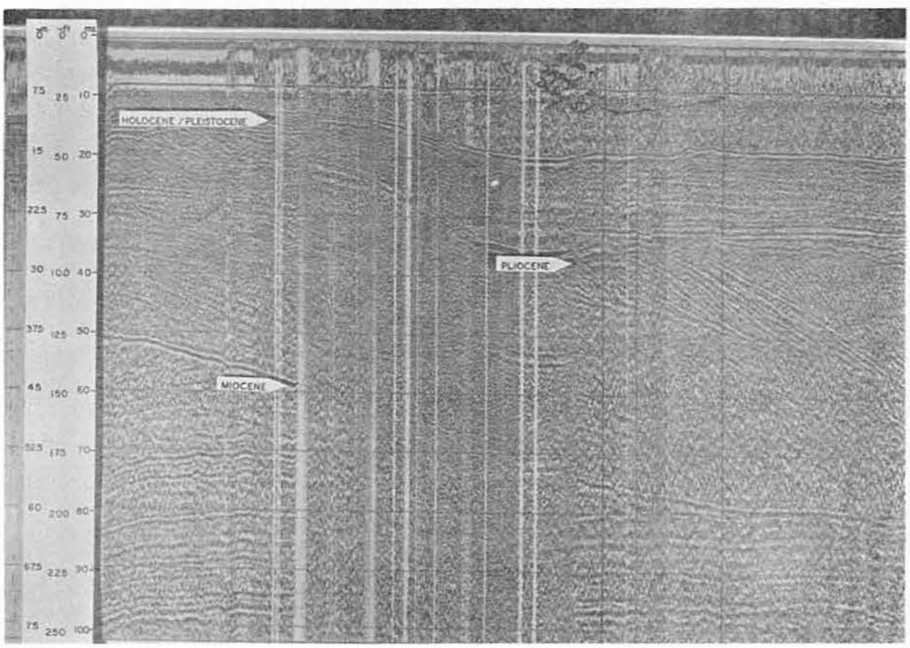


Plate 17

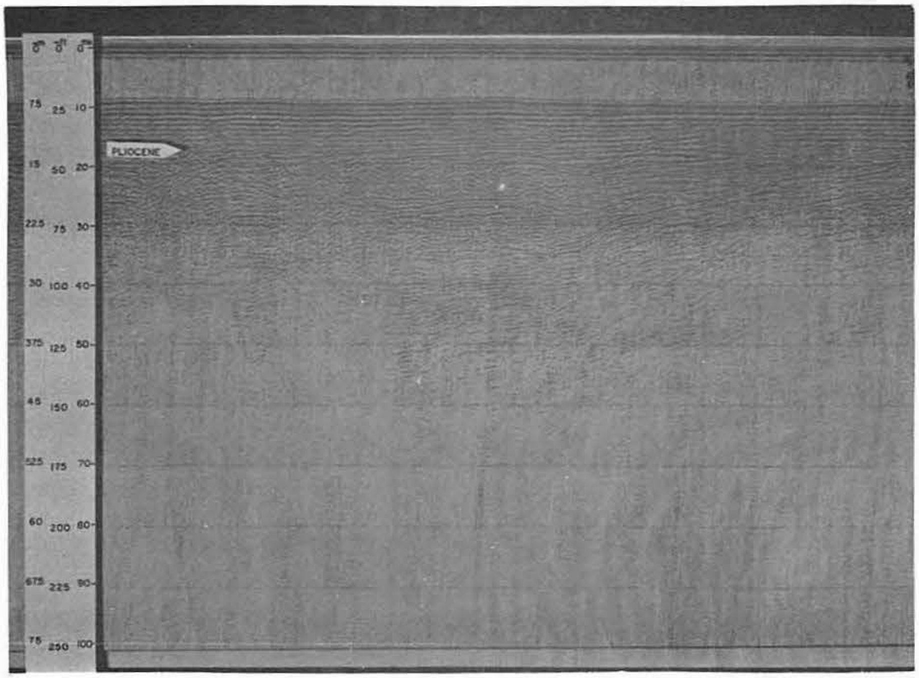
from W. (left) to E. (right). Note faint trace of irregular Miocene erosion surface.

