Krause

SUBSURFACE GEOLOGY OF THE OCALA LIMESTONE, COOPER MARL, AND SUWANNEE LIMESTONE IN GEORGIA

Steve Herrick

- Gulf Trough is interrupted by the "Interbasin Ridge" where the trough is absent. - p. 17-18.

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

Based on data from 346 wells the subsurface geology of the Ocala Limestone, Cooper Marl, and Suwannee Limestone has been restudied and updated.

The Coastal Plain consists of sediments in the shape of a wedge, which is thickest at the coast and thinnest in the interior. Moreover, this wedge-shaped mass of sediments is modified in certain areas by a number of subsurface structural features, as for example, sedimentary basins, or depressed areas, which cause it to be thicker in some parts than in others.

Interpretation of the stratigraphy of these formations is basically the same as in previous reports. Thus, the Cooper Marl and Twiggs Clay are the updip clastic equivalents of the Ocala Limestone. The Ocala consists of two members, which are differentiated on lithologic and faunal grounds. The Suwannee Limestone unconformably overlies the Cooper Marl and Twiggs Clay in updip parts of the Coastal Plain and the Ocala Limestone in downdip areas.

Foraminifera commonly occurring in each formation are listed. "Larger" foraminifers are common in the two limestone formations, but with one or two exceptions, are absent in the Cooper Marl. The Dictyoconus Zone, a prominent microfossil zone in the Suwannee, is shown to have value as an indicator of erosion that this formation has undergone during Miocene time.

Geologic structure of the Ocala and Suwannee Limestones is shown on three structure-contour maps. Structure of the Cooper Marl is indicated by means of two geologic cross sections. Eight major structural features affect these formations. These include (1) karst topography,

(2) sedimentary basins, (3) Gulf Trough, (4) Interbasin ridge, (5) Southwest Georgia embayment, (6) Southeast Georgia embayment, (7) Peninsular arch, and (8) Cape Fear arch. Four of these are described as to location, origin, and structural implications, the latter including, among other things, problems as to the availability and quality of ground water in certain parts of the Coastal Plain.

INTRODUCTION

This report deals with the subsurface geology of (oldest to youngest) the Ocala Limestone, Cooper Marl, and Suwannee Limestone in Georgia. Since publication of two earlier reports (See Herrick, 1961; also Herrick and Vorhis, 1963) much significant subsurface data have been made available through the drilling of many additional wells. Cores and cuttings from these wells as well as those on which the two earlier reports were based are the basis of this report.

Locations of wells utilized in this investigation are shown on the index map (pl. 1) by numbers. Reference to individual wells in the text and illustrations is by the letters, GGS (Georgia Geological Survey) followed by a number, as for example, GGS 772. Owing to congestion of wells in certain counties use of the letters, GGS, has been omitted.

The following account represents an updating of those parts of the two earlier reports dealing with the formations noted. Beginning with the Ocala Limestone these formations are briefly described as to areal extent, general lithology, and micropaleontology. In the part dealing with the micropaleontology of the Suwannee Limestone mention is made of an important microfossil zone occurring in this formation. Next is a discussion of four subsurface structural features as to their location, origin, and structural as well as practical implications. The report concludes with a summary followed by a listing of some coastal-plain studies requiring, in the writer's opinion, continued investigation. The area covered by this report is shown by the structure-contour maps (pls. 2 - 4) and the thickness map (pl. 5).

ACKNOWLEDGMENTS

The writer wishes to thank his co-workers of the Georgia District for the many services rendered during the preparation of this report. The writer is particularly indebted to R. E. Krause[1], who reconciled the rather voluminous data utilized in the computerized structure-contour maps and the thickness map (pls. 2 - 5). Likewise, thanks are due W. G. Hester[2] for preparation of the illustrations in this report.

PREVIOUS WORK

Relatively few published articles dealing with the subsurface geology of the Coastal Plain of Georgia contain detailed information on the three formations here discussed. The following publications represent the more significant reports dealing with Tertiary rocks in Georgia.

The report by Stephenson and Veatch (1915) has to be regarded as the initial attempt to present information on the subsurface rocks of Georgia's Coastal Plain. This report contains numerous, lithologically descriptive logs of wells which penetrated Cenozoic to Holocene sediments, as well as older rocks.

Following this report Prettyman and Cave (1923) published a report that contained logs of a number of wells, many of which penetrated Cenozoic and older rocks. These logs, chiefly lithologic, contained some stratigraphic information based on macropaleontology.

On the basis of well data from oil test wells the Applins (1944) reported on the lithology, micropaleontology, and structure of Tertiary and older rocks in Florida and adjacent parts of Georgia. This was the

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first publication in which microfossils were utilized in differentiating subsurface geologic formations in Georgia.

In that same year Warren (1944) published a report containing a structure-contour map made on the top of the principal artesian aquifer in Georgia - in this instance a map made on the top of the first reported limestone as interpreted from driller's logs.

On the basis of lithology and macrofossils as observed in well cuttings Richards (1945) reported on the stratigraphy and structure of Late Cretaceous, Cenozoic, and Quaternary rocks in the subsurface of the Coastal Plain in Georgia.

Toulmin (1952) discussed the volume of Cenozoic sediments in Florida and Georgia. Included in this report is a stratigraphic cross section showing the stratigraphy and structure of Cenozoic rocks in the subsurface of east-central Georgia.

Jordan (1954) published an article in which she presented her interpretation of the subsurface stratigraphy and structure of Florida and the Coastal Plain of Georgia.

E. Applin (1960) published an interesting article on the Late Tertiary rocks penetrated by an oil test well in Coffee County, Ga. The discovery of miogypsinids in this well formed the basis for extending the Oligocene section to include deposits not hitherto recognized in Georgia.

