PHYSIOGRAPHY

INTRODUCTION

Florida as it exists today is the land area of a much greater projection of the Continent of North America which extends south to separate the Atlantic Ocean from the Gulf of Mexico. This continental mass is the east rim of the Gulf Basin, part of the west rim of the Atlantic basin and about 60 per cent of it is covered by shallow marine water. The portion covered is wider on the Gulf side than that on the Atlantic, the land area and the submarine portion almost joining along the southern and southeastern tip of Florida.

That portion of the continent covered by marine waters ranging out from the shore line to a depth of about 300 feet of water is called the Continental Shelf, and the range of elevations on it probably represents the degree of change in sea level during the Pleistocene epoch, the shelf being alternatingly above and below sea level during this time. Evidence is rather conclusive that sea level during the Pleistocene occupied levels considerably higher and lower than that of today.

This extension of the continent of North America, including both the land area of Florida and the adjacent continental shelf was described by Shaler (1890) and was named "The Floridian Plateau" by Vaughan (1910). It projects out towards Cuba and almost joins a similar projection extending northeast from Central America, being separated from it by deep water of the Yucatan Channel and from Cuba by the Florida Strait.

GENERAL LAND FORMS OF FLORIDA

Fenneman (1932) placed the Floridian Plateau in the Coastal Plain Province and land forms recognized within this province constitute subdivisions of it. Cooke (1939, p. 14, 1945, p. 8) in reports on the geology of the State recognized a "Western Highlands", "Marianna Lowlands", "Tallahassee Hills", "Central Highlands" and "Coastal Lowlands" to cover significant land forms of Florida. Vernon (1942, p. 5) in an attempt to make the names of the topographic divisions in Holmes and Washington counties descriptive of their origin used "River Valley Province" for Cooke's "Marianna Lowlands"; "Coastal Plains Province" for Cooke's "Western Highlands" and his "Coastal Lowlands". Wayne E. Moore, who is preparing a report on the geology of Jackson County, has pointed out the duplication of Fenneman's more comprehensive term and the unde-

sirability of continuing the use of the term "Coastal Plains Province" for subdivisions of the physiography of the State.

Throughout most of western Florida, central Florida, southern Georgia and southern Alabama a large delta plain (Vernon, 1942, p. 8), made up of smaller coalescing subdelta plains (MacNeil, 1946, p. 60) was formed during the interval extending from late Miocene to early Pleistocene time. This plain is underlain by deposits placed in the "Citronelle formation" by Cooke (1939) and in Plio-Pleistocene beds by Vernon (1942).

During the Pleistocene these deltaic deposits were eroded and redeposited throughout several stages when sea level was alternately lowered and raised by the development and subsequent melting of glacial ice in high latitudes. A period of lowered sea level followed by a period of raised sea level constituted a cycle composed of a period of stream excavation and sub-aerial erosion followed by a period of stream alluviation and marine planation and deposition.

Periods of raised sea level were of sufficient duration to cut low seaward-facing embayed escarpments and to cut and construct broad plains, the most recently formed still displaying bars and beach ridges, and each being composed of a distinct depositional unit. Each marine plain has a fluviatile equivalent that extends up the streams of Florida as terraces that exhibit many characteristics of the Recent flood plains. Assuming a net gain of land with the completion of each cycle, brought about by one or more factors, including a progressive decreased deglaciation from early to late Pleistocene stages and the eustatic adjustments in land-sea relationships, a series of marine plains with seaward facing escarpments would result, each plain extending up stream valleys as flood plains and river terraces. This combination of marine and fluviatile agencies formed the greater part of the topography of Florida.

Five such cycles have been recognized in Florida by means of the sediments and the terrace-surfaces that were formed (Vernon, 1942, p. 26), the deposits and surfaces of each cycle being preserved possibly through uplift of Florida and by progressive smaller deglaciations throughout the stages of the Pleistocene. Five marine plains, including the present sea bottom, have been formed which merge with five stream surfaces, including the present flood plains, that are associated with the streams that occupy Florida today.

Some areas of Florida were apparently sufficiently high in elevation to extend through the blanket of clastic sediments formed by the delta

plain and by the stream and marine surfaces of Pleistocene age. Thus some local ground surfaces are composed of weathered Tertiary rocks and there is no younger sediment lying upon them.

The physiography of Florida can be grouped logically into four general subdivisions on the basis of origin. Highlands are composed of either sediments formed as a part of a high-level, widespread, aggradational delta plain or of Tertiary land masses rising above this plain. Lowlands have been formed either by deposition and erosion along coast lines by marine agencies or by alluviation and stream erosion along stream valleys. These obvious land forms can be grouped under four subdivisions of the Coastal Plain Province, namely *The Delta Plain Highlands, The Tertiary Highlands, The Terraced Coastal Lowlands*[7] and *The River Valley Lowlands.* These terms, applying to major subdivisions of the physiography of the State, can be subdivided to any degree and local names can be applied.

The Delta Plain Highlands, as thus proposed, would include Cooke's "Western Highlands" and "Central Highlands" and the 250-320 foot surface of Vernon's "Coastal Plains Province". The Tertiary Highlands would include Cooke's "Tallahassee Hills" as a general term although Tallahassee Tertiary Highlands would be appropriate as a local name. The Terraced Coastal Lowlands would include Cooke's "Coastal Lowlands" and part of Vernon's "Coastal Plains Province". The River Valley Lowlands is equivalent to Vernon's "River Plains Province", and Cooke's "Marianna Lowlands". The term "River Plains Province" (Vernon, 1942) has been changed to River Valley Lowlands because "lowlands" is more descriptive than "province", and some streams in Florida have not formed alluvial plains although all occupy valley lowlands.

GEOLOGIC CONTROLS

The development of land forms in Citrus and Levy counties is controlled by a warm, humid climate; high annual rainfall; a bedrock composed essentially of carbonates that are easily soluble in fresh water but highly resistant to marine erosion; low surface elevations; flat to gently dipping porous rock, covered by limited porous sand and phosphatic beds; heavily charged phosphoric, humic and carbonic acid waters; fracturing along the crest of the Ocala uplift and certain groundwater conditions.

---

[7]Term proposed by W. E. Moore, manuscript of the Geology of Jackson County, Florida.

Ground water is by far the most important agent altering the ground surface and rocks of Citrus and Levy counties today, although in the geologic past marine and fluviatile agencies were more important. In spite of an average rainfall of fifty inches, surface streams and runoff are ineffective in creating land forms in the counties. Thick sand cover on all high hills, karst topography on plains, and swamps in lowlands trap the large percentage of rainfall and result in heavy recharge to ground water. This is true in spite of the two counties being part of a discharge area for ground water contained in the system of artesian water of Florida generally. Springs are abundant and each stream in the area receives water from springs that empty from vents in the limestone valley walls. This is true of all stream valleys except along the upper reaches of the Waccasassa and Withlacoochee rivers where deep fills of alluvium form a system of interconnected swamps that are fed by ground-water seepage.

PHYSIOGRAPHY OF CITRUS AND LEVY COUNTIES

INTRODUCTION

Citrus and Levy counties compose a part of the Coastal Plain Province, and the physiography is roughly subdivided into three major units (see figure 2): 1) Tertiary Highlands; 2) Terraced Coastal Lowlands; 3) River Valley Lowlands.

The Tertiary Highlands consist of limestone and clay hills formed by the Suwannee and Ocala limestones and by the Hawthorn formation, which extend above younger sediments and create a rugged topography.

The Terraced Coastal Lowlands in other parts of Florida consist of four surfaces or plains that parallel the present coast. These plains are bounded by erosional escarpments and each is underlain by a distinct depositional unit. Marine deposits, such as bars, beach ridges, beach escarpments and fossils in the lowest, characterize the surfaces and place their origin within a marine environment. Vernon (1942, p. 18) recognized in western Florida four surfaces having shore lines at 220, 150, 105, and 30 feet above the present sea level. In peninsular Florida the two lowest surfaces are present but the bases of the bounding escarpments appear to be lower than they are in western Florida and the shore lines are near 100 feet and 25 feet. The two higher surfaces, with shore lines at 220 and 150 feet, have been so eroded in these counties that they cannot be separated into distinct units, although deposits associated with these surfaces are present.

Each of the two lower coastal surfaces includes a sandy beach developed along the coast line, and a limestone shelf cut by marine planation, upon the youngest of which marine shells and late Pleistocene sandy limestones were deposited.

The River Valley Lowlands include the limited narrow flood plains developed at the mouth of each of the streams crossing the counties, sand bars and alluvium deposited along the valley walls of the Suwannee and Withlacoochee rivers during the late Pleistocene, and Tertiary limestones exposed along the channels and valleys. The lower course of each valley has been recently entrenched into the limestone bedrock, probably since the last rise in sea level. This entrenchment has formed steep limestone-walled channels that end abruptly at the surface of each coastal terrace.

TERTIARY HIGHLANDS

Within these two counties, the Tertiary Highlands are present only in central Citrus County and because of limited exposures and a lack of details their distribution is greatly generalized on the physiographic map, figure 2. These highlands are erosional-remnant hills and ridges, composed of the Suwannee and Ocala limestones, sand and clays of the Alachua formation, and marine clays of the Hawthorn formation. Northward they merge with a high, rolling sand ridge that has been named the Coharie-Okefenokee Sand Ridge, page 25. In addition to the generalized mapping of the Tertiary Highlands in figure 2, they are also shown more specifically on Plate 1 as outcrops of the Suwannee limestone and the Hawthorn formation.

The highlands rise steeply above the surrounding plains, figure 3, to give an impression of relief considerably greater than the moderate relief of 150 feet, which is present. The highest limestone hill on the highlands is 192 feet. Because this hill has no younger beds covering it and early Pleistocene deposits are known to be present in the counties at elevations up to 220 feet, it is presumed that the Tertiary Highlands stood higher during the early Pleistocene and have since been reduced.

