STRUCTURE AND SECTIONS

INTRODUCTION

A well-developed regional anticline developed in surface rocks was described in a U. S. Geological Survey press release of 1920. The fold was exposed in eastern Levy County and was named the Ocala uplift. With the increased activity in prospecting for oil beginning about 1943, it was discovered that the structure of older and deeply buried sediments did not conform to the structure developed in Tertiary beds. The highest structure on Cretaceous and older beds was found to be centered under Union County, with the crest of the structure trending northwest and southeast from this area, paralleling the crest of the Ocala uplift. Largely because the crests of the two structures were parallel and perhaps for want of a better name, the Ocala uplift was thought to be assymmetrical toward the east with depth and the term "Ocala uplift" was extended to include the structure of older beds.

The study of the geology of Citrus and Levy counties shows that the Ocala uplift crests in these counties and Applin (1951a, pp. 3-5) illustrated that the axis of the surface structure does not coincide with that of the subsurface structure and that no close structural relations exist between the two features. He has contoured the subsurface structure and named it the Peninsular arch. According to Applin (1951a, p. 3) the arch

> ". . . is the dominant subsurface structural feature of eastern Florida and an adjacent part of southeastern Georgia. The anticlinal fold, or arch, which is approximately 275 miles long, trends south-southeastward and forms the axis of the Florida peninsula as far south as the latitude of Lake Okeechobee."

Applin showed conclusively that the deeper structure was formed during the Mesozoic and was covered by transgressing beds ranging in age from Lower Cretaceous through the Upper Cretaceous. Data are presented in the present study which definitely indicate that the area over the Peninsular arch was high through the Oligocene epoch and that the Ocala uplift was probably initiated during the lower Miocene epoch.

The term Ocala uplift is therefore restricted to its original usage to apply to the dominant structures formed in Tertiary beds, with the highest point of its crest located in eastern Citrus and Levy counties. Well data indicate that the two structures, the Ocala uplift and the Peninsular arch are not superimposed. Wells drilled on the crest of the Ocala uplift penetrate the Peninsular arch well down on its flanks, so that Tertiary beds which are structurally high overlie Mesozoic beds which are structurally low, and conversely wells drilled along the crest

of the Peninsular arch begin in Tertiary beds that are structurally low and end in older beds that are structurally high.

The structure map, Plate 2, has been drawn on the top of the Inglis member of the Moodys Branch formation. Controls are based on outcrops in Citrus and Levy counties and on well penetrations throughout the north and central portions of peninsular Florida. The map indicates that the Ocala uplift is not a simple, elongate, double-plunging anticline but that it is composed of four separate structures that have deformed Tertiary rocks. These structures include the crest of the Ocala uplift along the western Peninsula and structures named the *Kissimmee faulted flexure*, the *Sanford high* and the *Osceola low* in this report, Plate 2.

OCALA UPLIFT

The term "Ocala uplift" appears to have been published initially in a press release dated April 19, 1920, issued by the U. S. Geological Survey. The release was a summary of oil possibilities in Florida based on a study of surface geology and cuttings from wells made by O. B. Hopkins, and was summarized by Gunter in 1921. The term has been used to apply to dominant structural features of Florida since that time.

Hopkins' release clearly delineates that structure to which he applied the name "Ocala uplift". He stated:

> ". . . the anticlinal fold . . . trends south-southeast, and forms the axis of the Floridian Peninsula. The axis of this uplift passes near Live Oak, 10 to 20 miles west of Gainesville, and an equal distance west of Ocala, and represents the southern continuation of the broadly anticlinal area of south-central Georgia. There are two high areas along this anticline. One, called the Ocala uplift, appears to have its highest part or crest in eastern Levy County, and the other near Live Oak. Of these, the Ocala uplift is the larger and structurally higher."

Hopkins' identification of the Ocala uplift was based on surface outcrops of Eocene limestone in western peninsular Florida and this work has been well substantiated by later studies. However, his identification of the "Live Oak uplift" was based on an inaccurate correlation of the Oligocene-Suwannee limestone exposed along the Suwannee River with the Miocene-Hawthorn formation cropping out at Live Oak, on an assumed and inaccurate estimate of the thickness of beds covering the Ocala limestone at Live Oak, on the apparently directed course of the Suwannee River where it circles Live Oak before continuing its southerly course, and on scattered well data which indicated that the Ocala limestone was high at Live Oak.

In later years detailed work on additional data proved the Ocala limestone had been extensively eroded prior to having been covered

by lower Miocene sediments and the "Live Oak uplift" was not substantiated by this work. Up until this report on Citrus and Levy counties was nearing completion Tertiary structure maps were drawn on the top of the Ocala limestone. The structures thus represented were merely reflections of highs and lows in Tertiary beds and were not truly representative.

Toward the completion of the work in Citrus and Levy counties it was possible to subdivide the Ocala limestone, and a very characteristic bed at the base provided an uneroded top, the contouring of which provided a more accurate map of Tertiary structures. The map is presented as Plate 2, and it indicates that in fact Hopkins was partially correct in depicting the Live Oak area as structurally high. The fault-flattened crest of the Ocala uplift present in Levy, Citrus, Sumter, Lake and Polk counties divides into two gentle folds, at the north Levy County line, the crest of one trending almost due north from this point and passing east of Live Oak, and the other continuing the northwest trend of the crest of the Ocala uplift. The courses of the Suwannee and the Santa Fe rivers have apparently adjusted to the slopes of the bedrock developed along the flanks of these two folds.

The data on the geologic-history of the Ocala uplift and the structure of surface beds can be illustrated best in cross section. The series of six sections presented as figures 13 and 14 cross the State essentially perpendicular to the axis of the Ocala uplift and of the Peninsula. Sections A-A′, B-B′, C-C′, and E-E′ are drawn along U. S. Army Engineers routes 7-A, 8-A, 12 and 13-B, alternate routes for the proposed Florida Ship Canal. The ground surface for these sections is taken from published reports of the U. S. Army Engineers, but the surfaces in sections AA-AA′ and D-D′, and the eastern end of C-C′ are approximate. Excellent core-hole records and rock samples are available along each of the proposed ship canal routes. These are generally quite shallow and deeper water wells have been projected into these sections along the strike of the Inglis member of the Moodys Branch formation, used as a structural control bed. Sections D-D′ and AA-AA′ have been constructed from the records of scattered water wells. Section AA-AA′ extends easterly from Tallahassee to Monticello, Florida, and connects into section A-A′ at well W-1596. The location of each section is shown on the index maps of figure 13 and figure 14.