Hurst (1960) published a list of 113 oil test wells drilled in Georgia.

Herrick (1961) published descriptive logs on 354 wells, most of which penetrated Tertiary rocks in the Coastal Plain of Georgia.

Owen (1961) reported on the stratigraphy and structure of Early Tertiary to Holocene rocks in the subsurface of a part of southwestern Georgia.

Wait (1962) published a generalized section showing the stratigraphy of Late Tertiary to Holocene rocks in the subsurface of Glynn County, Ga.

Herrick and Vorhis (1963) reported on the stratigraphy, structure, and micropaleontology of Late Mesozoic, Tertiary, and Quaternary rocks in the subsurface of the Coastal Plain of Georgia.

Owen (1963) published valuable information on the stratigraphy and structure of Late Mesozoic to Late Tertiary rocks in the subsurface of Lee and Sumter Counties and adjacent parts of Dougherty and Schley Counties, Ga.

Wait (1965) added valuable information to the record by describing the stratigraphy, structure, and micropaleontology of Late Mesozoic to Tertiary rocks in the subsurface of Dougherty County and parts of adjacent counties, Ga.

The Applins (1964) published descriptive logs on 31 wells, half of which describe rocks of Tertiary age, in the Coastal Plain of Georgia.

McCollum and Counts (1964) reported on the stratigraphy and structure of Late Tertiary deposits in the subsurface of Chatham County, and adjacent parts of South Carolina.

McCollum and Herrick (1964) published an article showing an offshore extension of the stratigraphy, structure, and micropaleontology of Late Tertiary to Holocene sediments in the subsurface of Chatham County, Ga.

Herrick (1965) published information on the lithology, structure, and thickness of Quaternary deposits in the subsurface of the Coastal Plain of Georgia.

Maher (1965) reported valuable information on the subsurface stratigraphy and structure of Mesozoic and Tertiary rocks along the Atlantic Coast of Georgia.

Sever (1965a) published an article showing the stratigraphy and structure of Late Mesozoic and Cenozoic rocks in the subsurface of southwest Georgia and adjacent parts of western Florida.

Sever (1965b) published valuable information on the structure of Late Oligocene (Suwannee Limestone) rocks in the subsurface of Grady and Decatur Counties, Ga.

Sever (1966) published an article showing the subsurface structure of the Suwannee Limestone in Thomas County, Ga.

Sever and Herrick (1967) published a report describing the lithology, stratigraphy, and micropaleontology of Late Tertiary to Holocene rocks penetrated by a test well drilled for the City of Cairo, Grady County, Ga.

Herrick and Counts (1968) reported on the subsurface stratigraphy and structure of Late Tertiary deposits in eastern Georgia.

Maher and E. Applin (1968) reported on the subsurface stratigraphy and structure of Late Mesozoic and Tertiary rocks as interpreted from two oil test wells in Atkinson and Echols Counties, Ga.

Marsalis (1970) published a list of 119 oil test wells drilled in 45 coastal-plain counties of Georgia. When available, summaries of formations penetrated by these wells were included.

Pickering (1970) published information on the geology and paleontology of Middle and Late Eocene and Oligocene formations in a part of north-central Georgia.

Maher and E. Applin (1971) presented much valuable and detailed information on the subsurface stratigraphy, micropaleontology, and structure of Late Mesozoic and Tertiary rocks as interpreted from 15 oil test wells in in 13 counties in the Coastal Plain of Georgia.

Vorhis (1972) published structure-contour maps of three Tertiary formations in the subsurface of six counties in the west-central part of the Coastal Plain of Georgia.

STRATIGRAPHY

The rocks composing the Ocala Limestone, Cooper Marl, and Suwannee Limestone are present throughout the greater part of the Coastal Plain of Georgia but are known chiefly in the subsurface. These rocks are not horizontal but are gently inclined coastward as a consequence of which they come to the surface in updip parts of the Coastal Plain, where they crop out as relatively thin, linear bands. The Ocala Limestone, the oldest of these stratigraphic units, rests unconformably upon Middle Eocene deposits in downdip parts of the Coastal Plain, but conformably upon Early-Late Eocene sediments in updip areas. The Cooper Marl conformably overlies the Ocala Limestone and Twiggs Clay, but is unconformably overlain by the Suwannee Limestone, the youngest of the formations under discussion. Conclusions regarding the stratigraphy and structure of these three formations are based primarily on cuttings from wells utilized in this investigation. These formations are differentiated on the basis of lithology and Foraminifera, the latter occurring in a regular sequence in the wells studied. Paleontologic research shows that the lithologies and microfossil content of the Ocala and Suwannee Limestones in Georgia closely resemble those in equivalent rocks in Florida. Based on planktonic foraminiferal species the Cooper Marl, according to P. F. Huddlestun, 1/ (oral cummunication, 1973) is Late Eocene in age and equivalent to the Ocala Limestone. In this report the first observed marl occurring below the Suwannee Limestone has been logged as Cooper Marl and in some downdip areas as Cooper Marl-Marianna Limestone, Undifferentiated (fig. 6a).

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Ocala Limestone

The structure-contour map (pl. 2) of the Ocala Limestone shows the areal extent of this formation. Among other things this map shows the area underlain by this limestone as exceeding that of the other two formations, particularly the Cooper Marl. In support of this is the large area in southwest Georgia, known as the "Dougherty Plain" (fig. 1), where the Cooper Marl and Suwannee Limestone are absent, is underlain bhroughout by the Ocala Limestone.