DELTA PLAIN HIGHLANDS

Although Cooke (1945, p. 9) mapped the "Central Highlands", equivalent to the Delta Plain Highlands of this report, in Levy and Citrus counties, no sediments similar to those found toward the east in the Delta Plain Highlands of Lake and Polk counties or northward in western Florida, were found. Also no elevation in the counties extends

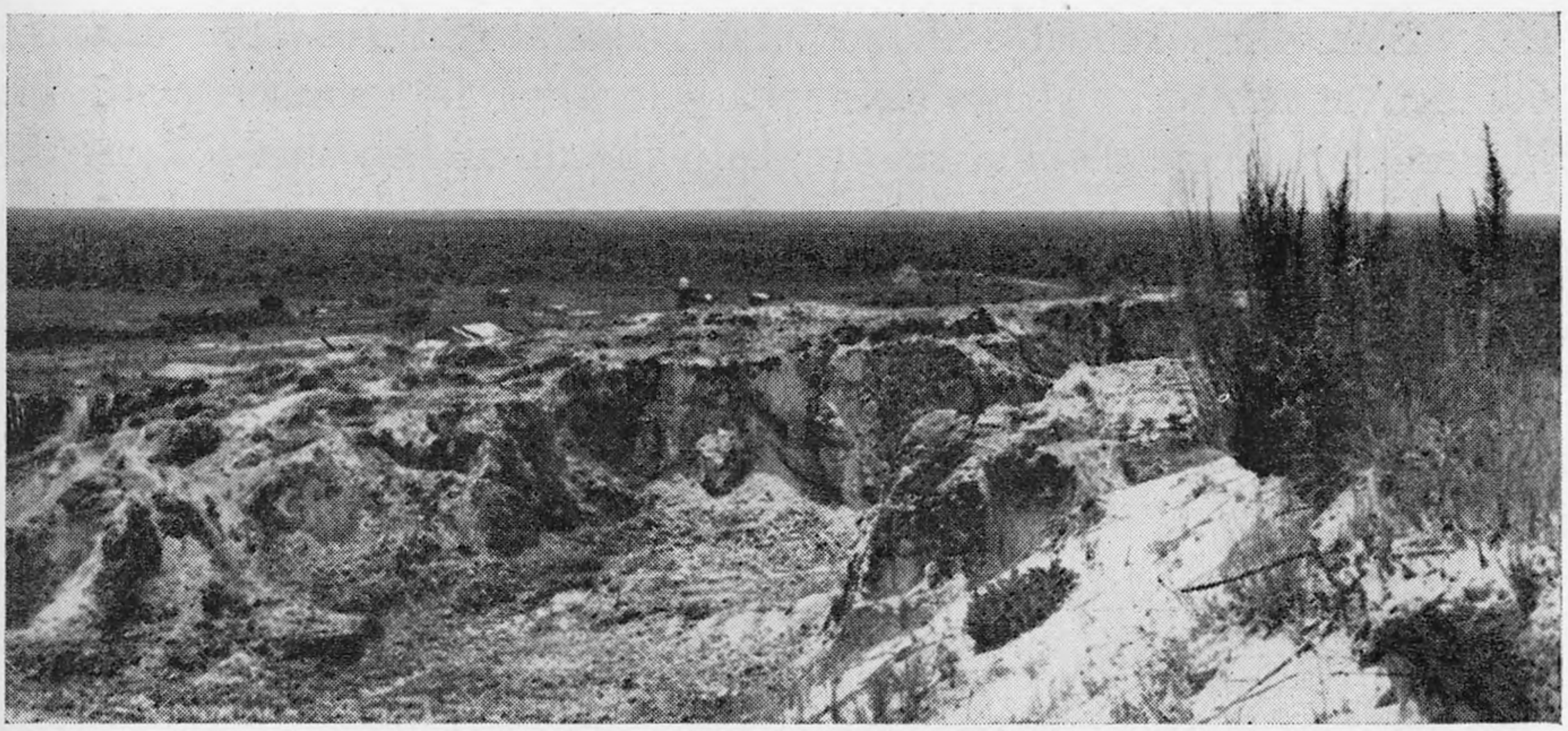

Figure 3. The Terraced Coastal Lowlands as seen from the Tertiary Highlands at the Crystal River Rock Company quarry, five miles southeast of Crystal River, Citrus County.

above 220 feet, which is the highest level of a definite Pleistocene shore line in the State. Since the Pleistocene terrace surfaces, formed seaward of the various shore lines, are aggradational (Vernon, 1942) and are composed of formational units confined to each surface, it is apparent that if the delta plain sediments ever extended across these counties they have been reworked and deposited as early Pleistocene sediments.

TERRACED COASTAL LOWLANDS

These lowlands cover approximately 90 per cent of both counties, and extend inland from the present shore to near the eastern extremities of the counties, and may have extended over the whole area at one time. Their continuity is broken only by lowlands developed along river valleys.

In other parts of Florida the Terraced Coastal Lowlands include four coastwise surfaces, and deposits found beneath each of these are probably present in these counties, but because of erosion the two higher surfaces could not be separated. Only the two lowest and youngest surfaces are well-developed and preserved. Deposits of the two oldest surfaces make, in part, a high sand ridge which is named the "Coharie-Okefenokee Sand Ridge". Tertiary rocks may compose a portion of this ridge in Citrus and are the base of the ridge in Levy County.

The names of three coastal terraces as used by Cooke (1945) and the term Okefenokee as used by McNeil (1949) have been applied to the Pleistocene sediments in Citrus and Levy counties as follows: The oldest and highest terrace is the Coharie with a shore line at 220

feet, the Okefenokee at 150 feet, the Wicomico at 100 feet, and the Pamlico at 25 feet. These have characteristics in common with the modern submarine plain at sea level. In the discussion that follows the modern plain and the youngest of the terraces are discussed first, the details preserved upon these aiding in understanding older and more eroded terraces.

Modern Submarine Plain

One attack on the problems in geology is to study the effects of geologic agencies that are active today. Marine deposition and erosion have controlled the formation of the coastal terraces that compose much of the land surface of the State. In an attempt to understand the marine plains of the Terraced Coastal Lowlands of these counties a study of the modern submarine plain was made. This study was limited to the evaluation of the submarine surface from hydrographic charts of the area, from a series of core holes placed at one-half mile intervals, 13 miles into Gulf waters by the U. S. Army Engineers along the route of the proposed ship canal, and from three days of collecting submarine rock exposures by diving and by sounding the bottom.

The sea bottom is a rolling plain sloping gently seaward and containing irregularities caused by sand bars, oyster bars, limestone shelves and reefs, and shell deposits. The submarine plain is composed of several parts, these varying in width depending on the location of streams, bay indentations and oceanic currents. Extending along a line drawn perpendicular to the shore, this plain is made up of narrow bands of sediment that parallel the modern coast line. Land along the entire coast is rocky except in the vicinity of the Suwannee River, where it is sandy. The rock is a fractured limestone and bays, inlets, islands and rock pinnacles are common. Sandy mud marshes have penetrated along the low places of the shore line, and the limestone stands above the sediment in these marshes five to eight feet, making an abrupt escarpment, see figure 4. This marsh averages two to three miles in width except for southern Citrus County where it approaches six miles, see figure 2. Extending out from shore and from the marshes there is a submerged plain, varying considerably in width, that is composed of two parts or belts. The coastal belt is covered by water that is very shallow, only rarely exceeding four feet; sand bars are common and make shoal areas. It is present from the shore out to where it ends, often abruptly, in deeper water that covers the seaward belt of Tertiary limestones that have been eroded to a rolling flat shelf. Depressions in the limestone belt have been filled by deposits of modern shells of marine

mollusks and foraminifers, some of which have been loosely cemented to form thin limestone beds. An occasional sand bar is present on the shelf and some high areas of the limestone rise 10 to 20 feet above the bottom as pinnacles.

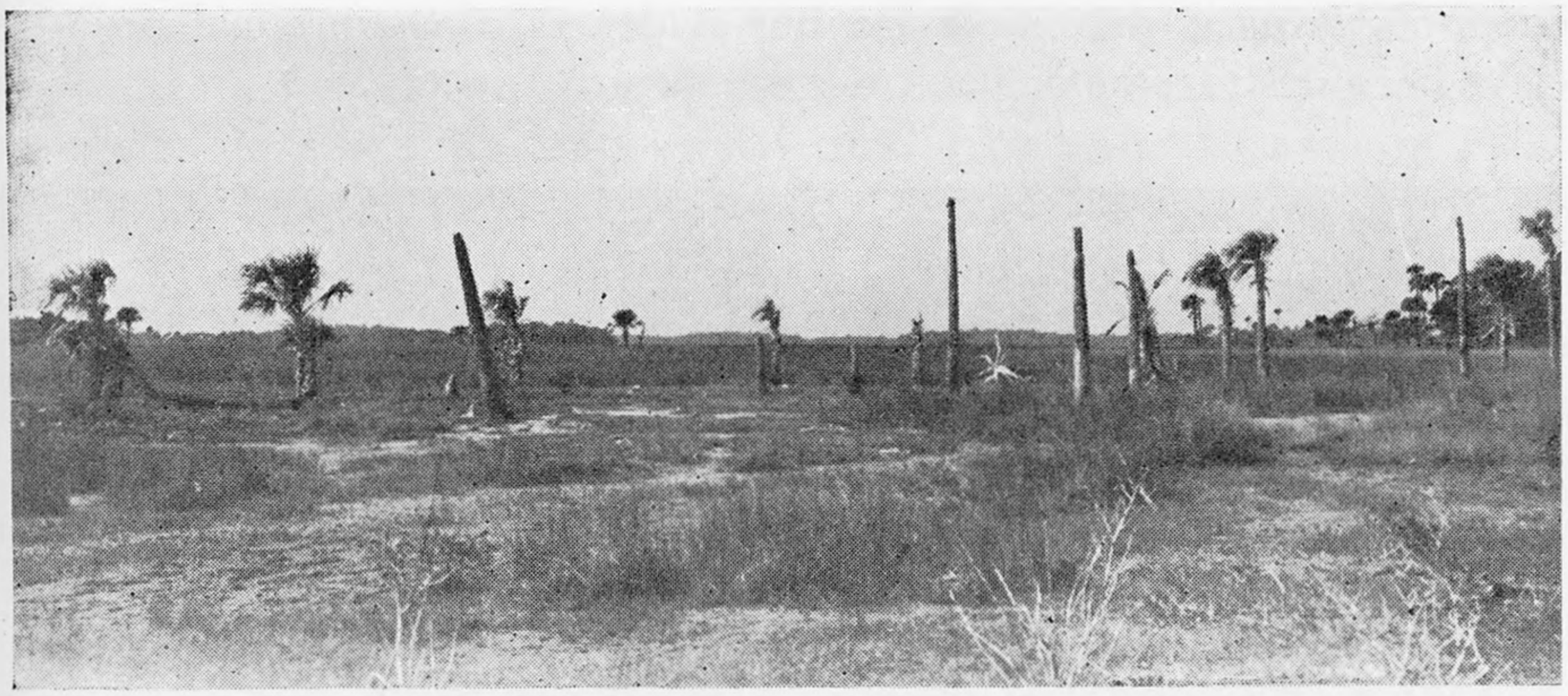

Figure 4. Drowning of coastal margins by salt-water marsh. Photograph taken facing due west at old Stevens Homestead, three miles northwest of Yankeetown, Levy County. Islands in the marsh in the background are composed of limestone of the Inglis member of the Moodys Branch formation.

Coastal Terraces

The physiographic map, figure 2, and the aerial map, figure 5, reveal two well-developed erosional escarpments across Citrus and Levy counties. These escarpments trend almost north and south and have been developed along the western foot of the Coharie-Okefenokee Sand Ridge. They are the landward boundaries of two Pleistocene seas, the Pamlico and Wicomico surfaces, with shore lines at 25 and 100 feet respectively.

Each shore line is marked by the development of a narrow belt of sand along the coastal margins and further seaward by a broader belt of limestone that has been planed by marine erosion to an irregular rolling shelf. In these respects the Pleistocene surfaces correspond to the modern submarine surface. The Pamlico surface has another characteristic in common with the modern submarine plain which is the development of fossiliferous marine sediments upon the limestone shelves. Fossils have not been noted in the sediments of the Wicomico surface.

A high sand ridge, the Coharie-Okefenokee Sand Ridge, developed to the east of the two definite Pleistocene surfaces covers most of eastern Citrus and Levy counties. Remnants of this sand over the Williston

Limestone Plain and in the Withlacoochee Valley indicate that the ridge was once present over these areas and has been removed. This ridge is underlain by the Alachua formation of Miocene (?) age and by unfossiliferous sand and clay deposits of early Pleistocene age. In other parts of Florida the Pleistocene deposits occur beneath two high surfaces occurring at definite levels, but evidences of the original surfaces have been destroyed along this ridge.

