Geologic Interpretation of the Gamma-Ray Aeroradiometric Maps of Central and Northern Florida

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1461

Prepared in cooperation with the Florida Bureau of Geology

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An analysis of the total count and spectral gamma-ray radiometric maps and their relations to the geology and mineral resources of the State of Florida

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By ANDREW E. GROSZ, JAMES B. CATHCART, DAVID L. MACKE,
MICHAEL S. KNAPP,[1] WALTER SCHMIDT,[1] and THOMAS M. SCOTT[1]

ABSTRACT

Total count and spectral gamma-ray contoured aeroradiometric maps of northern peninsular and panhandle Florida were field tested and found to be useful in locating potentially economic mineral deposits in some circumstances. An exposed deposit that contains radioactive minerals will exhibit radiometric contrast to the surrounding or adjacent sediment or rock. In principle, such contrast is detectable by airborne scintillation counters.

Aeroradiometric anomalies in the mapped area were classified on the basis of their geologic setting and spectral gamma-ray radiometric character by using regional geologic, land use–land cover, shoreline and terrace, and soil maps and ground-spectrometer data from samples taken in the field study. The gamma-ray aeroradiometric maps show anomalies caused by heavy-mineral and phosphate deposits, as well as those associated with cultural activities.

Radiometric anomalies associated with deposits of placer heavy minerals, whether fluvial or marine, have radioelement spectra dominated by thorium radiation. Although no economic placer deposits were discovered, six geographic areas are indicated as favorable for more detailed exploration. These include two that are already fairly well known—the Atlantic Coastal Lowland and the Trail Ridge system, which includes the Lake City Ridge and associated Okefenokee shoreline deposits that host the commercial heavy-mineral deposits currently being mined. The other areas are the Pamlico shoreline deposits in Taylor County, the Pamlico shoreline and associated barrier island deposits in Wakulla and Franklin Counties, the Pamlico shoreline deposits in southwestern Bay County, and the Citronelle Formation in northwestern Florida.

Anomalies associated with phosphate, whether river-pebble, land-pebble, marine phosphorite, or hardrock deposits, have radioelement spectra dominated by uranium radiation. Abandoned phosphate pits, operating mines, and weathered outliers of phosphatic rock are outlined clearly by the aeroradiometric maps. Because prospecting for phosphate in Florida has been very extensive, no new deposits were discovered.

Potash and phosphate in agricultural fertilizers have significant and highly variable effects on ground-radiometry. Radioactive calcium silicate slag (produced in making elemental phosphorus by thermal processing) is widely used as road metal. Anomalies associated with culture and cultural activity are characterized by the radioelement spectra of potassium or uranium radiation or both.

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INTRODUCTION

Aeroradiometric (rad) surveys for the southeastern Atlantic Coastal Plain States made to facilitate exploration for economic mineral deposits were contracted for by the U.S. Geological Survey (USGS). Funding for the surveys and subsequent field investigations was supplied by the Coastal Plains Regional Commission.

The study area for this report includes peninsular Florida north of the 28th parallel and the Florida panhandle from the Atlantic coastline to the Perdido River in western Florida (fig. 1). With the exception of the large urbanized areas of Jacksonville, Gainesville, Tallahassee, and Pensacola, the study area is agricultural and sparsely populated.

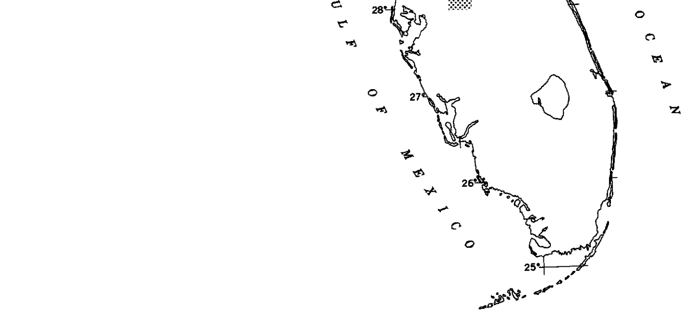

FIGURE 1.—Location of the study area.

HEAVY-MINERAL MINING AND EXPLORATION

Deposits of placer heavy minerals in nearshore marine sediments on the Atlantic Coastal Plain contain a variety of economically valuable minerals, particularly titanium minerals (ilmenite, rutile, and leucoxene), and monazite and zircon. Because most of the current demand for these minerals is supplied by imports (Lynd, 1978), this investigation focused on locating such deposits on the coastal plain of Florida by the use of gamma-ray maps. The rad maps also can be used in exploration for phosphate deposits that are areally more important than the heavy-mineral deposits.

Economic deposits of heavy minerals in sand on the Atlantic coast have been discovered by a variety of techniques. Geologic reasoning and shallow augering have led to the discovery of a deposit in eastern New Jersey (Markewicz and others, 1958) and in Trail Ridge, Fla. (Spencer, 1948; Thoenen and Warne, 1949). Rad surveys have played, or, in hindsight, would have played, a part in the discovery of several large deposits [Folkston, Ga. (Moxham, 1954), Green Cove Springs, Fla. (Jim Hetherington, personal commun., 1974), and Brunswick, Ga. (Stockman and others, 1976)]. Surface sampling combined with shallow augering has been the favored approach. The application of rad data, where large areas can be scanned at low cost, is warranted to reduce the high cost of augering and sampling programs.

Exploration for heavy-mineral deposits by using rad surveys is based on the presumption that radioactive heavy minerals (monazite and zircon) are concentrated with the nonradioactive heavy minerals (ilmenite, rutile, leucoxene, staurolite, and others). Economic heavy minerals are most common in shore and nearshore marine deposits. Such concentrations in ancient shoreline deposits that are now elevated and commonly parallel to the present shorelines were the major sources of preferred heavy-mineral assemblages, which contain mature suites of minerals (generally weathered assemblages that have relatively low garnet, epidote, and amphibole group contents and high TiO_2-content ilmenite). Radiometric contrast caused by monazite and, to a lesser extent, by zircon and sphene ideally is detectable by aerial and ground-radiometric surveys.

THE STUDY AREA

Placer concentrations of heavy minerals have been known in Florida for many years (Martens, 1928). Because radioactive minerals are present in the heavy-mineral placers of northeastern Florida (Martens, 1928; Pirkle and others, 1974; Calver, 1957), north-central Florida (Martens, 1935), and western Florida (U.S. Bureau of Mines, 1943; Lawthers, 1955), rad surveys were expected to be useful in locating new deposits.

Phosphate was discovered in Florida over a century ago. The river-pebble deposits found in 1881 along the Peace River by Captain J. F. Lebaron led to commercial mining in spring 1887 (Eldridge, 1892). Subsequent exploration defined deposits of land-pebble, hardrock, and softrock phosphate. For nearly half a century, the Florida deposits of phosphate rock have supplied much more phosphate than all the other domestic deposits combined (Calver, 1957) and have been and are the largest producer of phosphate in the world. The presence of uranium associated with apatite was not documented until the late 1940's (Cathcart, 1950).

PREVIOUS STUDIES

Although literature on the theory and use of airborne radiometric surveys is abundant (for example, Moxham, 1953, 1954; Pitkin and others, 1964; Stockman and others, 1976), little has been published on the applicability of such surveys to exploration for placer deposits in coastal areas until recently.

A classification of rad anomalies into types based on aerial spectral radiometric data used in conjunction with county soils maps, regional mineralogic trends, and regional geologic information was published by Force and others (1982). The study shows that rad surveys can be used to find detrital heavy-mineral accumulations in those deposits that contain radioactive minerals. However, the majority of rad anomalies in that study area were caused by deposits of uraniferous phosphate.

By applying total-count rad maps to the exploration for heavy-mineral deposits in the Outer Coastal Plain of Virginia, Grosz (1983) refined the method devised by Force and others (1982) by also screening anomalies by application of land use–land cover maps and ground gamma-ray spectrometry.

Rad anomalies in coastal Virginia have the following general modes of occurrence: (1) The most intense anomalies are associated with cultural overprints, such as roads made of granitic material, (2) the most frequently occurring anomalies of high to intermediate intensity, evidently caused by applications of phosphate and potash (both radioactive) as fertilizer, are associated with land used for agricultural purposes, and (3) anomalies of low to intermediate intensity that have ground-radiometric spectra dominated by thorium, and lesser uranium and minor potassium components, are associated with deposits of heavy minerals.

Rad surveys of uranium-bearing phosphorites and hardrock phosphate deposits were made in Florida by the USGS during the investigation for uranium and thorium in the early 1950's (fig. 2). Results of the surveys show good correlation between rad anomalies and exposures of uraniferous phosphate rock.

The principal and characteristic difference between phosphate- and heavy-mineral-caused rad anomalies is in their spectral gamma-ray radiometric signatures. Rad anomalies associated with concentrations of phosphate are dominated by eU (uranium radiation; uranium-238 content calculated based on field measurement of daughter product bismuth-214, hence eU-equivalent uranium), whereas anomalies associated with concentrations of heavy minerals are dominated by eTh (thorium radiation; thorium-232 content calculated based on field measurement of daughter product thallium-208, hence eTh-equivalent thorium) related to monazite.

PRESENT STUDY

Field investigations of rad anomalies were conducted in early spring 1979 and 1980. During that time, samples based on ground-radiometric studies were collected for analyses. Heavy-mineral-bearing samples were analyzed in USGS laboratories at Reston, Va., and phosphate-bearing samples, in USGS laboratories in Denver, Colo.

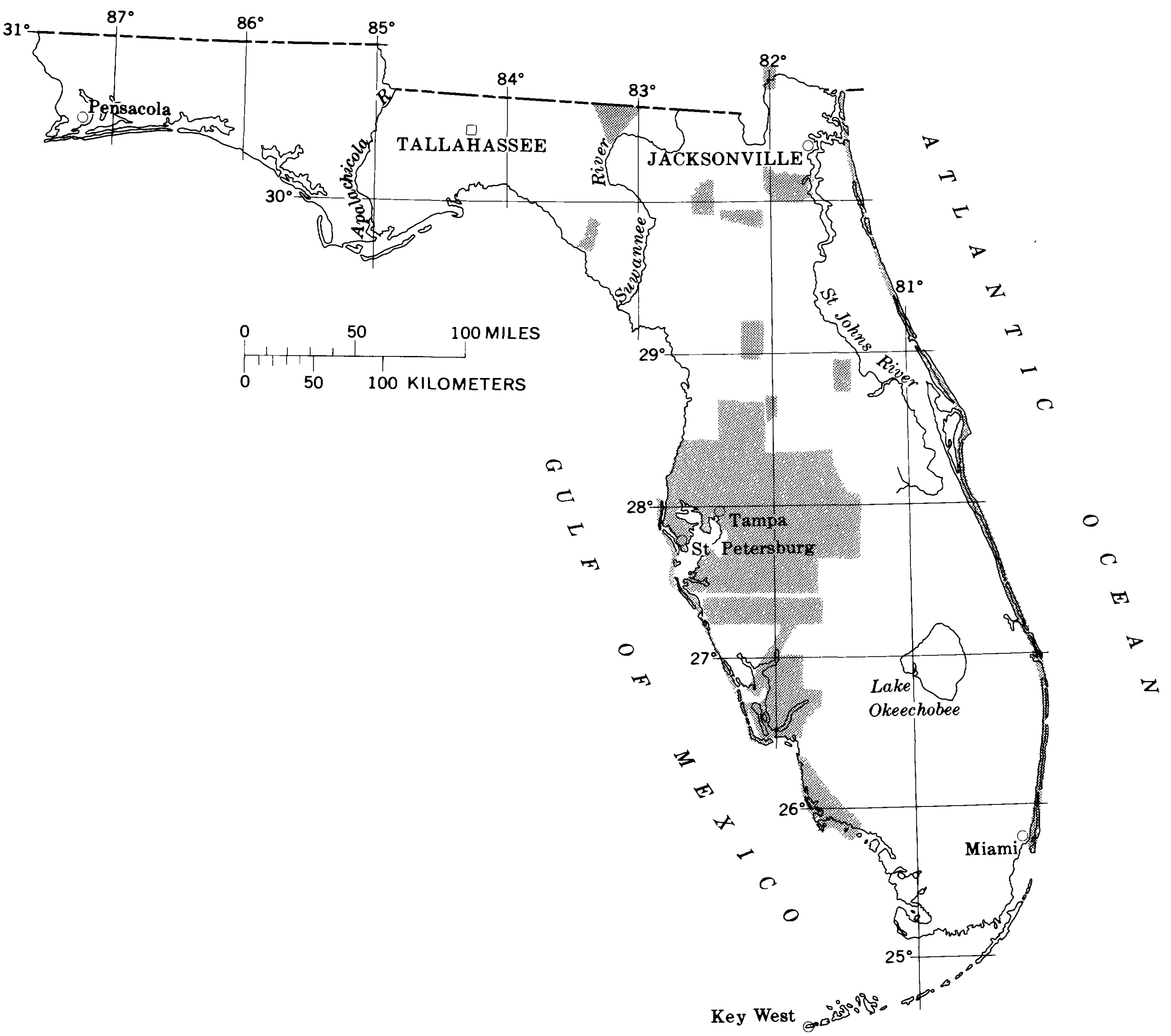

FIGURE 2.—The locations of previous aeroradiometric surveys. (From Calver, 1957.)

The method of study was based on methods and results from previous studies on the uses of rad maps. The rad maps were compared with geologic, land use–land cover, shoreline, soil, surficial lithology, and mineral-resource maps. Ground (gamma-ray) radiometric studies were used to discriminate eU-, eTh-, and K (potassium radiation; calculated based on field measurement of potassium-40)-dominated anomalies, and fertilizer distribution data were used to indicate anomalies caused by such materials. Thus, most anomalies can be assigned confidently to heavy minerals, phosphate occurrences, or cultural effects.

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Technical assistance by specialists has included X-ray mineralogical analyses by Patricia J. Loferski and William F. McCollough and scanning electron microscopy and photographs of phosphate samples by Courtney Williamson and Mike Pantea of the USGS.

Property owners throughout the study area were friendly and helpful. We are grateful to these people and many others for their generous help and consideration.

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GEOLOGY OF THE STUDY AREA

MORPHOLOGY

The State of Florida is part of a much larger, mostly submarine feature called the Floridian Plateau. This broad and nearly level platform is nearly 500 miles (mi) long and 250 to 400 mi wide. The part of the Floridian Plateau that lies above sea level—the State of Florida—was divided into physiographic regions by Cooke (1939) and was modified later by Puri and Vernon (1964). The physiographic divisions include the Coastal Lowlands, the Central Highlands, the Marianna Lowlands, and the Northern Highlands (fig. 3).

The Coastal Lowlands adjacent to both coastlines are low in elevation and are drained poorly. The characterizing features (barrier islands, lagoons, estuaries, coastal ridges, sand dune ridges, relict spits and bars, and coast-parallel valleys) have marine origins and, therefore, are generally parallel to the coasts. Deposits of placer heavy minerals in the Southeastern United States, and specifically in northeastern Florida, commonly are associated with such beach-complex sediments; their geomorphic expression is a principal guide to exploration for commercial deposits.

The Central Highlands include localized areas of high elevations and large areas of low elevations—the valleys of the major rivers. In general, the higher ridgelike areas and the larger river valleys are elongate and parallel to the length of the peninsula.

The Marianna Lowlands, located in the northern part of the panhandle of Florida, represent a topographic break in the otherwise continuous Northern Highlands. Stream erosion and solution activity have reduced the highland areas to lower elevations than the surrounding area. The land surface is well drained, and karst features, such as sinks, caves, and springs, are common.

The Northern Highlands extend across the northern part of the State from Alabama on the west to the north-central part of the peninsula on the east. This province is separated from the Central Highlands because of the greater dissection in the peninsula. The Northern Highlands are well drained by dendritic streams, and the higher areas are gently sloping plateaus.

STRUCTURE

Florida is located on the eastern margin of a large-scale depositional basin referred to by Murray (1961) as the Gulf of Mexico Sedimentary Basin. The peninsula of Florida has bordered this basin at least since Early Cretaceous time. Pressler (1947) divided the eastern part of the basin into the North and the South Florida Provinces. His North Florida Province, which includes the Florida panhandle, southern Georgia, and southeastern Alabama, was called the North Gulf Coast Sedimentary Province by Puri and Vernon (1964). It is characterized by clastic sedimentary rocks. The South Florida Province, which includes peninsular Florida, Cuba, and the Bahama Islands, is composed predominantly of carbonates and evaporites.

The dominant structural features of the Florida peninsula are the Peninsular Arch and the Ocala Uplift (fig. 4). Other structural features include the South Florida Embayment, the South Florida Shelf, the Broward Syncline, and the Southeast Georgia Embayment. The major structural elements of panhandle Florida are the Chattahoochee Arch, the Apalachicola Embayment, and the Suwannee Straits.

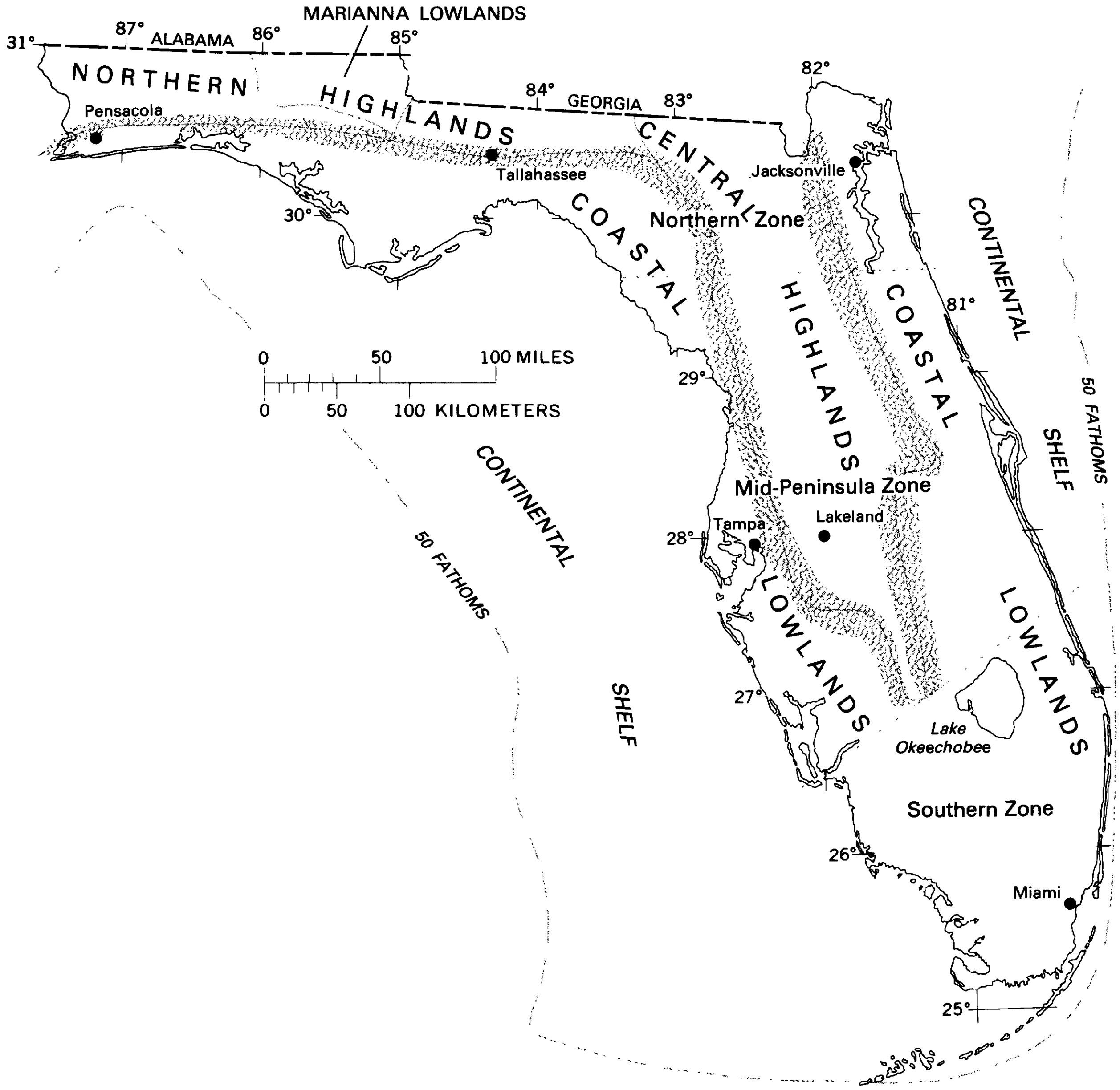

FIGURE 3.—Generalized locations of landforms. (From Puri and Vernon, 1964.)

The Peninsular Arch extends along the eastern side of the Florida peninsula from southern Georgia to Lake Okeechobee. The Peninsular Arch is a dominant subsurface structure and owes its present configuration to regional movements during Mesozoic and Cenozoic time (Applin, 1951).

According to Vernon (1951), the Ocala Uplift is "an anticline that developed in Tertiary sediments as a gentle flexure, approximately 230 miles long, and about 70 miles wide where exposed in central peninsular Florida." This structure is thought to have been active at least from late Eocene to early Miocene time, and, despite the development of this feature parallel to the Peninsular Arch, no structural association is reflected between the features.

Sediments in the South Florida Embayment are more than 15,000 feet (ft) thick (Pressler, 1947). The axis of the syncline, as shown in figure 4, is taken from Applin and Applin (1967). The term "South Florida Shelf" was proposed by them for "a relatively flat area in the Comanchee rocks (Lower Cretaceous) southwest of the Peninsular Arch and bordering the South Florida Embayment on the northeast"; they also proposed the term "Broward Syncline" for an area between the South Florida Shelf on the southwest and the Peninsular Arch on the northeast.