As far as the writer is aware the Applins (1944, p. 1683) were the first to recognize two lithologic, as well as faunal, divisions of the Ocala Limestone in Florida and southern Georgia. Since that time subsequent research in Georgia has borne out the validity of their findings (fig. 4a). Examination of the lower, or basal, member of the Ocala shows this formation to consist of limestone interbedded with cream, chalky, ooze-like (when wet) marl, which is much calcitized so as to be granular and often rather loosely consolidated. These sediments are often coarsely but sparsely glauconitic at depth and, in certain horizons, very fossiliferous, with "larger" foraminiferal species predominating. The upper member is flat-white, highly calcitized, somewhat denser than the lower member, abundantly fossiliferous, but with the "smaller" foraminifers predominating. Both members may be locally dolomitized, hence light to dark-brown in color depending upon the degree of dolomitization.

Anyone who has observed the Ocala Limestone both in the field and in well cuttings cannot fail to be impressed with its high fossil content, such fossils, in addition to Foraminifera, including molluscan shells, echinoid and bryozoan remains, and Ostracods. The lower member

Table 1:- Foraminifera of the Ocala Limestone

Lower Member

Amphistegina alabamensis Applin and Jordan

cosdeni Applin and Jordan

Nummulites mariannensis (Vaughan)

striatoreticulatus (Rutten)

~~willcoxi~~ Heilprini Hantken

Upper Member

Robulus alatolimbatus (Gümbel)

Planularia stavensis Bandy

truncana (Gümbel)

Dentalina fissicostata Gümbel

Lingulina ocalana Puri

Frondicularia virginiana Cushman and Cederstrom

Nonion planatus Cushman and Thomas

Nummulites floridensis Heilprin

heilprini (Hantken) ~~moodysbranchensis~~ (Gravell and Hanna)

Heterostegina ocalana Cushman

Bolivina jacksonensis Cushman and Applin

Uvigerina gardnerae Cushman

Angulogerina ocalana Cushman

Valvulineria texana Cushman and Ellisor

Stomatorbina kendrickensis Puri

Gyroidina crystalriverensis Puri

nassauensis Cole

springfieldensis Puri

Table 1 Cont'd.:

Upper Member

Eponides jacksonensis (Cushman and Applin)

Siphonina jacksonensis Cushman and Applin

Globorotalia crystalriverensis Puri

Planulina kendrickensis Puri

Cibicidina mississippiensis (Cushman)

ocalana (Cushman)

Cibicides lobatulus (Walker and Jacob)

Sphaerogypsina globula (Reuss)

vesicularis (Parker and Jones)

Lepidocyclina ocalana Cushman

Asterocyclina nassauensis Cole

Pseudophragmina flintensis (Cushman)

is fossiliferous only at certain horizons, whereas the upper member is apparently quite fossiliferous throughout. Certain horizons in the upper member may be composed almost entirely of echinoid and bryozoan remains. Foraminiferal species indicative of the Ocala Limestone are listed in table 1. For more detailed lists see reports by Applin and Jordan (1945), Herrick and Vorhis (1963), and Maher and E. Applin (1971).

Cooper Marl

Based on wells and known outcrops the approximate areal extent of the Cooper Marl is considerably less than that of either the Ocala Limestone or the Suwannee Limestone (fig. 3). Chiefly responsible for this is the fact, that the Cooper is the stratigraphic equivalent of the Ocala Limestone, hence is necessarily limited in its occurrence to updip areas of the Coastal Plain. Another contributing factor is its absence in the Dougherty Plain, as previously noted, and in the "Interbasin Ridge," a subsurface structural feature described below (fig. 3).

As observed in well cuttings and outcrop samples the Cooper is a marl, which, in some instances, is interbedded with occasional, relatively thin tongues of rather soft, argillaceous limestone. The marl is cream to white, somewhat sandy, locally cherty and glauconitic, and generally very fossiliferous.

The fossils observed in the Cooper consist of abundant echinoid and bryozoan remains, frequent thin-shelled mollusks, occasional corals, and common to abundant foraminifers, which are almost exclusively of the "smaller" type. For a listing of some of the macrofossils and

Table 2:- Foraminifera of the Cooper Marl

Spiroplectammina alabamensis (Cushman)

Textularia adalta Cushman

broussardi Howe and Wallace

danvillensis Howe and Wallace

dibollensis Cushman and Applin

tumidulum Cushman

Gaudryina gardnerae Cushman

Liebusella byramensis extans (Cushman)

byramensis turgida (Cushman)

Massilina decorata Cushman

Pyrgo inornata danvillensis Howe and Wallace

Robulus arcuatostriatus carolinianus Cushman

articulatus texanus (Cushman and Applin)

propinquus (Hantken)

vicksburgensis (Cushman)

Lenticulina convergens (Bornemann)

Planularia stavensis Bandy

truncana (Gümbel)

Marginulina cocoaensis Cushman

cf. *georgiana* Cushman

nuttalli Todd and Kniker

Dentalina basitorta Cushman

communis (D'Orbigny)

cooperensis Cushman

latejugata carolinensis (Cushman)

vertebralis (Batsch) var.

Table 2 Cont'd.

Nodosaria affinis Reuss

catesbyi D'Orbigny

longiscata D'Orbigny

Pseudonodosaria conica (Neugeboren)

Lagena acuticosta Reuss

Oolina hexagona (Williamson)

Fissurina laevigata Reuss

Guttulina austriaca D'Orbigny

byramensis (Cushman)

Globulina gibba punctata D'Orbigny

inaequalis Reuss

rotundata (Bornemann)

Pyrulina cylindroides (Roemer)

Pseudopolymorphina decora (Reuss)

dumblei (Cushman and Applin)

Sigmomorphina jacksonensis (Cushman)

semitecta (Reuss) var.

Polymorphina advena nuda Howe and Roberts

frondea (Cushman)

Nonion advena (Cushman)

affine (Reuss)

danvillensis Howe and Wallace

Nonionella hantkeni spissa Cushman

jacksonensis compressa Cushman and Todd

oligocenica Cushman and McGlamery

Nummulites panamensis Cushman

Sorites cf. dominicensis Ehrenberg

Table 2 Cont'd.