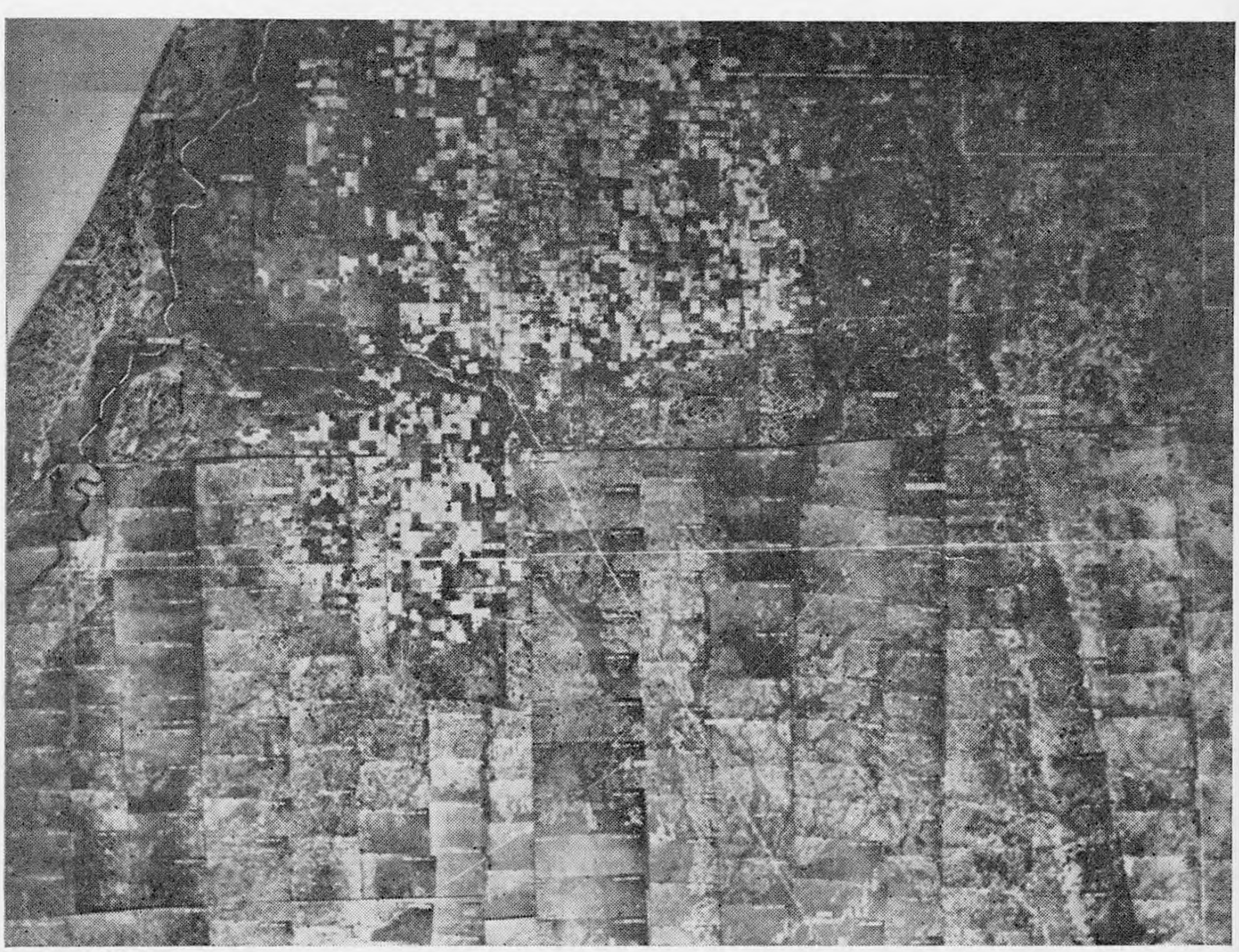

Figure 5. Mosaic of aerial photographs of northern Levy County illustrating the physiography and trace of the Long Pond Fault. Note the well-developed terrace escarpments along the right side of the figure, and the offsetting of the two blocks in the upper-left portion of the photograph.

Pamlico Terrace: This surface is well-developed in both counties and is underlain by sediments that characterize the surface and compose the Pamlico formation. The Pamlico formation is considered to be contemporaneous with sand bars developed along the Suwannee River at comparable elevations.

The present coast of Citrus and Levy counties is obviously submerged, as evidenced by the extensive coastal marsh, see figure 4, and the many drowned valleys and inlets, Plate 1. This indicates a rising sea level that

is out of adjustment to the land mass. As a result, the Tertiary limestones and younger beds that underlie coastal flat lands are being eroded along coastal margins to form a fairly continuous limestone escarpment, standing three to five feet above sea level. In the vicinity of the Suwannee River, sand bars deposited by the river obscure the limestone escarpment and modern dunes, developed along the coast from Cedar Keys to the Suwannee River, cover the Pamlico surface and create an irregular ridge-like topography of Recent origin on a flat plain of Pleistocene origin. This ridge, not separated on the physiographic map, figure 2, is included with the Pamlico surface.

The Pamlico marine plain, the lowest of the coastal terraces, extends inland from the coast to approximately the 25-foot contour which marks the foot of a 10 to 20-foot escarpment. The surface of the plain is about eight to ten miles wide in Citrus County but covers most of central Levy County, making a deep embayment along the Waccasassa River, where it merges with a fluviatile equivalent developed as a small delta plain at the mouth of a large stream that once occupied the valley, see pages 33 to 36.

The Pamlico surface is similar to the modern submarine plain in that it is composed of long, narrow belts of sediment that parallel the Pamlico coast line. A narrow band, up to three miles wide, extends seaward of the Pamlico coast line and makes a distinct pattern on aerial photographs, figure 5. This belt is composed of sand that makes a poorly drained flat surface, covered by slash pine and palmetto. Elevations range between 15 and 25 feet although ridges that were apparently sand bars in the Pamlico seas rise to slightly above 40 feet.

Toward the modern coast and seaward of the Pamlico coast line a broad limestone shelf, up to 12 miles wide, composes the Pamlico surface. This shelf lies near sea level at the modern shore line and rises inland to an elevation of 20 feet. The Tertiary limestones, Avon Park limestone, Moodys Branch formation, and Ocala limestone, have been eroded by fresh-water and marine erosion to rolling flat limestone plains. Irregularities produced by solution have been obliterated by a thin covering of Pleistocene sediments of Pamlico age. These sediments include beach coquina deposits, brackish-water sediments, sandy unfossiliferous pasty limestones, fresh-water marls, and sand. Prior to this coating of Pleistocene sediments the limestone surface was doubtless made rugged with considerable relief, but the effect of the deposition of these sediments has been to level this surface. In the vicinity of the Suwannee River, sand bars have been deposited over the limestone by the river.

The lower coastal margins of the limestone shelf have been drowned by salt-water marshes. Here the limestone extends as peninsulas and islands into these marshes rising three to eight feet above the sediment in the marsh. Along the Pamlico coast line the limestone shelf is covered by the sand belt described above. The contact of sand on limestone is distinct, being marked by a small definite depositional escarpment which connects the gentle slopes developed upon the two belts.

Because the limestone shelf (see figure 6) is connected with the artesian water system, the water levels in the ponds and lakes of the coastal areas fluctuate greatly. During high seasonal rainfall the area is flooded, ponds, lakes and streams coalescing to form a shallow swamp. In periods of droughts most of the surface is dry and paved with rock but the discharge from the aquifer maintains swamps in shallow basins. This shelf is greatly fractured which, combined with the heavy discharge from ground water, gives rise to numerous clear water springs scattered throughout the hammocks. These are beautifully set in a tropical vegetation and are so located as to combine fresh water along the upper parts and brackish water along the lower parts of the channels, and both fresh- and salt-water species of fish inhabit some of the springs.

Virtually the entire belt of the Pamlico terrace, shown on figure 2 as limestone flatwoods and hammocks, is a continuous hammock, various portions of which have been designated by the principal streams that

Figure 6. Limestone of the Inglis member forming the floor of the coastal hammocks along State Road 55, U. S. 19, six miles north of Crystal River, Citrus County

traverse them, such as Homosassa Hammock, Chassahowitzka Hammock and Gulf Hammock developed about Waccasassa Bay. These hammocks teem with game and fish and are valued as tourist attractions. Much of the timber of Florida, cypress, cedar, pine, tupelo, gum, maple, bay, cottonwood, willow, basswood, magnolia, poplar, oaks, hickories, walnut, ash, birch, elm, sycamore, palm and tropical vegetation, grows in such great abundance that the entire area is choked and virtually a canopy of vegetation is developed.

Wicomico Terrace: Like the Pamlico terrace and the modern submarine plain, the Wicomico terrace is composed of a belt of sand developed along the Wicomico shore line, and a submarine limestone shelf, named the Chiefland Limestone Plain. The sand belt is developed along the western foot of the Tertiary Highland and Coharie-Okefenokee Sand Ridge. It enters Citrus County along its eastern central margin and trends northerly to the vicinity of Bronson, Levy County, where it merges with fluviatile sediments deposited along the valley of the Waccasassa River. The belt is about two miles wide for the most part, but broadens in southern Citrus County and up the valley of the Withlacoochee River. The terrace is bounded on the east by an escarpment rising onto the Coharie-Okefenokee Sand Ridge and to the west by the escarpment of the Pamlico terrace. These escarpments and the terrace surface are clearly evident on the aerial photograph of figure 5.

Chiefland Limestone Plain: The limestone shelf that is associated with the Wicomico terrace is believed to have been preserved partly as the *Chiefland Limestone Plain*. In the vicinity of Chiefland a flat rolling surface, figure 7, has been eroded upon Eocene limestones. The irregular erosional surface has been leveled by the deposition of fine argillaceous sand in the low places. Surface elevations range from about 40 feet at Chiefland to about 80 feet near the Waccasassa Valley. The relations of the elevations of the Wicomico limestone plain to its contemporaneous sand belt is comparable to the distribution of elevations upon the sand belt and limestone shelf of the Pamlico terrace and the modern submarine plain.

Coharie-Okefenokee Sand Ridge: A high ridge of unfossiliferous sand, having considerable relief, extends almost north and south across the eastern portions of Citrus and Levy counties. The sand ridge merges with and partly covers the high hills of Citrus County, which are composed of Tertiary sediments. No consistent elevations or definite terraces were apparent, although elevations were generally higher on the eastern side of the ridge. A maximum elevation of 220 feet was noted

Figure 7. The Chiefland Limestone Plain northeast of Chiefland, Levy County, in the center of Township 11 South, Range 15 East. Photograph taken facing east.

on one hill in northern Citrus County. Here the sand covered the Suwannee limestone of Oligocene age.

The ridge is bounded to the west by the Wicomico terrace and its fluviatile equivalent and to the east by the *Williston Limestone Plain* in Levy County, and the Tsala Apopka Lake in Citrus County. The eastern boundary is much more irregular, and remnants of the sediments composing the ridge preserved on the lowlands along this boundary indicates that the ridge probably extended over these lowlands and has been removed.

The ridge is composed of Miocene (?) sediments of the Alachua formation, covered by thick deposits of late Pleistocene sand. The sediments and fauna of the Alachua formation indicate that they were formed under terrestrial conditions upon a very irregular limestone surface eroded prior to their deposition and subsequently greatly altered by the very erosive process of phosphate fixation, see pages 195 to 202. Erosion by phosphoric and carbonic acids formed numerous sinks that were partially filled by sediments of the Alachua formation.

Sands covering the irregular surface at elevations above 105 and below 220 feet and the presence of Pleistocene surfaces with shore lines at 150 and 220 feet throughout the State indicate that early Pleistocene seas deposited a thick cover of clastics over a broad area throughout the State. The greater portion of the sediments has been removed in these counties leaving a high ridge, the ground surface of which is sand.