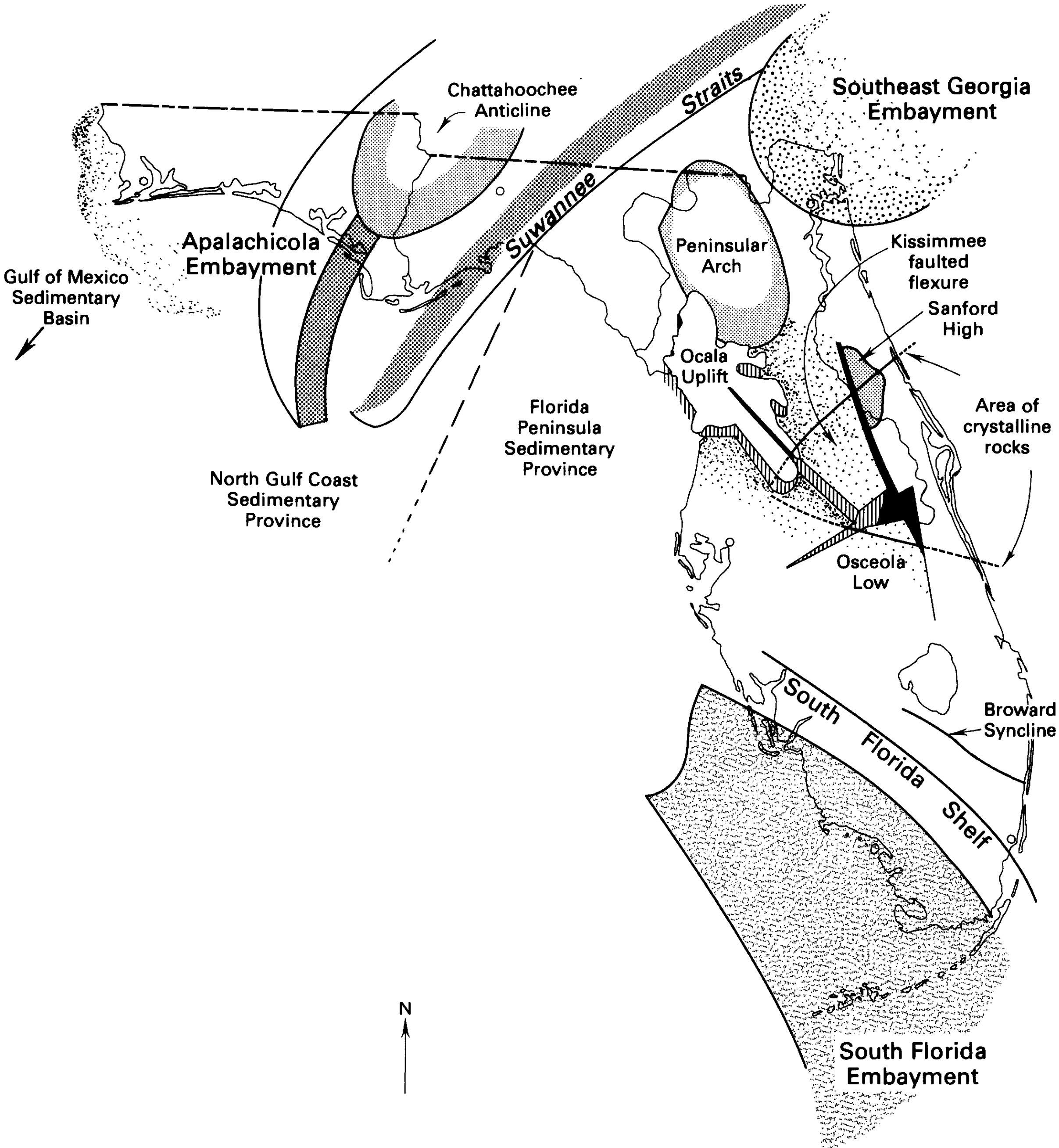

FIGURE 4.—Major structural elements affecting the State of Florida. (Modified from Puri and Vernon, 1964.)

The Southeast Georgia Embayment and the Suwannee Straits lie adjacent to each other in northern Florida and southern Georgia. The downwarped area of the Southeast Georgia Embayment plunges to the east beneath southeastern Georgia, northeastern Florida, and the adjacent Continental Shelf. Dall and Harris (1892) used the term "Suwannee Straits" to define an area that separated the continental border from Eocene and Miocene islands in peninsular Florida where Miocene sediments (Hawthorn Formation) were being deposited. Applin and Applin (1967) called this feature the Suwannee Saddle and described it as a subsurface syncline that extends approximately 200 mi in a broad arc from southeastern Georgia to north-central Florida. The Suwannee Straits may have connected the Southeast Georgia Embayment to the Apalachicola Embayment and has affected the deposition of Mesozoic and Cenozoic sediments.

The Chattahoochee Anticline (Veatch and Stephenson, 1911) is a gentle structural warp present in southwestern Georgia, southeastern Alabama, and the eastern panhandle of Florida. The Apalachicola Embayment is a basin or syncline between the Peninsular Arch and the Chattahoochee Anticline.

STRATIGRAPHY OF PENINSULAR FLORIDA

The Floridian Plateau is underlain by a highly variable thickness of sedimentary rocks lying on an irregular igneous and metamorphic Paleozoic basement complex. The thickness of sediments ranges from about 4,000 ft in north-central Florida to about 12,000 ft in the western panhandle and southern Florida. The pre-Mesozoic sedimentary rocks, known only from deep drilling, are entirely clastic. The Mesozoic sedimentary sequence in northwestern Florida is predominantly clastic at its base and contains increasing amounts of carbonate upsection until the uppermost Cretaceous is entirely carbonate. In southern Florida, Mesozoic rocks consist of carbonates and evaporites. Eocene and Oligocene rocks tend to be clastic in northern Florida and carbonate and evaporite in southern Florida. The evaporite content decreases in middle Eocene and Oligocene rocks. By the end of the Oligocene Epoch, clastic sediments from the north began interfingering and mixing with the platform carbonates, and upper Tertiary and Quaternary sediments throughout Florida consist of a mixture of carbonate, clastic, and mixed carbonate-clastic units.

The sediments exposed in the study area range in age from late middle Eocene through Holocene. They occur in roughly coast-parallel bands. The youngest sediments occur along the coast and become progressively older inland toward the western side of the peninsula and northward in the panhandle.

The oldest formation exposed at the surface in Florida is the middle Eocene Avon Park Limestone. Exposures of this unit are limited to areas in Levy and Marion Counties. In outcrop, the Avon Park Limestone is a crystalline dolomite, often containing carbonized plant remains.

The lower Eocene Ocala Limestone [Ocala Group of Puri (1957)] underlies the Suwannee Limestone and (or) the Hawthorn Formation and is exposed on the Ocala Uplift. The Crystal River, Williston, and Inglis Formations make up the Ocala Group. All are very pure limestones that have minor, if any, quartz sand.

The upper Oligocene Suwannee Limestone is a soft to hard, very porous calcarenite containing trace amounts of quartz sand in most areas. In scattered areas, the Suwannee Limestone has been dolomitized completely (Taylor County). The Suwanee Limestone crops out north and south of the Ocala Uplift but is absent east of this structural high due to nondeposition or to erosion or to a combination of both.

The Miocene Hawthorn Formation outcrops in an irregular band trending northwest-southeast from Hamilton County to southern Alachua County, and outliers of this unit are common in Marion, Sumter, and Hernando Counties. The Hawthorn is composed of mixtures of quartz sand, clay, and carbonate, which contain variable percentages of phosphate pellets and minor amounts of heavy minerals. The Hawthorn unconformably overlies the upper Oligocene Suwannee Limestone in Hamilton, Suwannee, and Columbia Counties in the north and Hernando and Sumter Counties in the south. Elsewhere within the study area, it overlies the Eocene Crystal River Formation of the Ocala Group.

Outliers of the Fort Preston formation [informal usage (Vernon and Puri, 1965)] occur in Clay, Putnam, and Volusia Counties (pl. 1). These outliers are separated by an erosional surface from the Fort Preston sediments that comprise much of the Central Highlands (White, 1970) and are composed of variegated clayey sand to sandy clay that may be crossbedded and thinly laminated. The sand component ranges from very fine to very coarse, and gravel is present. Heavy minerals are present in trace amounts. These sediments are lithologically similar to those in the upper Miocene and Pliocene Miccosukee–Citronelle Formations of western Florida and may represent a facies of these units.

The Alachua Formation is described by Vernon and Puri (1965) as "... terrestrial, in part possibly lacustrine and fluviatile, and is a mixture of interbedded irregular deposits of clay, sand, and sand-clay of most diverse characteristics."

Shell beds that have been assigned to the Choctawhatchee Formation (Pirkle and others, 1977), the Jackson Bluff Formation (Vernon and Puri, 1965), the Pliocene Charlton Formation, and to younger unnamed units that underlie the surficial sands. The shell beds contain highly variable combinations of shell, quartz sand, clay, and carbonate and trace to minor amounts of heavy-mineral and phosphate grains.

Underlying the Holocene deposits and landward of them is the Pleistocene Anastasia Formation. The Anastasia is a sandy coquina of predominantly molluscan shell and shell fragments. It forms the "backbone" of the Atlantic Coastal Ridge from the St. Augustine area southward out of the study area.

The geologic map of Florida (pl. 1) shows that much of northeastern Florida consists of Pleistocene and Holocene marine, estuarine, and terrace deposits, which consist of sand and clayey sand containing variable amounts of heavy minerals. Elevations of the terrace deposits range from near sea level to about 325 ft above sea level. Terrace deposits consist of sands of several different origins and ages, including aeolian, fluvial, and marine sands and possibly some weathering residuum (Altschuler and Young, 1960).

The youngest sediments occurring along the Atlantic coast are unnamed Holocene beach sands and associated shoreline features, such as dunes and bars. These sediments consist of quartz, a trace of feldspar, shell debris, and minor to trace amounts of heavy minerals.

MARINE TERRACES

Terraces and shorelines in Florida have been recognized and mapped since the early 1900's. Healy (1975) compiled a reference list of reports that deal with terrace mapping in Florida and compiled a map. His map includes the seven generally accepted terraces of Florida—the Silver Bluff that has elevations from 1 to 10 ft; the Pamlico, 8 to 25 ft; the Talbot, 25 to 42 ft; the Penholoway, 42 to 70 ft; the Okefenokee, 100 to 170 ft; the Coharie, 170 to 215 ft; and the Hazlehurst, 215 to 320 ft. The intervals described are based on elevation zones, which may not correspond to marine terracing episodes.

MacNeil (1950) recognized shorelines that represent maximum rises of sea level, which are ascribed to glacial oscillation (pl. 2). Four marine terraces and shorelines are recognized between present sea level and an altitude of 150 ft. The two highest, the Okefenokee and the Wicomico, are correlated with the Yarmouth and the Sangamon Interglacials, respectively. The next lower, the Pamlico, is correlated with a mid-Wisconsin ice recession. The lowest, the Silver Bluff, is regarded as post-Wisconsinan in age. The wide-spread fluvial deposits of the Citronelle Formation and terraces above 150 ft, whether fluvial or marine, are Pliocene or early Pleistocene in age.

Most scarps and terraces in Florida have been modified by erosional processes, and structural warping (Otvos, 1981) also may have altered the normally flatlying features. Winkler and Howard (1977) mapped three sequences of relict shorelines that are differentiated on the basis of "relative" age. Each shoreline sequence was mapped on the basis of lateral continuity and alignment, state of topographic preservation, and elevation, taking into account the possibility of regional warping. They stated that this method shows paleogeography and regional variations in erosion and deposition for each sequence. This approach appears useful because Florida's low elevation has made the State susceptible to repeated invasions of the sea, a process that reworks and redistributes the nearsurface sediments; however, it is strictly a geomorphic approach without use of biostratigraphic or lithostratigraphic data.

STRATIGRAPHY OF THE PANHANDLE OF FLORIDA

The panhandle of Florida has a similar sequence of sediments; with the exception of the Jefferson, Leon, and Wakulla County areas, the sediments of the panhandle are youngest near the coast, and older formations crop out to the north.

The younger formations onlap the northwestern end of the Ocala Uplift from the north and the west. To the north, overlying the Suwannee Limestone and the Hawthorn Formation is the Miccosukee Formation. It is composed of clayey sands and clays. To the west, in Leon and Wakulla Counties, are the St. Marks and the Jackson Bluff Formations, a sandy carbonate and an argillaceous sand to sandy-shell marl, respectively (Vernon and Puri, 1965). The remainder of the panhandle shows the south to north sequence of youngest to oldest as described above in the section on the stratigraphy of peninsular Florida.

Along the coastline and at varying distances inland (particularly along major drainage basins) are the marine and estuarine terrace deposits. The character of these sediments is also very similar to those sediments described in the section "Stratigraphy of Peninsular Florida."

Toward the Chattahoochee Anticline in the north, older formations crop out (Puri and Vernon, 1965). As described in the section "Stratigraphy of Peninsular Florida," the Fort Preston formation [informal usage (Vernon and Puri, 1965)] and the Jackson Bluff are encountered updip of the terrace deposits. On the eastern flank of the anticline and underlying the Fort Preston and cropping out of it to the north is the Tampa Formation. It consists of argillaceous, silty, sandy, chalky limestones interbedded with calcareous silts and impure siltstones (Puri and Vernon, 1965).

The Red Bay formation [informal name (Vernon and Puri, 1965)] and the Chipola Formation are west of the anticline. The Red Bay is a sandy, clayey, shell marl and crops out in a very limited area; the Chipola crops out higher on the flank of the anticline and is a " . . . highly fossiliferous marl . . . " that grades westward into a sandy limestone (Vernon and Puri, 1965).

The Oligocene "Duncan Church Beds" (Vernon and Puri, 1965) and the Marianna Limestone surround the nose of the anticline. The Duncan Church beds are described by Puri and Vernon (1965) as " . . . highly fossiliferous, shallow marine sediments . . . ." These replace the Suwannee Limestone in the panhandle. The Marianna Limestone is described as a granular, massive, highly fossiliferous limestone. Neither of these units contain abundant sand or heavy minerals. The upper Eocene Ocala Limestone is the oldest unit exposed on the anticline, and, as described in the section on the stratigraphy of peninsular Florida, it is a very pure limestone.

Highlands occur extensively in the western panhandle. These are comprised of the Citronelle Formation. The Citronelle consists of alluvial crossbedded sands, clays, and gravels. Special attention has been focused on this formation due to its high rad signature. Further discussion of the Citronelle can be found in the section "Fluvial Placers."

EVALUATION OF THE AERORADIOMETRIC DATA

TOTAL-COUNT GAMMA-RAY INTENSITY MAPS

Radioactive materials emit a spectrum of gamma-ray radioactivity that can be measured by airborne scintillometers when the materials are exposed at the surface. Airborne scintillometers commonly consist of a 400- to 500-cubic-inch (in^3) sodium iodide crystal coupled to an electronic system that records the activity registered by the crystal. An aerial system registers radioactivity from terrestrial, atmospheric, and cosmic sources. The strongest component is the terrestrial source, and atmospheric and cosmic sources generally account for a small portion of the total count rate observed but are highly variable with time, elevation, and prevailing atmospheric conditions. As a result, aerial surveys may register substantial and variable radiometric count rates over open bodies of water whose values should be low and constant.

Aerial surveys generally are flown at an elevation of 500 ft; flight lines are oriented to cross the strike of geologic contacts. Spacing between flight lines is commonly 1 to 1½ mi. Total-count-contoured rad maps are generally the end products of such surveys. Rad surveys, although limited in resolution and accuracy in comparison with surface methods, can best show regional variations in radiation intensity from which estimates may be made of terrestrial radioelement content and of relative surface radiation intensities.

The total-count gamma-ray intensity survey of Florida was flown and compiled for the USGS by Geodata International, Inc., in late 1976 and early 1977. Aerial coverage south of the 30th parallel was flown and compiled by Applied Geophysics, Inc., in 1978. The mismatch of rad contour lines at the border between the two surveys is a phenomenon common to overlapping rad surveys. The instruments for such surveys generally are not calibrated over pads of known radioelement concentrations, and, as a result, different instrument packages and, more importantly, different detector sizes will yield different results (in count rate magnitude) over the same sediments that can be correlated only with difficulty.

The rad maps (U.S. Geological Survey, 1978a–d) outline major water bodies and marshlands (pl. 1), indicating that location accuracy and instrument calibration are generally good. Numerous flight lines in both surveys covering the study area, however, show enhanced radioactivity throughout the length of the flight lines, indicating that portions of the surveys were subject to poor instrument response. Noisy flight lines are apparent on close inspection of the rad map. Accentuated linear breaks in radiation intensity trending east to west (along flight lines) are common at latitudes 29°20′ N., 29°40′ N., and, particularly, 30°25′ N. The overall effect of noisy flight lines is to introduce random fluctuations (positive and negative) of radiation intensity, thereby precluding accurate radiometric characterization of different lithologic units.

SPECTRAL GAMMA-RAY INTENSITY MAPS

Survey equipment used to gather the total-count rad data also measured specific gamma-ray intervals in the gamma-ray spectrum that yielded, through data reduction, the contributions from bismuth-214 (eU), thallium-208 (eTh), and potassium-40 (K) (Foote, 1978). Spectral data for the Jacksonville 1° x 2° Quadrangle and portions of the adjacent Valdosta 1° x 2° Quadrangle are given on plate 3. Analogous data for a 15-minute quadrangle (northeast corner coordinates are 30°30′00″ N. and 82°45′00″ E.) north of the city of White Springs are given on plate 4. Contoured eU/eTh, eU/K, and Th/K maps (pls. 3, 4) enhance anomalous occurrences of the individual radioelements.

The most easily discriminated patterns on the contoured spectral rad maps are those from elemental data. The ratio data, which usually provides more information from spectral surveys (International Atomic Energy Agency, 1979), are of less use than they might be because of the poor quality of the data—probably a function of detector crystal volume, level shifts between flight days, and inadequate filtering of the data.

The principal criterion for evaluation of spectral rad maps is the same as that used for total-count maps; that is, correlation of the outlines of major water bodies having very low to no radiometric signature. Alignment of enhanced or muted signatures along a flight line is indicative of poor instrument response and is an additional criterion useful for the evaluation of such maps.

The strong linear alignment of anomalies and low values along flight lines, coupled with significantly enhanced radioactivity over the Atlantic Ocean between approximately 30°11′ N. and 30°15′ N., limit the usefulness of these maps, but several trends occur that parallel the depositional strike of the beach ridges, indicating that the location accuracy and instrument calibration of portions of the survey are generally good.

The spectral rad maps of the 15-minute quadrangle north of the city of White Springs show rad patterns that correlate with the mine pits of the Suwannee River and Swift Creek phosphate mines of the Occidental Chemical Company (pl. 1, anomaly V9).

CORRELATION WITH SATELLITE IMAGE MAPS

National Aeronautics and Space Administration Landsat–1 satellite image maps (U.S. Geological Survey, 1973a–f, 1974a–c) were used in an effort to identify correlation between rad anomalies and image map characteristics. At the scale of the images used for comparison (1:500,000), few consistent associations of use were observed. Major commercial phosphate operations (Swift Creek Mine), a series of unreclaimed phosphate mines, some of the largest limestone quarries, and population centers show clear correlation. In northeastern Florida, where many rad anomalies associated with placer deposits occur, no significant correlation with the satellite images was observed, although the known active and recently shut down placer mining operations did correlate. Inasmuch as satellite image maps were found to be of little use in interpreting the rad maps, no further attempts were made, although such maps at larger scales may prove useful in limited areas.

Other types of maps compared with rad maps for which the correlations were better include land use–land cover, former shoreline, geologic, topographic, and other maps. These correlations are discussed in the sections "The Heavy-Mineral Anomalies," "The Phosphate Anomalies," "Cultural Anomalies," and "The Effects of Agricultural Fertilizer Applications on Gamma-Ray Radiometry." Characteristics of the principal rad anomalies in the study area are given in the Appendix.

FIELD METHODS

Field investigation consisted of ground checks of total-count and spectral rad anomalies and of sampling anomalous materials for laboratory analyses. Geographic areas where the rad signature is greater than local background were transferred onto county road maps for the purpose of field investigation. The steps are as follows. First, an anomalous area was traversed with a total-count scintillometer by vehicle to determine the geographic extent of the anomaly; this approach also verified that the anomaly registered by the aerial system was real. During the vehicle traverse, continuous readings were taken over sediment to find the anomalous material. Second, where this material was found, a four-channel, gamma-ray spectral scintillometer with a 113-in^3 sodium iodide detector was used to measure the components of the gamma radiation field. To achieve constant geometry at each locality, the detector unit of the instrument was suspended from a tripod about 1½ ft above the sediment surface. After temperature equilibration and standardization against a barium-133 gamma-ray source, the count rate was measured at the following gamma-ray energies: 1.46 megaelectronvolts (MeV) from potassium-40, 1.76 MeV from bismuth-214 in the uranium-238 series, and 2.62 MeV from thallium-208 in the thorium-232 series. The counting time at each locality did not exceed 10 minutes. The field data were reduced to radioelement concentrations by using the method given by Stromswold and Kosanke (1978). The data are given in table 1.

Sediment samples were taken immediately below the detector crystal by using a soil auger to a maximum depth of approximately 6 ft, or, where the anomalous material was exposed in a road cut, a channel sample or grab sample was taken. More extensive sampling was done where opaque minerals in a sample were observed in quantities that exceeded 1 percent by visual estimate. Several grab samples also were collected where heavy minerals were concentrated visibly in roadside drainage ditches in areas that show no rad anomalies.