<u>Bolivinella</u> <u>rugosa</u> Howe

<u>subpectinata</u> Cushman

<u>Nodogenerina</u> <u>cooperensis</u> Cushman

<u>Buliminella</u> <u>elegantissima</u> (D'Orbigny)

<u>Bulimina</u> <u>byramensis</u> Cushman and Todd

<u>cooperensis</u> Cushman

<u>cuneata</u> Cushman

<u>Virgulina</u> <u>dibollensis</u> Cushman and Applin

<u>vicksburgensis</u> Cushman

<u>Bolivina</u> <u>byramensis</u> Cushman

<u>choctawensis</u> Cushman and McGlamery

<u>costifera</u> Cushman

<u>danvillensis</u> Howe and Wallace

<u>gardnerae</u> Cushman

<u>jacksonensis</u> Cushman and Applin

<u>mexicana</u> Cushman

<u>mornhinvegi</u> Cushman

<u>ouachitaensis</u> Howe and Wallace

<u>spiralis</u> Cushman

<u>striatella</u> Cushman and Applin

<u>Bitubulogenerina</u> <u>hiwanneensis</u> Howe

<u>Tubulogenerina</u> <u>vicksburgensis</u> Howe

<u>Reussella</u> <u>byramensis</u> Cushman and Todd

<u>oligocenica</u> Cushman and Todd

<u>rectimargo</u> (Cushman)

<u>Uvigerina</u> <u>cocoaensis</u> Cushman

<u>farinosa</u> Hantken

Table 2 Cont'd.

Uvigerina gardnerae Cushman

glabrans Cushman

vicksburgensis Cushman and Ellisor

Angulogerina byramensis (Cushman)

multicostata yazooensis Bergquist

vicksburgensis Cushman

Trifarina advena Cushman

Ellipsonodosaria cocoaensis (Cushman)

jacksonensis (Cushman and Applin)

pilulata Cushman and Todd

Spirillina vicksburgensis Cushman

vivipara Ehrenberg

Patellina advena Cushman

Discorbis arcuatocostatus Cushman

assulatus Cushman

globulospinosus Cushman

orbicularis (Terquem)

patelliformis (H. B. Brady) Cushman

tentorius Todd

Valvulineria texana Cushman and Ellisor

cf. *venezuelana* Hedberg

Gyroidina danvillensis Howe and Wallace

elongata Cushman and Bermudez

obesa Bandy

vicksburgensis (Cushman)

Eponides advenus (Cushman)

byramensis (Cushman)

campester Palmer and Bermudez

Table 2 Cont'd.

Eponides carolinensis Cushman

cf. crebbsi Hedberg

ouachitaensis Howe and Wallace

Pararotalia mecatepecensis (Nuttall)

parva (Cushman)

Siphonina advena eocenica Cushman and Applin

jacksonensis Cushman and Applin

Cancris cocoaensis Cushman

Baggina marielina Cushman and Bermudez

Asterigerina bracteata Cushman

subacuta Cushman

Alabamina mississippiensis Todd

wilcoxensis Toulmin

Cassidulina crassa D'Orbigny

globosa Hantken

laevigata D'Orbigny

Hantkenina alabamensis Cushman

Globorotalia cocoaensis Cushman

mariannensis (Cushman)

Anomalina bilateralis Cushman

cocoaensis Cushman

danvillensis Howe and Wallace

Planulina byramensis (Cushman)

camagueyana Bermudez

cocoaensis Cushman

cooperensis Cushman

Cibicidina americana (Cushman)

Table 2 Cont'd.

Cibicidina mississippiensis (Cushman)

ocalana (Cushman)

Cibicides choctawensis Cushman and McGlamery

cocoaensis (Cushman)

lobatulus (Walker and Jacob)

lobatulus (Walker and Jacob) var.

pippeni Cushman and Garrett

planoconvexus Cushman and Todd

pseudoungerianus (Cushman)

Sphaerogypsina globula (Reuss)

vesicularis (Parker and Jones)

Lepidocyclina mantelli (Morton) Gumbel

foraminiferal species indicative of the Cooper Marl see a report by Pickering (1970). Foraminifera observed by the writer and regarded as indicative of the Cooper are listed in table 2.

Suwannee Limestone

The structure-contour map (pl. 3) shows the area underlain by the Suwannee Limestone. Except for the Dougherty Plain, in southwestern Georgia, and eastern Charlton County and Camden County, in southeastern Georgia, the Suwannee underlies an area that is approximately the same as that of the Ocala Limestone.

The Suwannee Limestone generally consists of rather pure, massive, cream, saccharoidal limestone. However, in some updip, peripheral areas it may be somewhat sandy and locally very cherty. In downdip areas it may often be considerably dolomitized, therefore light to dark-brown in color, depending upon the degree of dolomitization. A good example is the Cairo area, Grady County, where the Suwannee is dolomitized to some degree throughout most of its areal extent in this county.

The Suwannee is marine throughout and is quite fossiliferous at certain horizons, with molluscan shells, some corals, echinoid and bryozoan remains, ostracods, and foraminifers. Some of the more commonly occurring foraminiferal species found in this formation are listed in table 3. For more extended lists see reports by Applinand Jordan (1945), Herrick and Vorhis (1963), and Maher and E. R. Applin (1971).