These sections and the structure map, Plate 2, indicate that the Ocala uplift developed in Tertiary sediments as a gentle flexure, approximately 230 miles long, and about 70 miles wide where exposed in central peninsular Florida. The anticline is composed of two well-defined shal-

low folds, the more westerly being higher structurally, see figure 13 and Plate 2. Along the Florida-Georgia State line the east fold is separated from the west fold by a shallow trough, 54 miles wide. The folds converge southward and in Levy and Citrus counties they are separated by only a few miles and their crests are extensively fractured and faulted. The crests trend northwest-southeast through Levy and Citrus counties, but in Sumter, Orange and Polk counties they diverge, the east fold merging with a large fault block, named in this report the Kissimmee faulted flexure, and the west fold continuing in a south-southeasterly direction and gradually merging with the regional dip.

The development of vertical dip-slip faults, the traces of which parallel the crest of the Ocala uplift, tend to flatten the crest and to lengthen its cross-section. From the limited core hole evidence available for this study the dip of the fault planes could not be determined, nor was it possible to estimate the extent of faulting at depth. There are numerous possibilities, one fault may terminate at depth against another or it may cross to form a graben and horst structure. Figure 14 is one interpretation of the geologic section along the proposed Florida Ship Canal and here a graben and horst structure is clearly indicated. The fault planes are drawn in at angles greater than 60 degrees and may be steeper. They are thought not to dip at angles less than 60 degrees because of the straight-line traces of the faults and because the closely spaced core holes do not penetrate any thinning or thickening of the beds.

THE KISSIMMEE FAULTED FLEXURE

Throughout an irregular area in the vicinity of Kissimee in Orange, Osceola and Lake counties, wells penetrate a variable thickness of Miocene sediments lying upon the Avon Park limestone. The Moodys Branch formation, the Ocala limestone (restricted), and the Suwannee limestone are not present, although they occupy their normal stratigraphic positions in the surrounding areas. This high is the southern extremity of a wedge-shaped block that is approximately 90 miles long along its longest axis, 54 miles across the northwest border which is open, and 17 miles across the southeast margin, which ends at a fault forming the northwest boundary of the Osceola low. The block is tilted with the southeast end being upthrown, and it apparently has been rotated also, the southwest boundary being higher than the northeast and the outcrop pattern of the Avon Park limestone being extended along the southeast boundary. The beds within the fault block are greatly disturbed, many small folds and structural irregularities being present. Numerous irregular fractures, figure 11, are present throughout the block and at

least one well-developed fault, Plate 2 and section D-D′ of figure 13, has been identified. Fractures appear to be concentrated toward the southeastern extremity.

The southern portion of the block appears to be a small anticlinal fold that trends west-northwest-east-southeast and terminates in both directions against a fault. The Inglis member has been thinned over much of the top of the block and removed from over the fold.

THE SANFORD HIGH

A semicircular area bordering the northeast boundary of the Kissimmee faulted flexure in the vicinity of Sanford, Seminole County, is similar to the southeastern extremity of the Kissimmee faulted block in many respects. Wells here penetrate the Avon Park limestone beneath a thin veneer of Miocene sediments. The structure appears to be a closed fold that has been faulted, the Sanford high being located on the upthrown side of the fault. The Inglis member of the Moodys Branch formation has been thinned by erosion along the flanks of the fold and removed from off the crest.

The similarity of the structures forming the Kissimmee faulted flexure and the Sanford high, the presence of a fault separating them, and the reconstruction of the stratigraphic section imply that the structures were once continuous and have been offset by faulting and subsequently eroded and covered by Miocene sediments. The reconstruction of the pre-Ocala land surface and of this anticline indicate that it trended west-northwest across the Peninsula and possibly connected the outcrop area in Citrus and Levy counties. The presence of a structural high in and near these counties during the early Eocene is indicated by the extensively cross-bedded limestones of the Inglis member that were formed as shallow-water marine deposits that covered a land mass composed of the Avon Park limestone. This land mass is also indicated by elements of the Avon Park limestone reworked into the base of the Inglis member and by an unconformity present at the base of the Moodys Branch formation.

The faults bounding the Kissimmee faulted flexure cut all beds of Eocene age and the irregularities created by erosion have been filled by Miocene sediments. The age of these faults can thus be dated as post-Eocene and pre-Miocene.

THE OSCEOLA LOW

The Osceola low is a wedged-shaped downthrown [illegible]k bounded on the northwest and east by normal faults, and open on th[illegible] southwest. Three wells, Florida Geological Survey wells W-1728, W-1749 and

W-1770, located in the northeast extremity of the low, penerate the Inglis member at depths ranging from minus 412 to minus 482 feet. The Inglis member lies below a normal thickness of the Williston member, 50 feet of Ocala limestone and a very thick section of Miocene sediments, up to 350 feet thick. This depth to the Inglis member contrasts with the penetration of the bed at depths less than 200 feet to the east and the absence of the bed along the fault block to the northwest.

The base of the Miocene contains no identifiable reworked fragments of Eocene sediments. The absence of these implies that the faulting was probably associated with movements that formed the Ocala uplift but the faulting is younger than that which created the Kissimmee faulted flexure and Sanford high.

STRUCTURES WITHIN CITRUS AND LEVY COUNTIES

Citrus and Levy counties are situated upon the crest of the Ocala uplift and the regional dips of the Tertiary beds are southwest and northeast along the flanks and northwest and southeast along the plunge of this broad elongated arch, see Plate 2, figures 13, 14, and 15. The dips are slight, the regional average approaching nine feet per mile on the flanks and three feet per mile along the plunge, but dips greater than these are present locally along small folds and in faulted blocks.

The Ocala uplift has been breached by erosion in these counties and the Avon Park limestone of middle Eocene age is exposed in an irregular dendritic pattern in southern and central Levy County and in northeastern Citrus County, see Plate 1. Younger beds of Eocene age crop out in a concentric pattern about the Avon Park limestone. These ribbons of outcrop are interrupted by horst-graben normal faults and outcrops have been extended along the faults irregularly. In western Levy County and west-central Citrus County two small sharply raised domes are indicated by annular outcrop bands. These two domes and three major faults crossing the counties are named and shown in figure 15. Smaller graben and horst faults are well-developed but have not caused significant changes in the regional outcrop pattern and although mapped on Plate 1 and Plate 2 they are not shown on figure 15 and are not named.