The principal problem encountered during field investigation of the rad anomalies is related to the poor accessibility of those anomalous areas in river basins and marshlands. Many anomalous localities in northwestern Florida, particularly those in the Apalachicola River basin were inaccessible. Similarly, anomalies associated with modern and former shorelines on the gulf and the Atlantic coasts were inaccessible by vehicle. Supplementary data, such as geologic maps and previously published mineralogical analyses of surficial sediments in these areas, however, allowed us to categorize such anomalies with a fair degree of confidence.

LABORATORY ANALYSIS TECHNIQUES

Laboratory procedures were directed to find the amount of economic minerals in each sample. Because mined heavy minerals are normally present in coarse to fine sand, approximately 300 to 700 grams of bulk sample were split and sieved in dry condition into three textural classes–gravel and very coarse sand, greater than 14 or greater than 16 mesh; coarse to fine sand, less than 14 or less than 16 to greater than 325 mesh; and very fine sand to clay, less than 325 mesh. The coarse to fine sand fraction was processed for its heavy-mineral content in bromoform (S.G.>2.85). The bromoform float fraction (light minerals), consisting dominantly of quartz, was generally discarded. Large

TABLE 1.—*Ground spectral gamma-ray signatures of aeroradiometrically anomalous localities in the study area*

[A and B represent replicate samples]

Sample number	Time (s)	Potassium-40 count	Bismuth-214 count	Thallium-208 count	Percent K	eU (ppm)	eTh (ppm)	eU/K	eTh/K	eU/eTh
001A	120	3908	5786	911	0.38±0.10	35.64±1.11	8.97±0.81	94	24	4
B	120	3815	5844	870	0.30±0.10	36.14±1.12	8.41±0.81	121	28	4
003	240	1882	2518	700	0.02±0.003	0.94±0.04	0.49±0.03	47	25	2
005A	240	1352	1477	1293	0.12±0.02	3.20±0.20	7.87±0.26	27	66	0.4
B	600	2201	2621	2096	0.06±0.01	2.37±0.12	5.06±0.15	40	84	0.5
006A	240	1089	1248	1080	0.08±0.02	2.72±0.17	6.54±0.24	34	82	0.4
B	240	1069	1181	1076	0.09±0.02	2.50±0.17	6.53±0.23	28	73	0.4
007A	240	3830	2291	2210	0.77±0.03	4.61±0.31	13.53±0.41	6	18	0.3
B	240	3725	2260	2336	0.74±0.03	4.36±0.31	14.32±0.41	6	19	0.3
011A	240	2310	2457	2346	0.21±0.03	5.07±0.30	14.27±0.39	24	68	0.4
B	240	2342	2481	2343	0.22±0.03	5.15±0.30	14.24±0.39	23	65	0.4
022	360	2140	2008	1921	0.17±0.02	2.75±0.17	7.80±0.23	16	46	0.4
029	360	2386	2276	2618	0.17±0.02	2.75±0.20	10.68±0.27	16	63	0.3
030	360	6584	3931	4217	0.87±0.04	4.92±0.34	17.26±0.43	6	20	0.3
031	360	3076	3276	3087	0.19±0.02	4.55±0.25	12.51±0.31	24	66	0.4
034	360	3287	3088	3090	0.26±0.02	4.12±0.25	12.56±0.31	16	48	0.3
035	360	3964	3586	3718	0.33±0.03	4.87±0.29	15.13±0.36	15	46	0.3
041	360	5099	6343	6950	0.14±0.04	8.01±0.47	28.28±0.55	57	159	0.3
046	360	1991	2656	953	0.90±0.02	5.00±0.19	3.62±0.18	6	4	1.3
051	360	4920	6807	1308	0.22±0.04	13.77±0.43	4.52±0.33	63	21	3
053	600	1111	1145	624	0.05±0.01	1.18±0.06	1.48±0.07	24	30	0.8
054	360	1201	1258	1293	0.77±0.01	1.65±0.12	5.26±0.17	2	7	0.3
060	240	3921	4066	4829	0.34±0.04	7.19±0.48	29.57±0.62	21	87	0.2
064	360	1744	2060	2114	0.07±0.02	2.72±0.17	8.59±0.23	39	123	0.3
067	240	1292	1382	1216	0.12±0.02	2.98±0.19	7.27±0.25	25	61	0.4
072	240	3067	1613	1632	0.67±0.03	3.13±0.24	10.02±0.33	5	15	0.3
074	240	2617	1953	1694	0.44±0.03	4.20±0.26	10.30±0.33	10	23	0.4
076	240	1466	1688	1696	0.10±0.02	3.38±0.22	10.33±0.31	34	103	0.3
077	240	1927	1940	1846	0.20±0.02	4.01±0.25	11.23±0.33	20	56	0.4
078	240	1877	2000	1740	0.18±0.02	4.34±0.25	10.55±0.32	24	59	0.4
080	240	2072	1606	1932	0.31±0.02	2.78±0.23	11.86±0.34	9	38	0.2
081	240	3135	1845	1407	0.66±0.03	4.18±0.25	8.55±0.32	6	13	0.5
082	240	1457	1879	570	0.11±0.02	5.43±0.22	3.19±0.20	49	29	1.7
083	240	1458	1751	1611	0.09±0.02	3.70±0.22	9.77±0.30	41	109	0.4
088	360	551	515	331	0.05±0.01	0.84±0.06	1.32±0.08	17	26	0.6
090	240	1670	1719	1421	0.18±0.02	3.82±0.22	8.60±0.28	21	48	0.4
091A	120	6198	8827	1002	0.78±0.14	55.32±1.64	8.82±1.17	71	11	6.3
B	120	5997	8980	1015	0.58±0.14	56.33±1.65	8.89±1.17	97	15	6.3
092	120	767	1067	237	0.10±0.03	6.39±0.29	2.53±0.24	64	25	2.5
093A	240	556	540	352	0.07±0.01	1.32±0.10	2.11±0.13	19	30	0.6
B	600	1362	1335	822	0.07±0.01	1.33±0.07	1.96±0.09	19	28	0.7
094A	120	2863	3029	438	0.77±0.06	18.67±0.65	4.28±0.51	24	6	4.4
B	240	5605	5871	905	0.76±0.05	18.02±0.58	4.51±0.46	24	6	4

amounts of sample must be used for heavy-mineral separation because some mineral species, such as monazite, are present in quantities so small that lesser amounts of sample would have yielded poor counting statistics.

The heavy minerals of each sample were separated into three magnetic fractions (0.0–0.5, 0.5–1.0, and greater than 1.0 ampere) after the highly magnetic minerals were removed by use of a handheld magnet, and each fraction was studied independently by using petrographic and binocular microscopes. The identification of some opaque minerals was made by X-ray techniques. Visually estimated percentages of mineral species in each magnetic fraction were summed and converted to weight percentages. Compensation was not made for density.

For selected samples, the very fine sand to clay fractions also were processed for their heavy-mineral content in bromoform, but, because the very fine grained nature of the heavy minerals precluded microscopic identification, X-ray techniques were used to identify mineral species in bromoform float and sink fractions. Results are given in table 2.

Samples of Hawthorn and hardrock phosphate were screened into greater than 20, less than 20 to greater than 200, and less than 200 mesh fractions. The mineralogy of the individual fractions was determined microscopically and by the use of X-ray techniques. Scanning electron microscope photographs were taken of some of the phosphate samples to show textures of the phosphatic minerals.

Phosphate samples were treated in the laboratory following the metallurgical practices of the phosphate companies. The samples were dried and weighed and then disaggregated and deslimed. The slime fraction was separated by wet screening at 200 mesh. Only enough -200 mesh material was saved to make a pellet for the X-ray diffractogram; the rest was discarded. The +200 mesh was dried and screened at +10-, +20-, and +200-mesh intervals. All fractions were weighed, and weight percentages were calculated. The weight percentage of the slime fraction was calculated by difference.

The +10- and +20-mesh fractions (equal to the "pebble" of industry) were combined, and a split was prepared for making an X-ray diffractogram. The -20- to +200-mesh fraction (equal to the "feed" of industry) was treated in bromoform (S.G.>2.85) to obtain a heavy sink fraction, composed largely of carbonate fluorapatite particles and approximately equal to the concentrate fraction of industry, and a light fraction, composed largely of quartz particles and equal to the tailing fraction of industry. A split of the heavy fraction was prepared for X-ray diffraction.

Some of the samples of hardrock phosphate were not screened; the total sample was prepared for X-ray diffraction, and a diffractogram was made. Samples of pelletal apatite, the hardrock apatite, and the thoroughly weathered surficial material were prepared for examination with the scanning electron microscope (SEM).

SPECTRAL RADIOMETRIC CHARACTERIZATION OF ANOMALIES

Previous studies on the applicability of spectral radiometric data to the exploration for heavy-mineral deposits in coastal areas, particularly in beach sands, have shown that such deposits have characteristic radioelement spectra where radioactive heavy minerals, such as monazite and zircon, are present. The radioactive elements are in the crystal lattices, in the chemically and physically stable minerals as inclusions, or both, and, therefore, secular equilibrium of the daughter products with the parent element can be assumed. Where an anomaly is not caused by radioelements in resistate heavy minerals, the assumption of equilibrium is possibly not valid.

Application of spectral rad data to the characterization of anomalies in the Charleston, S.C., area (Force and others, 1982) shows that heavy-mineral concentrations have spectral rad signatures in which all spectra are anomalous, eTh is anomalous with eU and K normal, or eTh and eU are anomalous with K normal, whereas anomalous eU together with eTh and K normal is indicative of uraniferous phosphate. Robson and Sampath (1977), Mahdavi (1964), and Grosz (1983) also showed that heavy-mineral concentrations in eastern Australia and the gulf and the mid-Atlantic coasts, respectively, are characterized by dominant thorium and lesser uranium and potassium components.

THE HEAVY-MINERAL ANOMALIES

Anomalies due to heavy-mineral accumulations have three general modes of occurrence—marine placers, fluvial placers, and anomalies associated with tailings dumps of heavy-mineral beneficiating operations.

MARINE PLACERS

MODERN BEACHES

Marine placer concentrations occur on the Atlantic and the gulf coasts at low elevations corresponding to the Silver Bluff Terrace of Healy (1975). Rad anomalies on the Atlantic coast are, for the most part, of relatively high intensity, which indicates the presence of significant amounts of radioactive heavy minerals, whereas the rad anomalies of the gulf coast are of much lower intensity because of the relative scarcity of radioactive minerals in the heavy-mineral assemblage.

Competing land use in coastal areas precludes the commercial development of modern beach heavy-mineral deposits; therefore, anomalies in these areas were investigated only cursorily, partially as a guide to the nature of older deposits.

The mineralogy of samples of placer deposits from modern beaches is given in table 3.

Sample 037 is a surface composite from eastern St. George Island, an area that is straddled by weak rad anomalies, and sample 038 is an auger sample from a dune deposit on St. George Island that contained visible heavy minerals in topset bedding. Both samples contain the same mineral species (table 3); the relative abundance of the radioactive species monazite and zir-

TABLE 2.—*Mineralogy of the less than 325-mesh fraction of selected samples from aeroradiometrically anomalous localities in the study area*

[P—present. Analyses by W. F. McCollough]

Sample number	Thickness sampled (ft)	Quartz	Chlorite	Feldspar	Gibbsite	Rutile	Zircon	Kaolinite	Anatase	Illite	Mica	Gold	Goethite	Diaspore	Barite	Cassiterite	Ilmenite	Apatite	Hematite	Microcline
009	Grab---	P	---	---	---	---	---	---	---	---	P	---	P	---	---	---	---	---	P	---
010	0-3	P	---	---	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---
011	0-1.5	P	P	---	---	---	?	---	---	---	---	---	---	---	---	---	---	---	---	---
014	0-3	P	P	---	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
015	0-6	P	---	---	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---
016	0-2	P	---	---	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---
017	0-2	P	P	P	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---
017	2-4	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
018	Grab---	P	P	---	P	---	---	---	---	---	---	---	P	---	---	---	---	---	---	---
019 BF[1]	-- do --	P	---	---	---	---	P	---	---	---	---	---	---	---	---	---	---	---	---	---
019 BS[2]	-- do --	P	---	---	---	---	P	---	---	---	---	P	---	---	---	---	---	---	---	---
020	0-6	P	P	---	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---
021	0-3	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
022	0-2	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
022	2-4	P	---	---	---	P	---	---	---	---	---	---	---	P	P	---	---	---	---	---
023	0-3	P	P	---	---	---	---	P	P	---	---	---	---	---	---	---	---	---	---	---
024	0-2	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
025	0-3	P	P	---	---	---	---	P	---	P	---	---	---	---	---	---	---	---	---	---
026	0-3	P	P	---	---	---	---	---	---	---	P	---	---	---	---	---	---	---	---	---
027	0-2.5	P	P	---	---	---	---	---	---	P	---	---	---	---	---	---	---	---	---	---
028	0-6	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---	---	---	---
029	0-3	P	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
030	0-2	P	P	P	---	P	---	---	---	---	P	---	---	---	---	---	---	---	---	---
031	0-2	P	---	---	---	---	---	P	---	---	---	---	---	---	---	---	---	---	---	---
032 BF	0-2	P	---	---	---	P	---	---	---	---	P	---	---	---	---	---	---	---	---	---
032 BS	0-2	P	---	P	---	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---
033	0-3	P	P	---	---	---	---	P	---	---	P	---	---	---	---	---	---	---	---	---
034	0-3	P	P	P	---	---	---	P	---	---	---	---	---	---	---	---	---	---	---	---
035	0-3	P	P	---	---	---	---	P	---	P	---	---	---	---	---	---	---	---	---	---
036	0-3	P	---	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
041 BF	0-2	P	---	---	---	---	P	---	---	---	---	---	---	---	---	---	---	---	---	---
041 BS	0-2	P	P	---	---	P	P	---	---	---	---	---	---	---	P	---	---	---	---	---
041 BF	2-3	P	---	P	---	---	---	---	---	---	---	---	---	---	P	---	---	---	---	---
041 BS	2-3	P	---	---	---	---	---	---	---	---	---	---	---	---	P	P	P	---	---	---
042	0-2	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
043	0-2	P	P	P	---	---	P	---	---	---	---	---	---	---	---	---	---	---	---	---
044	0-2.5	P	P	P	---	---	---	---	---	---	P	---	---	---	---	---	---	---	---	---
045	0-2	P	P	P	---	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---
050	Grab---	P	---	---	---	---	---	---	---	---	---	---	P	---	---	---	---	P	---	P
053	0-2	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
053	2-4	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
053	4-5	P	P	P	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[1]Bromoform float (S. G. <2.85).
[2]Bromoform sink (S. G. >2.85).

TABLE 3.—*Sieve and heavy-mineral analyses of modern beach sands from aeroradiometrically anomalous localities in the study area*

[P—present (<0.1 percent). ND—none determined]

							Weight percent of S.G.>2.85 fraction																			
Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
St. George Island																										
037	Conc---	29°42′15″ 84°45′45″	---	---	---	---	2	15	5	15	ND	P	P	20	ND	3	12	5	ND	15	18	ND	ND	ND	ND	ND
038	0–2	29°42′15″ 84°45′45″	0.00	99.88	0.12	2.26	9	22	4	12	ND	P	P	32	ND	P	8	1	ND	8	4	ND	ND	ND	ND	ND
	2–4	29°42′15″ 84°45′45″	0.00	99.71	0.29	2.09	10	25	3	14	ND	P	P	28	ND	P	12	1	ND	6	1	ND	ND	ND	ND	ND
	4–5	29°42′15″ 84°45′45″	0.00	99.72	0.28	1.88	7	21	4	13	ND	P	P	23	ND	P	13	P	ND	13	6	ND	ND	ND	ND	ND
Amelia Island																										
057	0–3	30°34′30″ 81°27′00″	P	99.98	P	2.34	19	25	6	10	P	P	P	6	ND	6	9	8	ND	2	9	P	ND	ND	ND	ND
058	0–2	30°34′30″ 81°27′00″	0.00	99.98	P	0.68	18	22	10	6	ND	1	P	11	ND	3	2	3	ND	5	6	13	ND	ND	ND	ND
Santa Rosa Island																										
070	0–3	30°19′15″ 87°12′45″	P	99.93	P	0.82	P	9	ND	29	ND	ND	P	39	ND	1	5	3	P	9	5	ND	ND	ND	ND	ND
071	0–1.5	30°19′15″ 87°12′45″	P	99.89	P	0.33	ND	7	ND	30	ND	ND	P	25	ND	P	12	1	ND	15	10	ND	ND	ND	ND	ND

con, however, is greater in sample 037. This relative abundance of monazite and zircon on the surface area surrounding the sampled dune probably is due to aeolian concentration.

Sample 057 was collected from a dune deposit on American Beach (Amelia Island), and sample 058, from the intertidal zone on the beach. Both samples contain relatively large amounts of radioactive minerals. Several other rad anomalies that can be assigned confidently to heavy-mineral concentrations are present along the Atlantic shoreline south of Amelia Island. These anomalies were not checked during field investigations primarily because economic development of these deposits is precluded by competing land use.

Sample 070 is a channel sample of dune foreset beds, and sample 071 is an auger sample of the intertidal zone on western Santa Rosa Island. Heavy-mineral contents of these samples are small, the greater concentration being in the dune sample.

The heavy-mineral suites from St. George and Santa Rosa Islands, off the gulf coast, are comparable in their relatively large contents of sillimanite and kyanite and staurolite. The suite of heavy minerals from Amelia Island, however, contrasts markedly with the suite from the gulf coast in its large content of altered ilmenite, leucoxene, and monazite. The relative abundance of zircon, monazite, and phosphate in the Amelia Island sediments is responsible for the intensity of the rad signature, and the relative lack of these minerals is responsible for the lower intensity anomalies on the gulf coast.

PLEISTOCENE BEACH AND NEARSHORE MARINE SEDIMENTS

Marine placer concentrations in the ancient beach sands of northeastern Florida are commercial sources of heavy minerals. Published literature on the occurrence and the mineralogy of heavy-mineral-bearing sands in northeastern Florida by Liddell (1917), Martens (1928), Spencer (1948), Thoenen and Warne (1949), Carpenter and others (1953), Overstreet (1967), Garnar (1972), Pirkle and others (1974), and others indicates that monazite is present in these sediments from trace quantities up to 2 percent of the heavy-mineral concentrates. Monazite from marine placers in northeastern Florida is reported to contain between 4.5 percent [45,000 parts per million (ppm)] (Kremers, 1958) and about 5 percent (50,000 ppm) $Th0_2$ (Calver, 1957) and also contains small amounts of uranium ranging from 0.42 percent (4,200 ppm) to 0.55 percent (5,500 ppm) U_30_8 (Calver, 1957).

The spectral gamma-ray intensity maps of the northeastern Florida area (pl. 3) show the usefulness of such maps in exploration for heavy-mineral deposits. One of the most obvious features on the maps, and one useful for checking locational accuracy, is the St. Johns River; other useful location features include Amelia (anomaly J1) and Little Talbot Islands (anomaly J2).

North of the St. Johns River and east of the 30-ft contour as outlined by MacNeil (1950) is an area of high values on total-count and spectral rad maps. Presumably because of monazite, the high values show up particularly well on the eTh map (pl.3) and define an area from Jacksonville due north extending into Georgia. This is the area between the Pamlico mainland and the barrier island sequences of MacNeil (1950) and corresponds to the lagoonal environment of that higher sea-level stand; it is also the area of the delta of the ancestral St. Marys River, which drained the Okefenokee and High Terrace areas to the northwest and was down-current from the Altamaha River to the north. The increase in radiometric values here may coincide with decreased water infiltration capacity of the thinner sands (shelly sand and clay; Scott, 1979) and possibly increased retention of radioactive fertilizers. The rivers, particularly the Altamaha, were probably important sources of heavy minerals. The area of highest rad intensity in the Pamlico Intracoastal Waterway [MacNeil (1950); the Effingham sequence of Winkler and Howard (1977)] corresponds to an area of coast where the barrier islands to the east were possibly least developed and where the wave energy reaching the coast was at its highest. Poor preservation of barrier island elements in this area could be the result either of nondeposition or of erosion and prevents more definitive explanations.

This same pattern of high values, especially high potassium values, is present between the 80- and 90-ft contours east of Trail Ridge and the associated barrier island deposits along the valley now drained by the northward-flowing portion of the St. Marys River. This general pattern contrasts markedly with that of the shoreline and barrier island features themselves, which are dominated by uranium and thorium and a minor potassium component in the radiometric signature.

The area to the south and west of Doctor's Inlet is another example of this deltaic type signature; in the area traversed by Black Creek, the same general signature is present. This is an area that would have been a tidal outlet for at least the 80- to 90-ft sea-level time and supports the contention that tidal shoaling was important in the development of current radiometric patterns. In this context, it must be noted that the DuPont Company owns the mineral rights to a large heavy-mineral holding (1,200 acres) on the peninsula extending north between Doctor's Inlet and the St. John's River and that the Green Cove Springs heavy-mineral deposit occurs along the Pamlico shoreline just south of this inlet.

The same pattern repeats, only less strongly, in the gap between shoreline features near Bryceville, where the St. Mary's River breaches Trail Ridge, and the subsequent lower shorelines.

The relatively high potassium signature of Amelia and Little Talbot Islands is closer to that of the ancient intracoastal waterways as opposed to that of the ancient shoreline features. In addition, shoreline features to the south show less of this potassium signature than the ancient shoreline features. The modern intracoastal waterway does not have a rad signature due to the attenuation of radiation by water in the modern intracoastal area.