Phosphate fixation and the solution of limestone bedrock is continuing today and the entire ridge is marked by slumps and sink holes, the sediments forming the ridge being greatly distorted and the ground surface made irregular.

RIVER VALLEY LOWLANDS

The River Valley Lowlands covers all stream valleys in the two counties being found only along stream courses, and are very narrow except for the specialized broad valley of the Withlacoochee River in Citrus County and the Williston Limestone Plain in Levy County, a part of the Waccasassa River Valley Lowland. These two valleys are developed along the eastern portions of both counties, and lie east of the Tertiary Highlands and the Coharie-Okefenokee Sand Ridge.

Stream Valleys

A number of sluggish clear water streams cross Citrus and Levy counties, most of them flowing from high sand hill divides in a westerly and southwesterly direction to the Gulf of Mexico. Only two originate from outside the counties, the Suwannee River that borders the northwestern portion of Levy County and the Withlacoochee River that circles Citrus County along the southeastern, eastern and northern boundaries.

The Waccasassa River, Otter Creek, Cow Creek, Ten Mile Creek, Turtle Creek and Wekiva River in Levy County; Crystal River, Halls River, Homosassa River, and Chassahowitzka River in Citrus County, are the larger streams of those originating within the counties. These streams, as are the Suwannee and Withlacoochee rivers, are almost entirely spring fed (see Vernon, 1947, p. 18), and all but three originate in springheads. The Waccasassa River, Otter Creek, and Ten Mile Creek flow in their upper courses over sandy soils and rise from swamps and sinks as poorly defined and poorly connected channels that gradually develop into definite stream courses. Their waters are heavily charged with dissolved solids of surface origin, largely humic acids and organic muds, and differ from the clear spring water of the other streams. In the lower courses, their valleys are formed in limestone, the same as other streams of the area.

Each of the streams originating in a springhead rises from caverns that extend back into the limestone bedrock, and the upper portions of many of the stream channels appear to be collapsed caverns. From the springhead to the mouth each stream channel is formed in bedrock. These streams, together with the larger Suwannee and Withlacoochee rivers,

flow throughout much of their length in limestone channels that are broken by a maze of fractures and caverns, from which large flows of ground water issue. Levy and Citrus counties are located in a discharge area of the Florida artesian ground-water system.

Both counties have poor surface drainage, sand covered plains and hills and karst topography capturing the large part of the surface waters. Good surface drainage is present only along the coast, in central Levy County, and along the valleys of the two major streams that cross the area. Elsewhere ground-water drainage is predominate.

Stream Terrace Sediments

Stream terraces have been described in Florida by Vernon (1942) and their origin discussed. In Citrus and Levy counties patches of alluvium lie along the valley walls of the Suwannee River and the Waccasassa River well above the flood plains. These sediments occur at two definite levels and stream cut escarpments are present where the deposits are in contact. Each of the levels represent a period of alluviation at a time when the streams were adjusted or were adjusting to sea levels, higher than the present level.

The deposits that occur as sand bars along the Suwannee River Valley are narrow and extend up the valley somewhat parallel to the present flood plain. The bars have been well-preserved since their deposition because of their great porosity and resistance to erosion by surface wash. The deposits along the Waccasassa River are apparently unrelated to the modern river system. The lowest of these deposits is a large valley fill and delta that covers central Levy County at elevations from 20 to 50 feet above sea level. The valley is flat and gently sloping from its upper portion to the center of the county where the stream deposits merge with marine deposits of Pamlico age. The lower part of the valley was probably a bay and sandy limestones of possible bay origin are found interbedded with the alluvium. Alluvium is also preserved at altitudes of 100 to 120 feet above the sea level, along the west side of this valley, figure 2, covering a broad limestone plain in the vicinity of Newton, Florida. These sediments are believed to be remnants of a flood plain developed along a stream, larger than the Waccasassa River, that once occupied and developed the valley the Waccasassa now occupies. This flood plain occurs at levels comparable to the coastal terrace that is a part of the Wicomico marine plain developed when sea level stood at 100 feet above modern sea levels.

Suwannee River Valley Lowland

The Suwannee River Valley, a narrow band of alluvium, thinly veneering limestone bedrock except at the mouth where the fill of alluvium is greater, extends along the northwestern boundary of Levy County. The river empties into the Gulf of Mexico at Suwannee Bay where the lower section of the valley is drowned and the flood plain is covered by salt-water marsh. The river carries almost no sediment other than fine muds and dissolved solids. During floods, fine to medium sand is reworked along the river banks and dropped as sand bars along the valley walls. Muds and dissolved solids are deposited along the lower reaches of the valley at its mouth and in Suwannee Bay.

The valley of the Suwannee River is a solution valley and outcrops of limestone are almost continuous throughout its length. Thin sand bar ridges veneer the limestone bedrock away from the channel. This sand occurs at two definite levels above the flood plain and the river is presumed to have occupied its present course since the late Pleistocene. If sand bars of the Suwannee River were deposited during the early Pleistocene they have either been removed by marine planation, or they have been incorporated with other sediments from which they could not be separated.

Withlacoochee River Valley Lowland

The Withlacoochee River rises in Polk County and for the most part, throughout its course to the Gulf of Mexico, at Inglis, it flows on limestone and through a limestone-walled channel. A flood plain is developed only along its course in Citrus County, above Dunnellon, Marion County. From Dunnellon to the coast the channel is cut in limestone and only a thin veneer of highly organic mud has been deposited along its banks. Along this portion of the river the flats of the Terraced Coastal Lowlands continue without a break to the edge of the channel walls, the river having cut a deep trench to the coast, modified by almost no alluviation. The mouth is drowned by Gulf waters and is marshy.

The river crosses the crest of the Ocala uplift in the vicinity of Dunnellon, and has had difficulty maintaining a course across it. The river is clearly antecedent and the fold of the Ocala uplift has ponded the river above Dunnellon to form the Tsala Apopka Lake. The valley below Dunnellon is a limestone solution valley and where it crosses the Coharie-Okefenokee Sand Ridge the banks are steep and the Alachua formation and early Pleistocene sands make a deep V-shaped valley, con-

taining a deep alluvial fill composed of sediments re-worked from the Alachua formation and Pleistocene sand.

Tsala Apopka Lake: Tsala Apopka Lake is part of a rolling plain area, up to 14 miles wide and 25 miles long, extending along both sides of the Withlacoochee River and gradually merging up stream in Hernando County with normal flood-plain topography. This plain is part of a broad valley that is bounded by high sand hills to the southwest and northeast. The northeastern (right) side of the valley is a broad swamp broken by a few lakes, of which Lake Panasoffkee in Sumter County is the largest. The southwestern (left) side of the valley is a system of connected lakes, Tsala Apopka Lake, partially separated by rolling flat peninsulas and islands.

The land surfaces are composed of Eocene limestones, over which there is present a thin residuum of the Alachua formation, which apparently was once of much greater extent, and largely has been removed to form the valley. The land surface of the valley is one of considerable relief, the low places being filled with water and the high places being land, paved with limestone, predominantly the Inglis member of the Moodys Branch formation. Phosphorite, clay and sand of the Alachua formation thinly veneer the limestone and has filled fractures and sinks to considerable depths. Near the river and along abandoned river courses alluvium has been deposited, filling deep cut channels.

The water levels in lakes and swamps stand at elevations of 35 feet in the lower, and 45 feet in the upper part of the valley. Land elevations are commonly less than 60 feet but may rise to about 80 feet. The river is a few feet lower than adjacent swamp and lake levels in the lower part of the valley, but in the upper part the channel of the river is not clearly distinguishable from swamp and lake. The river meanders torturously through the upper Tsala Apopka Lake, the channel often being recognized only by relatively unobstructed water passing through dense cypress and other water growths. Where the channel is obstructed by hyacinths it is exceptionally difficult to locate and it is almost impossible to traverse the river. Numerous tributaries, the Panasoffkee River, Juniper Creek, Dead River and smaller streams contribute to the complicated pattern of channel crossings through the lake.

From a study of the stream patterns and the geology along the Withlacoochee River, it is evident that the river is antecedent, at least in part, to movements forming the Ocala uplift. The course of the Withlacoochee River, for the most part, is along the top of the Ocala uplift. It apparently has adjusted to the fractures developed along the crest

of the uplift, the course of the river paralleling the fracture pattern of the area, see figure 11. In the vicinity of Dunnellon the river departs from this pattern and heads westerly toward the Gulf of Mexico. This course is across the crest of the Ocala uplift and the river has cut a deep limestone-walled channel to the coast. The most striking feature of the upper Withlacoochee River is that the stream channel is not formed continuously in bedrock as it is toward the coast, instead deep alluvial fills more than 100 feet thick, reaching depths to 83 feet below sea level are present, see well W-1198 of figure 14.

This information indicates that the river was established along its present course by erosion of a deep valley cut into the Alachua formation and Eocene limestones. The river has meandered across its valley along the east flank of the Ocala uplift and has eroded a broad valley and filled it with alluvium. This ponded water has accelerated groundwater recharge to the underlying limestone bedrock. Solution of the limestone has created depressions throughout the valley, and these, together with flood plain lowlands, form the basins of the many lakes that occupy the valley.

There is no evidence of either erosion or deposition that indicates the river has occupied its position for any great time. Its valley is steep and V-shaped where it crosses the Coharie-Okefenokee Sand Ridge and no high level river terrace deposits are found along its valley walls, which suggests that the river was established during the late Pleistocene. If this is true, periodic structural movements along the Ocala uplift must have continued into the Pleistocene, although there is evidence that the major movement was during the Miocene.

Matson (1913, pp. 33, 34) used the name Tsala Apopka Terrace for a marine terrace surface lying between elevations of 40 and 60 feet, in the vicinity of Tsala Apopka Lake. In view of the evidence developed during the study of Citrus and Levy counties this surface is clearly fluviatile in origin and the abandonment of the name as a physiographic term by other writers is substantiated.

Waccasassa River Valley Lowland

The Waccasassa River rises as a poorly defined channel connecting swamps and tyty ponds in Gilchrist County. Along its upper course in Levy County the stream is a sluggish, poorly connected series of swamps, lakes and ponds that have formed in a valley up to three and one-half miles wide, see figures 8 and 9. Approximately two miles south of Newton, Levy County, this valley fans out, and one side extends westerly

toward Long Pond and breaches the Chiefland Limestone Plain at this point. The other continues southerly along the foot of the Coharie-Okefenokee Sand Ridge. The pattern of this widened valley and the sediments that underlie the flat surface exhibit characteristics of an alluvial plain, see figure 2. The limestone bedrock is buried 14 to 18 feet beneath cross-bedded sands and clays throughout the area.