"Dictyoconus Zone

As observed in numerous wells several foraminiferal species, originally described from the Middle Eocene of Florida, represent a well defined zone within this unit (fig. 4b). Prominent amont the fossils of this zone is the readily recognizable genus, Dictyoconus, after which this

Table 3:- Foraminifera of the Suwannee Limestone

Spiroplectammina alabamensis (Cushman)
Valvulina floridana Cole
martii Cushman and Bermudez
Pseudochrysalidina floridana Cole
Dictyoconus floridanus (Cole)
Quinqueloculina byramensis Cushman
leonensis Applin and Jordan
Pyrgo byramensis Cushman and Todd
monroei Cushman and Todd
Lingulina mesonensis Cole
Nonion advena (Cushman)
Nonionella hantkeni byramensis Cushman and Todd
oligocenica Cushman and McGlamery
Reussella byramensis Cushman and Todd
oligocenica Cushman and Todd
Discorinopsis gunteri Cole
Uvigerina vicksburgensis Cushman and Ellisor
Discorbis byramensis (Cushman)
Eponides byramensis (Cushman)
Pararotalia byramensis (Cushman)
mecatepecensis (Nuttall)
Siphonina advena Cushman
Asterigerina subacuta Cushman
Cibicides lobatulus (Walker and Jacob)
Lepidocyclina undosa Cushman
Sphaerogypsina globula (Reuss)

zone is named. Associated with *Dictyoconus*, though not always present, are four other species belonging to the genera, *Valvulina*, *Discorinopsis*, and *Pseudochrysalidina* (table 3). This zone, marked by the first observed occurrence of *Dictyoconus*, generally occurs well below the top of the Suwannee (fig. 4b). However, in certain parts of the Coastal Plain this zone has been observed occurring close to, and in several instances, at the top of this formation. Where this is the case the inference is, that the part of the Suwannee normally occurring above this zone has been subsequently removed by erosion, a significant fact whose implications become apparent in the discussion that follows.

STRUCTURE

The subsurface structure of the Ocala and Suwannee Limestones is shown by structure-contour maps made on three different datums (pls. 2 - 4). One thickness map (pl. 5) and two structure cross sections (fig. 6, a and b) supplement the structure-contour maps, the cross sections in particular, showing the structure of the Cooper Marl.

The Ocala Limestone, Cooper Marl, and Suwannee Limestone compose a relatively small fraction of a sedimentary blanket that forms the Coastal Plain. This blanket, which is thickest at the coast and thinnest in the interior, overlies much older rocks, i.e. the pre-Cretaceous, or basement complex. These ancient rocks, besides being highly metamorphosed, have been structurally deformed in certain areas, such deformation resulting in regional structures, or anomalies. These include the Cape Fear arch, Peninsular arch, Southwest Georgia embayment, and Southeast Georgia embayment (fig. 2). For more detailed information on these structures see reports by P. Applin (1951), Murray (1961, p. 92 - 98), Maher (1965, p. 22 - 25), and Stringfield (1966, p. 73 - 76). These structures in the basement rocks are believed to have been either directly, or indirectly, responsible for certain other subsurface structural features including karst topography, sedimentary basins, Gulf Trough, and Interbasin Ridge, each of which is discussed below.

Karst Topography

As shown by the two structure-contour maps (pls. 2 and 3) the most prominent surficial feature of the Ocala and Suwannee Limestones is the occurrence of numerous depressions, or sinkholes, of various shapes and sizes, which, collectively, constitute karst topography. According to Stringfield (1966, p. 194) wherever limestone is at or near the surface solution, aided by subaerial erosion, has resulted in this type of topography. He further points out (1966, p. 195), that Tertiary limestones in Georgia and Florida are at or near the surface in two principal areas:

1. In updip areas where sedimentary formations come to the surface as the result of normal regional dip.

An excellent example is the Dougherty Plain (fig. 1), in southwestern Georgia. Here both the Suwannee Limestone and the Cooper Marl are absent, having been removed through a combination of solution and erosion. For a description of how this process has operated in Baker and Mitchell Counties see article by Herrick and LeGrand (1964).

2. In areas that are on top of regional structure. Examples of this are Chatham County, in eastern Georgia, and a large area in extreme southern and southeastern Georgia, both areas affected by the Cape Fear arch and the Peninsular arch, respectively. In ~~both~~ these areas much of the Suwannee Limestone has been removed through solution and erosion and

karst formed on top of the remainder. Some idea of the amount of limestone that has been removed is seen by the fact, that most, and in some instances all, of the Suwannee normally occurring above the Dictyoconus Zone is missing in these two areas. An example of an area in which this process has been carried to the extreme is Camden and eastern Charlton Counties, where the Suwannee is missing altogether.

Erosion, such as indicated, is thought to have taken place during Miocene time when erosion on a regional scale is known to have occurred in northeastern Florida and adjacent parts of Georgia. Regarding erosion in northeastern Florida Stringfield states (1966, p. 73),-"During Miocene time the northern part of the peninsula (of Florida) was uplifted, causing the complete removal of Oligocene rocks from a broad area and the irregular erosion of the upper part of the Eocene Series (i.e. the Ocala Limestone).-"

Stringfield further states (1966, p. 79) that where limestones occur at depth and are covered with a relatively thick sedimentary blanket, karst has also developed, but in this case chiefly during periods of eustatic changes of the Pleistocene sea. An example is the McIntosh-Glynn County area, in the Southeast Georgia embayment. Here changes in Pleistocene sea level as much as 300 feet, and more, below present sea level have permitted karst to develop on top of the deeply buried Suwannee and Ocala Limestones, particularly the latter.

Sedimentary Basins

As shown by the thickness map (pl. 5) another prominent structural feature affecting these formations is the occurrence of two major sedimentary basins, or depo-centers, situated within the Southwest Georgia embayment and Southeast Georgia embayment. That major depo-centers occur in these two embayments was first demonstrated in a report by Toulmin (1952) and later-on by Herrick and Vorhis (1963).