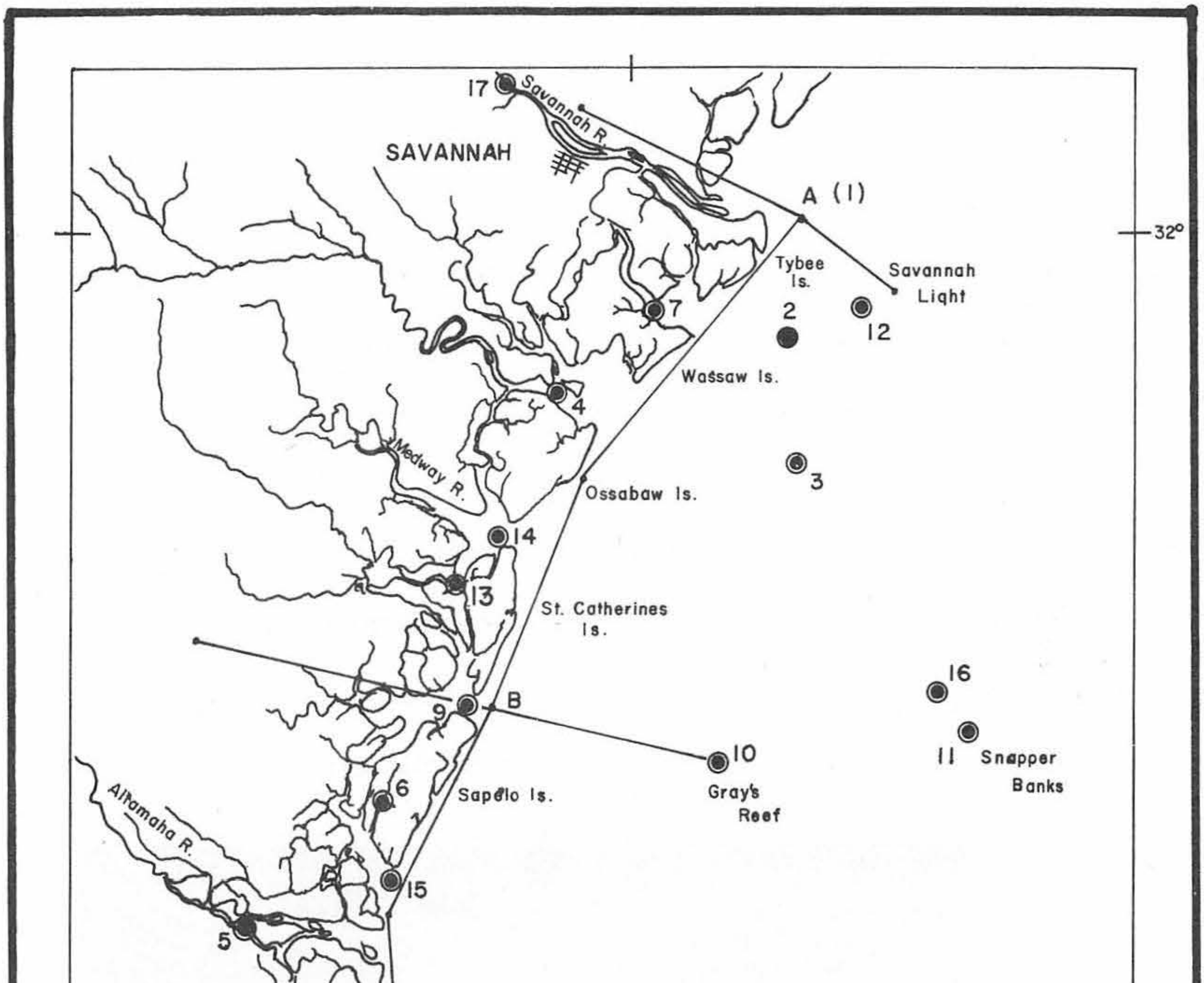
17) Seismic section, Savannah River, 1 kilometer west of Black Creek entrance, extending from W. (left) to E. (right). Folding of Lower Miocene clays possibly related to sliding or slumping on seaward dipping Oligocene strata. Disregard multiples superimposed on Middle Miocene traces.