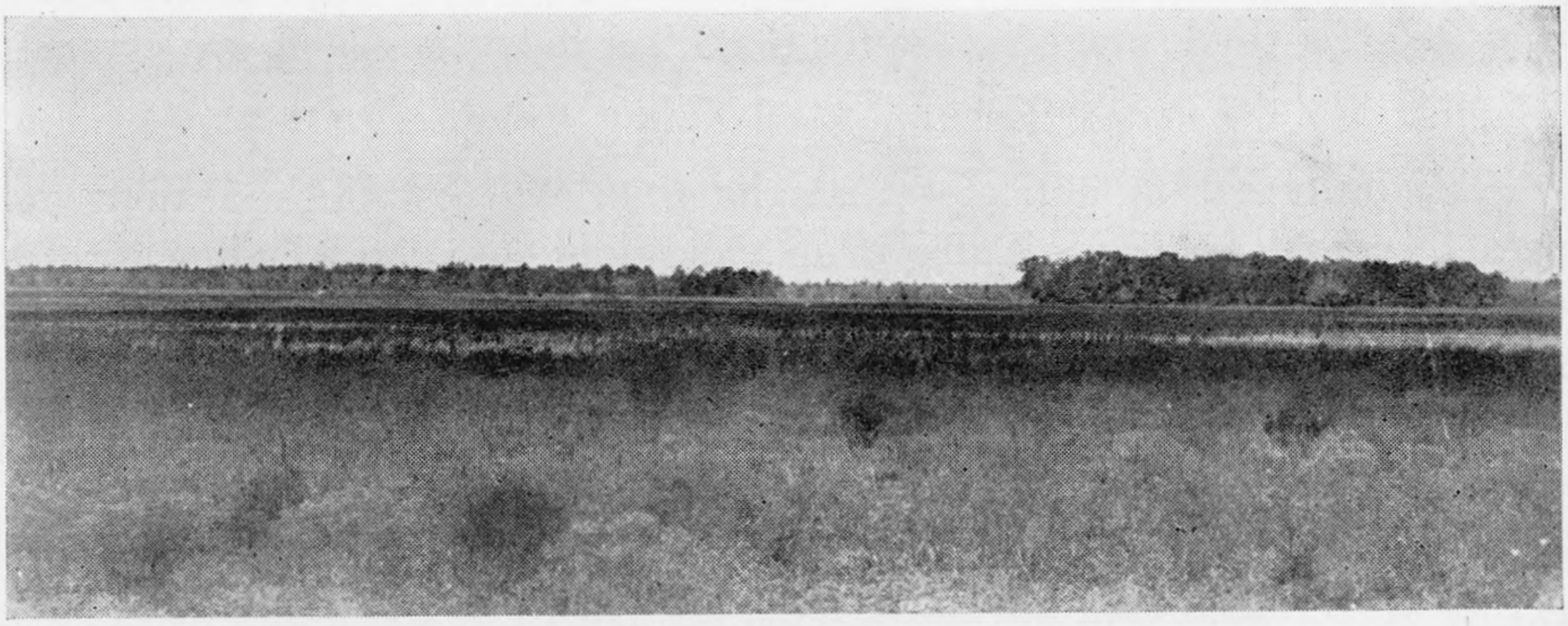

Figure 8. Broad lake-filled valley now occupied and only partially drained by the Waccasassa River. Photograph taken facing south in Section 13, Township 11 South, Range 16 East.

From the point where State Road No. 34 crosses the river to the coast the river flows through a limestone-walled channel that is a trench cut by the river into the flat surfaces of the Terraced Coastal Lowlands and of the alluvial valley described above. Throughout its lower course the river is spring fed and has all the characteristics of other streams of the area. A modern narrow flood plain of organic muds and sand is present only in the lower portion where the river merges with the marshes formed by drowning of the mouth of the river.

In northern Levy County, northeast of Newton, the Eocene limestones are covered by a thin deposit of alluvium containing Pleistocene sands and sediment reworked from the Alachua formation, see figure 2, and limestone exposures are rare. This alluvium lies at an average elevation of 110 feet and is believed to have been deposited by a stream larger than the Waccasassa, see pages 33 and 36, that occupied the valley during Wicomico time when sea level stood at 100 feet, and the Chiefland Limestone Plain was a marine shelf.

Williston Limestone Plain: Over most of eastern Levy County, particularly in the vicinity of Williston where it is well-developed, there is a gently rolling limestone plain. Exposures of Eocene limestones are common and only a thin veneer of sand and residuum of the Alachua forma-

tion covers the bedrock. Pockets of phosphate of the Alachua formation, preserved upon this plain, were the sites of the early hard-rock phosphate mines in the area. The plain ranges in elevations from 60 to 80 feet with an occasional knoll rising to 100 feet. Shallow prairies, sinks and lakes mark its surface irregularly.

The plain has very irregular boundaries, being bound to the west by the Coharie-Okefenokee Sand Ridge and to the east by high sand hills composed of sediments similar to those of the Coharie-Okefenokee Sand Ridge. The plain is about 10 miles across at its widest and extends east and south into Marion County, narrowing and branching to the south. Toward the north in Alachua County the plain widens and branches to include Payne Prairie, other large prairies, lakes and much of the Arredondo quadrangle. The plain can be traced across the western portion of Alachua County into Gilchrist County where it joins the broad valley now occupied by Cow Creek and Waccasassa River.

In its pattern, sediments and physiography, this broad plain resembles the Tsala Apopka Lake region and is believed to have had a similar origin, to have been occupied once by a well-developed stream or stream system. This stream emptied westward into the Waccasassa River Valley Lowland prior to stream capture in that valley. Prairie Creek now emptying into Payne Prairie may have been this stream, which was captured by underground drainage. Its tributaries meandering down the eastern slope of the Ocala uplift could have removed in early Pleistocene time the unconsolidated sediments that covered the Tertiary limestone.

Stream Capture

The broad and shallow valley present in northern and central Levy County that is occupied now by the Waccasassa River contains no definite and significant streams for the most part, and the width of the valley does not correspond to the size of the streams that occupy it, see figure 8. On the aerial photograph, figure 9, this valley can be traced from central Levy County across Gilchrist County to the Santa Fe River where it ends. The valley trends almost due north and south being slightly concave toward the east; and is bounded to the west by good farm land developed upon the undulating Ocala limestone plains and to the east by high sand hills composed of the Alachua formation and Pleistocene terrace sands.

The valley is flat and sandy and contains a maze of small prairies, tyty ponds, and small open lakes. Much of the valley is now drained underground by sinks and during heavy rainfall many of the swamps,

Figure 9. Aerial photograph of a broad, poorly drained valley crossing Gilchrist County into northern Levy County.

prairies and lakes are connected. Some of the prairies and swamps are arcuate and enclosed and resemble old meander scars in pattern and distribution. This is particularly true in the vicinity of Franklin Sink, Gilchrist County.

The valley is drained in the north by Cow Creek and in the south by Waccasassa River and, for the most part, is not occupied by any definite continuous drainage. The two streams that drain the extremities of the valley are sluggish and swampy and are too small to have formed such a broad valley. It is presumed that the valley was once occupied by a large stream which has been beheaded by stream capture in the vicinity of its juncture with the Santa Fe River Valley, or that the stream may have been captured by underground drainage.

Stream capture and water diversion is not uncommon to the north in Columbia County, several dry stream valleys, such as Long Arm Hammock, being present.[8] Likewise numerous collapsed-cavern water courses which connect between natural bridges are present in the county. These are prominent on aerial photographs of Columbia County, the Itchtucknee River and Olustee Creek with their subterranean connections being good examples.

The presence of confirmed dry stream courses in Columbia County suggests the possibility of stream capture in adjacent counties. Cow Creek is separated by an almost imperceptible divide from the swamps forming the headwaters of Waccasassa River, and its course is more clearly defined than that of the river indicating a higher gradient in Cow Creek, presumably the reversed portion of a larger stream with the Waccasassa River being the beheaded remnant. Cow Creek is also most peculiar in that it has a northerly course, whereas most streams of the area run south and southwest toward the coast. Each of these facts considered together indicate stream capture, but the valley may have resulted from the modification of a Pleistocene marine terrace and escarpment, since such a terrace and escarpment is known to be present along the east side of the valley. It is believed, however, from a study of the character and distribution of sediments of northern Levy County that once a large stream formed a delta (shown in figure 2) that extended over much of central Levy County forming a thin veneer of clastics on limestone bedrock. These sediments are cross-bedded sands and clays containing elements of the Alachua formation, presumably eroded from the eastern side of the valley along the base of the escarpment rising onto the Coharie-Okefenokee Sand Ridge of eastern Gil-

[8]Personal communication from J. C. Simpson, February 7, 1951.

christ and Levy counties. This stream was probably the ancestor of the Waccasassa River, which remains as a sluggish stream, occupying a portion of a broad valley, largely abandoned.

The stream capture is dated by the Pleistocene history and sediments. The alluvium along the Waccasassa River merges with marine deposits of the Pamlico and Wicomico formations. A major stream obviously occupied the valley during Pamlico time when sea level stood at 25 feet. This is the youngest coast line in the area and is believed to be late Pleistocene in age. The stream capture probably occurred during entrenchment of streams into the limestone bedrock following the uplift of the land during the late Pleistocene and the last rise in sea level. If this premise is true, the date of capture would be early Recent.

PLEISTOCENE HISTORY IN FLORIDA

TERRACED COASTAL LOWLANDS

Many studies have been made and numerous publications covering terraces in Florida have been printed. The major contributions on terrace studies were summarized by Vernon (1942, pp. 15-18). From these studies two basic theories of terrace origin within the State have been developed. One theory proposes that these terraces are essentially marine planation surfaces cut during cyclic eustatic and permanent lowering of sea levels throughout the Pleistocene epoch. These surfaces were cut into older Tertiary beds and a widely developed bed of clastic sediments, named the Citronelle formation of Pliocene age. In part these cut surfaces are thinly veneered by as much as 50 feet of reworked clastic and other sediments. In the mouths of streams that emptied along the coast of each marine surface, limited deltaic deposits were formed.

According to this theory the terraces are preserved because sea levels rising during interglacial stages never reached the position of an older stand of the sea and younger surfaces were cut at lower elevations. The progressive decrease in the elevations of sea levels throughout the stages of the Pleistocene resulted from greater deglaciation during early Pleistocene than during late. Additional stands of sea level were produced by the development of large oceanic deeps at various irregular intervals during the Pleistocene. The formation of these deeps enlarged the oceanic basins and decreased sea levels throughout the world.

Cooke (1939, 1945, pp. 12, 13) is the principal proponent of this theory and has described up to nine surfaces, including the modern

submarine plain, that occur throughout the Atlantic and Gulf Coast States.

Four similar terrace surfaces occurring along the central Gulf Coast States have been described by Fisk (1938, 1940). These are stream terraces, the coastal ends of which are widely-developed deltaic plains. Each terrace surface is aggradational and underlain by sediments that are characteristic of the terrace, being a depositional sequence of coarse clastics at the base and finer clastics at the top. This theory of terrace origin presents evidence that the surfaces are deposited as deltas and as alluvium in erosional valleys, each terrace being comparable to the present delta plains and flood plains of Louisiana today. Terraces were formed by adjustments of streams and coasts to eustatic changes in sea level resulting from cyclic withdrawals from and filling of oceanic basins during stages of the Pleistocene. Glacial stages were periods of lowered sea level, valley cutting and broader land areas. Interglacial stages were periods of elevated sea level, valley alluviation and flooding of land areas. Each terrace has been segregated by the tilting and uplift of the land adjusting to the extensive sedimentation of the Gulf of Mexico.

Evidence presented by Vernon (1942) and developed during the study of the physiography of Citrus and Levy counties does not allow the complete application of either theory in Florida. The topography of Florida is dominated by a series of uplifted broad flat surfaces that rise in step-like patterns from the coast inland to highlands composed of Tertiary and younger deltaic sediments. These flat surfaces or plains occur in four belts that extend completely around the State parallel to the modern coast. Each plain has a fluviatile terrace extension up the major streams of western Florida and sand bar deposits occur at comparable elevations along the streams of the Peninsula. Each uplifted plain contains upon it features of the modern submarine plain, and its fluviatile extension has features that characterize the modern stream flood plain and deposits, all in varying degrees of preservation.