According to these reports great thicknesses of Late Eocene deposits, including the Ocala and Cooper Marl, occur in both embayments. However, available data show that maximum thickness of the Ocala Limestone is in the Southeast Georgia embayment, where it exceeds 500 feet in coastal Chatham County (fig. 4c). According to Toulmin (1952, fig. 6), maximum thickness of the Suwannee Limestone is in the Southwest Georgia embayment, where it attains an approximate thickness of 200 feet. As shown in the cross section (fig. 6a) the Suwannee exceeds 200 feet in thickness throughout most of the Gulf Trough, which is an extension of this embayment (fig.). Likewise, the Cooper attains its greatest thickness in this trough northward of which it thins to its area of outcrop.

Gulf Trough

Still another structural feature affecting these three stratigraphic units is the Gulf Trough, a linear, depressed area extending diagonally between, but not connecting the two embayments (fig. 5). The name, "Gulf Trough," was proposed by Herrick and Vorhis (1963, p. 55) for a subsurface feature in Southwest Georgia, a structure first recognized by the Applins (1944, p. 1727) as "extending southwestward across Georgia through the Tallahassee area of Florida, to the Gulf of Mexico." As described by Herrick and Vorhis, this trough is a "linear feature extending northeastward from Grady County through northwestern Thomas and Colquitt, (possibly continuing) through Tift, Irwin, and notthern Coffee Counties." In this report (See fig. 5) this trough extends from Decatur, Grady, and

Thomas Counties, northeast to Coffee County, where it is apparently absent. Northeast of Coffee County, as indicated by wells, it seems to be present in Jeff Davis County and parts of Montgomery, Toombs, and Tattnall Counties. Again on the basis of wells and other data this trough continues in a northeasterly direction across Candler, Bulloch, and Screven Counties to the Savannah River (fig. 5). That figure 5 represents the true course of this subsurface trough is substantiated by figure 7. This figure shows closely spaced contours, which, collectively, form a narrow band whose course across Georgia closely approximates that of the Gulf Trough as shown in figure 5. Moreover, examination of wells situated in the area represented by this band of contours revealed the presence, at depth, of Cooper Marl. The Cooper is a formation with known low permeability, hence would reflect piezometric levels as shown in figure 7.

Regarding the origin of the Gulf Trough geologists have expressed varying opinions several of which have been previously suggested in a report by Patterson and Herrick (1971), but are here somewhat expanded in the light of more recent data.

As might be expected, foremost among these hypotheses is the so-called, "graben" theory, which by necessity entails a certain amount of faulting. According to this theory the Gulf Trough is included as part of the much larger Southwest Georgia embayment, both regarded as downfaulted. As evidence in support of faulting in connection with this structure Murray states (1961, p. 103), "- geologic and geophysical data attest to the presence in the basin (i.e. the Southwest Georgia embayment) of local anomalies, both positive and negative, resulting from uplift and faulting of various kinds." However, as observed in wells, some of which are deep oil tests, evidence in support of faulting on a regional scale is noticeably lacking. In the writer's opinion, therefore, this theory is inadequate as an explanation of the Southwest Georgia embayment and its adjoining Gulf Trough.

Another, somewhat similar theory is that the Southwest Georgia embayment and the Gulf Trough represent a synclinal downwarp between the Ocala and Chattahoochee uplifts (Murray, 1961, p. 103). However, a possible weakness in this idea is that, according to Patterson and Herrick (1971), the Chattahoochee uplift, or anticline, as it is called in many reports, is nonexistent. In the writer's opinion, a change in dip, as further noted by Murray (1961, p. 103), between the prevailing regional dip in eastern Alabama and that in Southwest Georgia is probably sufficient to account for this structure, at least in its initial stage. Later-on (in geologic time) such a negative area could have been further deepened through prolonged sedimentation within this trough, the latter involving isostatic adjustment accompanied by some localized faulting (See pl. 5).

Still another possibility, also noted by Patterson and Herrick (1971, p. 12), is that the Gulf Trough may represent a buried solution valley, such as found in areas exhibiting karst topography. Evidence in support of this includes:

1. Presence of sinkholes encountered at depth and on a regional scale.
2. Occurrence of slickensided fragments of clays, or shale-like clays, as observed in well cuttings of the overlying Miocene deposits.

Evidence of limestone-solution on a regional scale has been reported by Toulmin and Winters (1954), Herrick and LeGrand (1964), and Stringfield (1966, p. 66 - 88). That solution has played a part, possibly an important part, in the formation of the Gulf Trough seems likely, but that it was the sole cause does not seem probable, particularly when viewed in the light of other evidence about to be presented. As for slickensided clay fragments constituting evidence of solution of limestones on a regional scale, such an idea seems highly unlikely. Such a feature could only have been produced through movement resulting from solution of one block (of limestone) with respect to another. This phenomenon, though doubtless commonplace in karst areas, is necessarily local as to area involved and therefore limited in scope.

Probably the most likely explanation of the Gulf Trough is the theory that it represents a submarine valley, or strait. That it represents the "Suwannee Strait"[1/] of authors was probably first suggested by Rainwater (1956), later by Chen (1965), and still later by Patterson and Herrick (1971). In this regard it should be stated here, that the Suwannee Strait of previous reports and the Gulf Trough as here postulated, represent two separate and distinct subsurface features (See fig. 2). The problem, therefore, is to show how the Gulf Trough could also have been the Suwannee Strait, in support of which the following evidence is presented.

1. Chen (1965, figs. 41 - 44), by means of a series of figures, shows a progressive northwesterly shifting of Dall's Suwannee Strait, which Chen calls, "Suwannee Channel," across Georgia throughout most of Tertiary time, beginning in the Paleocene and ending by Late Eocene time, when he thinks this strait ceased to function. Regardless of the validity one attaches to Chen's theory the fact remains that the position of

1/ Name originally proposed by Dall and Harris (1892, p. 111, 121-122.) For an excellent summary of reports dealing with this strait see article by the Applins (1967, p. G30, G31.