18) Seismic section, Brunswick River, approximately 1 kilometer west of Highway 17 bridge, extending from W. (left) to E. (right). Possible normal fault of about 7 meter vertical displacement in semi-indurated Pliocene sediments. Disregard multiples giving appearance of continuity through fault zone.

19) Location map of seismic sections by plate number.

Plate 18




17
Savannah R.
SAVANNAH
A (1)
32°
Tybee Is.
Savannah Light
7
2
12
Wassaw Is.
4
Medway R.
3
Ossabaw Is.
14
13
St. Catherines Is.
16
B
9
10
11
Snapper Banks
Gray's Reef
6
Sapelo Is.
Altamaha R.
15
5
8
St. Simons Is.
BRUNSWICK
18
Jekyll Is.
31°
Cumberland Is.
PLATE 19
LOCATION MAP
Seismic section
Cross section
GEORGIA
0
10
20
Kilometers
81°

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AN APPARENT DOMAL STRUCTURE IN WAYNE COUNTY, GEORGIA

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Close examination of a 5-band (red, 600-700 nm.) scanned image from N.A.S.A.'s Earth Resources Technological Satellite has revealed a series of concentric features centered in southern Wayne County, Georgia. Similar concentricity is evident on 7-band (infrared, 800-1100 nm.) images. This frame, which our agency designates H-2, covers 13,500 square miles the southeastern from an altitude of 570 miles.

Drainage on Little Satilla Creek, Penholoway Creek, Little Creek, and at least thirty smaller streams curve about the flanks of a roughly circular area more than twenty miles in diameter. The feature was first noted on images scanned on April 10, 1973; examination of all other clear-weather frames imaged of the area since that date during 1972, 1973, and to date in 1974 shows the feature to remain quite constant in appearance. Color enhancement of these images, by combining bands 5 and 7 with distinctive color filtration, adds to the ability to readily discern drainage and vegetation patterns.

In October of 1973, N.A.S.A. photographed the entire Georgia coast and coastal emerged shoreline area on 1" = 2 mile scale from an ultra-altitude U-2 reconnaissance jet. This color infrared photography allows delineation of a minimum of five concentric semicircular lineations within the feature.

Wayne County, in southeast Georgia, is underlain by approximately 4300 feet of unmetamorphosed Cenozoic and Mesozoic clays, limestones, and sands. Basement here is a complex of meta-arkose