The area around Yulee, which is host to an undeveloped heavy-mineral ore body, also shows a signature similar to that of Amelia and Little Talbot Islands. The intensity of signature, however, may be enhanced partly by the contrast between the low-lying marshlands and the adjacent higher ground.

Spectral rad maps for the area north of the city of White Springs (pl. 4) were very useful in the classification of anomalies. In accord with the results of published studies, we were confident that eTh-dominated anomalies were indicative of heavy-mineral concentrations. Field investigations of anomalies in this area proved the classification scheme correct. Anomalies dominated by radioelements other than eTh are discussed in the sections "The Phosphate Anomalies," "Cultural Anomalies," and "The Effects of Agricultural Fertilizer Applications on Gamma-Ray Radiometry."

Previously published reports on the occurrence and mineralogy of heavy-mineral concentrations in northwestern gulf coast beach sands (Martens, 1928; Bureau of Mines, 1943; Lawthers, 1955) indicate the presence of potentially economic deposits that are mineralogically comparable to deposits currently being mined in northeastern Florida. The extent and average grade of the gulf coast deposits are unknown and can only be determined by a drill sample program; however, the relatively high percentage of minerals high in TiO_2 content (64.8–98.4, and an average of 77, unpublished reports of the Crane Company) indicate this region to be favorable for detailed investigation.

Sieve and heavy-mineral analyses of samples collected from aeroradiometrically anomalous localities that correspond to former shoreline and marine terrace deposits (MacNeil, 1950; Healy, 1975) are given in table 4. The heavy-mineral contents of these surficial sands are well below that of sands currently being mined.

Beach and nearshore marine sand deposits in eastern and northeastern Florida (the Atlantic Coastal Lowlands and portions of the Central Highlands) are hosts of commercial heavy-mineral deposits. Commercial deposits average between 2 and 4 percent total heavy minerals, roughly 50 percent of which are the titanium minerals ilmenite, rutile, and leucoxene. With the exception of a few samples from areas that are known to contain economic deposits, none of the samples from eastern Florida were found to contain heavy minerals in quantities comparable to currently economic deposits. It should be noted, however, that, with the possible exception of the deposit near Boulogne, heavy-mineral deposits are covered by variable thicknesses of sands that contain very small amounts of heavy minerals; drilling of these sands remains the only true technique for defining ore-grade deposits.

Evaluation of the rad anomalies in eastern Florida indicates that the anomalies in the Atlantic Coastal Lowlands probably are associated with heavy-mineral enrichments. The locations of these anomalies generally correspond approximately to the Pamlico shoreline (MacNeil, 1950) and, therefore, are considered to be primary targets for further exploration.

Rad maps of the area surrounding the Swift Creek phosphate mine (anomaly V9) indicate several anomalies that are characterized by high eTh signatures (pl. 4). In the vicinity of the mine itself, four eTh anomalies of limited geographic extent are associated with heavy-mineral-bearing sands of the Okefenokee shoreline that probably were stripped to allow access to the underlying phosphate deposit. To the south of this locality, a very strong eTh anomaly (V10) occurs. Samples from this anomaly (041, 084, 085, table 4) contain relatively large amounts of monazite (particularly sample 041) and other economic minerals. To the north, however, the other samples contain much smaller amounts of heavy minerals in sand that rests upon a cavernous limestone. The small percentage of heavy minerals and the shallowness of this deposit limit the probability of commercial exploitation. This strong eTh anomaly, surrounded by eU anomalies, is exemplary of the relative usefulness of spectral rad data as compared to total-count rad data in exploration for heavy-mineral deposits because total-count maps smear the separate effects. Comparison of ground-spectral radiometric (table 1) with rad data for the Swift Creek Mine area and vicinity shows good correlation. The phosphate ore at the Swift Creek Mine has a ground-radiometric signature (samples 094A, B) that is dominated by eU, whereas the sand overburden (samples 093A, B) is characterized by a very weak rad signature. The eTh anomaly (V10) on the spectral rad maps also has a ground-radiometric spectrum dominated by eTh (sample 041, table 1).

FLUVIAL PLACERS

THE RIVERS

Rad anomalies on the flood plains and islands of major rivers in the study area are caused by placer concentrations of heavy minerals and (or) phosphate. Where the flood-plain sands of the major rivers could be sampled, they contained relatively small amounts of heavy minerals (table 5). However, the potential exists for economic deposits in such sediments because fluvial processes are known to form placers efficiently. (Macdonald, 1983).

Although none of the flood-plain deposits sampled contain commercial quantities of heavy minerals, their mineralogy is comparable to the economic deposits in that economic minerals (ilmenite, rutile, leucoxene, zircon, monazite, and sillimanite and kyanite) constitute the bulk portion of the heavy minerals.

Morphology-guided drilling of flood-plain and island sediments in the major drainage basins may prove that sizable deposits of commercial value are present.

CITRONELLE FORMATION

The surficial deposits in much of northwestern Florida consist of the Pliocene Citronelle Formation and Pleistocene alluvial terrace deposits. These sediments have been difficult to differentiate due to the lack of biostratigraphic markers within either formation. The origin of the Citronelle is not clear. In the past, these sediments have been considered to be fluvial terrace deposits (Fisk, 1938; Alt and Brooks, 1965), Pleistocene glacial deposits (Hilgard, 1866), marine deposits (McGee, 1891; Harris and Veatch, 1899), transitional marine deposits (Matson, 1916), or deposits of preglacial coalescing braided streams (Rosen, 1969).

TABLE 4.—*Sieve and heavy-mineral analyses of aeroradiometrically anomalous Pleistocene beach and nearshore marine sediments from the study area*

[P—present (<0.5 percent), ND—none determined]

Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Weight percent of S.G.>2.85 fraction: Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
003	0 -3	29°47′45″ 82°25′30″	0.69	96.87	2.44	0.26	P	8	P	26	ND	1	1	50	P	1	6	5	ND	1	1	ND	ND	ND	ND	ND
	3 -6	29°47′45″ 82°25′30″	0.49	97.91	1.60	0.28	P	10	ND	24	ND	P	P	52	P	1	6	5	ND	1	1	ND	ND	ND	ND	ND
004	Conc - -	30°19′30″ 82°11′30″	---	---	---	---	P	4	ND	7	ND	ND	P	21	P	P	27	10	ND	7	23	ND	ND	ND	ND	1
006	0 -2	30°25′25″ 85°12′30″	3.60	93.05	3.35	0.34	ND	18	ND	10	P	ND	P	17	ND	4	10	19	P	6	14	ND	1	ND	ND	1
	2 -3.5	30°25′15″ 85°12′30″	4.00	90.68	5.32	0.36	ND	13	ND	18	P	ND	P	13	ND	3	12	16	ND	7	18	ND	1	ND	ND	ND
	3.5-5	30°25′15″ 85°12′30″	10.25	85.64	4.11	0.23	P	14	ND	14	ND	ND	P	17	ND	3	14	12	ND	9	11	ND	4	ND	ND	2
010	0 -3	30°36′45″ 87°17′00″	0.02	99.53	0.45	0.83	ND	29	2	5	ND	ND	P	6	ND	3	9	8	12	6	14	ND	1	ND	5	ND
011	0 -1.5	30°44′30″ 87°21′45″	47.49	47.19	5.32	0.42	ND	P	ND	7	ND	ND	1	15	ND	P	11	4	ND	8	6	ND	41	ND	ND	7
014	0 -3	30°56′15″ 87°22′00″	23.80	71.20	5.00	0.23	ND	2	ND	P	ND	ND	9	P	ND	P	P	P	ND	P	P	ND	89	ND	ND	ND
015	0 -6	30°55′30″ 87°13′00″	7.65	91.21	1.14	0.30	ND	P	ND	14	ND	ND	P	27	ND	P	8	3	ND	6	5	ND	ND	ND	ND	37
016	0 -2	30°55′30″ 87°13′00″	0.41	96.87	2.72	2.24	ND	P	ND	5	ND	ND	ND	16	ND	1	9	3	P	1	15	ND	ND	ND	ND	50
020	0 -6	30°55′00″ 86°54′30″	0.70	94.47	4.93	0.14	ND	7	ND	24	ND	ND	ND	15	ND	ND	10	P	ND	18	5	ND	P	ND	21	ND
021	0 -3	30°28′45″ 85°58′00″	0.54	95.20	4.26	0.29	ND	18	ND	23	ND	ND	P	26	ND	P	4	6	ND	8	6	ND	3	ND	2	4
022	0 -2	30°29′30″ 85°53′45″	0.00	97.13	2.87	0.81	2	19	3	19	ND	ND	P	16	ND	2	12	5	ND	12	10	ND	ND	ND	ND	ND
	2 -4	30°29′30″ 85°53′45″	0.00	97.64	2.36	0.65	1	20	1	21	ND	ND	P	12	ND	1	8	8	ND	16	12	ND	ND	ND	ND	ND
023	0 -3	30°26′00″ 85°54′00″	0.00	94.64	5.36	0.20	ND	20	ND	18	ND	ND	1	33	ND	1	4	P	ND	15	7	ND	ND	ND	1	ND
024	0 -2	30°28′15″ 85°52′00″	1.81	96.33	1.86	0.11	ND	22	ND	21	ND	ND	P	26	ND	P	11	2	ND	14	4	ND	ND	ND	ND	ND
025	0 -3	30°36′15″ 85°50′30″	0.00	96.46	3.54	0.25	ND	7	ND	17	ND	ND	P	27	ND	1	12	9	ND	15	12	ND	ND	ND	ND	ND
026	0 -3	30°42′30″ 85°47′30″	5.40	92.90	1.70	0.46	ND	10	ND	12	ND	ND	P	41	ND	ND	14	ND	ND	13	10	ND	P	ND	ND	ND
028	0 -6	30°18′45″ 85°27′00″	1.44	96.80	1.76	0.31	ND	18	ND	21	ND	ND	P	31	ND	ND	9	1	ND	19	1	ND	P	ND	ND	ND
029	0 -3	30°35′00″ 85°05′15″	10.96	87.18	1.86	0.32	ND	14	ND	11	ND	ND	P	34	ND	P	14	3	ND	6	6	ND	12	ND	ND	ND

TABLE 4.—*Sieve and heavy-mineral analyses of aeroradiometrically anomalous Pleistocene beach and nearshore marine sediments from the study area*—Continued

							Weight percent of S.G.>2.85 fraction																			
Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
033	0 -3	30°19′15″ 35°17′00″	1.37	95.50	3.13	0.15	ND	3	ND	9	ND	ND	P	47	ND	P	11	4	ND	15	11	ND	P	ND	ND	ND
034	0 -3	30°16′15″ 85°01′30″	0.41	96.54	3.05	0.36	1	34	ND	13	ND	ND	P	18	ND	P	13	1	ND	10	8	ND	2	ND	ND	ND
035	0 -3	30°05′45″ 85°01′45″	0.43	95.94	3.63	0.38	1	28	ND	5	ND	ND	P	16	ND	P	12	1	ND	9	10	ND	13	ND	5	ND
036	0 -3	29°59′45″ 85°00′00″	0.41	95.06	4.53	0.56	1	24	ND	11	ND	ND	ND	20	ND	1	12	2	P	18	9	ND	P	ND	2	ND
041	0 -2	30°16′30″ 82°54′00″	0.56	93.73	5.71	1.46	1	14	P	5	ND	ND	P	35	ND	3	17	6	ND	5	14	ND	ND	ND	ND	ND
041	2 -3.5	30°16′30″ 82°54′00″	0.86	92.34	6.82	1.43	P	11	ND	5	ND	ND	P	37	ND	3	18	12	ND	4	10	ND	ND	ND	ND	ND
044	0 -2.5	30°19′30″ 83°19′30″	0.45	98.33	1.22	0.37	P	3	ND	11	ND	ND	P	30	ND	P	15	12	ND	18	11	ND	ND	ND	ND	ND
053	0 -2	30°18′45″ 82°11′15″	0.26	98.79	0.95	0.82	P	2	ND	9	ND	ND	P	32	ND	P	25	10	ND	10	12	ND	ND	ND	ND	ND
	2 -4	30°18′45″ 82°11′15″	0.21	98.86	0.93	0.87	ND	2	ND	11	ND	ND	ND	24	ND	P	21	13	ND	13	16	ND	ND	ND	ND	ND
	4 -5	30°18′45″ 82°11′15″	0.00	98.82	1.18	0.84	ND	2	ND	7	ND	ND	ND	24	ND	P	21	13	P	13	20	ND	ND	ND	ND	ND
054	0 -3	30°40′00″ 81°33′30″	0.26	99.32	0.42	1.20	2	31	P	16	ND	ND	ND	19	ND	1	10	5	ND	6	10	ND	P	ND	ND	ND
	3.5-5	30°40′00″ 81°33′30″	0.05	99.58	0.37	1.40	1	31	ND	14	ND	ND	P	17	ND	P	10	7	ND	18	2	ND	ND	ND	ND	ND
055	0 -5.5	30°39′45″ 81°32′30″	6.43	93.23	0.34	2.76	7	33	5	12	ND	P	P	17	ND	2	10	4	ND	3	7	ND	ND	ND	ND	ND
056	0 -3	30°38′15″ 81°32′45″	0.19	99.36	0.45	10.01	17	28	ND	8	ND	ND	P	12	ND	4	11	4	ND	4	12	ND	ND	ND	ND	ND
059	0 -2	30°37′00″ 81°29′45″	0.45	99.12	0.43	0.69	6	19	P	16	ND	P	P	33	ND	1	7	4	ND	6	8	ND	ND	ND	ND	ND
060	0 -2	30°45′15″ 81°48′00″	2.59	93.75	3.66	1.61	2	33	1	5	ND	P	P	20	ND	4	11	7	ND	2	14	ND	1	ND	ND	ND
061	Grab - -	30°45′00″ 81°55′45″	---	---	---	---	P	35	ND	4	ND	ND	P	23	ND	P	12	20	ND	5	P	ND	ND	ND	ND	ND
062	- - do - -	30°35′15″ 81°59′30″	---	---	---	---	P	13	P	8	ND	ND	P	30	ND	P	5	30	ND	7	7	ND	ND	ND	ND	ND
063	0 -3	30°32′30″ 81°45′45″	0.80	96.23	2.97	0.57	4	26	ND	17	ND	ND	P	22	ND	1	14	6	ND	3	7	ND	ND	ND	ND	ND
064	0 -2	30°20′15″ 82°06′45″	0.66	98.59	0.75	0.56	ND	14	ND	14	P	ND	P	24	ND	6	10	11	ND	12	9	ND	ND	ND	ND	ND
	2 -3.5	30°20′15″ 82°06′45″	0.00	98.99	1.01	0.92	P	16	ND	10	P	ND	P	39	ND	1	11	9	P	7	7	ND	ND	ND	ND	ND

TABLE 4.—*Sieve and heavy-mineral analyses of aeroradiometrically anomalous Pleistocene beach and nearshore marine sediments from the study area*—Continued

Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Weight percent of S.G.>2.85 fraction																			
							Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
066	0 -3	30°33'45" 84°31'30"	0.00	62.81	37.19	0.02	ND	36	ND	2	ND	ND	P	50	ND	ND	P	10	ND	ND	2	ND	ND	ND	ND	ND
067	0 -5	30°39'30" 84°38'45"	17.41	79.97	2.62	0.26	ND	4	ND	4	ND	ND	P	51	ND	ND	11	8	ND	9	8	ND	5	ND	ND	ND
075	0 -2	30°59'00" 87°10'00"	0.00	5.43	94.57	0.12	P	15	ND	15	ND	ND	P	15	ND	P	10	20	ND	12	10	ND	ND	ND	3	ND
076	0 -1	30°48'45" 86°41'30"	5.83	86.62	7.55	0.37	ND	3	P	4	ND	ND	P	32	ND	P	12	9	ND	9	9	ND	22	ND	ND	ND
077	0 -1	30°48'45" 86°41'30"	6.34	86.91	6.75	0.36	ND	3	P	3	ND	ND	P	29	ND	P	13	10	ND	9	8	ND	25	ND	ND	ND
078	0 -1	30°48'45" 86°41'30"	5.75	87.30	6.93	0.34	ND	2	P	4	ND	ND	P	31	ND	P	9	10	ND	9	9	ND	24	ND	ND	ND
080	0 -5	30°36'45" 85°32'00"	2.40	96.21	1.39	0.38	ND	9	ND	15	P	ND	P	18	ND	1	9	6	ND	16	11	ND	15	ND	ND	ND
082	0 -1	30°00'00" 83°46'00"	1.94	96.32	1.74	0.52	ND	4	P	8	ND	ND	P	24	ND	P	6	2	ND	3	14	ND	32	ND	ND	7
084	0 -2	30°17'30" 82°54'00"	5.44	92.76	1.80	0.68	ND	6	P	2	P	P	P	38	ND	3	20	12	ND	6	13	ND	P	ND	ND	ND
	2 -3.5	30°17'30" 82°54'00"	0.42	96.47	3.11	0.63	P	13	P	6	ND	P	P	23	ND	2	18	17	ND	7	14	ND	P	ND	ND	ND
085	0 -3.5	30°18'30" 82°54'00"	1.55	96.39	2.06	0.43	ND	6	1	10	ND	P	P	19	ND	1	21	19	ND	9	14	ND	ND	ND	ND	ND
087	0 -1.5	29°26'45" 81°16'00"	0.00	82.79	17.21	0.25	P	15	ND	25	ND	ND	P	25	ND	P	12	13	ND	3	7	ND	ND	ND	ND	ND
	1.5-2.5	29°26'45" 81°16'00"	0.70	92.02	7.28	0.30	3	9	ND	17	ND	ND	P	24	ND	1	10	5	ND	24	7	ND	P	ND	ND	ND
	2.5-3.5	29°26'45" 81°16'00"	0.55	98.93	0.53	0.18	1	16	ND	11	ND	ND	P	30	ND	P	8	3	ND	12	10	ND	11	ND	ND	ND

Marsh (1966) described the sediments of the Citronelle as quartz sand and numerous lenses, beds, and stringers of clay, sand, and gravel. The sands are described as being angular to subangular, very poorly sorted, ranging in size from very fine to very coarse, and typically light yellowish brown to reddish brown. The sediment types change abruptly in lithology over short distances. A distinctive rock type that occurs in the area is a limonite-cemented sandstone that generally overlies the clay beds. These limonitic layers were formed after deposition of the Citronelle and resulted from the oxidation of iron compounds in the ground water.

The separation of the Pleistocene terrace deposits from the Citronelle can be established by the presence of garnet, hornblende, and epidote in many of the younger deposits. Further facts that aid in this separation are their topographic expression and stratigraphic position and the gross lithology of the sediments. The heavy minerals that Isphording and Riccio (1969) reported as occurring in the Citronelle in Escambia County, Fla., are kyanite, rutile, staurolite, tourmaline, zircon, leucoxene, and ilmenite, which are common, and sillimanite, which is rare.