DOMES

There are included under this term two areas in which the outcrop patterns are annular. These small domes have comparatively narrow diameters and very slight dips. They may in fact be only minor flexures in the folds forming the Ocala uplift. There is a possibility that they may be the expression of deeply buried domes. Almost nothing is known about their subsurface characteristics and until they are prospected in

detail the features are tentatively called domes because of their outcrop patterns.

Homosassa Springs Dome: This dome is located just north of Homosassa Springs in Citrus County. It exposes the Inglis member of the Moodys Branch formation and is circled by a band of the Williston member of that formation. The dome is about five by three miles, and adjoins a small basin in which the Ocala limestone (restricted) is exposed and the Crystal River springs are located. The northeast margin is bound by a small graben, the southeast fault of which is exposed in the Crystal River

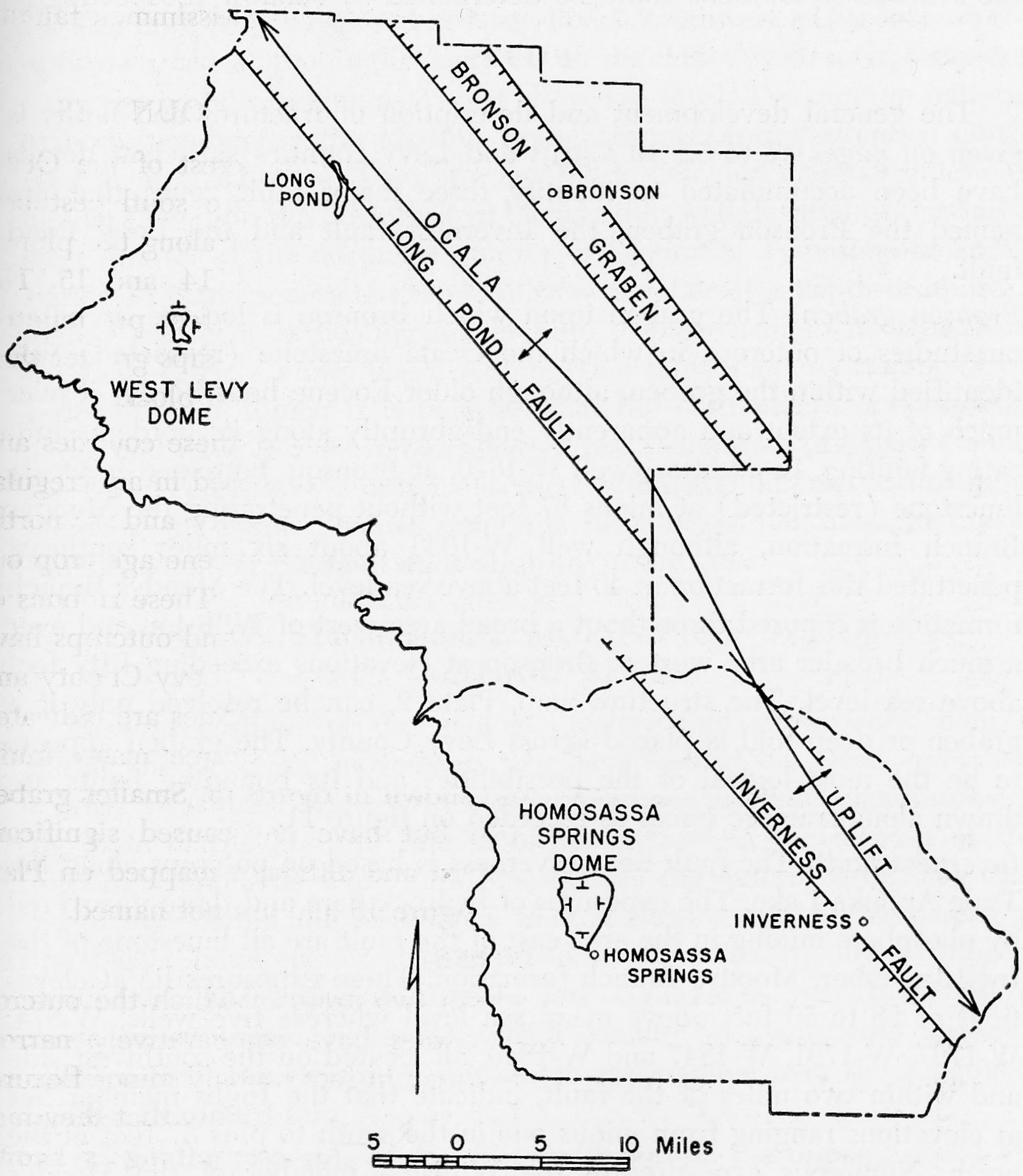

Figure 15. The Principal structures in Citrus and Levy Counties.

Rock Company quarry, located in Section 6, Township 19 South, Range 18 East.

The West Levy Dome: A small dome in western Levy County is exposed as an island in the broadly developed hammocks along coastal and Suwannee River lowlands. The area occupied by the dome is an outcrop of the Inglis member and it is surrounded by a broad outcrop of the thin Williston member of the Moodys Branch formation. The broadness of the Williston outcrop implies very gentle dips westward, and the dome is of little significance. Little is known of its subsurface characteristics but the attitude of the beds could be determined by shallow prospecting.

FAULTS

The general development and description of fractures and faults is given on pages 47 to 52. In Citrus and Levy counties sufficient details have been accumulated to identify three major fault zones that are named the Bronson graben, the Inverness fault and the Long Pond fault.

Bronson graben: The graben upon which Bronson is located, is based on studies of outcrops in which the Ocala limestone (restricted) was identified within the graben, although older Eocene beds border it over much of its extent and apparently end abruptly along its borders, indicating faulting. In addition, well W-1870, at Bronson, bottomed in Ocala limestone (restricted) at minus 87 feet without penetrating the Moodys Branch formation, although well W-1633 about six miles southeast penetrated this formation at 40 feet above sea level. The Moodys Branch formation is exposed throughout a broad area west of Williston and over a much broader area west of Bronson at elevations exceeding fifty feet above sea level. The structure map, Plate 2, can be resolved only if a graben or deep fold is placed across Levy County. The graben appears to be the most logical of the possibilities and its bounding faults are drawn along fracture traces as recorded on figure 11.

Inverness fault: The fault near Inverness is based on outcrops along the Tsala Apopka Lake. The exposures of bedrock here and those uncovered by phosphate mining in the area east of the fault are all limestone of the Inglis member, Moodys Branch formation. These exposures lie at elevations of 28 to 50 feet above mean sea level whereas five wells, W-874, W-1767, W-1791, W-1847 and W-1848, all located on the southwest side and within two miles of the fault, indicate that the Inglis member lies at elevations ranging from minus one in the south to plus 37 feet in the north. Numerous exposures of the Williston member of the Moodys Branch formation, the Ocala limestone (restricted) and the Suwannee

limestone on the hills southwest of the fault indicate comparable displacements.