The marine plains and fluviatile equivalents are separated by erosional escarpments and are considered to be terraces.

In Florida, auger holes and wells penetrating the Pleistocene deposits that underlie the terraces, indicate that the base of each rests upon an erosional surface, which lies at a lower elevation than similar cut surfaces, older in age. Each terrace surface is aggradational, except where Tertiary limestones have resisted erosion and have been planed off to the level corresponding to the elevation that the sea stood during the creation of the terrace. In western and most of peninsular Florida, where

abundant sediments were available and where the Tertiary formations were easily eroded, each surface is underlain by its unit formation. In Citrus, Levy and adjacent counties, however, the Tertiary limestones were not eroded and each surface is made up of belts of beach sediments and limestone planation shelves that contain in irregularities in the limestone, thin deposits of Pleistocene sediments. Along the most southern portion of Florida these Pleistocene terraces are represented by marine limestones and the erosional escarpments that bound each terrace are represented by fresh-water marls.

The terraces are thought to have been segregated by uplift of the State caused by adjustments to the filling of the Gulf by sediment, and through the progressive decrease in deglaciation from early to late Pleistocene.

The creation of the fluviatile terraces of Florida can be explained most easily by Fisk's valley cutting and subsequent alluviation theory, with the exception that there is present a high level delta plain, entirely disassociated with the streams that traverse the State, and there is present a very low alluvial terrace (Vernon, 1942, pp. 13, 14) which is not recognized by Fisk[9]. He recognizes, however, a low escarpment-bound, alluvial surface which has been referred to in Louisiana as "second bottoms" or "high level flood plains". It would seem logical that the same geologic controls and conditions creating Fisk's higher terraces would also most easily explain the formation of this low terrace.

Cooke, in a series of papers, has recognized nine terraces, one of which is covered by the modern sea, and one which he has not named[10] and which corresponds to the Okefenokee Terrace of this report. Only four of these terraces are widely developed in Florida, and this writer has seen no evidence of a general development of terraces with shore lines at 270, 170, 70, and 42 feet. If these terraces of Florida were formed through the cyclic eustatic adjustments in sea level throughout the Pleistocene, a period of stream and sub-aerial erosion followed by a period of fluviatile and marine deposition, each marine terrace should have a fluviatile extension up the streams of Florida. Only four stream terraces are present and these merge with coastal terraces associated with former coast lines at 220, 150, 100 to 105, and 25 to 30 feet above the present sea level.

According to Cooke[11] additional terraces were formed over the states

---

[9]Personal communication, 1939.
[10]Personal communication, 1942.
[11]Personal communication, 1942.

of the southeast where sea level was lowered by irregular increases in the size of oceanic basins through the formation of deeps. There is no evidence of deep valley erosion along the streams of the Gulf Coast that would indicate stream adjustment to a permanently lowered sea level. Five erosional sub-valleys compose each of the modern stream valleys in the State, each of these sub-valleys in succession having been cut and then filled to form four terraces and a flood plain along the modern valley.

By definition, a terrace is a flat surface, either deposited upon or cut into bedrock, that is limited by definite escarpments. These surfaces and escarpments, because of destruction by erosion and of the development of slopes instead of escarpments along some bays, can not be uniformly and continuously present. However, they must be present throughout the State at intervals sufficiently frequent to establish their identity. For each coastal terrace there would be developed in the valleys of principal streams of the State a fluviatile terrace equivalent. Theoretically, the sea as it withdrew from off the land during a glacial stage stood for brief periods at all elevations from the position of its highest shore line to the position of its lowest shore line, located somewhere out on the continental shelf. The withdrawal of any of the Pleistocene seas was controlled by climatic conditions and brief periods of warmer climate during any glacial period may have stabilized sea withdrawals momentarily and allowed some reworking of sediments and deposition of sand bars sufficient to create some minor features which may have been interpreted as terraces. These features have no fluviatile depositional equivalents and are not universally developed as are the four terraces generally recognized by most workers.

Minor terraces such as Cooke's Sunderland, Talbot and Penholoway, which are not present in any area worked in detail by the writer, possibly represent temporary pauses by the sea in withdrawing from the land mass. The writer does not consider these to be representative of a cyclic period of erosion and fill, and therefore not terraces as used in this report.

The four Pleistocene terraces, composed of a marine plain and a fluviatile equivalent, together with a highlands delta plain as recognized by Vernon (1942) are shown in Table 5, with possible correlations of seven of Cooke's (1945) terraces and his Citronelle formation and of Fisk's four delta plains and his "high level flood plain and second bottoms". The terms Pamlico, Wicomico and Coharie have been used in this report for levels and deposits present in Citrus and Levy counties

TABLE 5.—Correlations of Pleistocene Terraces

Fisk, 1940	Cooke, 1945 (*Elevations of shore lines in feet*)	*Western Florida* Vernon, 1942 (*Elevations of shore lines in feet*)	*Citrus and Levy Counties, Florida* Vernon, 1951	*Tentative Age Assignment of Terraces in Florida*
Williana	Citronelle fm. Brandywine, 270	Delta plain	Not present	Early Nebraskan and possibly pre-Nebraskan
Valley erosion		Valley and sub-aerial erosion	Valley and sub-aerial erosion	Nebraskan (glacial)
Bentley	Coharie, 215	220	Deposits of Coharie, 220	Aftonian (interglacial)
Valley erosion		Valley and sub-aerial erosion	Valley and sub-aerial erosion	Kansan (glacial)
Montgomery	Sunderland, 170	150	Deposits of Okefenokee, 150	Yarmouth (interglacial)
Valley erosion		Valley and sub-aerial erosion	Valley and sub-aerial erosion	Illinoian (glacial)
Prairie	Wicomico, 100 Penholoway, 70 Talbot, 42	105	Wicomico, 100	Sangamon (interglacial)
Valley erosion		Valley and sub-aerial erosion	Valley and sub-aerial erosion	*Wisconsin* — Glacial stage
Second bottoms and high level flood plains	Pamlico, 25	30	Pamlico, 25	*Wisconsin* — Interglacial stage
Valley erosion		Valley and sub-aerial erosion	Valley and sub-aerial erosion	*Wisconsin* — Glacial stage
Modern delta	Modern submarine plain	Sea level	Modern submarine plain and stream food plains	Recent (interglacial)

at elevations comparable to those of Cooke. However, since Cooke recognizes no terrace at 150 feet, the term Okefenokee is preferred as used by MacNeil (1949) as a name for the terrace in Florida with levels below 150 feet.

STREAM VALLEYS IN WESTERN FLORIDA

In western Florida each of the stream valleys is composed of a series of uplifted flat surfaces that border the present flood plain and extend up stream valleys in step-like discontinuous patterns. These surfaces have been interpreted as the former flood-plain alluviation of valleys cut into older alluvium and Tertiary rock by the stream now occupying the valley (Vernon, 1942). Detailed work has proved that each of these surfaces is underlain by a definite depositional sequence, from coarse sand and gravel at the base to silts and clays at the top, and that each has present upon it features of modern flood-plain deposition such as natural levees and rim swamps.

The origin of such alluvial surfaces as a combination of cyclic Pleistocene eustatic changes in sea level and uplift was proposed by Fisk (1938) for Louisiana and was extended to Florida by Vernon (1942) with the application of the theory of progressive decreased deglaciation throughout the Pleistocene. Thus valleys cut during low sea level glacial stages were filled with alluvium as sea level rose with the melting of glacial ice during the interglacial stages. The continuous uplift of Florida throughout the Pleistocene that has progressively raised and separated these terraces, is presumed to be associated with the thick alluviation of the Gulf of Mexico, principally by the Mississippi River, and adjustment to this alluviation. Uplift does not account for the separation of the lower terraces, however, because these surfaces would be covered by alluviation if all the ice on polar caps should melt. It is presumed that more ice melted during the stages of the early Pleistocene than during the stages of late Pleistocene.

The modern flood plain and four depositional surfaces are associated with each major stream in western Florida. Each alluvial surface ends on a broad flat plain that extends all around Florida, the modern flood plain ending on the modern submarine plain and each alluvial terrace ending on a coastwise surface exhibiting marine characteristics.

STREAM VALLEYS IN CITRUS AND LEVY COUNTIES

Marine coastwise surfaces are present across Citrus and Levy counties, but alluvial surfaces are not present. At the elevations that alluvial

terraces are found in western Florida, only sand bar ridges have been deposited in the Citrus-Levy County area.

The bedrock of the area is essentially carbonates, greatly fractured and cut by caverns. The amount of dissolved solids in ground water indicates that the limestone is being continuously reduced by solution in surface and subsurface waters. During stages of the Pleistocene when sea level dropped, and streams in western Florida were excavating their valleys, the streams of these counties found it easier to drain through fractures and caverns into the underlying bedrock and did not excavate deep valleys. Subsequently as sea level rose during the interglacial stages, the limited sediment available to these streams was deposited in Levy and Citrus counties as sand bars, and the streams adjusted their channels to the uplift of the area through accelerated solution to form limestone-walled channels. In effect no valleys were cut during glacial stages to be filled by sediment during interglacial stages of the Pleistocene so that terraces have not been formed.

KEYS

The word *Key* is a modification of the West Indian word *cayo,* meaning small low island, and is used in southern Florida for an island of any rock composition in marine waters. In Citrus and Levy counties these keys are composed of limestone thinly coated with sand or they may be essentially sand. Most of the keys of Cedar Keys and north to the Suwannee River are sand islands, the sand probably being reworked into bars and spits from deposition made by the river along its lower course.

The keys of the coast south of Cedar Keys are limestone islands, the entire coast being rocky. Islands are remnants and pinnacles of limestone, left after solution, which have been drowned by salt-water marshes. None of these are coral reefs, as found along the Florida coast to the south.

Tidal passes up to 15 miles long, and deep enough to traverse in shallow draft boats wind past the islands and connect the Gulf with spring fed streams emptying along the coast line.

SOLUTION

INTRODUCTION

Citrus and Levy counties are underlain by limestone and other calcareous deposits. Except for the portion covered by the Coharie-

Okefenokee Sand Ridge these deposits lie at or near the ground surface. The bedrock is greatly fractured and very porous and almost all the rain that falls in the area is absorbed by loose sand or is captured by solution holes and the fractured porous bedrock. These waters are highly charged with organic and carbonic acids and solution plays a conspicuous rôle in the development of the physiography of the area. The ground water that passes through these carbonates to emerge as springs or seeps carries in solution great quantities of mineral solids, since limestone is readily dissolved in organic and mineral acids contained in water.

CAVERNS

Limestone is as a rule jointed vertically and bedded horizontally and openings along these joints and beds provide easy avenues of travel for water. The ultimate source of all of Florida's ground water is from the rain and precipitates from the atmosphere. As the rain water falls through the air it becomes charged with carbon dioxide gas that combines with water to form carbonic acid. On the ground humic acids from rotting vegetation is added. These are the common natural solvents of limestone. A good portion of this acid charged water soaks into the ground, and as it descends small portions of the rock are dissolved, but where the rock is saturated and bathed continuously in these weak acids, solution is most active. Because of the pressure of water entering the rock, ground water tends to move horizontally along bedding planes which offer the easiest exit. As it moves through pores and open spaces in the limestone it acts as a slow solvent to increase the size of the openings and to connect them to form a continuous system of channels. As these channels are expanded by solution, cave systems are developed horizontally and one system may lie over another and may be connected by vertical tubes and rooms.