In a study of well cuttings from the Citronelle, Coe (1979) indicated two very distinct sedimentary trends—

TABLE 5.—*Sieve and heavy-mineral analyses of aeroradiometrically anomalous flood-plain sediments from the study area*

[P—present (<1.0 percent), ND—none determined]

							Weight percent of S.G.>2.85 fraction																			
Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
												Suwanee River														
005	0–2	30°18′45″ 83°13′30″	2.59	93.20	4.21	0.45	P	15	ND	20	P	ND	P	14	P	1	20	6	ND	4	20	ND	ND	ND	ND	ND
	2–4	30°18′45″ 83°13′30″	2.24	93.07	4.69	0.59	P	18	ND	24	P	ND	P	13	ND	P	11	11	ND	7	15	ND	ND	ND	ND	1
	4–5	30°18′45″ 83°13′30″	2.43	93.60	3.97	0.38	P	17	ND	12	ND	ND	P	23	ND	5	11	13	ND	6	13	ND	ND	ND	ND	ND
042	0–2	30°24′00″ 83°11′15″	0.49	96.52	2.99	0.50	1	19	ND	6	ND	ND	P	18	ND	1	26	12	ND	6	12	ND	ND	ND	ND	ND
045	0–2	30°03′45″ 83°04′30″	0.72	97.57	1.71	0.47	1	15	ND	11	ND	ND	P	24	ND	P	17	7	ND	12	13	ND	P	ND	ND	ND
083	0–2	29°59′45″ 82°57′00″	2.15	96.16	1.69	0.29	1	20	ND	6	ND	ND	P	17	ND	1	14	11	ND	13	17	ND	ND	ND	ND	ND
	2–4	29°59′45″ 82°57′00″	3.42	95.05	1.53	0.24	P	15	ND	7	ND	P	P	17	ND	1	16	18	ND	14	12	ND	ND	ND	ND	ND
086	0–3	30°24′30″ 83°04′30″	8.40	90.97	0.63	0.32	ND	8	1	20	ND	ND	P	22	ND	P	16	16	ND	4	13	ND	P	ND	ND	ND
												Apalachicola River														
007	0–2	30°21′15″ 85°05′45″	2.56	89.89	7.55	0.68	1	35	1	12	ND	ND	P	13	ND	1	8	4	ND	10	15	ND	P	ND	ND	ND
	2–3	30°21′15″ 85°05′45″	16.00	75.82	8.18	0.26	3	41	P	5	P	ND	P	17	ND	7	7	2	P	7	11	ND	ND	ND	ND	ND
030	0–2	30°29′30″ 85°01′00″	0.74	97.48	1.78	0.78	9	32	3	7	ND	ND	P	22	ND	3	7	P	ND	9	7	ND	ND	ND	1	ND
031	0–2	30°25′30″ 85°02′45″	1.91	93.26	4.83	0.35	ND	4	ND	P	ND	ND	P	4	ND	P	1	P	ND	P	1	ND	86	ND	ND	4
032	0–2	30°20′30″ 85°03′15″	0.31	87.42	12.27	1.23	20	21	8	7	ND	ND	P	16	ND	2	5	1	1	12	4	ND	ND	ND	ND	3
												Escambia River														
073	Grab --	30°46′15″ 87°20′00″	0.59	98.21	1.20	0.88	ND	23	ND	11	ND	ND	P	28	ND	3	17	P	ND	7	10	ND	1	ND	ND	ND
074	0–1.5	30°54′15″ 87°18′00″	10.32	70.08	19.60	0.21	2	18	ND	2	ND	ND	P	9	ND	1	6	5	ND	9	9	ND	39	ND	ND	ND
095	Conc --	30°58′00″ 87°12′30″	---	---	---	---	1	24	ND	18	ND	ND	P	26	ND	1	15	5	ND	4	6	ND	ND	ND	ND	ND
												Blackwater River														
017	0–2	30°40′00″ 86°58′30″	0.64	90.54	8.82	0.18	ND	9	ND	11	ND	ND	2	27	ND	P	14	4	ND	14	5	ND	P	ND	P	14
	2–4	30°40′00″ 86°58′30″	0.97	93.84	5.19	0.22	ND	6	ND	14	ND	ND	P	41	ND	P	12	2	ND	8	3	ND	1	ND	ND	13

TABLE 5.—*Sieve and heavy-mineral analyses of aeroradiometrically anomalous flood-plain sediments from the study area*—Continued

Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Weight percent of S.G.>2.85 fraction: Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
							Pine Barren Creek																			
008	Grab	30°30′30″ 87°20′45″	---	---	---	0.81	P	10	1	7	ND	ND	2	29	ND	11	6	6	ND	20	8	ND	P	P	ND	ND
							Withlacoochee River																			
043	0–2	30°28′15″ 83°16′15″	1.85	96.74	1.41	0.48	ND	15	ND	21	ND	P	P	22	ND	P	7	10	ND	19	6	ND	P	ND	ND	ND
							Choctawhatchee River																			
027	0–2.5	30°48′15″ 85°49′00″	0.21	95.80	3.99	0.22	ND	23	ND	17	ND	ND	P	18	ND	P	11	5	ND	17	9	ND	ND	ND	ND	ND

a fining upward sequence and a coarsening upward sequence. The fining upward is not traceable from one well to the next and sometimes is found at different depth intervals in adjacent wells. In some of the wells, the sediments coarsen upward from a sand and silty clay directly into a sand and gravel section that further coarsens upward into a gravel and then fines back into a sand and gravel. He concluded that the sediments of the Western Highlands are much more easily correlatable in the north-south direction than in the east-west, suggesting that the streams that deposited the sediments generally were flowing in a southerly direction. This, combined with the observation that the general fining upward characteristic of stream deposition is not correlatable from one well to the next but, rather, is found at various depths in adjacent wells, implies that a number of smaller rivers may have been depositing sediments at different times and at different horizons in the Citronelle. Coe (1979) also noted that more pure sand and gravel and a higher percentage of gravel are found in the northern portion of the study area than in the southern portion. The percentage of gravel in these sediments has been shown to decrease to the east in Florida and to the west in Alabama (Schmidt, 1978a), indicating that one or several streams were depositing their sediment load in the estuary or marsh environment in the form of small localized deltas at the time. However, the vertical repetition of the sand and gravel beds and the sand and silty-clay beds may correspond to transgressions and regressions of sea level during Pliocene time. Thus, it is thought that the upper 200 ft of the Citronelle represents a transitional environment from an estuary to a marsh, the area became crisscrossed by many braided coalescing streams upon subaerial exposure, and rising and lowering of sea level was characteristic of this region during the Pliocene.

Coe (1979) identified rutile, tourmaline, zircon, and muscovite that had weathered to illite, staurolite, sillimanite, kyanite, and ilmenite, which shows signs of weathering to leucoxene. He observed that, in general, these minerals do not show any significant intrastratal solution features and constitute 1 to 2 percent of the sands by weight. Over 50 percent of the heavy-mineral assemblage is composed of kyanite, sillimanite, staurolite, and ilmenite, and the abundance of these minerals remains relatively constant within the upper 200 ft of the Citronelle. The heavy minerals are angular to subangular; the tourmaline retains its idiomorphic form, and the rutile crystals show very little rounding. The only mineral in the assemblage that is an exception is zircon, in which the crystals are rounded to subangular. It is possible that some of the well-rounded zircons have their original shapes or have been reworked from previously deposited sediments; Coe suggested that the reworking of the zircons is only minor. The abundance of kyanite, sillimanite, and staurolite indicates that the source rocks for these sediments were high-rank metamorphic rocks. Samples collected from rad anomalies in the Citronelle (table 6) contain heavy-mineral assemblages consistent with those reported by previous investigators. None of the samples collected for this study contain heavy-mineral assemblages that compare qualitatively or quantitatively with the assemblage found in presently mined deposits in northeastern Florida.

It is probable that dense grid drilling of the Citronelle in northwestern Florida may show higher absolute concentrations of heavy minerals in sandy facies; however, the rapid horizontal and vertical facies changes, as noted above, limit the probability of defining sizable ore bodies.

Reworking of Citronelle heavy minerals into younger Coastal Plain sediments and into offshore sands may have produced possibly economically attractive heavy-mineral assemblages.

Rad anomalies associated with the Citronelle are extensive and of relatively high intensity, particularly

TABLE 6.—*Sieve and heavy-mineral analyses of samples from aeroradiometrically anomalous localities in the Citronelle Formation*

[P—present (<1.0 percent), ND—none determined]

							Weight percent of S.G.>2.85 fraction																			
Sample number	Thickness sampled (ft)	Latitude (N.) Longitude (W.)	Gravel (weight percent)	Sand (weight percent)	Mud (weight percent)	S.G.>2.85 (weight percent)	Epidote	Altered ilmenite	Amphibole	Staurolite	Sulfide	Garnet	Magnetite	Sillimanite and kyanite	Glauconite	Monazite	Rutile	Leucoxene	Mica	Tourmaline	Zircon	Phosphate	Limonite, goethite, and hematite	Sphene	Clayballs	Unidentified opaques
008	Grab --	30°30′30″ 87°20′45″	0.00	100.00	0.00	0.81	P	10	1	7	ND	ND	2	29	ND	11	6	6	ND	20	8	ND	P	P	ND	ND
011	0–1.5	30°44′30″ 87°21′45″	47.49	47.19	5.32	0.42	ND	P	ND	7	ND	ND	1	15	ND	P	11	4	ND	8	6	ND	41	ND	ND	7
012	Grab --	30°59′00″ 87°33′45″	---	---	---	---	Limonite pebbles																			
013	-- do --	30°59′00″ 87°33′45″	---	---	---	---	1	39	ND	7	ND	ND	P	10	ND	1	11	2	P	4	24	ND	P	ND	ND	1
015	0–6	30°55′30″ 87°13′00″	7.65	91.21	1.14	0.30	ND	P	ND	14	ND	ND	P	27	ND	P	8	3	ND	6	5	ND	ND	ND	ND	37
016	0–2	30°55′30″ 87°13′00″	0.41	96.87	2.72	2.24	ND	P	ND	5	ND	ND	ND	16	ND	1	9	3	P	1	15	ND	ND	ND	ND	50
017	0–2	30°40′00″ 86°58′30″	0.64	90.54	8.82	0.18	ND	9	ND	11	ND	ND	2	27	ND	P	14	4	ND	14	5	ND	P	ND	P	14
017	2–4	30°40′00″ 86°58′30″	0.97	93.84	5.19	0.22	ND	6	ND	14	ND	ND	P	41	ND	P	12	2	ND	8	3	ND	1	ND	ND	13
018	Grab --	30°44′00″ 86°53′45″	0.19	96.56	3.25	12.57	Limonite, mica, magnetite																			
019	Grab --	30°43′30″ 86°53′00″	2.72	96.68	0.60	6.43	ND	13	ND	10	ND	ND	P	17	ND	1	9	9	ND	17	24	ND	ND	ND	ND	ND
020	0–6	30°55′00″ 86°54′30″	0.70	94.47	4.93	0.14	ND	7	ND	24	ND	ND	ND	15	ND	ND	10	P	ND	18	5	ND	P	ND	21	ND
075	0–2	30°59′00″ 87°10′00″	0.00	5.43	94.57	0.12	P	15	ND	15	ND	ND	P	15	ND	P	10	20	ND	12	10	ND	ND	ND	3	ND
076	0–1	30°48′45″ 86°41′30″	5.83	86.62	7.55	0.37	ND	3	P	4	ND	ND	P	32	ND	P	12	9	ND	9	9	ND	22	ND	ND	ND
077	0–1	30°48′45″ 86°41′30″	6.34	86.91	6.75	0.36	ND	3	P	3	ND	ND	P	29	ND	P	13	10	ND	9	8	ND	25	ND	ND	ND
078	0–1	30°48′45″ 86°41′30″	5.75	87.30	6.93	0.34	ND	2	P	4	ND	ND	P	31	ND	P	9	10	ND	9	9	ND	24	ND	ND	ND

in areas where the surficially exposed materials are clayey or rich in hydrous ferric oxide (limonite) gravels, although these sediments have very low radioactive heavy-mineral contents. A possible explanation for these rad anomalies is that clayey material normally contains potassium-40 in clay minerals, such as muscovite, biotite, and illite, and uranium-series nuclides adsorbed on clay minerals; hence, areas where clay is common should be anomalous with respect to sandy terranes. Similarly, adsorption of radioactive nuclides onto hydrous ferric oxides may be the cause of rad anomalies in gravelly terranes.

THE PHOSPHATE ANOMALIES

FLORIDA PHOSPHATE DEPOSITS

Rad anomalies associated with phosphate deposits in Florida have five general modes of occurrence—hardrock, river-pebble, and land-pebble deposits; abandoned and unreclaimed mines or pits; and currently operating mines (pl. 2).

From the time of their discovery, the phosphate deposits of Florida have been classified into hardrock, river-pebble, and land-pebble types. To these, a fourth type should be added—marine phosphorite, deposited in the Hawthorn Formation. Although this last type has been included as a part of the land-pebble type, either directly or by implication, it differs from it in that no enrichment or concentration has occurred.

The phosphate mineral in the Florida deposits is a carbonate fluorapatite. The primary apatite is microcrystalline (no crystal form can be seen at 1,000 diameters magnification), the secondary apatite of the hardrock is much more coarsely crystalline, and the most coarsely crystalline material is wavellite that grows into open spaces at surficial temperature and pressure.

The rad anomalies are caused by radioactivity of uranium that is within the structure or adsorbed onto the apatite mineral.

URANIUM IN PHOSPHATE ROCKS

All apatites contain uranium as a trace constituent in amounts that typically range from 0.001 to 0.030 percent (10–300 ppm). The apatite mineral in marine phosphorite deposits normally contains from 0.005 to 0.030 percent (50–300 ppm) uranium, although individual samples may contain up to 0.5 percent (5,000 ppm).

Uranium is associated with the apatite mineral as U (IV) replacing calcium in the apatite structure (Altschuler and others, 1958) or is adsorbed as the uranyl ion to the apatite crystal surface (Sheldon, 1959).

The uranium in marine phosphorite deposits has been shown to be syngenetic (Cathcart, 1978), and the extremely small amounts of uranium in sea water probably accounts for the low, uniform content of uranium in one-cycle marine phosphorites, which contain from about 0.006 to 0.008 percent (60–80 ppm).

Uranium is leached readily from apatite during weathering; under acid conditions, apatite is dissolved, and uranium is released. Uranium in solution, however, is taken up readily by apatitic bones, concretions, pebbles, and pellets, where it may be strongly enriched. Uranium contents of replacement deposits generally range from 0.001 and 0.017 percent (10–170 ppm), but preferential enrichment in uranium may occur and contents of as much as 0.1 percent (1,000 ppm) have been noted (Altschuler and others, 1958).

Weathering of sandy phosphorites produces zones of porous, light-weight, light-colored rocks that contain aluminum phosphate minerals. The deposits are characterized by the change from apatite to crandallite and wavellite and a change of the original clay minerals to kaolinite. Uranium is enriched in these deposits and is associated with the phosphate minerals, either apatite or the calcium aluminum phosphate minerals, crandallite and millisite.

HARDROCK DEPOSITS

The hardrock phosphate deposits occur in a northwest-southeast-trending belt that, according to W. L. Akin (*in* Mansfield, 1942), extends from the northern part of Pasco County to Suwanee County and an outlying area (the Steinhatchee district) in Lafayette County (pl. 1) approximately in the position of the crest of the Ocala Uplift. G. H. Eldridge (map, *in* Day, 1892) showed the hardrock district to be continuous through the Steinhatchee district almost to Tallahassee. Akin (*in* Mansfield, 1942) pointed out that his outline encompassed the known hardrock mines and also those areas where prospecting showed the presence of phosphate. He further pointed out that only about 10 percent of the area enclosed within the lines is underlain by phosphate. A phosphate occurrence reported near the town of Eridu in northwestern Taylor County (Zellars-Williams, Inc., 1978) is probably of the hardrock type, so it is possible that the hardrock district should be extended to include the occurrences in Taylor and Lafayette Counties.

Espenshade and Spencer (1963) reported that samples of secondary hardrock phosphate contain from 0.003 to 0.011 percent (30–110 ppm) uranium. The slime fraction (-150 mesh) contains from 0.004 to 0.008 percent (40–80 ppm) uranium. The slime fraction of the upper clayey sands of the hardrock district contains an average of about 0.01 percent (100 ppm) uranium (hence the intensity of anomalies) in what are probably aluminum and calcium aluminum phosphate minerals.

Crandallite and millisite, along with wavellite, are common in the altered (weathered) materials. Samples of secondary hardrock phosphate that are not weathered are characterized by a very high content of apatite and only minor amounts of diluting materials. The apatite mineral is a carbonate fluorapatite but is close to the fluorapatite end of the series.

The hardrock phosphate deposits were mined by open pit methods—first by pick and shovel and later by dredge or small dragline. Because most of the mines were abandoned many years ago, they have not been reclaimed, and the phosphate that remains in the pits is exposed; consequently, the old open pits show distinct rad anomalies.

The hardrock deposits are small and erratic in distribution, and some are sinuous in plan. The latter are evidently old river channels.

The hardrock deposits are in the Alachua Formation of post middle Miocene age, which rests on the eroded surfaces of the Ocala Limestone, the Suwannee Limestone, and the Tampa Formation. The Alachua Formation is, in part, the nonmarine equivalent of the Bone Valley Formation and consists of the collapsed and partly reworked residue of the Hawthorn and younger formations. As such, this unit is only locally recognizable as a geologic formation. The hardrock deposits occur in the lower part of the Alachua (Vernon, 1951). The phosphate occurs as detrital pebbles or pellets, phosphatized carbonate fragments of various sizes, and irregular masses and plates of precipitated phosphate in a matrix of quartz sand, clay, and fine-grained phosphate clay. Secondary chert, silicified limestone, and limestone fragments are also present. The surficial parts of the Alachua have been altered by weathering, and the apatite has been altered to aluminum phosphate minerals.

The hardrock phosphate deposits are complex in their origin, most probably derived from pebbles and pellets originally deposited in the Hawthorn Formation. Phosphate from these pellets, taken into solution by ground water, moves downward and is precipitated at the change in pH at the surface of the underlying carbonate rock. The phosphate may replace the carbonate rock or may form a crust on the surface of the carbonate rock. Secondary hardrock phosphate is reworked as particles from fine sand to boulder size into younger formations. Boulder-sized pieces have been called lump rock or plate rock, depending on their textures.

Erosion, following or during the weathering, moved pellets and pebbles of apatite and pieces of clayey or dolomitic and phosphatic material, so the reworked hardrock deposits contain secondary apatite fragments and rounded, primary fragments. Recent drilling in the eastern part of the Ocala National Forest showed that surficial materials (Pleistocene and Holocene) contain mixtures of unweathered phosphatic dolomite grains and phosphate pellets derived from the Hawthorn and some wavellite and kaolinite (products of weathering).

Hardrock phosphate may be lamellar (precipitated phosphate, fig. 5), massive (structureless replacement of carbonate rock, fig. 6), or breccia (phosphatized carbonate rock broken by weathering and erosion and recemented by apatite, fig. 7).

LAMELLAR

This rock consists of irregular, subparallel, dense, white bands that range in thickness from about 0.8 to 2.5 millimeters and open spaces that are about the same thickness (fig. 5). The open spaces are lined with laminae that are botryoidal in texture and are composed of crystalline apatite. In thin section, the bands show extinction crosses, and the apparently dense white bands are composed of small round "balls" that have dense microcrystalline centers and thin crusts of more crystalline apatite; that is, they are oolitic. The dense centers may represent a replacement of carbonate by apatite, and the outer laminae, a precipitation of apatite along the voids. The apatite mineral is very close to a fluorapatite in its X-ray pattern.

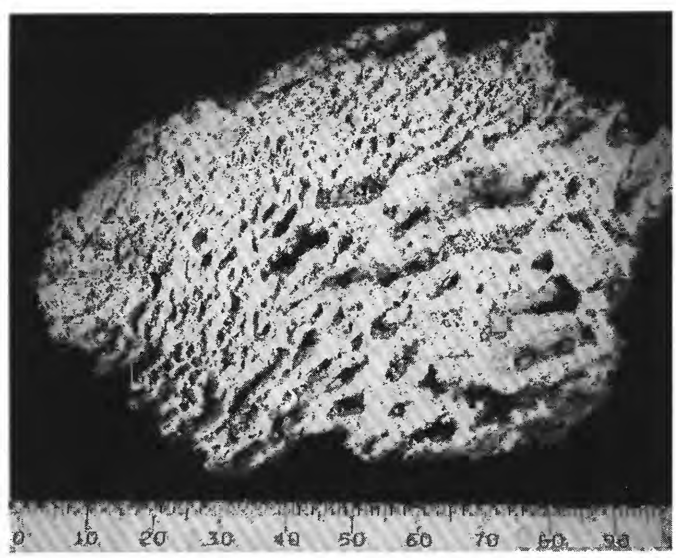

FIGURE 5.—Cut slab of lamellar hardrock phosphate. The sample was taken from locality 047, an abandoned open pit mine a few miles southeast of Dunnellen. X-ray diffraction shows that the rock contains major apatite, minor quartz, and a trace of muscovite.

MASSIVE

This rock is white, dense, and structureless (fig. 6). The sample was taken at the surface, and the right side of the sample in the photograph is coarsely porous. Thin section of the rock shows that, in the porous area, the open spaces are lined with very fine crystalline apatite and crandallite. X-ray data show that the sample contains major apatite, minor quartz, and a trace of the aluminum phosphate mineral, crandallite. The apatite mineral is very close to a fluorapatite, as in the sample of lamellar rock.

BRECCIA

The rock consists of dense, white, angular fragments of replaced carbonate rock and fragments of lamellar rock cemented by secondary apatite (fig. 7). X-ray data show that the rock contains apatite, minor quartz, and a trace of crandallite—nearly an identical pattern to the massive type from the same locality. The apatite mineral is close to fluorapatite. Evidently, this rock formed by replacement of carbonate rock by phosphate, then the breaking up of the phosphatic rock by erosion, and finally recementing by apatite. As in the other rocks, the dense parts are cryptocrystalline under the microscope, but the second apatite precipitation is of a more coarsely crystalline material than that which lines the open spaces in the rock.

In addition to the samples of hardrock phosphate taken at locality 050, a sample of lightweight, porous, light-colored rock was taken from a section closer to the surface. This rock is composed of wavellite, crandallite, quartz, minor kaolinite, and virtually no apatite. In thin section, the rock is composed of rounded quartz grains cemented by very dense crandallite and a feltwork of wavellite needles (fig. 8). This rock is derived from apatitic quartz sands above the typical hardrock phosphate by subaerial weathering. The sample is from the upper part of the section, possibly from the upper part of the Alachua.

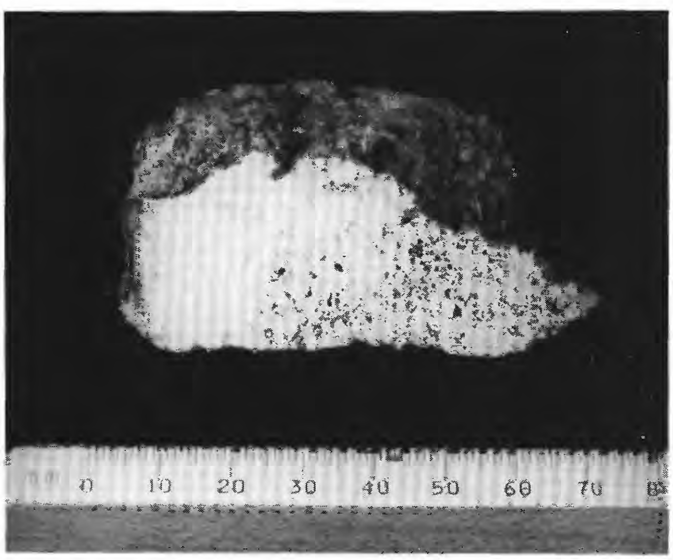

FIGURE 6.—Cut slab of massive hardrock phosphate. The sample was taken from locality 050, an open pit mine near Dunnellen. X-ray diffraction shows that the sample contains major apatite, minor quartz, and a trace of crandallite.