The northeast block has been tilted in faulting, the southeastern portion being upthrown with a displacement of as much as 50 feet, whereas the northwest portion is downthrown with displacements as much as 20 feet. The fault could be traced northeast into the Avon Park limestone outcrop where it is either obscured or the structure absorbed by possible incompetent beds.

Long Pond fault: This fault is the major fault in the area, and as much as 160 feet of displacement has been recorded, see section E-E′, figure 14. The fault is well exposed at Long Pond. Southwest of the lake on the upthrown block, the Inglis member of the Moodys Branch formation crops out on hills as high as 35 feet above sea level. The outcrop patterns of both members of the Moodys Branch formation are extended northwest along this fault on the upthrown block. One and one-half miles east of Long Pond on the downthrown block a dug well, located in the northwest quarter of the northeast quarter of Section 8, Township 12 South, Range 15 East, penetrated the Williston member at a depth of approximately sea level, indicating a minimum displacement of 50 feet. Near the Levy-Citrus County line the Long Pond fault trace is paralleled by a series of small faults. It is believed that the fault planes of these converge and have formed minor horst-graben structures. In Citrus County the Long Pond fault is either obscured within the outcrop of the Inglis member, the displacements along the fault being too small to breach the formation, or the fault ends abruptly in the area.

DATES OF STRUCTURAL MOVEMENTS DEFORMING TERTIARY BEDS

Several portions of the geologic history and stratigraphy help in dating the structural movements that have formed the Ocala uplift and related structures. Some evidence is contained in the unconformity at the base of the Moodys Branch formation and in the overlap of this formation upon the Avon Park limestone in the outcrop area. The fault zones that bound the Kissimmee faulted flexure cut beds as young as the Ocala limestone (restricted) and are covered by lower Miocene sediments. The adjacent Osceola low contains a very thick fill of Miocene sediments, figure 33, which contain no identifiable residuum derived from the erosion of the limestones exposed over the Kissimmee faulted flexure.

Along the east side of the Florida Peninsula the upper Eocene and Oligocene sediments are thin to absent when compared to the thickness

of these sediments over the crest and on the southwestern flank of the Ocala uplift, the structural high in Tertiary rocks today, see sections of figures 13 and 14. In Brevard, Orange, Seminole, Volusia and Flagler counties, as shown in sections C-C′ and D-D′, the Ocala limestone (restricted) and even the Moodys Branch formation are absent and the Miocene rests directly upon the eroded surface. This unconformity continues northward into Georgia along the coast, where the Oligocene is absent and the Hawthorn formation of lower Miocene age rests on the Ocala limestone.

The Eocene and Oligocene beds are thin along the eastern coast line of Florida even though the area is structurally low. The thinning of these beds corresponds roughly with the crest of Applin's (1951a) Peninsular arch, and the thinning and removal of Tertiary beds, apparently from erosion, across the crest of this arch suggests that the eastern part of the Florida Peninsula was high throughout the post-Oligocene, and that the movements forming the Ocala uplift are post-Oligocene and pre-Miocene in age. The inclusion of some basal Miocene beds in faulting along the Ocala uplift, see section E-E′, the overlap of a very eroded limestone surface and the wedging out of Miocene sediments against the Ocala uplift, see sections of figures 13 and 14, dates these movements fairly definitely as lower Miocene in age. However, some of these structural movements may have continued irregularly throughout later epochs, see pages 29 to 31.

The Hawthorn formation is a wedge-shaped deposit, excessively thickened toward the northeast and south, overlapping and pinching out onto the structures composing the Ocala uplift. From the evidence presented in the sections and structure map the structural axis in Tertiary beds through at least post-Oligocene time coincided with the axis of the Peninsular arch and was located along the eastern seaboard. A secondary axis may have been present during the late Eocene, extending more westerly across the central Peninsula from Seminole County to Citrus County, see pages 56 to 57.

Following an extensive period of post-Oligocene erosion Florida was flooded by lower Miocene seas. The sequence of beds in the Miocene indicate that these seas transgressed upon the Ocala uplift by a series of overlaps and Miocene deposits pinch out against a well-developed erosional surface. This transgression was apparently accompanied by downwarping of the eastern and southern portions of Florida and the elevation of the Ocala uplift along the western Peninsula. Evidence presented under the discussion of the Alachua formation, pages 195 to 200, indicates that a large area situated upon the Ocala uplift was land throughout the Miocene period, and was never covered by Miocene seas.

STRATIGRAPHY

PREVIOUS WORK[12]

The knowledge of Florida stratigraphy and structure was pioneered by J. A. Cushman, W. H. Dall, E. H. Sellards and Herman Gunter. In particular, Dall and Cushman deserve recognition for their identifications of the faunas of the different formations upon which much later stratigraphic work was based. Cushman (1919) recognized the major subdivisions of the Oligocene and Eocene and provided much of the early identifications of foraminifers. Dall (1890-1903, 1892, 1894, 1897, 1915) recognized much the same subdivisions and his identifications of mollusks were most important in the later classification of beds ranging from Eocene to the Recent.

Cooke (1915) determined the Ocala limestone to be Jackson in age. Sellards (1919), based his stratigraphy on fossil identifications of Cushman and Dall, prepared a sketch map of the geology and structure of Florida and recognized the major stratigraphic subdivisions and regional Tertiary structures of the State in a generalized fashion. This work was amplified by Sellards and Gunter in 1922.