Chen's "Suwannee Channel" during Late Eocene time coincides closely with the Gulf Trough as shown in this report, thereby strongly suggesting that the Suwannee Strait, as generally conceived, and the Gulf Trough were one and the same at the close of Eocene time.

2. Additional support for coincidence of the Suwannee Strait and the Gulf Trough is seen when one considers the Gulf Trough as marking the boundary between two distinct sedimentary facies as does Chen in regard to his Suwannee Channel. Thus Chen states,-"The channel (i.e. his Suwannee Channel) was a natural boundary....between two distinct sedimentary facies in the area.-" This also describes the area marked by the Gulf Trough. Thus, north and northwest of this trough Cooper Marl, along with the remainder of the Ocala Limestone (i.e. the Tivola Tongue)[1/], is present, while south of it only carbonates, i.e. the Ocala Limestone, occur (figs. 5 and 6).

Other evidence in support of a change in facies occurring along a line marked by the Gulf Trough is seen in figure 7, the significance of which has already been noted.

Interbasin Ridge

A fourth subsurface structural feature affecting these three formations is the Interbasin Ridge. The name, "Interbasin Ridge," is proposed for a subsurface feature situated approximately midway between the two embayments (fig. 2). On the basis of well cuttings it seems apparent, that Cooper Marl was never deposited on top of this tongue-like ridge extending northward from Irwin and Coffee Counties, possibly as far north as Wilcox and Dodge Counties (fig. 5). This ridge, if indeed it is a ridge, is interpreted as a northward extension of the Peninsular arch, a structure that stood too high to have been covered by the sea in which

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1/ Name given by Cooke (1943, p. 70) to all updip Ocala Limestone in Georgia.

the Cooper was deposited.

In support of such a subsurface structure Murray (1961, p. 103) speaks of -"a low positive area" as separating the two embayment areas in Georgia. Likewise P. Applin (1951, fig. 2) also suggests such a positive ridge in his structure-contour map of the basement rocks in Georgia. However, probably the best evidence in support of this ridge is furnished by wells drilled on top of this structure. Examples are GGS 509, Coffee County (See fig. 6a), and GGS 3037, Ben Hill County, neither of which encountered Cooper Marl before entering the Ocala at depth.

Before concluding this discussion certain practical implications related to the Gulf Trough deserve further consideration. Owing to unusual thicknesses of sediments occurring in the Gulf Trough, particularly the Cooper Marl (See fig. 6a), the area underlain by this structure is directly responsible for problems, such as the availability and quality of underground water supplies. In the search for underground water the tops of potential subsurface aquifers, such as the Suwannee and Ocala Limestones, may lie so deeply buried in this trough as to entail costly, and in many instances, prohibitive drilling costs. An example, is a well drilled in southeastern Tift County to a depth in excess of 650 feet and still in Miocene clays, at which point the well was terminated. In other instances, where the Ocala had actually been reached, this normally excellent aquifer was found to be too thin to satisfy even the smallest of domestic needs. In still other instances the Ocala was absent thus necessitating additional and still more costly drilling. In the majority of cases where wells had to be abandoned through failure to reach potential aquifers investigation showed such wells to be situated in parts of the Gulf Trough containing excessive thicknesses of post-Oligocene (chiefly Miocene clays) deposits as well as unusual thicknesses of Cooper Marl, both representing sediments with low permeabilities. The unusual thickness of the Cooper Marl and the surprisingly overall thinness, and in some instances complete absence, of the Ocala in the Gulf Trough are explained by the fact, that this trough marks a change in facies resulting in two contrasting types of lithology. Thus, much, and in some cases, all of the Ocala Limestone has changed to Cooper Marl, the latter thus becoming the updip equivalent of the Ocala (fig. 6 a and b).

By way of contrast, in areas that are on top of the Interbasin Ridge, successful water wells are the rule rather than the exception. Here, Cooper Marl, normally occurring below the Suwannee Limestone, and excessive thicknesses of post-Oligocene deposits are noticeably lacking, thereby rendering deep and costly drilling unnecessary in this area.

Besides problems involving availability of ground water, great thicknesses of sediments in the Gulf Trough have apparently been also responsible for qualitative problems in parts of the Coastal Plain underlain by this structure. Examples are the Cairo and Thomasville areas, in Grady and Thomas Counties, respectively, both of which are underlain by the Gulf Trough. In both areas mineralized ground water is often a serious problem, particularly in the Cairo area. One reason for mineralized water in these areas could be poor circulation through the deeply buried water-bearing limestones. Some evidence for this is seen in the high percentage of dolomitized limestones occurring in these areas, a condition that is particularly true of the Cairo area. An alternative to using the Suwannee and Ocala Limestones in these areas is to utilize still more deeply buried and hitherto unused aquifers. However, this was tried in the Thomasville area, but with disappointing results, as salt water was encountered at depth. Whatever the solution to this problem may be the fact remains that the answer is still not known.

SUMMARY

Summarizing the data presented above the following should be noted:

Of the three formations discussed above the Ocala Limestone is the largest as to areal extent, the Cooper Marl, the smallest. Since the Cooper Marl is an updip equivalent of the Ocala, it is limited in its occurrence to updip parts of the Coastal Plain. The Suwannee everywhere overlies the Ocala and Cooper Marl Formations except in the Dougherty Plain, in Southwest Georgia, and Camden and eastern Charlton Counties in southeastern Geoggia.

These three formations represent two contrasting depositional facies. The Ocala and Suwannee Limestones represent moderately deep-water carbonates, or limestones, the Cooper, a relatively shallow-water clastic, or marl.