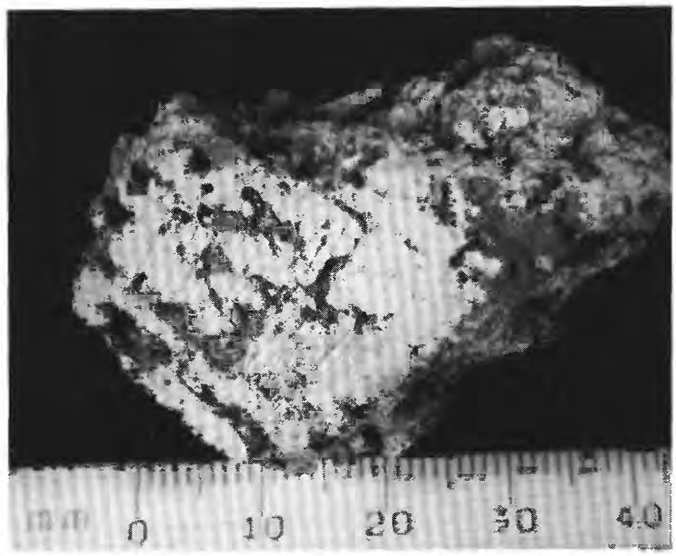

FIGURE 7.—Cut slab of breccia hardrock phosphate. The sample was taken from locality 050, an open pit mine near Dunnellen. X-ray diffraction shows that the sample contains major apatite, minor quartz, and a trace of crandallite.

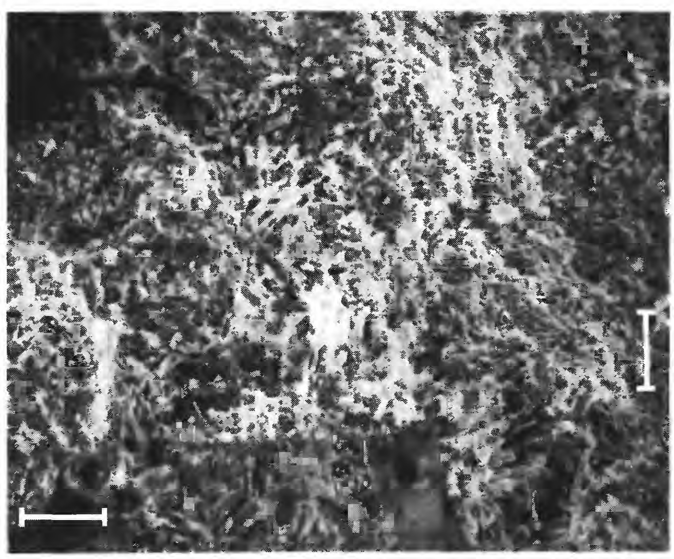

FIGURE 8.—Sample from locality 050, an open pit mine near Dunnellen. The photograph shows a dense feltwork of fine-grained wavellite needles. The length of the bar is 14.3 micrometers. Xray diffraction shows that the sample contains major wavellite and quartz and minor crandallite, millisite, and kaolinite.

Resources of hardrock phosphate are very difficult to estimate. Mansfield (1942) based his estimate of about 1 billion short tons on data from the prospecting of W. L. Akin. Espenshade and Spencer (1963) thought that Mansfield's estimate was excessive, although they did not give a number for resources. It seems likely that large resources (perhaps hundreds of millions of tons) are present in the hardrock phosphate belt but in small, scattered deposits, and it is impossible at this time to make an adequate estimate of the tonnage.

Rad anomalies attributable to hardrock phosphate are within the limits of one of the hardrock belts, and many are within the outcrop limits of the Alachua (pl. 1). Some of the anomalies may be associated with outcrops of the Hawthorn; however, many are on or adjacent to inactive hardrock pits and can be assigned confidently to hardrock phosphate. Anomalies assigned to hardrock phosphate that are present in the Gainesville and the Plant City 1° x 2° Quadrangles are listed in table 7; none are known to be in the Valdosta Quadrangle, although a hardrock-type deposit was mined near Boston, Thomas County, Ga., just north of the Florida State line. It is, therefore, possible that hardrock-type deposits may be present in the Valdosta Quadrangle.

The secondary hardrock phosphate types (figs. 6–8), which are high in phosphate content, contain relatively coarsely crystalline apatite, as indicated by very sharp, clear X-ray patterns. Relative coarseness also is shown in figure 9, a SEM photograph of a sample from anomaly 47. X-ray data for this sample show only apatite and minor quartz. The crystal size ranges from 0.5 to about 3 micrometers (μm).

Screen and mineralogic analyses of hardrock samples are given in table 8.

THE HAWTHORN FORMATION

The Hawthorn Formation, which is of lower and middle Miocene Age, consists of carbonate rock (mostly dolomite and some limestone), sand, clay, and combinations of these lithologies. The formation is characterized by varying amounts of phosphate pellets and pebbles; none of the older formations in Florida contain phosphate.

The Hawthorn may be divided into an upper, dominantly clastic unit and a lower, dominantly carbonate unit. The clastic unit generally contains more phosphate than the carbonate unit, and some beds in the clastic unit are phosphorites. Younger formations of late Miocene, Pliocene, and Pleistocene or Holocene ages do contain phosphate, but most of this phosphate has been derived by reworking from the Hawthorn.

The first phosphate deposits found in Florida were in the Hawthorn. According to Day (1886, p. 452), a mining pit or quarry near Hawthorn, Fla., was located by Dr. C. A. Simmons. Dr. Simmons began mining the rock and using it as a fertilizer in 1879, but the mining was discontinued sometime before 1885.

The Hawthorn extended across the Ocala Uplift but probably was thinned over the crest of the uplift, which started to rise in the early Miocene (Cooke, 1945; Vernon, 1951). In the area of the crest of the Ocala Uplift, the Hawthorn is present today only as erosional remnants of phosphatic rocks.

In many places, the only remnants of the Hawthorn are outcrops of quartz sand cemented by aluminum phosphate minerals and clay. A sample from locality 040 contains quartz, wavellite, and minor kaolinite. A SEM photograph of this sample (fig. 10) shows the development of radiating crystals of wavellite. The wavellite crystals range from about 1 to 10 μm wide and from 5 to 60 μm long. This crystalline material is found only in open spaces in the rock and in surface exposures.

Another sample (052) also contains major quartz and wavellite and minor kaolinite. A SEM photograph of the sample (fig. 11) is of interest because of the siliceous diatoms shown. Some kaolinite and wavellite also are visible in the photograph.

A sample from anomaly G24 contains 0.019 percent (190 ppm) uranium (Cathcart, 1954). Several holes were drilled in the area of the series of anomalies to the south of the city of Ocala. These holes ranged from a total depth of 7 to 71 ft and bottomed on carbonate rock; the surface of the underlying Ocala Limestone is very irregular. In general, the thickness of the Hawthorn increases from a feather edge on the crest of the Ocala Uplift, where the Ocala outcrops, to several tens of feet to the east, at the eastern edge of the Ocala National Forest.

Figure 12 shows the relations of the hardrock deposits and the phosphate of the Hawthorn. Anomaly G10 is an abandoned hardrock mine (Espenshade and Spencer, 1963). At this mine, the Hawthorn is not present, and the Ocala Limestone is overlain by a rubble zone of hard and soft secondary phosphate from 5 to 15 ft thick. This zone, in turn, is overlain by sand and phosphate pellets that extend to the surface. It is likely that the phosphatic sediments above the Ocala represent the post middle Miocene. The lower part probably is hardrock phosphate reworked into younger beds, possibly upper Miocene as indicated by Espenshade and Spencer (1963). The overlying sand and some pelletal phosphate may be Pleistocene or Holocene in which the phosphate has been reworked from unaltered Hawthorn at higher elevations to the east and north.

TABLE 7.—*Hardrock-phosphate-related aeroradiometric anomalies*

Anomaly number	Latitude (N.) Longitude (W.)	Counts per second (rad)	Age	Elevation (ft)	Comments
			Gainesville Quadrangle		
G4	29°03′ 82°28′	300	Post-Miocene	60	Alachua Formation on Ocala Limestone, at mine.
G5	29°56′ 82°44′	75	?	50	Could be radioactive road material.
G6	29°47′ 82°40′	200	Post-Miocene	60	Alachua Formation on Ocala Limestone, at mine.
G7	29°41′ 82°41′	200	do	80	Do.
G8	29°29′ 82°33′	200	do	100+	Do.
G9	29°29′ 82°29′	150	do	75	Do.
G10	29°19′ 82°23′	225	do	70	Alachua and Hawthorn Formations on Ocala Limestone.
G11	29°19′ 82°09′	175	Middle Miocene and post-Miocene.	100	Mines nearby.
G12	29°19′ 82°07′	275	do	100	Do.
G13	29°20′ 82°06′	275	do	90	Do.
G14	29°13′ 82°18′	200	do	90	Alachua and Hawthorn Formations on Ocala Limestone, no mine.
G15	29°13′ 82°20′	200	do	65	Alachua and Hawthorn Formations on Ocala Limestone, mine.
G16	29°16′ 82°23′	225	do	75	Alachua and Hawthorn Formations on Ocala Limestone, no mine.
G17	29°13′ 82°22′	300	Post-Miocene	60	Alachua Formation on Ocala Limestone, mine.
G18	29°09′ 82°23′	175	do	75	Alachua Formation on Ocala Limestone, no mine.
G19	29°07′ 82°27′	175	do	100	Do.
G20	29°01′ 82°26′	300	do	100	Alachua Formation on Ocala Limestone, mine, sample 047A, B.
G21	29°03′ 82°20′	100+	do	60	Alachua Formation on Ocala Limestone, no mine.
			Plant City Quadrangle		
PC1	28°59′ 82°24′	250	Post-middle Miocene	75	Alachua Formation on Ocala Limestone, mine, sample 002.
PC2	28°55′ 82°23′	400	do	50	Alachua Formation on Ocala Limestone, samples 049, 050.
PC3	28°49′ 82°21′	250	do	75	Alachua Formation on Ocala Limestone, no mine.
PC4	28°42′ 82°22′	200	Middle Miocene	125	Hawthorn Formation on Ocala Limestone, clay? mine.
PC5	28°45′ 82°18′	175	Post-middle Miocene	50	Alachua Formation on Ocala Limestone, mine.
PC6	28°43′ 82°18′	250	do	50	Do.
PC7	28°41′ 82°18′	150	do	50	Do.
PC8	28°37′ 82°17′	175	do	75	Alachua Formation on Suwanee Limestone, no mine.
PC9	28°34′ 82°14′	325	do	95	Do.
PC10	28°30′ 82°17′	175	do	100	Alachua and Hawthorn Formations on Ocala Limestone, no mine.
PC11	28°30′ 82°16′	225	do	100	Do.
PC12	28°31′ 82°14′	200	do	105	Alachua Formation on Suwanee Limestone, no mine.
PC13	28°28′ 82°15′	175	do	100	Alachua and Hawthorn Formations on Suwanee Limestone, no mine.

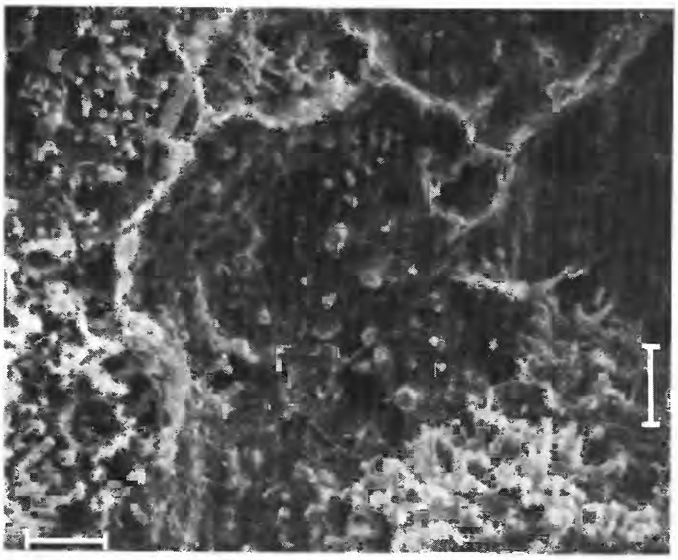

FIGURE 9.—Sample from locality 047. The photograph shows hexagonal apatite crystals that range in size from 0.5 to 5.0 micrometers in a very dense microcrystalline groundmass. The length of the bar is 10 micrometers.

Locality 044 was drilled on a rad anomaly. A very thin veneer of Pleistocene or Holocene sand is found at the surface. A gray-brown clayey sand from 2.5 to 8 ft below the surface is highly radioactive. It is underlain by a light-gray to blue-green clay containing phosphate, and, at 16 ft below the surface, the rock is too hard to penetrate. The blue-green clay and phosphate is a typical Hawthorn lithology, and the underlying hard material may be dolomite of the Hawthorn or limestone of the Ocala. A grab sample of the rock from 6 to 16 ft contains 0.013 percent (130 ppm) uranium. The highly radioactive material from 2½ to 8 ft is a leached residue of the underlying blue-green clay.

The location in section 13, T. 16 S., R. 26 E., is a drill hole. The upper 48 ft consist of an orange, tan, and white sand and clayey sand that may represent Pleistocene and Holocene. It is underlain by 19½ ft of dark-gray to black sandy clay or clayey sand containing abundant shell fragments and some phosphate. The base of this section is a pebbly sand of black phosphate and pea-sized quartz grains. The shell material has decomposed and shatters on exposure to air. This unit is thought to be late Miocene in age; the phosphate a lag gravel derived from the erosion of the underlying Hawthorn. The Hawthorn that underlies this gravel bed consists of an upper unit about 33 ft thick, composed of gray- and blue-green sandy clay and clayey sand containing abundant phosphate pellets and nodules. The clay-sized fraction is dolomitic. The lower unit of the Hawthorn is a hard dolomite containing phosphate pellets and pebbles, quartz sand, and some clay. The unit is about 48 ft thick. The hole bottomed on white limestone of the Ocala.

The surficial sand of post-Miocene age contains sparse pellets of shiny phosphate and grains of dolomite containing fine-grained phosphate pellets of the Hawthorn. These pellets must have been eroded from the Hawthorn on the Ocala Uplift and must have been carried by water into these sands. The mineralogy of these surficial sands is a mixture of material from unweathered Hawthorn and thoroughly leached and weathered material. Samples contain apatite, dolomite, attapulgite, and montmorillonite, typical of unweathered Hawthorn dolomite, and kaolinite, quartz, and the aluminum phosphate mineral, wavellite. One sample also contained some gibbsite—an ultimate product of lateritic weathering. It is likely that weathering of the Hawthorn produced the thoroughly leached material and that erosion removed this material and also broke up and moved unweathered material, which were deposited in the surficial Pleistocene and Holocene sands. Screen and mineralogic analyses of Hawthorn samples are given in table 9.

PHOSPHATE AND URANIUM IN THE HAWTHORN FORMATION

In recent years, much prospecting for phosphate has been done in the Hawthorn Formation in northern Florida. Almost all the prospecting has been done by phosphate companies, and, therefore, detailed data on the chemistry of the rocks are not available. Data on uranium contents of surface and drill hole samples are given by Espenshade and Spencer (1963). For the total rock, uranium contents range from 0.001 to 0.022 percent (10–220 ppm). In samples of separated phosphate particles (pebble and concentrate), uranium ranges from 0.003 to 0.040 percent (30–400 ppm). Weathered samples at the surface or from shallow drilling are higher in uranium than are the deeper samples that have not been weathered. Fresh samples of the phosphate particles contain about 0.006 percent (60 ppm) uranium. Scattered, sparse data on uranium contents from southern Florida indicates that the phosphate particles may average about 0.006 percent (60 ppm).

Many geographically small anomalies can be assigned confidently to outcrops of the Hawthorn on the Gainesville and the Valdosta Quadrangles (table 10). The anomalies occur in a belt that starts to the south of Ocala and extends to the northwest to the town of Live Oak. The anomalies occur in this belt because it is along the edge of the Ocala Uplift, where Pleistocene and Holocene sands are thin. The surficial sands thicken to the east, where they are tens of feet thick (fig. 12). Although abundant phosphate occurs in the deeply buried Hawthorn, no anomalous radioactivity can be

TABLE 8.—*Screen and mineralogic analyses of hardrock phosphate samples*

Sample Number	Description	Mesh size	Weight percentage	Mineralogy	Comments
047A	"Slime" from old phosphate operation—grab sample. Anomaly G20. Yellow-gray, dense, clayey material. X-ray—Head sample: Major quartz, kaolinite, crandallite, minor apatite, muscovite, montmorillonite.	+20	0.1	White, dense phosphate fragments, some quartz. X-ray: quartz, apatite, wavellite.	The data indicate that this is a "slime" fraction from the old mining operation, where both leached and unleached material was treated in the plant. Note that both weathered and unweathered material is present.
		-20+200			
		Conc - - -	0.3	White, dense phosphate.	
		Tail - - - -	20.0	Quartz, some phosphate fragments.	
		-200	79.6	Yellow-gray powder. X-ray: kaolinite, quartz, crandallite, apatite, wavellite, montmorillonite.	
047B	Grab samples of hardrock phosphate from old mine pit. Anomaly G20.			A. White, soft, dense phosphate. X-ray: apatite, trace quartz. B. (outer rind) Dense, hard white phosphate. X-ray: apatite, quartz. C. Breccia ore, see figure 4. X-ray: apatite, trace quartz. D. Lamellar ore, see figure 2. X-ray: apatite, trace quartz.	The apatite patterns for all samples are identical. The mineral is a carbonate fluorapatite, but is close to the fluorapatite end of the series, and the very sharp X-ray pattern indicates relatively coarse crystallinity.
002	"Ore" sample from Buttgenbach mine. Anomaly PC1. White clayey sand, contains white, angular, laminated phosphate crusts.	+10	4.6	X-ray: crandallite, millisite, quartz, kaolinite.	The sample is thoroughly leached. The clay mineral is kaolinite, the phosphate minerals are entirely aluminum calcium phosphates, and there is no apatite. Trace amounts of wavellite were noted in one X-ray pattern. This is not a sample of the ore but is of the leached zone derived from the ore.
		-10+20		X-ray: crandallite, millisite, quartz, kaolinite.	
		-20+200			
		Conc - - -		X-ray: crandallite, millisite, quartz, kaolinite.	
		Tail - - - -		Quartz grains, some fragments of dull-white aluminum phosphate.	
		-200		X-ray: quartz, crandallite, kaolinite, millisite.	
049	0.5-m channel sample in phosphate pit. Anomaly P2. Light-yellow-brown sandy clay containing abundant irregular, subangular fragments of brown-red and dull-white phosphate.	+10	28.4	X-ray: apatite, minor quartz, goethite.	The clay sized material (slime) of this sample is almost entirely apatite. This size fraction, during processing became what was called soft phosphate or colloidal phosphate. It was used as a fertilizer filler, and some small tonnage is still being used this way. The apatite mineral is a carbonate fluorapatite, but close to the fluorapatite end. X-ray pattern is very sharp.
		-10+20	7.1	X-ray: apatite, minor quartz, goethite.	
		-20+200			
		Conc - - -	8.6	X-ray: apatite, minor quartz, goethite.	
		Tail - - - -	5.5	Quartz grains, some white apatite fragments and minor iron oxide.	
		-200	50.4	X-ray: apatite, minor montmorillonite, trace quartz.	
050	Grab samples from abandoned mine pit. Anomaly P2.			A. White-cream to light-yellow, massive, dense to coarsely porous, almost a "boxwork" texture at the surface of the sample (see fig. 4). X-ray: major apatite, minor quartz, trace crandallite. B. White, dull, clayey quartz sand. Leached. Coarse secondary porosity. X-ray: quartz, crandallite, wavellite, kaolinite. C. Secondary silica precipitate. White to light-yellow, slightly clayey sand. Secondary "vesicular" texture, fine-grained quartz crystals line the open spaces in the rock. X-ray: major quartz, trace apatite.	The apatite mineral is a carbonate fluorapatite, but is close to the fluorapatite end of the series. There is very little CO_3 substitution in the apatite structure. The sharp, clear X-ray pattern indicates fairly coarse crystallinity. Thin section: dense, massive "isotropic". Open spaces are lined with relatively coarsely crystalline apatite that shows a clear extinction cross. This is a typical sample of leached phosphate rock.

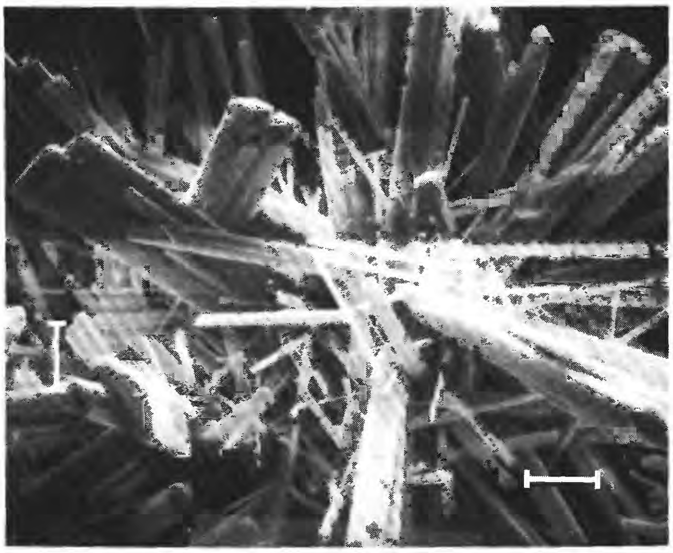

FIGURE 10.—Sample from locality 040. The photograph shows radiating needles of wavellite. The length of the bar is 10 micrometers. X-ray diffraction shows that the sample consists of major quartz and wavellite and minor kaolinite.