Important studies of stratigraphy and structure were presented by Stuart Mossom (1926) in which the first structure map of Florida was issued, the contours being drawn on the top of the Ocala limestone; Herman Gunter (1928) announced the discovery of "basement rocks" in a Marion County oil test well; Cooke and Mossom (1929) described the surface geology of the State; Gravell and Hanna (1938) described and figured several important guide fossils and recognized several zones in the Tertiary, useful for correlation throughout much of the Gulf Coast; Robert Campbell (1939) announced the discovery of Lower Cretaceous beds in a deep oil test drilled in Monroe County, based on the identification of foraminifers by E. R. Applin; Robert Vernon (1942) prepared a report covering surface outcrops in Holmes and Washington counties, Florida; Cole (1938, 1941, 1942, and 1944) in studies of wells drilled in the State described and figured numerous species of Foraminifera, and contributed to the knowledge of the subsurface stratigraphy. His 1942 study was of the Florida Oil Discovery-Sholtz and the Suwannee Petroleum-Sholtz wells in Levy County, during which he subdivided the Eocene section into an upper, middle and lower Eocene. He proposed his Cedar Keys formation for the lower Eocene in his study of 1944. The Applins (1944, 1947) and Applin and Jordan (1945) contributed to the

[12]Previous studies have been summarized by the Applins (1944, pp. 1674-77). These are briefly listed here, with additions of work completed since 1944.

knowledge of the subsurface stratigraphy of the State. They described and figured numerous species of Foraminifera, prepared excellent lists of guide fossils, subdivided early and middle Eocene and the Cretaceous and illustrated their studies by numerous sections and maps; Paul Applin (1951a) recognized and named a deeply buried structure in rocks older than the Mesozoic and subdivided these rocks into three general classifications; crystalline rocks of possible pre-Cambrian age, Paleozoic sediments, and possible Paleozoic volcanics. His study is an important contribution to the knowledge of the early geologic history of Florida, fundamental to the later geologic history.

Early in 1943 the writer found an exposure of dolomite south of Gulf Hammock, Levy County, Florida, in which he found numerous casts and molds of specimens of *Coskinolina* and *Dictyoconus*. These he believed at the time represented beds older than the Ocala limestone. Both the writer and Sidney A. Stubbs, formerly with the Survey, prepared in 1943 well logs in which beds of middle Eocene, "The Coskinolina zone", were recognized. David Ericson (1945), working with the geologists of the U. S. Army Engineers, recognized beds which he believed to be equivalent to the Avon Park limestone and named surface outcrops the "Gulf Hammock formation". The study of the geology of Citrus and Levy counties was begun in 1946.

FLORIDA GENERAL STRATIGRAPHY AND STRUCTURE

The rocks that compose Florida are a portion of the Floridian Plateau, which has apparently always been part of continental masses, since the oldest sediments penetrated by deep oil test wells are shallow-water marine deposits formed on continental shelves and no sediments formed in deep oceanic basins are present. The sedimentary section of peninsular Florida consists essentially of fragmental and pasty marine limestones, sandstones and shales reaching a known cumulative thickness in excess of 18,000 feet. Only three deep wells have penetrated crystalline rocks in Florida, granite was cut by the Humble Oil and Refining Company, Carroll well No. 1 in Osceola County, by the Oil Development Company, Arnold well No. 1 in Lake County and hornblende diorite by the Sun Oil Company, Powell well No. 1 in Volusia County. Because of their stratigraphic position and crystalline texture, Applin (1951a) believed that the diorite is questionably pre-Cambrian and the others either pre-Cambrian or Paleozoic intrusives. From Mr. Applin's study it can be inferred that the core of the Floridian Plateau is pre-Cambrian and that upon this rather poorly defined area dominantly marine Paleozoic sediments, ranging in age from late Cambrian or early Ordovician to

Devonian, were formed. Twenty-seven deep wells in the State have cut sandstones of the lower and middle Ordovician series, the Stanalind Oil and Gas Company, Perpetual Forests, Inc., well No. 1 in Taylor County penetrating a thickness of 2,250 feet of these sandstones. Three wells cut black shales and sandstones of Lower Devonian or Upper Silurian age, the Humble Oil and Refining Company, J. P. Cone well No. 1 in Columbia County penetrating a thickness of 906 feet of these sediments. These Paleozoic rocks were subsequently exposed to erosion and were folded, possibly faulted and preserved in structurally low regions throughout an extensive erosional period.

This eroded pre-Mesozoic surface, as described by Applin (1951a), is highest in an arch centered at Union County, Florida. This structure trends south-southeastward and was named the Peninsular arch. Folding was accompanied by downwarping in southern Florida, and a thick deposit of marine and deltaic sediments, largely carbonates, ranging in age from possible Triassic to Recent, formed upon this land mass. Applin (1951a), recorded that an extensive submergence began at the south end of the Peninsula during the early Cretaceous and possibly Jurassic. This is indicated in the Gulf Oil Corporation, State of Florida Lease 373, well No. 1 on Plantation Key, Monroe County, which penetrated more than 15,000 feet of limestone, dolomite, and anhydrites of Tertiary, Upper Cretaceous, Lower Cretaceous and possibly Jurassic ages, whereas the Sun Oil Company, Ruth M. Bishop well No. 1 in Columbia County penetrated only beds of Tertiary age and those equivalent to the Austin of the Upper Cretaceous. The submergence apparently advanced northward along the Peninsula because the series of wells north of Sunniland, Collier County, in which the beds of Trinity age are penerated at 13,000 feet show that beds of Trinity, Fredericksburg and Washita age overlap and encroach progressively upon the floor of eroded pre-Mesozoic rocks. These definitely marine beds interfinger northward into a clastic facies of red and green shale, sandstone and siltstone that occupies the south flank of the Peninsular arch and are correlatives of Trinity to Washita sediments (the Comanche series of the Lower Cretaceous), see figure 16, section B-B′.

The Peninsula of Florida was covered by shallow marine waters throughout the period extending from the Paleocene to the Recent, except for brief periods when it stood as land and was weathered and eroded. Except for the sediments of Miocene to Recent age these deposits are composed essentially of carbonates, with thin beds of evaporites, sandstone and shale.

In general the Tertiary sediments of the State are composed of two

depositional facies, an essentially marine and carbonate facies and a more shallow-water clastic facies, a small proportion of which is also marine. The coastal plains of western Florida and states westward to Texas have been in general a region of active deltaic sedimentation. On the other hand peninsular Florida, removed from large streams and continental sedimentation is dominantly marine. The two extremes merge through interfingering phases in the coastal areas of Alabama, western Florida, and northern-central Florida. As the Applins (1944, pp. 1679-80) stated:

> ". . . On the one hand, west Florida and southern Georgia are occupied by a clastic facies which is similar in its broader aspects to the sediments of the Western Gulf Coastal Plain and is composed largely of sand and shale with some limestone and chalky marl. On the other hand, over most of the peninsula, the sedimentary section is almost continuous limestone from the top of the Oligocene into the Lower Cretaceous . . . In northern Florida and in the north quarter or north third of the peninsula, the limestone and clastic facies grade laterally into each other. In general, with the passage of time, the limestone of the peninsula encroaches upon the clastic facies, spreading northward in successive stages . . . In general also, the foraminiferal microfaunas of the clastic facies resemble those present in formations in the western Gulf Coast, whereas the microfaunas of the limestone facies in the peninsula from the top of the early middle Eocene to the top of beds of Taylor age resemble those of Cuba, the West Indies, Mexico, and Europe, with only few species present that are known in other places in the United States. Species of ostracods and bryozoans show a like dissimilarity with those found in western faunas. Beginning with the top of the beds of Taylor age in the peninsula, the more familiar Gulf Coast microfaunas again appear. Some mingling of faunas of the two facies has been noted in a few wells in north Florida in the early middle and lower Eocene, but none in the Paleocene or late Upper Cretaceous. The fauna of the Lower Cretaceous limestones of southern Florida again resembles that found in certain derived deposits in Cuba and also that of the El Abra limestone of southern Mexico (Cenomanian-Albian) there designated as Middle Cretaceous."