These solution holes are formed principally while the limestone is saturated by ground water. Since many large caves and vertical tubes, now completely dry, are present west of Long Pond, south of Newton in Levy County and in the vicinity of LeCanto in Citrus County, it is obvious that the levels of ground water have been lowered over most of the area. The remains of land vertebrates of Pleistocene, Pliocene and Miocene ages (see pages 184, 192 and 212) that are found in deposits in the caves indicate that many were dry during at least some stages of these epochs. These caves are now being modified through the deposition of calcite along the walls and floors, to form icicle-shaped masses called stalactites that hang from the ceilings and more columnar masses called

stalagmites that extend upward from the floor, and pavement coatings along many of the walls.

SINKS

As solution progresses, cavities of irregular shape are gradually cut out and enlarged. Some of these may expand to a point near the ground surface where surface deposits, largely sand in Florida, will collapse into the cavern and a sink hole is formed. The larger part of Florida's natural lakes, sinks, depressions and ponds are the result of the solution of limestone. The features range from small pits a few feet in diameter to large depressions several miles broad. Many are perfectly round, others highly irregular. Some are cone-shaped with rocky bottoms and walls, some have broadly-developed, sediment-filled flat bottoms and are known as prairies. Still others are vertical tubes, only a few inches in diameter in some cases, that extend as much as 100 feet down into the limestones. These are "natural wells", or solution pipes.

As Vernon (1947) has indicated, the generally accepted theses of the solution of limestone rarely include a conception of the effect of artesian water upon soluble aquifers such as limestone. Citrus and Levy counties are a part of a large artesian ground-water system, in which water gains entrance into a thick limestone aquifer in areas centered at Polk and at Pasco counties. The water is confined in these limestones under hydrostatic head and discharges in Citrus, Levy and other coastal counties. This water is heavily charged with natural acids and the active circulation through the aquifer removes large tonnages of rock. The solution holes thus formed are filled with water and where they emerge at the ground surface springs and seeps of water issue from them. Since artesian water is under pressure it tends to expand upward along joints and more soluble rock because of greater porosity toward the ground surface. The localization of this movement vertically may explain the formation of solution pipes and "natural wells", see figure 10. Where solution by artesian water removes a large section of limestone the overlying beds may collapse and create a sink hole, or the solution of the limestone may be more gradual and a spring opening may be expanded to the proportions of a sink.

LAKES

Lakes in Citrus and Levy counties are largely water-filled solution depressions except for Tsala Apopka Lake and Long Pond, the basins of which originated as structural and fluviatile irregularities and were modified by solution. Water to fill the lake basins comes from local

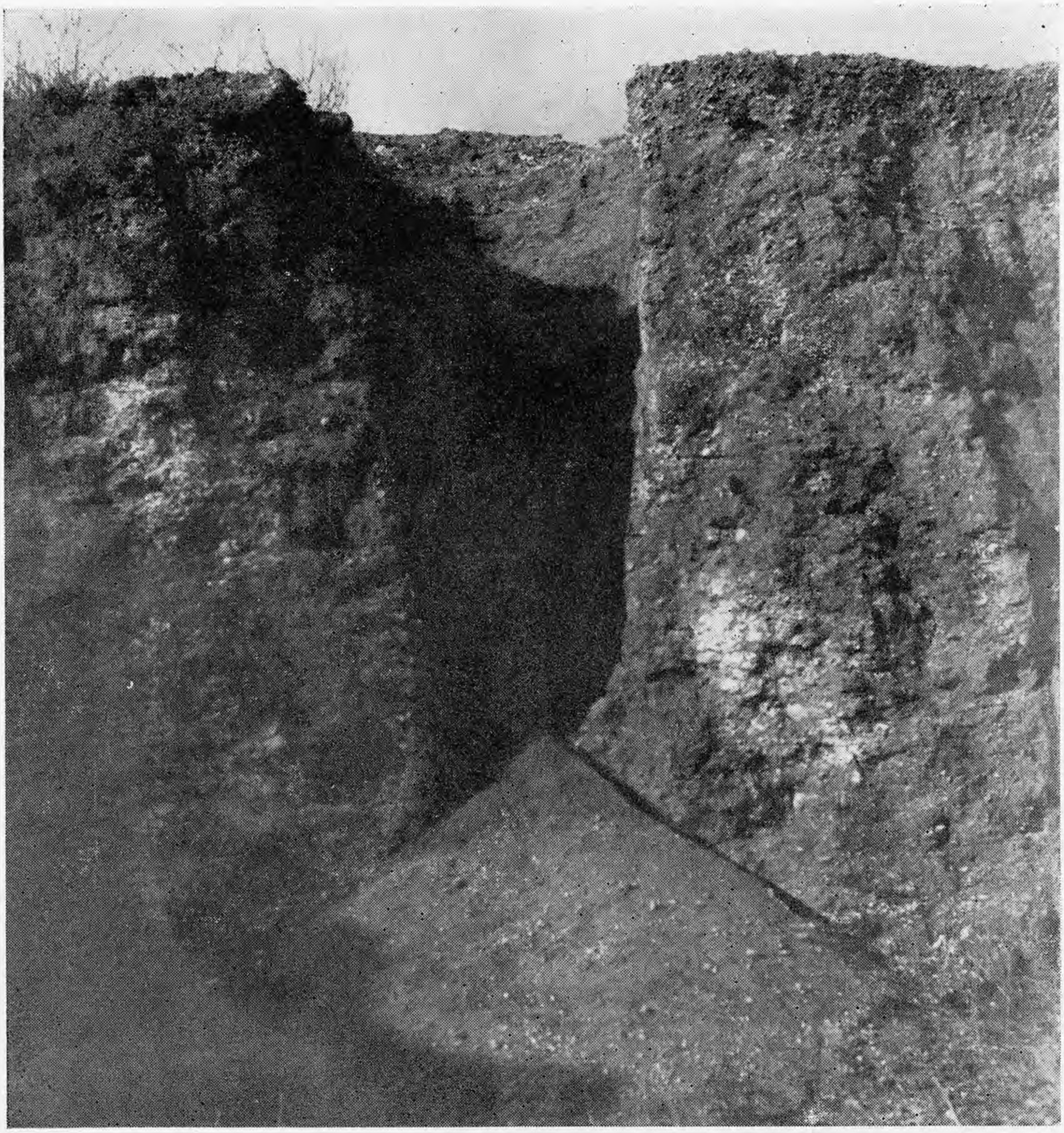

Figure 10. Solution pipe formed in the Ocala limestone (restricted) and bisected by the Levy Lime Rock Company quarry located at the Atlantic Coast Line Railroad in the southeast corner of Section 19, Township 12 South, Range 19 East. The clay filling has been washed out and deposited as a cone at the base of the quarry face.

rainfall, local ground water, artesian ground water or a combination of these sources. Where the basin intersects the artesian aquifer, water will fill the basin to the elevation of the static water levels, and will flow if the rim of the basin is below the piezometric surface. Where the surface of the ground and the ground-water levels are approximately the same elevation, swamps are present along the low areas, and if this relationship is present in a basin, a prairie is formed.

Many of the lake basins are located at the foot of Pleistocene escarpments along which irregularities localize the ground-water recharge and accelerate solution. Others are close to and are developed along well-developed fractures in the underlying limestone that provide channels for ground-water movement. In addition to physiographic irregularities, those created by structural movement also localize ground-water recharge.

Long Pond: The basin of Long Pond is of particular interest since it was formed by a combination of solution, structural movements, and Pleistocene erosion and deposition. The lake is located one mile south of Chiefland, Florida, in sections 7, 16 and 19, Township 12 South, Range 13 East, and is a slightly arcuate lake, two and one-third miles long and one-quarter mile wide. It lies along the western margin of the Waccasassa River delta plain that composes a portion of the Pamlico Terrace. The lake is bound to the west by limestones of the Moodys Branch formation exposed along the upthrown side of a fault that passes through the lake and makes a high escarpment along the western margin.

The lake basin extends along the foot of the escarpment to near the north end of the lake where a well-developed valley branches off and runs westerly toward the Suwannee River widening as it nears the river. This valley is walled with limestone but the floor is composed of a fill of sand and reworked Alachua sediments similar in lithology to that contained in the delta plains to the east. The sediments in the valley and brackish water deposits along the lake basin of Long Pond indicate that the area about the lake was a bay during Pamlico time, and that this bay was filled by alluvium deposited from the east by a large stream once occupying the Waccasassa River valley. The valley draining westerly from Long Pond and breaching the Chiefland Limestone Plain probably was occupied by a distributary of this stream. During extreme flooding today, the excess water from Long Pond drains through this valley.

The basin of Long Pond may have developed initially along the foot of the fault escarpment in irregularities of the ground surface, solution of the limestone bedrock possibly being accelerated by fracturing along the fault zone. The downthrown side of the fault would develop a wide and irregular basin, which apparently has been narrowed by alluviation and deposition of brackish-water sediments during the Pamlico stage.

SPRINGS

Springs are of two types. In one the water is derived from local rainfall under ground-water table conditions, in which the water enters at a high

elevation and emerges along lower elevations in stream valleys and lake basins. In the other the water rises from depth under artesian head, the water having moved from some distance through the aquifer to emerge in these counties. The first type are generally small springs or seeps, but artesian water may issue as small springs, seeps and also as copious flows of water. Several large artesian springs are present in these counties and the water is beautifully clear and colored blue to green, the color depending on the depth of water and the degree to which light transmitted by the water is scattered by the water molecules.

Wekiva Springs, Fanning Springs and Manatee Springs, in Levy County, Homosassa Springs, Chassahowitzka Springs and springs in the head of Crystal River in Citrus County are the larger and more beautiful springs in the counties. Numerous seeps and springs in the coastal hammocks are sources of water for sportsmen, and hunter's camps are developed commonly at these sources. The channels of streams are a maze of springs and seeps issuing from out of the limestone bedrock. The springs are utilized in stock raising and as recreational areas, Manatee being a proposed State Park. Many are commercialized. Excellent descriptions of the large springs in the State were published in Florida Geological Survey Bulletin 31 in 1947.

FRACTURING

Faulting has not been previously recognized in Florida and is mapped in figure 11, and on Plate 1, for the first time. The fracture patterns, shown as figure 11, were mapped from their physiographic expressions as shown on mosaics and contact prints of aerial photographs, available for each county except Orange, Taylor and a portion of Marion. They have been checked geologically in the core hole section along the proposed ship canal that crosses the western Peninsula at the Citrus-Levy County line, by surface geology, and by preparation of detailed geologic sections, figures 13 and 14 and a structure map, Plate 2.

In Citrus and Levy counties regional fractures parallel the axis of the Ocala uplift and locate the crest of the fold exactly. These fractures trend generally northwest-southeast. A secondary system trending northeast-southwest intersects this system at large angles and are irregularly spaced along the flanks of the uplift. Geologic sections crossing the Ocala uplift show that many of the fractures paralleling the axis of the fold are faults, but insufficient data are available on geologic sections crossing transverse joints to determine the displacement along these.

Figure 11 illustrates a fundamental regional pattern made by the regular development of two systems of fractures trending northwest-southeast and northeast-southwest. These are grouped irregularly at wide intervals of 20 to 30 miles to form a rough rectangular pattern where they intersect. Cross joints are only poorly developed along the crest of the Ocala uplift, but are strongly developed and numerous along the northwest plunge of the uplift in Jefferson, Madison, Hamilton and Suwannee counties and sharply delineate the northwestern limit of the crest of the fold. The southeast plunge of the fold is not as sharply marked. The zero contour of the Inglis structure, Plate 2, has been drawn on the map of the fracture pattern to illustrate the relationship of these fractures to the Ocala uplift.