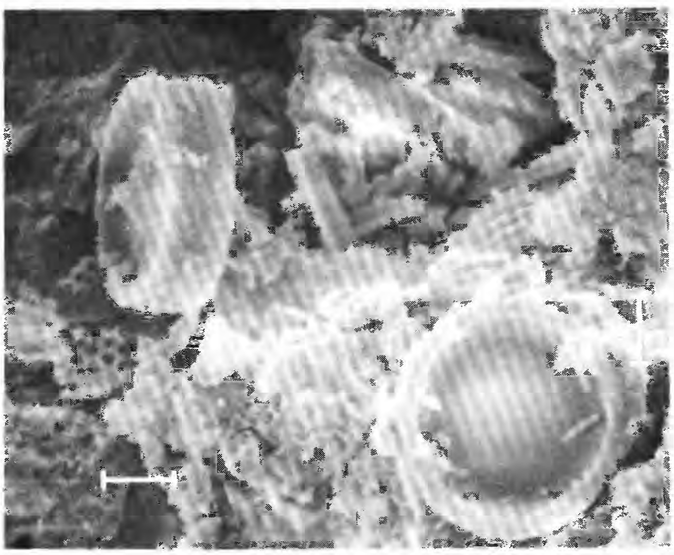

FIGURE 11.—Sample from locality 052. The photograph shows siliceous diatoms and fossil fragments, wavellite crystals, and irregular formless kaolinite. The length of the bar is 10 micrometers. X-ray diffraction shows that the rock consists of major quartz and wavellite, minor kaolinite, and a trace of crandallite.

detected at the surface. The Hawthorn outcrops around the Ocala Uplift and is present in the subsurface throughout most of peninsular Florida to the east and north of the outcrop of the Ocala and the Suwannee Limestones.

Resources of phosphate in the Hawthorn total billions of tons; minable reserves are much less but still form significant tonnage of phosphate.

LAND-PEBBLE DEPOSITS

The land-pebble phosphate deposits of Florida occur within the Hawthorn and younger formations (Bone Valley Formation and equivalents and Pleistocene and Holocene sediments), where much of the phosphate was reworked from the Hawthorn. The land-pebble deposits were first mined adjacent to the Peace and the Alafia Rivers in Polk and Hillsborough Counties (south of the study area) as an extension into the land from river-pebble mines; hence the name "land-pebble." Deposits in Hamilton County in northern Florida are stratigraphically and lithologically similar to the deposits in Polk and Hillsborough Counties; the deposit in Alachua County, described by Pirkle (1956), is also of the same type.

The reworking, enrichment, and concentration make the land-pebble deposits characteristically higher in uranium than in unaltered phosphate in the Hawthorn.

The only rad anomaly confirmed as a result of a land-pebble-type deposit is that in Hamilton County (V9). The very strong anomalies at this locality are over open pit mines of the Suwannee River and the Swift Creek Mines (table 11) of the Occidental Chemical Company. The section in table 11 is typical of the mine area, except that the top bed sampled (10–14 ft) contains more abundant coarse phosphate at many places.

The anomalies to the northwest of Gainesville in Alachua County, which are thought to be Hawthorn anomalies, may be land-pebble types, and the anomalies to the southwest of Lake City, also thought to be Hawthorn, may be, in part, of the land-pebble type. The difference between land-pebble and Hawthorn anomalies is a difference in degree, rather than in kind—the two types grade into one another. Both anomalies are caused by radioactivity of uranium that is within the structure of or absorbed onto the apatite mineral.

A SEM photograph of a phosphate pellet from the Swift Creek Mine in Hamilton County is shown in figure 13. The pellet is very dense and extremely fine grained. The somewhat equant particles that make up the pellet can be imagined to be hexagonal in shape and may represent finely crystalline apatite. The size of the particles is about 0.5 μm or less.

RIVER-PEBBLE DEPOSITS

River-pebble deposits of Pleistocene and Holocene age occur as bars in the rivers or in the flood plains of streams that have cut their channels into the phosphatic Hawthorn and Alachua Formations.

As phosphate is leached from the pebbles by acid streams, uranium also is removed, and the river pebble

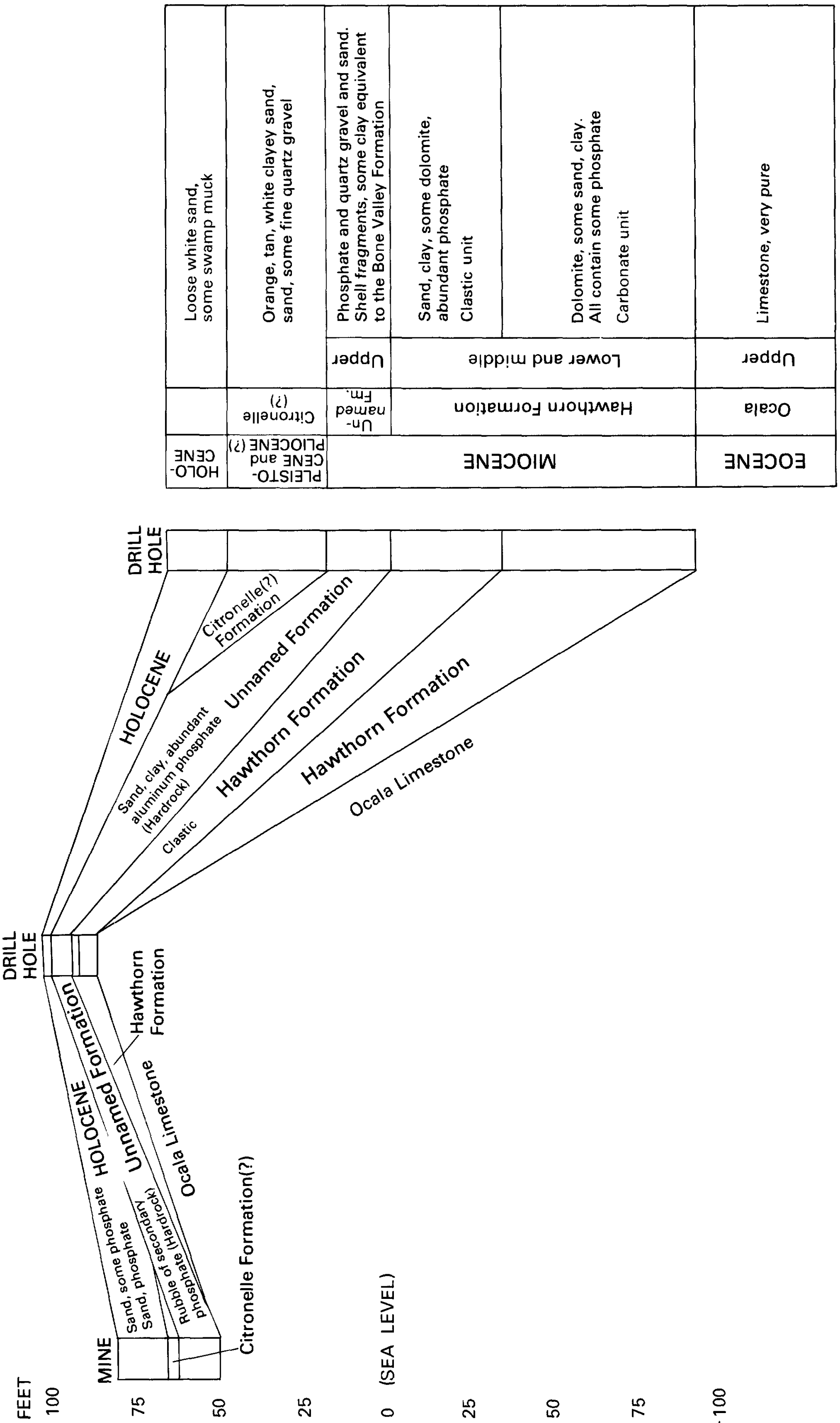

FIGURE 12.—Relations of hardrock phosphate and the Hawthorn Formation.

TABLE 9.—*Screen and mineralogic analyses of phosphate samples from the Hawthorn Formation*

Sample Number	Description	Mesh size	Weight percentage	Mineralogy	Comments
039	1-m channel sample. Anomaly G24. Leached Hawthorn Formation. Tan-brown quartz sand cemented by white aluminum phosphate and clay.	+20	11.2	Vesicular textured brown sandstone fragments. White cement is aluminum phosphate and clay. X-ray: quartz, wavellite, kaolinite, trace crandallite.	
		-20+200			
		Conc ---	Trace -----	Heavy minerals: zircon, sillimanite, rutile, tourmaline, garnet, black opaques.	
		Tail-----	52.5	Quartz grains	
		-200	36.2	Tan powder. X-ray: kaolinite, quartz, wavellite, crandallite, trace goethite.	
AGG-040C	Grab sample from 3-4 ft below surface of road. Anomaly G24.			Fragments of tan-brown sandstone, "vesicular" textured; cavities filled with radiating, clear needles of wavellite. X-ray: quartz, wavellite, trace kaolinite.	SEM photograph (fig. 8) shows the relatively coarsely crystalline wavellite needles.
040	Samples from hand auger drill hole. Anomaly G24.				
0-3 ft	Sand, slightly clayey, brown. Quartz grains are iron stained.	+20	0.9	Fragments of yellow-weathered, phosphatized dolomite, and major quartz. X-ray: quartz, wavellite, minor crandallite, kaolinite, trace apatite.	
		-20+200			
		Conc ---	0.1	Yellow fragments	
		Tail-----	87.0	Iron-stained quartz grains, some clay fragments.	
		-200	12.0	Brown powder. X-ray: quartz, kaolinite, wavellite, crandallite, iron oxide.	
040A					
3-4 ft	Brown-tan clayey sand, fragments of white leached sandstone, cemented by aluminum phosphate and clay.	+20	3.9	Angular fragments of white and rust-brown sandstone. X-ray: minor kaolinite, quartz, wavellite, crandallite.	
		-20+200	0.1	Heavy minerals	
		Conc ---			
		Tail-----	82.2	Iron stained quartz	
		-200	13.8	Brown powder. X-ray: quartz, montmorillonite = kaolinite, muscovite, wavellite, iron oxide.	
4-5 ft	Brown clayey sand, with rounded fragments of phosphate cemented sand.	+20	7.8	Tan-rust and white sandstone fragments, aluminum phosphate and clay cement.	
		-20+200			
		Conc ---	0.3	Heavy minerals.	
		Tail-----	65.3	Yellow-stained quartz	
		-200	26.6	Brown powder. X-ray: wavellite, quartz, montmorillonite, trace crandallite, kaolinite, iron oxide.	

TABLE 9.—*Screen and mineralogic analyses of phosphate samples from the Hawthorn Formation*—Continued

Sample Number	Description	Mesh size	Weight percentage	Mineralogy	Comments
040B	Hand auger samples—on road surface. Anomaly G24.				
1–3 ft	Gray-tan sandy clay, rust mottled. X-ray: quartz, montmorillonite, trace wavellite.	+20	1.3	White, irregular, flat pieces of aluminum-phosphate–cemented sandstone, and white, softer, clayey material. X-ray (cement): quartz, wavellite, montmorillonite.	
		-20+200			
		Conc	0.2	do	
		Tail	32.1	Quartz, some white clay and sandstone fragments	
		-200	66.4	Tan-brown powder. X-ray: montmorillonite, quartz, minor wavellite.	
3–4 ft	Green and red mottled sandy clay. White nodules of phosphate cemented sandstone.	+20	1.0	White clay-cemented sandstone. White crusts of silica. X-ray: trace montmorillonite, quartz and wavellite.	
		-20+200			
		Conc	0.1	Heavy minerals	
		Tail	18.8	Quartz grains	
		-200	80.1	Yellow-brown "clay." X-ray: montmorillonite, quartz, trace wavellite.	
052	Outcrop sample from anomaly G13. Weathered Hawthorn Formation on Ocala Group. Quartz sand cemented by dense white clay-sized material. Vesicular textures. Vesicles are lined with fine-grained wavellite needles. X-ray (of cementing material): wavellite, crandallite, quartz, kaolinite.				
			Other Samples		
046	Gulf Hammock T. 15 S., R. 16 E. Levy County 6-to 8-in. auger sample. Red-brown clayey sand.	+20	4.0	Yellow limestone pellets and red-brown iron pellets. X-ray (yellow): calcite. X-ray (red): goethite, quartz, trace calcite, clay (kaolinite?).	
		-20+200			
		Conc	0.4	Red-brown iron concretions, some heavy minerals.	
		Tail	57.7	Quartz, calcite	
		-200	37.9	Dark brown powder. X-ray: quartz, calcite, kaolinite, goethite, montmorillonite.	
JBC–8–79	Clayey sand, 1.0-ft thick, resting on Avon Park Limestone. Dark-brown clayey sand containing small fragments of yellow carbonate rock.	+20	10.8	Limestone fragments and red-brown iron pellets. X-ray (limestone): calcite. X-ray (iron pellets): goethite, quartz.	
		-20+200			
		Conc	1.3	Red-brown iron pellets, some heavy minerals	
		Tail	51.4	Quartz, some iron pellets	
		-200	36.5	Dark-red-brown powder. X-ray: goethite, trace kaolinite and montmorillonite.	

TABLE 10.—*Phosphate aeroradiometric anomalies in the Hawthorn Formation*

Anomaly number	Latitude (N.)	Longitude (W.)	Counts per second (rad)	Elevation (ft)	Comments
			Valdosta Quadrangle		
V10	30°15.5′	82°54.0′	300	100	Surficial sand and Hawthorn Formation.
V11	30°17.0′	82°52.5′	300	90	Do.
V12	30°17.5′	82°50.0′	300	100	Do.
V13	30°09.0′	82°57.5′	220	115	Do.
V14	30°11.5′	82°52.5′	225	150	Do.
V15	30°12.0′	82°50.0′	200	100	Do.
V16	30°01.0′	82°46.5′	200	75	Hawthorn Formation outlier on Suwannee Limestone.
			Gainesville Quadrangle		
G22	29°51.0′	82°30.5′	200	125	Surficial sand and Hawthorn Formation.
G23	29°53.5′	82°20.0′	200	110	Do.
G24	29°51.5′	82°19.5′	175	110	Do.
G25	29°47.5′	82°28.5′	200	150	Do.
G26	29°48.5′	82°26.5′	275	150	Do.
G27	29°46.0′	82°30.0′	300	100	Do.
G28	29°44.5′	82°30.5′	200	125	Hawthorn phosphate, some may be younger.
G29	29°44.0′	82°29.0′	175	160	Do.
G30	29°42.0′	82°27.5′	175	175	Do.
G31	29°44.5′	82°25.5′	275	150	Do.
G32	29°41.0′	82°25.0′	325	125	Do.
G33	29°42.0′	82°22.5′	250+	125	Do.
G34	29°38.0′	82°20.5′	200	125	Hawthorn Formation and surficial sand.
G35	29°28.5′	82°15.0′	100+	100	Do.
G36	29°26.0′	82°16.0′	225	125	Do.
G37	29°23.5′	82°15.5′	150+	150	Do.
G38	29°24.0′	82°11.0′	200	85	Do.
G39	29°14.5′	82°02.0′	225	65	Do.
G40	29°08.0′	82°09.5′	40+	125	Hawthorn Formation on Ocala Group (weathered).
G41	29°06.0′	82°08.0′	300+	100	Do.
G42	29°06.5′	82°06.0′	375	75	Do.
G43	29°02.0′	82°05.0′	200	80	Do.
G44	29°02.0′	82°08.0′	200	100	Do.
G45	29°01.5′	82°06.0′	200	110	Do.
G46	29°02.0′	82°05.5′	225	100	Do.
G47	29°00.0′	82°05.0′	400+	100	Do.
G48	29°00.0′	82°04.0′	200+	75	Do.

tends to be low in uranium content, ranging from 0.001 to 0.005 percent (10–50 ppm). Many bars are exposed along the rivers, and the river-pebble deposits have anomalous radioactivity that can be detected during rad surveys. Deposits are known along the following rivers: Withlacoochee North, Alapaha, Olustee, Black, Steinhatchee, Santa Fe, Withlacoochee South, Blackwater, Alafia, Peace, Manatee, Little Manatee, Horse, and Caloosahatchee. Mining, however, was confined almost entirely to the Peace and the Alafia Rivers, which drain the area of the rich land-pebble deposits of Polk and Hillsborough Counties (outside the study area). Small and irregular rad anomalies on or adjacent to any of these streams may be caused by river-pebble deposits. Rad anomalies along the Peace River, outlined by aerial surveys of the 1950's (Moxham, 1954), were found to be caused by small deposits of river-pebble phosphate.

It is possible that some of these anomalies may be caused by heavy-mineral concentrations along the streams. Company prospecting along and adjacent to the Steinhatchee River shows that phosphate is present in the area; these anomalies most probably are caused by river-pebble deposits. The anomaly on the Withlacoochee River at the southern end of the Gainesville Sheet certainly is due, in part, to old hardrock phosphate mines in the area; the southern part of the anomaly, however, is over the river and may be caused by river-pebble deposits.

TABLE 11.—*Swift Creek Mine*

Section in SW1/4 NW1/4 Section 10, T. 1 S., R. 15 E.

	Thickness (feet)
Surficial sand. Unconsolidated, gray and white. Not sampled.	
Gradational contact	
Uppermost Miocene—unnamed formation equivalent to the Bone Valley Formation	10
Sand, gray, massive, clayey. Contains abundant white, soft phosphate, partly leached. Weakly cemented by aluminum phosphate and clay. X-ray: quartz, wavellite, kaolinite, apatite, and trace crandallite	4
Sand, gray, slightly clayey, bedded. Thin lenticular, green clay lenses. Phosphate, fine-grained, tan, gray-green, brown, white, and black very shiny pellets, phosphatized rocks, and some phosphatized fossil molds and shark's teeth. Some pieces of weakly cemented groundmass. Cement is aluminum phosphate and clay. X-ray: quartz, apatite, montmorillonite, trace kaolinite, and crandallite	8
Sharp contact, marked by a crust of phosphate precipitated on dolomite—middle Miocene Hawthorn Formation.	
Sand, clayey, gray-green and white, mottled and bioturbated. Irregular bedding. Abundant phosphate pebbles and brown precipitated crusts of phosphate. Tan, brown, gray, white, and black shiny phosphate pellets, phosphatized fossil molds, phosphatized rocks. X-ray: quartz, apatite, montmorillonite. Trace kaolinite and crandallite	4
Sand, dark-gray, slightly clayey. Thin lenticles of green clay. Abundant fine-grained phosphate. Gray-green, tan, brown, and black very shiny pellets. White, shiny phosphatized fossil molds and phosphatized rocks. (Bottom of bed under water, only top part of this unit could be sampled.) X-ray: quartz, apatite, montmorillonite, trace kaolinite, wavellite, pyrite, and mica	4+

Total resources of river-pebble deposits in Florida were estimated by Mansfield (1942) to be 50 million short tons, but the deposits are small, irregular in extent, and scattered. Mining of river-pebble deposits stopped in 1908. No river-pebble anomalies were sampled during this investigation, but small anomalies along streams in peninsular Florida probably are due to bars (placers) of river pebble. None are likely to be of economic importance in the foreseeable future because of their small size. Possible river-pebble-related rad anomalies are listed in table 12.

CULTURAL ANOMALIES

Land use–land cover classification of rad anomalies (U.S. Geological Survey, 1972–74) within the study area shows that many anomalies correspond with urban areas and apparently are caused by man's activity. Those associated with Jacksonville, Tallahassee, and Pensacola are the most extensive geographically; however, smaller cities, such as Alachua, Ocala, and Panama City, also show rad anomalies. Spectral rad data indicate that the principal radioelement involved in the rad signature of the Jacksonville area is potassium (pl. 3) and lesser thorium and minor uranium. Similarly, potassium and thorium are the principal radioelements involved in the anomaly southwest of Jacksonville. Within the confines of the city limits of Jacksonville, at least one anomaly, that near the Regency Square shopping center, is associated with dry and wet mill tailings of a heavy-mineral processing plant operated for NL Industries in the early 1950's. Other anomalies within the city limits may be caused by heavy minerals in the Pamlico sands but primarily are due to granitic materials used in the construction of buildings and roads. The strong potassium-dominated anomaly is associated with a cement plant.

Tallahassee and Pensacola have strong rad signatures (pl. 1) associated with roads and buildings made of granitic materials. Alachua and Ocala, situated on the phosphate belt, have rad signatures that are obscured by the general trend of the rad anomalies of the phosphate belt.

Other cultural anomalies (such as G53 and the vicinity of sample 048) are caused by roads made of pseudowollastonite slag. According to Young and Altsculer

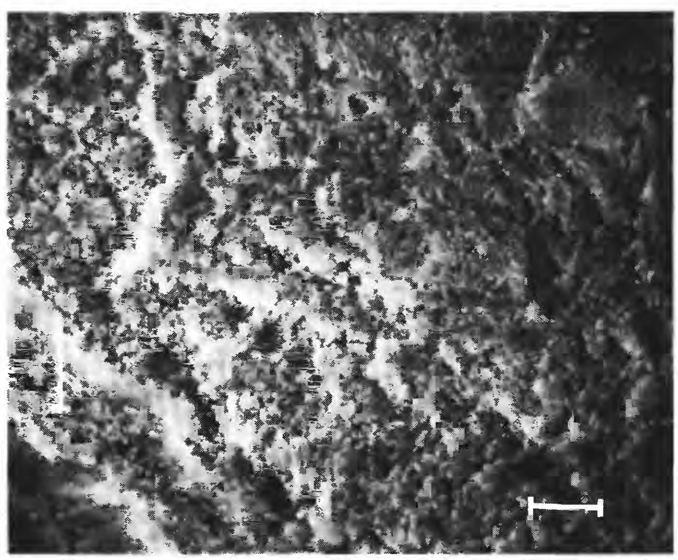

FIGURE 13.—Interior of a broken phosphate pellet. The sample is from a bed equivalent to bed 2 of the stratigraphic section of the Swift Creek Mine (table 11). The length of the bar is 10 micrometers. X-ray diffraction shows that the rock contains major apatite and a trace of quartz.