GENERAL STRATIGRAPHY OF CITRUS AND LEVY COUNTIES, FLORIDA

Oil prospects have nowhere in Citrus and Levy counties passed through beds older than Paleozoic. In Levy County, the Coastal Petroleum Company's James B. and Julian P. Ragland No. 1 well bottoms in beds believed to be Upper Silurian or Lower Devonian, and the Humble Oil and Refining Company's C. E. Robinson et ux No. 1 well and the Sun Oil Company's J. T. Goethe well No. 1 ended in sandstone of the Middle Ordovician.

The data from these wells indicate that Cretaceous beds lie directly on beds of Paleozoic age, separated by an unconformity representing

TABLE 6.—Geologic Formations in Citrus and Levy Counties, Florida

	Era	System	Series	Formation
Surface Beds	Cenozoic	Quaternary	Recent	Sand, peat and clay, unnamed
			Pleistocene	Lake Flirt marl, of late Wisconsin glacial stage
				Pamlico formation, of Peorian age
				Wicomico formation, of Sangamon age
				Okefenokee formation, of Yarmouth age
				Coharie formation, of Aftonian age
		Tertiary	Miocene	Alachua formation Terrestrial ? — ? Hawthorn formation Marine
			Oligocene	Suwannee limestone
			Eocene	Ocala limestone, of Jackson age
				Moodys Branch formation Jackson age: Williston member; Inglis member
				Avon Park limestone, of Claiborne age
				Lake City limestone, of Claiborne age
				Oldsmar limestone, of Wilcox age
			Paleocene	Cedar Keys formation, of Midway age
Sub-Surface Beds	Mesozoic	Cretaceous	Gulf	Lawson limestone, of Navarro age
				Beds of Taylor age
				Beds of Austin age
				Atkinson formation: Beds of Eagle Ford age; Beds of Woodbine age
			Comanche?	Undifferentiated shale and sand, "red beds"
		Triassic?		Quartz diabase, possible sill?
	Paleozoic	Lower Devonian or Upper Silurian . . ? . . . ? . . . ? . . Lower Ordovician		Possible fault contact

several geologic periods. see figure 16, section A-A′. This would indicate that the western peninsula of Florida was land for a long period prior to deposition of the Cretaceous beds. This and the geologic history as interpreted from well penetrations imply that these counties have been a part of a structurally stable land mass which was gradually covered by overlap of Cretaceous and younger sediments. The area, essentially a peninsula since the early Cretaceous, was a shoal, surrounded by deeper water, or land that separated the Gulf from Atlantic waters.

The sequence of formations, penetrated by wells, and those exposed at the ground surface of Citrus and Levy counties is given in Table 6.

PALEOZOIC ERA

The deeper oil prospects in Citrus and Levy counties bottomed in beds believed to be Lower Ordovician and Upper Silurian or Lower Devonian in age. However, several wells drilled as oil tests in the State have penetrated additional Paleozoic sediments. Dr. Josiah Bridge and Dr. Jean Berdan have been engaged during the past two years in a study of these beds. They have completed their study and have been kind enough to prepare for inclusion in this paper some notes on the Paleozoic strata of Citrus and Levy counties.

Since no conclusions can be drawn on the limited information available from the samples taken from the three wells that penetrate Paleozoic sediments in these counties, and time has not permitted a critical study of wells outside these counties, the paper by Drs. Berdan and Bridge is presented here.

PRELIMINARY NOTES ON THE PALEOZOIC STRATA BENEATH LEVY AND CITRUS COUNTIES, FLORIDA

By Jean Berdan and Josiah Bridge

Three deep wells drilled in southern Levy County in search of oil encountered early Paleozoic strata lying unconformably beneath Mesozoic rocks. Data on these wells are summarized in Table 7. No other deep wells in either county have reached Paleozoic rocks, but they have been encountered in a number of wells in the counties lying immediately to the north and east of Levy County and in a single well in Hernando County, directly south of Citrus County. From this it is reasonable to assume that both counties are underlain by Paleozoic rocks, and evidence from other areas indicates that they are quite thick. Still farther to the south and southeast several wells pass directly from Mesozoic sediments into crystalline rocks of various types that are believed to be of Pre-Cambrian or early Paleozoic age.

The top of the Paleozoic rocks in southern Levy County lies at depths between 3960 feet (Goethe) and 5792 or 5810 feet (Ragland) below sea level, and this taken in conjunction with the elevations of the top of the Paleozoic in wells in adjacent counties indicates the presence of a well-developed peneplane surface on the Paleozoic rocks. This surface slopes gently southwest from an elevation of about 3500 feet below sea level in the northeastern part of Levy County to around 7000 feet below sea level in the southwestern part of Citrus County; the average slope of the surface being about 100 feet per mile, or slightly more than one degree (see Applin, 1951, p. 4).

The Ragland well cut about 40 feet of soft, laminated, somewhat silty, finely micaceous and pyritic, very dark gray to black shale, of which only the bottom 10 feet was cored. This bottom core contains a poorly preserved fauna consisting of crinoid stems, hyolithoids, cephalopods, pelecypods (probably *Actinopteria*) and a few other forms. A similar association of fossils in a better state of preservation has been found in the Humble Oil and Refining Company's J. P. Cone No. 1 well, in northern Columbia County, which cut 962 feet of a lithologically similar black shale without passing through it. From this it seems reasonably safe to infer that the Ragland well may have penetrated only the upper part of a considerably thicker shale section. A preliminary study of the better preserved fossils in the Cone well indicates that the probable age of this black shale fauna is Upper Silurian or Lower Devonian.