The systems of fractures can be traced from county to county throughout the State and the northwest-southeast fractures appear to be the major system. However, two well-developed patterns of fractures are present that deviate from either of the systems described above. A particularly well-developed set of fractures, radiating in all directions from Union County, resemble in their pattern the fracturing that is present over salt domes of the Gulf Coast. Another system located in the southeast corner of figure 11 has fractures that trend more westerly and are somewhat more irregular in pattern. The geologic-control data in these areas are widely scattered and sufficient only to generalize on possible causes of these fractures. Applin (1951a) has recently published a critical analysis of the subsurface geology of the State. When the data he has developed are superimposed upon the fracture pattern (see figure 11) they indicate some possible causes. The dome-like patterns in Union County are located almost exactly over the area where Applin's peneplaned pre-Mesozoic surface has been folded into an anticline, named the Peninsular arch.

The distribution of possible pre-Cambrian crystalline rocks as mapped by Applin (1951a), corresponds remarkably well with the more westerly trending fractures shown in the southeastern corner of figure 11. It is probably more than coincidental also that Applin's boundary, believed to be a fault, separating Paleozoic sediments to the northwest from rhyolite, tuff and agglomerate to the southeast corresponds closely to the most strongly developed and distinctive northeast-southwest fractures mapped on figure 11.

If the fracture pattern can be assumed to reflect these ancient land masses, they must do so through several thousand feet of Cretaceous, Tertiary and younger sediments. The thickness may in fact provide the

mechanism for such expression, in the adjustment of relatively unconsolidated sediments over structurally stable and fundamental land masses. The writer does not attempt to explain the association of these fractures with deeply buried structures, but the remarkably close relationship suggests such a possibility.

The regional fracturing associated with the Ocala uplift is believed to reflect structural movement during the late Tertiary. Stream patterns and sink alignment commonly parallel both the northwest and the northeast systems of fractures. Particularly well-developed expression of these joints or faults are shown by the control of portions of the valleys of the Ocklawaha, Withlacoochee and Kissimmee rivers, all of which show strongly developed, rectangular trends northeast-southwest and northwest-southeast with large angle turns. Some of the bay entries occur where fractures intersect the coast, the high sand areas of Polk and Hillsborough counties are bounded by strongly developed patterns, and most of the larger springs of Florida lie in or along these fractures. The fundamental pattern of joints and faults appears to be differential crustal shifts along straight line fractures. Judging from their distribution and alignment with the Ocala uplift the fractures are associated with land movements of a regional nature and the stresses forming the folds of the Ocala uplift created these joints and faults.

Considering the physical properties, low rigidity, high porosity, brittleness and inherent weaknesses of the poorly consolidated Tertiary limestones in which this fracture has occurred it seems impossible that the Ocala uplift could have been formed in any other way than by compressive stresses acting from the west against the Peninsular arch. When thus analyzed there exists an arch about 230 miles long by 70 miles broad which was gently folded and arched by compressive orogenic forces. During the time these forces were elevating this heavy mass of rock into an elongate anticline they were opposed by the weight of the rock and there were two vertical compressive shearing stresses that created horizontal tensional stresses at right angles to the compressive forces and to each other. The fractures mapped in figure 11, are believed to have formed under a combination of tensional stresses over the anticlinal flexure. The presence of tensional forces and stresses over folds is almost universally accepted although they are not recognized to be a local phenomenon. The compressive stresses effective all along the arch would tend to concentrate shearing parallel to the axis of the fold, although bulging along the flanks would have a similar effect. Most of the traces on the crest, parallel to the axis, appear to be shear faults of normal type. Primary tensile stresses would be developed parallel to the

compressive forces. Because of inequalities in these forces secondary tensile stresses are developed at right angles to the primary tensile stresses. Thus tensile fractures would be most strongly developed along the axis of any folding and along the axes of flank bulges. This combination of stresses is capable of producing the regional fractures mapped in figure 11. The poorly consolidated sediments composing Tertiary rocks of Florida favor adjustments to strain by step fracturing rather than by bending.

Because the tensional and shearing stresses would be greatest over the up arched area of the Ocala uplift fracturing developed by them would tend to occur in groups along the axis of the fold and to indicate the direction of greatest stress and of the elongation of the arch. If these joints are tensional they would tend to die out with depth because stretching is greatest toward the outside and least toward the inside. Available geologic data indicate that only tensional fractures are present in the area and that these are shallow.

At least seven well-developed faults have been recognized in the geological section drawn along the proposed Florida Ship Canal crossing the State along the Levy-Citrus County line into Marion County, see Plate 1, and figure 14. Each of these faults can be readily traced on aerial photographs, on which they appear as continuous trough-like depressions and ridges marked by significant vegetation changes and soil colorations. These straight and continuous lines correspond exactly with the map positions of vertical displacements of twenty to one hundred and sixty feet along the section of figure 14. These vertical throws are distributed along many closely spaced parallel faults, the planes of which probably are inclined into the crest of the Ocala uplift. It was impossible to make measurements on the limited exposures of the fault traces, but the straight course of the faults across a very uneven topography suggest that the planes of the faults are inclined very steeply.

The broad flat crest of the Ocala uplift, the straight-line traces and presumable high dips of the fault planes, the inclinations of the fault planes into the crest of the fold, the grouping of several essentially parallel faults along the crest of the fold indicate that these faults are normal dip-slip shear faults that have formed graben depressions and horst ridges and flattened the crest of the Ocala uplift. The displacement in the faults is apparently essentially vertical since the traverse fractures are not interrupted where they cross known faults. The only indication of horizontal movement is an abrupt change in the trend of the strongly developed fractures running southwest from the Ocklawaha River Valley to the point where the southern line of Hernando County intersects the

coast. At the point where these fractures cross a fault near the southern boundary of Citrus County the trend changes abruptly to a more southerly direction and splits into three parallel joints. This change in trend makes an angle too small to show in figure 11 on the scale at which the map is reproduced but is evident on aerial photographs.

Following the development of the graben and horst structure, waste would be expected to accumulate on the low-standing blocks, and the fault traces would be concealed by sand and a residuum cover that masks the structure. A definite fault zone, however, is exposed on the northeast side of the Crystal River Rock Company quarry where the red sands and clays of the Alachua formation have been deposited up against and over large slump blocks, a fault breccia developed along one of these faults. Well-developed fractures are also rarely exposed at the surface because younger sediments cover them and mask the identifying features, but some evidence can be seen in joints exposed along the highway to Cedar Keys; along the old highway near Inglis in the center of the northeast quarter of Section 35, Township 16 South, Range 16 East, figure 12; and at Red Level where dolomitization has apparently extended along one of these fractures. It is not surprising that in a thick limestone section containing little close zonation and covered by con-

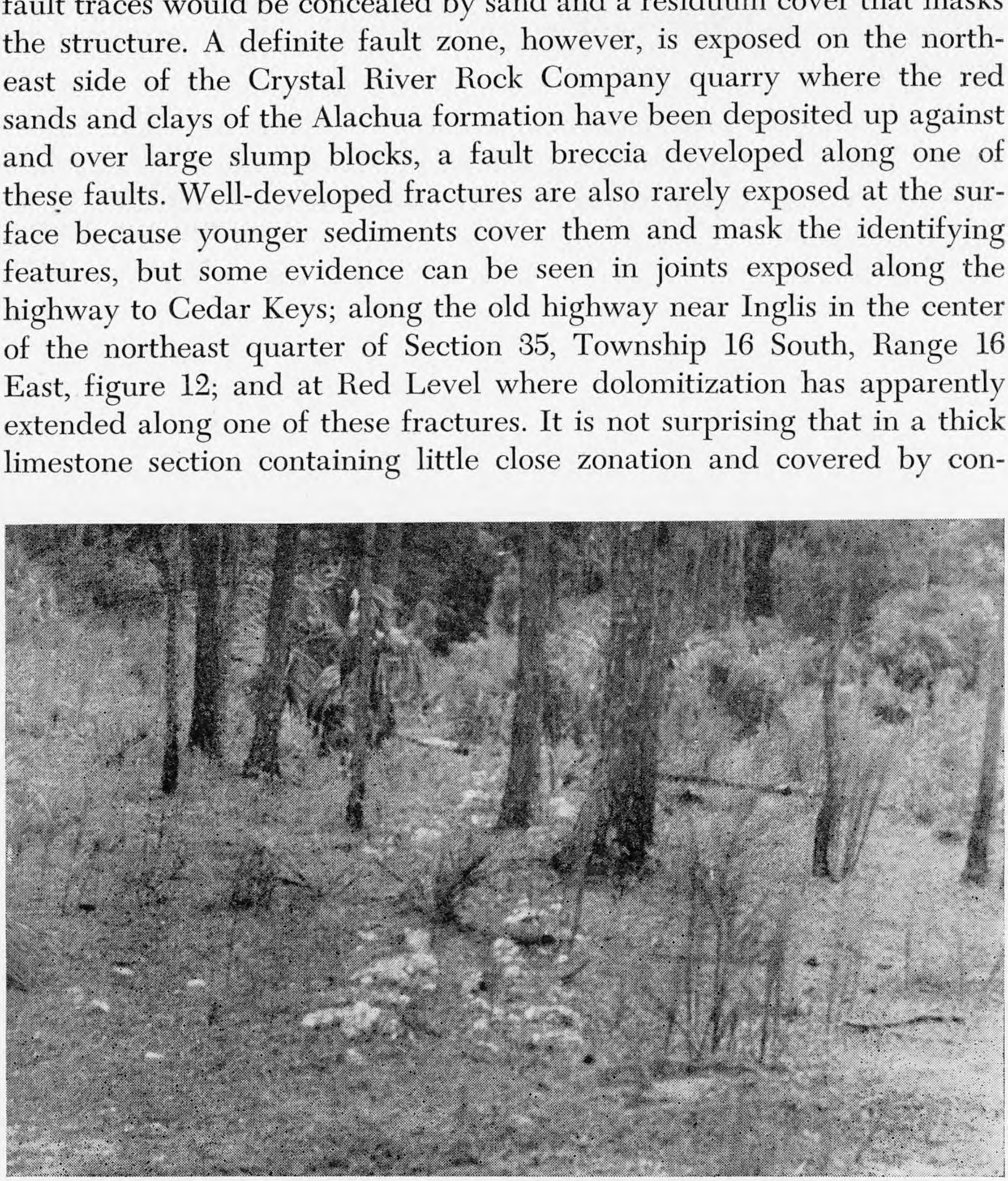

Figure 12. Differential weathering along a fracture in the limestone of the Inglis member, Moodys Branch formation, trending northwest-southeast as exposed in Section 35, Township 16 South, Range 16 East.

siderable Pleistocene and Recent alluvium and marine deposits that these small faults have gone so long without being recognized. Under these conditions only a large fault would be obvious and it has been necessary to piece together small bits of evidence and to make careful observations and correlations to obtain a reasonably accurate structural pattern and history. There will undoubtedly be added by future explorations much data that may completely change the interpretation of the structure as described herein. Perhaps this description will serve as a basis for discussion from which the complete structural history of the area may be developed.

In mapping the joint pattern an attempt was made to include all irregular trends whether poorly marked or well-developed, and to include only the well-developed trends running northwest-southeast or at right angles to this set.