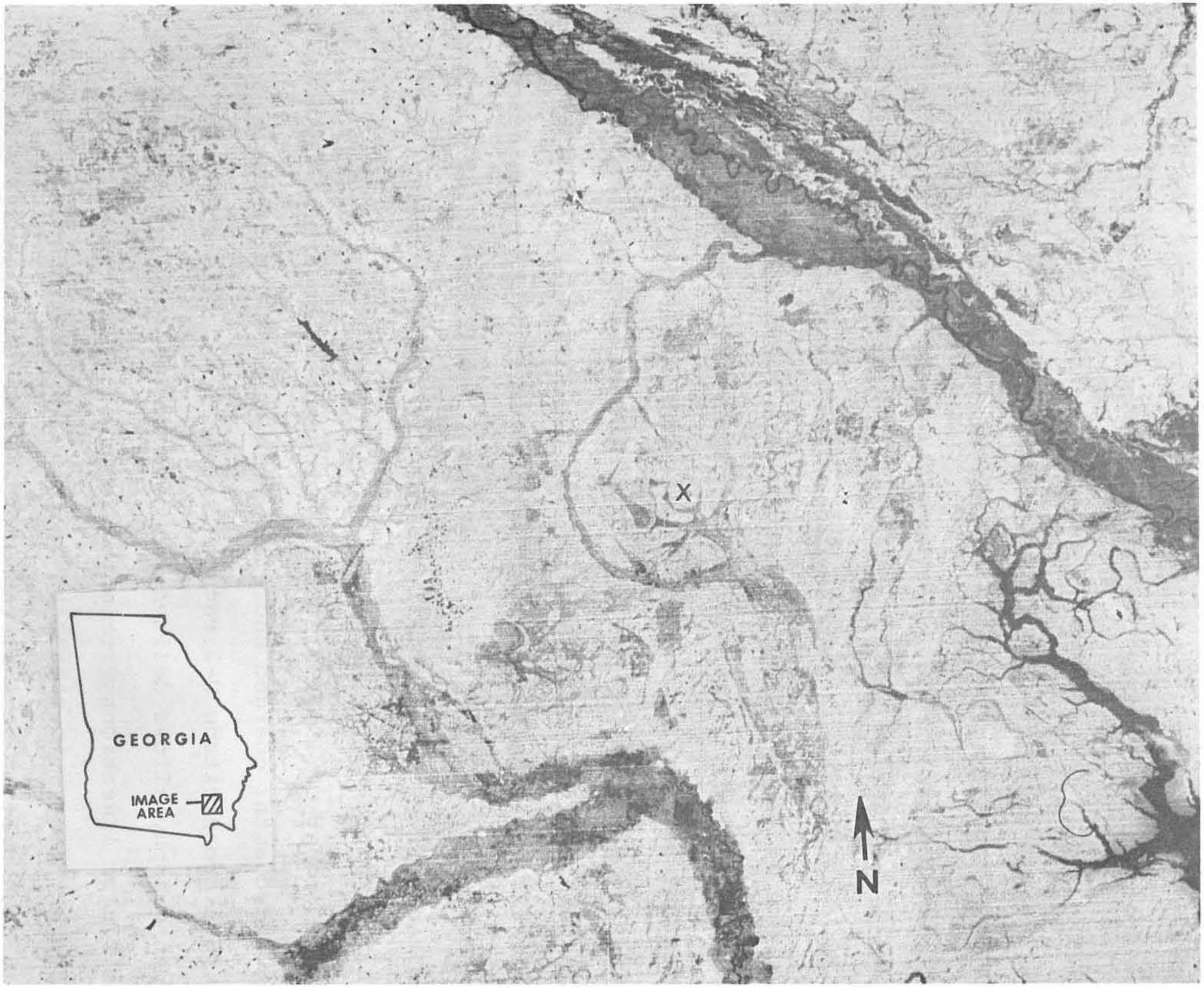

Figure 1   Portion of ERTS-1 image of southeast Georgia, illustrating concentric drainage anomaly. Center of feature is indicated by **X**.

and fine-grained bedded ash, which is presumed to be Paleozoic or older.

The concentric drainage and topography of the feature noted from the satellite images may reflect a positive structure at depth. No indurated rock strata crop out in the area, so the semicircular topographic lineaments are not the result of differential erosion. A more reasonable explanation for the shape of the feature is that existing streams were diverted away from the topographic high at the center of the apparent uplift area. On the flat sand plains of the Georgia coast uplift sufficient to have caused the drainage pattern could have amounted to less than twenty feet; however, deeper strata could be more disturbed.

Several shallow core holes were drilled to determine if substantial stratigraphic displacement were apparent to depths of 650 feet. Lack of precise marker beds and uncertainties of elevation made a clear determination impossible, but the drilling indicates that uplift of more than a few tens of feet has not occurred in the top 600 feet of strata.

A single preliminary gravity survey traverse was made in late 1973 by geophysicists at the Georgia Institute of Technology. This work indicates a 2 to 3 milligal positive anomaly approximately centered on the feature. Additional gravity work, and also magnetic and seismic profiles, are recommended to determine the potential of the area for petroleum or natural gas.

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