Overlying the black shale in the Ragland well is about 18 feet of unctuous yellow, gray, lavender and pink variegated well-stratified shale, the age of which is still under discussion. It is comparable in position and lithology to a zone of unctuous variegated shale which occurs over the black shales in the Cone well, and which contains fossils similar to those found in the underlying black shales. In the Ragland well this material is unfossiliferous, but has been considered by some to be analogous to the shales in the Cone well, which are believed to represent a weathered phase of the Paleozoic shales which is still in place and therefore a part of the Paleozoic sequence. However, others believe that the variegated shales are reworked and redeposited material derived from the weathering and subsequent erosion of the Paleozoic beds, which has been transported and rearranged and is therefore the basal part of the Mesozoic sequence. As, in the Ragland well, these beds are overlain by a conglomerate of quartzite pebbles which is apparently early Mesozoic in age, and as deeply weathered strata are a normal occurrence just beneath a peneplaned surface and their preservation and subsequent burial beneath the sediments of a younger cycle is not unusual,

the first hypothesis is preferred and the variegated shales are considered to represent a weathered part of the underlying black shales.

The Robinson well penetrated one or more sills or flows of diabase, 46 feet thick, presumably of Triassic age and lying just beneath the peneplane surface, and then cored 232 feet of Paleozoic sediments, chiefly light gray, hard, quartzitic sandstone, locally interbedded with films and thin beds of rather hard, dark gray to black, somewhat silty, micaceous shale. A few fossils, chiefly linguloid brachiopods belonging to two or more species, were found in the quartzites in the upper part of this section (between 4390 feet and 4424 feet), and, on this basis, the strata in this well have been correlated with those in the Union Producing Company's E. P. Kirkland No. 1 well in Houston County, Alabama, just north of the Florida line and 211 miles northwest of the Robinson well. The same types of linguloid brachiopods and the same lithology are found in both wells, and the Kirkland well also carries abundant graptolites associated with the linguloids. The graptolites fix the age of the strata containing them as Lower Ordovician, equivalent to a part of the Deepkill shale of New York. This zone is not known in the southern Appalachian Valley, but is represented by beds carrying the same types of graptolites in Arkansas (shale beds in the Blakely sandstone) and in West Texas (part of the Marathon formation).

Another feature common to the Paleozoic strata of both wells are vertical worm borings of the *Scolithus* type. These average about 0.25 inch in diameter, and may be as much as 8 inches long. They occur in zones or beds from 4 to 8 feet thick, separated by barren intervals of about the same thickness. The tubes are filled with sand cemented to quartzite, and within them all traces of bedding are destroyed. They contain no visible shale particles, and where they cut through shale layers and films, appear as white, circular spots on the bedding planes. Where the tubes cut across the individual laminae, the latter are commonly disturbed and deflected. Although these tubes are admittedly facies fossils, restricted to a sandy environment, they nevertheless appear to have definite value in local correlation.

The J. T. Goethe No. 1 well, about 10 miles north of the Robinson well, cut 37 feet of gray quartzitic sandstone and micaceous black shale similar to the material just described from the Robinson well. A part of this interval was cored, and these cores contain vertical worm tubes similar to those just described. Although no other fossils were found, a circumstance which is not surprising in view of the limited amount of material available for study, it seems quite reasonable to correlate this material with some part of the section found in the Robinson well. Most

of the deep wells in the adjoining counties also penetrated similar rock, and one of these, the Sun Oil Company's Perpetual Forest No. 1 well in Section 5, Township 11 South, Range 11 East, in Dixie County, cut 2250 feet of similar material without passing through it. It seems certain that the sections encountered in the Robinson and Goethe wells represent some part or parts of the section cut in the Perpetual Forest well, that the Paleozoic section underlying Citrus and Levy counties is of considerable thickness, and that somewhere beneath it at unknown depths crystalline rocks would probably be found.

No other types of Paleozoic sediments have been penetrated in the wells drilled in Levy and adjoining counties, but Paleozoic strata belonging to some of the intervening Ordovician and Silurian horizons have been found in wells drilled in northern Florida and southern Georgia. This stratigraphic and structural relations of the Ordovician and Silurian rocks underlying these counties are not known. From the fact that the strata are essentially flat-lying, and because other horizons that would normally lie between them are unknown here, it is believed that they are possibly in fault contact (see figure 16), the age of the faulting being pre-Cretaceous.

MESOZOIC ERA
TRIASSIC SYSTEM

Triassic Sediments and Intrusives

As indicated on page 69, a thin section of variegated shales occurring at depths of 5,792 to above 5,810 feet in the Coastal-Ragland well is believed by some workers to have been reworked and redeposited sediment derived from weathering and erosion of Paleozoic rocks. This bed has been tentatively placed in the Lower Cretaceous system by some workers, and it could be Triassic, but is considered a logical part of the Paleozoic system in this paper.

The Humble-Robinson well penetrated a sill(?) of igneous rock at least 46 feet thick at depths of 4,331 to 4,377 feet. The upper portion (4,331 to 4,344 feet) of the rock is considerably altered and the rock is quite calcareous. Serpentine and alteration products are common, and portions of the weathered material appear to have been reworked and included in the overlying light-greenish, soft sandstone of Mesozoic age. The rock is believed to have intruded Paleozoic sediments and its weathered surface to represent a long period of erosion and peneplanation extending through the early Mesozoic. It is a greenish-black diabase made up largely of thin laths of plagioclase feldspars, augite and a rhombic pyroxene, enstatite, with interstitial quartz and needles of apatite. The lower part

TABLE 7.—Paleozoic Rocks in Citrus and Levy Counties.

Company	*Well*	*Date Completed*	*Elev.*	*Depth to top of Paleozoic and* T.D.	*Elev.–Top Paleozoic below zea level*	*Thickness Paleozoic penetrated*	*Lithology of Paleozoic*	*Type of record*	*Age*
Coastal Petroleum Co.	JB & JT Ragland No. 1; Sec. 16, T. 15 S., R. 13 E.	Oct. 18, 1947	15	5810′ or 5792′ *5850′*	–5795′ or –5777′	40′ or 58′	Black, silty shale.	Cuttings, core 5840–50	Upper Silurian or Lower Devonian
Sun Oil Co.....	JT Goethe No. 1; Sec. 31, T. 14 S., R. 17 E.	June 8, 1946	45	3960′ *3997′*	–3915′	37′	Gray qtzitic ss. and black, micaceous shale.	Cuttings and core	Lower Ordovician?
Humble Oil and Refining Co.....	CE Robinson No. 1; Sec. 19, T. 16 S., R. 17 E.	Aug. 20, 1949	58	4377′ *4609′*	–4319′	232′	Gray qtzitic sandstone and black, micaceous, silty shale	Core	Lower Ordovician

has many inclusions of a black, waxy, clay-like substance and much calcite occurring as veins and as alterations of silicates along the veins.