Likewise, the microfaunas contained in these two contrasting lithologies reflect the environments in which they originated. Thus, in addition to "smaller" foraminifers the Ocala and Suwannee Limestones also contain frequent to abundant "larger" foraminiferal species, the latter being virtually absent in the Cooper.

The Dictyoconus Zone, a prominent microfossil zone in the Suwannee, is significant by the fact, that it indicates erosion of this formation during Miocene time. Moreover, its position relative to the top of the Suwannee provides an approximate measure of the amount of erosion that the Suwannee has undergone. Examples of areas where the Suwannee has been subjected to extensive erosion are Chatham County, in eastern Georgia, and Brooks and Lowndes Counties, in South Georgia. Both these areas are on top of subsurface structures viz. the Cape Fear arch and the Peninsular arch, respectively.

Formations composing the Coastal Plain generally dip coastward, but may be locally modified by a number of subsurface structural features, four of which are briefly described as to location, probable origin, and structural significance. These include (1) Karst Topography, (2) Sedimentary Basins, (3) Gulf Trough, (4) Interbasin Ridge, (5) Southwest Georgia embayment, (6) Southeast Georgia embayment, (7) Peninsular arch, and (8) Cape Fear arch.[1/]

Karst occurs on top of the Ocala and Suwannee Limestones as the result of solution acting on them over a long period of time. Karst has formed on these formations where they lie close to the surface, as in updip areas and in areas situated on top of subsurface structures. A special case is the occurrence of karst on top of these formations where they are deeply buried, as in the Southeast Georgia embayment. Here karst has resulted but has been aided in its formation through changes in Pleistocene sea level.

Sedimentary basins, or depo-centers, occur in the two embayments and contain unusually thick sedimentary deposits. The Cooper and Suwannee Limestone attain their greatest thickness in the Southwest Georgia embayment, while the Ocala Limestone is thickest in the Southeast Georgia embayment.

The Gulf Trough, an extension of the Southwest Georgia embayment,

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1/ For the locations of structural features, 5 - 8, see figure 2.

represents a relatively narrow, depressed, linear area whose axis trends southwest across Georgia from the Savannah River, in southern Screven County, to Decatur, Grady, and Thomas Counties, in southwestern Georgia. It is narrowest at its northeastern extremity and widest at its southern end. Moreover, it is not continuous but is interrupted by the Interbasin Ridge, where it appears to be absent. The Gulf Trough contains thick deposits of post-Oligocene sediments and Cooper Marl, as well. The presence of thick deposits of Cooper Marl in the Gulf Trough is significant through the fact, that this trough marks a change in facies as between the Ocala Limestone of downdip areas and the Cooper Marl of updip areas. As a result of this change from a limestone to a marl plus the presence of thick post-Oligocene deposits successful water wells are difficult to obtain in the area underlain by this structure. For the same reason qualitative ground-water problems also exist in certain parts of this area.

As to the origin of the Gulf Trough four theories - graben, synclinal downwarp, solution valley, and marine strait - are briefly discussed. Of these the "strait" theory, which holds that this trough represents the former site of the "Suwannee Strait," is considered the most likely. Coincidence of the Gulf Trough with Chen's "Suwannee Channel" plus the fact, that this trough marks a change in facies involving the Ocala Limestone and Cooper Marl, are cited as supporting evidence.

The Interbasin Ridge, a subsurface structure believed to be an extension of the Peninsular arch, is shown as occupying a position approximately midway between the two embayments. It is further postulated as extending northward from Irwin and Coffee Counties, possibly as far as Wilcox and Dodge Counties. Owing to the absence of Cooper Marl in this area water wells are feasible.

FUTURE STUDIES

Although progress has been made much still remains to be discovered regarding the geology and hydrology of coastal-plain aquifers and their aquecludes in Georgia. With the current emphasis on the need for energy, particularly petroleum, more deep oil tests may be forthcoming in the not too distant future, thus providing much needed subsurface information. Continued systematic studies are needed on the subjects discussed in this report as well as many others some of which are as follows:

Additional studies are needed regarding the paleontology and stratigraphy of the Miocene in Georgia. For example, is the phosphatic, shelly limestone, previously placed in the basal Miocene, really Miocene or is it Oligocene in age?

The age of the deposits occurring between known Miocene and the overlying Pleistocene sands ~~requires~~ needs further study. Is this part of the Late Tertiary Pliocene, a series until recently not recognized in Florida? Planktonic foraminifers should provide definitive answers.

The updip limits of the Cooper Marl still remain to be determined. Based on available wells and a few known outcrops the approximate area underlain by this formation is shown in figure 5.

Closely related to the above is the age of the Cooper Marl. Earlier reports, including the one by Herrick (1961), reported the Cooper as Latest Eocene, while the U. S. Geological Survey presently regards this formation as Oligocene. Planktonic foraminifers should provide the answer to this problem.

The Interbasin Ridge requires considerable additional study. Does such a ridge exist and if so what are its areal limits? More and deeper wells are needed in order to determine the validity of this subsurface feature.

The availability and quality of ground water in the area underlain by the Gulf Trough are current problems requiring much more investigation. Are water wells feasible in this area and if so, at what depths may suitable aquifers be reached?

Permeabilities of known aquifers and their aquecludes require continued furture study. For example, is the Cooper Marl in the Gulf Trough an actual barrier to re-charge to the principal limestone aquifer, as indicated in figure 7, and if so, to what extent?

Closely related to permeability studies are those concerned with re-charge to major aquifers, such as the Suwannee and Ocala Limestones. In areas, where re-charge to these two aquifers is known to be taking place, how much re-charge is actually going on? As the Coastal Plain continues to become more and more industrialized the necessity for forming reasonable estimates of ground-water reserves becomes correspondingly more important as time goes on. Re-charge studies of these two aquifers, and others, would go far toward furnishing answers to this problem.

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