Because of the known distribution of diabase in Triassic sediments of the eastern United States along the Appalachian Mountains of the Atlantic border, the similarity of diabase penetrated in Florida to that of known Triassic rock, and its placement in Paleozoic and burial by Cretaceous sediments this rock has been referred to the Triassic system. Their hardness and resistance to weathering suggests that these sills stood as ridges forming some relief on the great plain developed on top of the Paleozoic rocks.

The Humble-Robinson well in Central Levy County also penetrated 13 feet of green arkosic sandstone containing brown sideritic shale lenses which was apparently derived from the weathering of the Triassic (?) diabase. This sandstone lies below Lower Cretaceous sediments and because of this association is believed to represent the basal part of these beds developed as mantle rock during the early Cretaceous and covered by Lower Cretaceous beds sometime later. There is the possibility, however, that this development of the weathering profile extended over periods of time prior to the Lower Cretaceous.

If the sediments described from the Coastal-Ragland and Humble-Robinson wells are Triassic in age there would be an unconformity at the base of the Triassic system in Levy and Citrus counties. These sediments rest directly on Lower Devonian or Silurian rock and it is known that in other parts of North America the Paleozoic era is represented by a large interval of time which is missing in the section of Levy and Citrus counties. There would likewise be a missing interval of time separating this apparently deeply weathered Paleozoic shale from the overlving Lower Cretaceous sediments and an erosional unconformity is present.

The evidence of Triassic diabase is limited to discontinuous diamond cores and the relationship of the flow or sill to the underlying rock can only be surmised. Nothing can be detected as to the large structures of the igneous body. A careful study of the sediment under the lava indicates a two-inch black, silicified, dense shale which may be a contact reaction zone.

The fresh rock of the cores is a deep bluish-black color, and the weathered a light-greenish to yellowish gray. Both effervesce with cold diluted hydrochloric acid, the weathered doing so much more freely. In thin-sections[13] both rocks show an even granular diabasic texture

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[13]Petrology determined by Dr. James L. Calver, Geologist, Florida Geological Survey from thin-sections cut from the top and bottom of a six-foot core taken at depths of 4,344 to 4,350 feet.

and a subordinate aphitic structure. Extreme alteration of the ferromagnesian and feldspar minerals have taken place and the feldspars have in many places been replaced by calcite. This replacement is greater in the weathered specimens of the rock. What is presumed to represent the weathered upper surface also contains pale-green, fibrous aggregates of serpentinous and chloritic substances, and more calcite than the fresh rock. Chlorite is more abundant than the serpentine which is probably the variety bastite, a weathering product of the rhombic pyroxene. In the weathered rock the pyroxene has been altered to ferrous oxides and carbonates, largely siderite and limonite. Fractures in the rock are filled by calcite, siderite, and rarely a serpentinous mineral. The fractures in the weathered diabase are laminated with alternating layers of calcite and siderite, but fractures in the unweathered diabase are rarely filled by secondary minerals. No distinct pattern to the fracture is observable from the limited cores made available to the Survey. In these cores the contact at the base of the diabase is sharp but that at the top is gradational because some of the products of weathering of the diabase are included in the overlying sediments.

The diabase rests on a two-inch bed of black, dense, hard, silicified shale, which lies on unweathered quartzitic sandstone of Paleozoic age. Since it is known that much of the time record represented elsewhere by upper Paleozoics is absent in these counties and that a long erosional period is represented at the top of the Paleozoic section of Citrus and Levy counties, the shale may represent a soil zone developed on the Paleozoic sandstone and baked and silicified by a diabase flow, but more probably it is a metamorphosed contact zone beneath a sill.

The lower part of the diabase is greatly fractured, although the diabase is unweathered, and calcite has filled the fractures. This bottom also contains phenocrysts and inclusions of oily, greenish-black, unctuous greatly altered shale from below. The fracturing at the base may indicate cooling followed by a continued flow during emplacement.

CRETACEOUS SYSTEM

INTRODUCTION

The weathered mantle rock developed over the crest of the Peninsular arch was almost completely removed and relatively unaltered Paleozoic sediments and igneous rocks lying beneath Upper Cretaceous marine sandstone, shale and chalk are penetrated by wells. This mantle rock, deposited along the flanks of the land mass and merging with marine

sediments, has resulted in a generalized two-fold division, a red-bed clastic facies and a marine and evaporite facies. The red-bed clastic facies is confined largely to the Lower Cretaceous although some of these clastics in western Florida have been called Triassic. The basal Upper Cretaceous is commonly marine sand, sandstone and shale in peninsular Florida but red-bed clastics are present in southern Georgia[14] in beds as young as the Austin equivalent.

The distribution and relationship of the Cretaceous beneath Levy and Citrus counties can best be shown in cross section and by structure maps, figure 16. Section A-A′ is based on six wells in Levy County and B-B′ on five wells, the Coastal-Ragland well in Levy County being common to both sections, and includes four additional wells toward the south in Hernando, Hillsborough, Hardee and Highlands counties. Section B-B′ is modified from data published as chart A-A′ of the Southeastern Geological Society Mesozoic Committee, 1949.

In the continuous line of wells connecting the Highlands County well with the Coastal-Ragland well, progressive marine overlap of Cretaceous beds is clearly shown and the possibility that some of the Lower Cretaceous red-bed clastics are shallow-water equivalents of these marine beds is also indicated.

Section A-A′ illustrates the abrupt thinning of the Lower Cretaceous clastics toward the crest of the Peninsular arch, and both sections show that the Cretaceous is dipping away from the crest of the arch, indicating some movement in the structure following deposition of the Upper Cretaceous beds. The dip and strike of Cretaceous sediments are illustrated further by the structure map of figure 16. The top of the Lower Cretaceous and a characteristic shale break in the basal beds of the Taylor equivalent as penetrated by wells in Levy and adjacent counties have been contoured. The dips of both beds are approximately the same, being about 20 feet per mile south in Levy County and counties to the north and steepening to about 40 feet per mile further south. The approximate eastern limit of the Lower Cretaceous clastic red beds is also shown.

The Atkinson formation, equivalent of the Eagle Ford shale and the Woodbine sand, shown in sections A-A′ and B-B′ pinches out toward the crest of the Peninsular arch and is overlapped by limestones and chalks of the Austin equivalent.

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[14]Southeastern Geological Mesozoic Committee, Mesozoic cross sections, 1949.