TABLE 12.—*Possible river-pebble-related aeroradiometric anomalies in Pleistocene or Holocene sediments*

Anomaly number	Latitude (N.) Longitude (W.)	Counts per second (rad)	Elevation (ft)	Comments
		Valdosta Quadrangle		
V1	30°31′ 83°02′	281	49	Bar, Alapaha River.
V2	30°26′ 83°06′	312	48	Flood plain, Suwanee River.
V3	30°25′ 83°06′	323	48	Bar, Suwannee River.
V4	30°26′ 83°08′	308	48	Flood plain, Suwannee River.
V5	30°26′ 83°13′	308	48	Do.
V6	30°22′ 83°12′	304	47	Do.
V7	30°18′ 83°13′	300+	47	Do.
V8	30°01′ 82°33′	200+	100	Do.
		Gainesville Quadrangle		
G1	29°43′ 83°21′	113	20	Flood plain, Steinhatchee River.
G2	29°54′ 83°16′	150	45	Bar, Steinhatchee River.
G3	29°55′ 82°30′	150	100	Flood plain, Santa Fe River.
G4	29°03′ 82°28′	300	60	Bar, Withlacoochee River.

(1958), these slags are derived from thermal processing of phosphate rock to make elemental phosphorus and contain an average of 0.018 percent (180 ppm) uranium.

The use of agricultural fertilizers is also a source of cultural anomalies and is discussed in the following section.

THE EFFECTS OF AGRICULTURAL FERTILIZER APPLICATIONS ON GAMMA-RAY RADIOMETRY

Previous work with rad maps in coastal areas indicated that rad anomalies associated with agricultural land may be caused by radioactive fertilizers (Grosz, 1983). Radioactive heavy minerals in samples from some agricultural areas are present in quantities thought too small to be solely responsible for the intensity of anomalies.

Fertilizer mixtures consist of variable amounts of nitrate, potash, and phosphate. Potash and phosphate are radioactive—potash because of potassium-40 and phosphate because of its associated uranium.

Natural soils rarely contain enough soluble phosphate for continued large-crop production. Fertilizers added to soils are taken up by crops, retained by the soil, removed by solution in drainage water, lost as a gas, or removed by erosion (Cooke, 1981). Most intensive agriculture involves building up reserves of soil phosphate and maintaining amounts that are considerably larger than those in natural soils. Water-soluble phosphates are leached into the subsoil of very light acid sandy soils, whereas the insoluble phosphates, basic slag, and mineral rock phosphates have longer lasting effects on crops than superphosphates. Experiments have shown that, in loamy sand soils, four-fifths of the phosphate applied accumulates in the soil, and, on heavier soils, two-thirds of each dressing accumulates (Cooke, 1981).

The concentration of potassium ions in soil is much larger than the concentration of phosphate ions, and potassium ions diffuse much more rapidly than phosphate ions. Partly as a result of this, a much larger proportion of a dressing of potassium fertilizer is taken up by a single crop. Potassium ions are much more mobile in soil than those of phosphate; however, the immediate loss of potassium added as fertilizer is prevented because $K+$ ions displace other cations on the exchange complex and are retained there (Talibudeen, 1981). In soils composed mainly of sand or of only kaolinitic minerals, much potassium may be lost by leaching; soils and micaceous-type clay minerals, however, fix potassium.

Rad anomalies in north-central and panhandle Florida commonly are associated with land used for agricultural purposes, as indicated by land use–land cover maps (U.S. Geological Survey, 1976a–h) and field investigations. Heavy-mineral contents of these sediments are generally small; the radioactive species (monazite and zircon) are present in trace quantities, but generally not in sufficient quantities to cause anomalies having the intensities indicated by aerial and ground radiometry. Natural phosphorite also is absent in most places.

Anomaly P5 (pl. 1) is an example of an anomaly associated with fertilized farmland. The sediment is a red, clayey, gravelly sand typical of the Citronelle Formation of the Northern Highlands. Samples 076, 077, and 078 (pl. 1) were collected from a dirt road surface (unfertilized), a corn field, and an oat field, respectively, within a distance of about 50 ft of one another; ground-radiation measurements at the three sample localities show 212, 242, and 237 counts per second, respectively. Spectral radiometric data (table 1) indicate an 80- to 100-percent increase in potassium-40 radiation and a 19- to 28-percent increase in the bismuth-214 radiation level. Heavy-mineral contents of the sediment samples are low and relatively constant, and trace monazite and about 9 percent zircon are in all concentrates. Variation in the eTh values is minimal, indicating significant radiation enhancement due to fertilizer use.

No data are available on the amounts and types of fertilizer used other than for the corn field, where 0–20–20 (K–P–N) granular fertilizer was applied at the rate of 500 pounds per acre per year (O. J. McDonald, personal commun., March 25, 1980).

Fertilizer consumption by counties (Florida Department of Agriculture and Consumer Services, 1977) immediately adjacent to the Apalachicola River drainage basins and due west of the Perdido River for the period from July 1, 1976, to June 30, 1977, is given in table 13. The data indicate that in Calhoun County, for instance, where a broad and irregular area of high rad signatures is indicated, relatively large amounts of fertilizer are applied annually. Land use-land cover maps (U.S. Geological Survey, 1976a–h) show that the anomalous areas in this county are associated almost exclusively with agricultural land or cultivated evergreen forest land as observed during field investigations. Cultivated forest lands commonly are fertilized by using slowly soluble phosphates, such as basic slag; almost 17 percent of the State total was used in Calhoun County. The use of fertilizer materials in Gadsden County is at least partially responsible for the intensity and distribution of anomalies. Widely distributed prime and unique farmlands in Gadsden County total approximately 59,000 acres (U.S. Department of Agriculture, 1977), which is roughly 30 percent of the surface area of the county. Anomalies in the east-central portion of Gadsden County are associated with phosphatic sands and clays, limestones, and fullers earth mines. Of the counties listed in table 13, Jackson is the single largest consumer of fertilizer mixtures; land use–land cover classification of anomalies indicates agricultural and evergreen forest lands to be the principal anomalous areas.

Anomaly P5 in Okaloosa County is classified as a farming area by land use–land cover information (U.S. Geological Survey, 1976d, Pensacola). Large amounts of potash materials (table 13), as well as liquid fertilizers high in phosphate and potash, are used in this county, and radioactive heavy minerals are scarce in the heavy-mineral suites of these sediments.

Anomalies associated with farmlands and cultivated forests should be expected to show significant enhancement in radioactivity in K and eU. The anomalies should be checked by measuring eTh, using either aerial or ground spectrometry, before they can be dismissed as being caused solely by fertilizers.

The effects of agricultural fertilizers on rad and ground-radiometric measurements are significant but probably highly variable as a function of the types of soil, crops grown, and fertilizers used and the moisture content of the soils.

Efficient preliminary exploration for heavy-mineral deposits in agricultural terranes, therefore, should rely almost exclusively on spectral radiometric information, where heavy-mineral deposits are indicated by a strong eTh signature.

THE ROLE OF AERORADIOMETRIC SURVEYS

PLACER HEAVY-MINERAL EXPLORATION

Rad data used in conjunction with geologic, soil, geomorphologic, land use–land cover, and shoreline and terrace maps and ground-spectrometer, fertilizer use, and mining- and mineral-resource data allowed us to classify confidently anomalies probably caused by heavy-mineral concentrations.

The results of our study show that, with very few exceptions, heavy-mineral concentrations exposed at the surface exhibit strong radiometric contrast to their host sediments if radioactive minerals are present—even if in relatively minor concentrations. Furthermore, our data are in agreement with previous studies in

TABLE 13.—*Summary of fertilizer materials and mixtures consumed in northwestern Florida from July 1, 1976, to June 30, 1977*

[In tons]

				Phosphate materials				Potash materials	
County	Total consumption[1]	Bulk and bag fertilizer	Liquid	Basic slag	Di-ammonium phosphate	Ammonium polyphosphate solution	Superphosphate	Muriate of potash 60 percent	Sulfate of potash-magnesia
Bay	6,007.98	4,109.97	404.62	---	---	---	---	---	---
Calhoun	35,387.71	10,701.03	479.09	964.75	---	---	---	---	---
Escambia	29,029.65	16,606.60	20.10	---	878.07	---	---	---	---
Franklin	381.16	275.14	.05	---	---	23.16	---	---	---
Gadsden	25,302.55	8,087.43	1,556.98	---	---	---	---	---	---
Gulf	13,719.32	3,714.48	20.04	---	---	---	2,066.20	---	---
Holmes	23,263.98	8,931.05	949.88	---	---	---	---	479.08	---
Jackson	117,933.08	30,554.86	5,174.31	---	---	1,087.45	---	---	---
Liberty	3,714.11	2,043.52	22.30	---	---	---	---	4.00	16.07
Okaloosa	25,589.68	13,290.05	462.21	---	---	---	---	475.63	147.90
Santa Rosa	56,162.84	27,425.61	25.18	---	444.49	---	---	---	457.25
Walton	15,434.58	6,846.73	589.05	---	1,097.20	---	---	650.29	---
Washington	18,353.49	9,138.63	811.67	---	---	---	176.10	---	---
Total	368,280.13	141,725.10	10,515.48	964.75	2,419.76	1,110.61	2,242.30	1,609.00	621.22
State total	2,006,108.77	462,370.46	220,418.27	5,760.04	3,933.66	2,225.50	12,340.39	23,812.34	12,078.81
Percent of total	18.46	30.65	4.77	16.75	54.65	49.90	18.17	6.83	5.14

[1]As reported by registrants to the Commissioner of Agriculture. Includes secondary and micronutrient materials, natural organics and gypsum for direct application. Does not include agricultural liming materials.

recognizing thorium (in monazite) as the principal radioelement involved in the radiometric expression of heavy-mineral placer concentrations in southeastern Atlantic Coastal Plain sediments.

Our method of approach to heavy-mineral exploration in Florida with the use of rad maps is summarized as follows:

1. Reduce (or enlarge) the rad and supplementary data to the same scale. The large geographic extent of our study area forced us to use the 1:500,000 scale.
2. Define localized areas on the maps that show rad values higher than those of the surrounding region. We found color coding of count-rate contour intervals to be most effective in outlining anomalous areas. The criteria used for separating real anomalies from false ones are that real anomalies span several flight lines and are of comparable intensity from flight line to flight line, whereas false anomalies are parallel to flight lines and are of highly variable intensities. Where spectral rad maps are available, thorium-dominated anomalies or those where thorium is involved are indicative of heavy-mineral concentrations.
3. By the use of supplementary data, define anomalies that are associated with former shorelines and marine terrace deposits (coarse-medium, well-sorted sand in the C horizon from soils maps), and fluvial flood-plain deposits (geomorphologic or surficial lithology data). Areas so defined are primary targets for exploration. By the use of land use–land cover data, we removed all urban or built-up areas from consideration; anomalies in these areas are probably cultural in origin. Similarly, where land used for agricultural purposes is moderately anomalous, we checked the data on types and quantities of fertilizers used; such anomalies likely are caused by fertilizers, but, if soils maps indicate coarse-medium sand in the C horizon, then field checking is required.
4. Anomalies associated with known heavy-mineral deposits used as standards against which other anomalies can be compared in magnitude and geographic trend.
5. Field investigation of anomalies by using a calibrated portable gamma-ray spectrometer, preferably with a large detector crystal, that shows a significant or major contribution from thorium indicates heavy-mineral placers.
6. Sampling of the surficial material within a rad anomaly. Samples from the top few inches of sediment will include the minerals directly responsible for ground and rad anomalies. Auger sampling (in our experience limited to sediments above the water table) will give an indication of the vertical continuity of heavy-mineral percentages and is more likely to indicate economic potential.

7. Laboratory analyses of the quantity and the types of heavy-minerals in a sample then can be used to guide exploratory drilling.

Based on the approach outlined above, we defined the following broad areas where the potential for economic deposits exists. First, and the most promising, the Atlantic Coastal Lowland that contains rad anomalies approximately coincident with the Pamlico shoreline and associated marine features, which are comparable in count-rate magnitude and geographic trend with known deposits in the same general area; second, the Trail Ridge system, including the Lake City Ridge and associated Okefenokee shoreline deposits as mapped by MacNeil (1950); third, the Pamlico shoreline deposits in Taylor County that have a radiometric anomaly pattern suggestive of heavy-mineral deposits; fourth, anomalies associated with the Pamlico shoreline and associated barrier island deposits that span southern Wakulla and northern Franklin Counties; fifth, anomalies in southwestern Bay County also associated with Pamlico shoreline features; and sixth, the sediments of the Citronelle Formation in northwestern Florida, which are of considerable thickness and have relatively large heavy-mineral contents as described by Coe (1979).

PHOSPHATE EXPLORATION

The rad maps of central Florida and, to a lesser extent, of northern Florida show anomalous radioactivity associated with exposures of uraniferous phosphate deposits. The majority of these anomalies are associated with unreclaimed former mines and processing plant sites or with weathered outliers of the phosphatic Hawthorn Formation that do not represent commercial deposits. A small number of anomalies are associated with river-pebble phosphate and outcrops of leached phosphate rock.

Rad surveys, as a means of undertaking rapid low-cost reconnaissance of large areas, are well suited to exploration for uraniferous phosphate deposits. The one serious limitation, first recognized during the early 1950's exploration period, is the presence of nonradioactive overburden that covers much of the potential phosphate areas. This overburden, where thicker than a foot or so, attenuates the radiation intensity of the underlying phosphate to an undetectable level.

Broad and marginally anomalous zones widely scattered in the study area may be associated with radon emanations from phosphate rocks covered by thin, permeable overburden. This may be the case at a number of weak rad anomalies in the Osceola National Forest, where drilling indicates phosphate deposits in the shallow subsurface. Such anomalies associated with sandy sediments also may be caused by uranium in phosphate because phosphatic detritus commonly is incorporated into sediments overlying phosphatic rocks and sediments during deposition.

GEOLOGIC MAPPING

The usefulness of rad maps in geologic mapping of the central and northern Florida area is limited severely by several factors. The principal limitation is the sand veneer that covers almost the entire study area. The thickness of this unit varies from a feather edge to tens of feet and attenuates or masks the radiometric character of the underlying geology. Extensive marshlands throughout the study area also attenuate the radiometric expression of the underlying geology because of the opacity of water to gamma-ray radiation.

General radiometric trends, associated with exposures of phosphatic rocks and unconsolidated sediments, are evident on total-count and spectral radiometric maps, indicating that, at least in some areas, generalized geologic mapping by use of rad data is possible.

The most evident trend is associated with exposures of the Hawthorn Formation and immediately overlying unconsolidated sediments into which phosphate from the Hawthorn has been reworked. Other radiometric trends are associated with heavy-mineral-bearing shoreline sands of the Atlantic and the Gulf Coastal Lowlands and particularly with the Trail Ridge system in the eastern Central Highlands.

Results of our investigation show that total-count rad maps are less useful for geologic mapping than spectral rad maps; however, both applications are limited severely to localized areas where high radiometric contrast in surficial units overwhelms other effects.

SPECIALIZED APPLICATIONS

During the course of our investigations, it became apparent that aeroradiometry may prove useful in applications other than mineral exploration. Although these applications are speculative, we feel obliged to point them out as promising foci for further work.

Land reclamation progress of mined-out areas and monitoring of mine development possibly may be achieved by successive rad surveys, where mined material had anomalous radioactivity. The present rad data can be used to locate mined-out areas that have not been reclaimed; such areas would be indicated by strong localized anomalies characterized, in the case of phosphate, by dominant uranium and lesser potassium and thorium components.

Appropriately calibrated surveys may be capable of outlining fertilized farming areas, planted evergreen

forests, and fluctuations in the levels of swampy terranes.

REFERENCES CITED

Alt, D., and Brooks, H. K., 1965, Age of the Florida marine terraces: Journal of Geology, v. 73, p. 406-411.

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geological Survey Professional Paper 314, p. 45-86.

Altschuler, Z. S., and Young, E. J., 1960, Residual origin of the "Pleistocene" sand mantle in central Florida uplands and its bearing on marine terraces and Cenozoic uplift: U.S. Geological Survey Professional Paper 400-B, p. B202-B203.

Applin, P. L., 1951, Preliminary report on buried pre-Mesozoic rocks in Florida and adjacent states: U.S. Geological Survey Circular 91, p. 28.

Applin, P. L., and Applin, E. R., 1967, The gulf series in the subsurface in northern Florida and southern Georgia: U.S. Geological Survey Professional Paper 524-G, p. 34.

Brooks, H. K., 1966, Geologic history of the Suwanee River, *in* Southeastern Geological Society Guidebook, 12th annual field trip: p. 37-45.

Calver, J. L., 1957, Mining and mineral resources: Florida Geological Survey Bulletin 39, 132 p.

Carpenter, J. H., Detweiler, J. C., Jr., Gillson, J. L., Weichel, E. C., Jr., and Wood, J. P., 1953, Mining and concentration of ilmenite and associated minerals at Trail Ridge, Florida: Mining Engineering, v. 5, no. 8, p. 789-795.

Cathcart, J. B., 1950, Notes on the land-pebble phosphate deposits of Florida, *in* Snyder, F. G., ed., Symposium on mineral resources of the Southeastern United States: University of Tennessee Press, Knoxville, p. 137- 151.

——— 1954, Drilling of airborne radioactivity anomalies in Florida, Georgia, and South Carolina: U.S. Geological Survey open-file report, p. 10.

——— 1978, Uranium in phosphate rock: U.S. Geological Survey Professional Paper 988-A, p. A1-A6.

Coe, C. J., 1979, Geology of the Plio-Pleistocene sediments in Escambia and Santa Rosa Counties, Florida: Unpublished M.S. thesis, Florida State University.

Cooke, C. W., 1939, Scenery of Florida interpreted by a geologist: Florida Department of Conservation Geological Bulletin 17, p. 118.

——— 1945, Geology of Florida: Florida Geological Survey Bulletin 29, p. 339.

Cooke, G. W., 1981, The fate of fertilizers, *in* Greenland, D. J., and Hayes, M. H. B., eds., The chemistry of soil processes: New York, John Wiley and Sons, Ltd., p. 563-592.

Dall, W. H., and Harris, G. D., 1892, The Neogene of North America, U.S. Geological Survey Bulletin 84, p. 349.

Day, D. T., 1886, Phosphate rock: Mineral Resources of the United States, U.S. Geological Survey, p. 452-454.

——— 1892, Report on Mineral Industries in the United States, *with a map of* phosphate areas of Florida: Census, 11th, 1890, p. 688.

Eldridge, G. H., 1892, A preliminary sketch of the phosphates of Florida: A paper read before the American Institute of Mining Engineers, New York City, p. 36.

Espenshade, G. H., and Spencer, C. W., 1963, Geology of phosphate deposits of northern peninsular Florida: U.S. Geological Survey Bulletin 1118, p. 115.

Fisk, H. N., 1938, Geology of Grant and LaSalle parishes: Louisiana Geological Survey Bulletin, v. 10, 246 p.

Florida Department of Agriculture and Consumer Services, 1977, Summary report of fertilizer materials and fertilizer mixtures consumed in Florida for fiscal year July 1, 1976, to June 30, 1977: p. 35.

Foote, R. S., 1978, Evaluation of gamma ray spectral surveys in the southeastern coastal plains: a paper presented at the Coastal Plains Industrial Minerals Forum, Atlanta, Ga., 21 p.

Force, E. R., Grosz, A. E., Loferski, P. J., and Maybin, A. H., 1982, Aeroradioactivity maps in heavy-mineral exploration—Charleston, South Carolina, area: U.S. Geological Survey Professional Paper 1218, 19 p.

Garnar, T. E., Jr., 1972, Economic geology of Florida heavy mineral deposits, *in* Proceedings of the 7th Forum on the Geology of Industrial Minerals: Florida Bureau of Geology special publication 17, p. 17-21.

Grosz, A. E., 1983, Application of total-count aeroradiometric maps to the exploration for heavy-mineral deposits in the Coastal Plain of Virginia, *with a section on* Field spectrometer data reduction, by K. L. Kosanke: U.S. Geological Survey Professional Paper 1263, 20 p.

Harris, G. D., and Veatch, A. C., 1899, A preliminary report on the geology of Louisiana: Louisiana State University, State Experimental Station Report, 138 p.

Healy, H. G., 1975, Terraces and shorelines of Florida: Florida Department of Natural Resources, map series No. 71.

Hilgard, E. W., 1866, On the Quaternary formations in the State of Mississippi: American Journal of Science, v. 91, p. 311-325.

International Atomic Energy Agency, 1979, Gamma-ray surveys in uranium exploration: Technical Report 186, 90 p.

Isphording, W. C., and Riccio, J., 1969, Petrology and identification of the Citronelle Formation in Alabama [abs.]: 21st annual meeting, Southeastern Section, Geological Society of America, Abstracts, v. 4, no. 2, p. 82-83.

Knapp, M. S., 1978a, Environmental geology series, Valdosta sheet: Florida Bureau of Geology map series 88.

——— 1978b, Environmental geology series, Gainesville sheet: Florida Bureau of Geology map series 79.

Kremers, H. E., 1958, Commercial thorium ores: Society of Mining Engineers of American Institute of Mining Engineers preprint 5819A18, p. 1-14.

Lawthers, Robert, 1955, Investigation of "black sand" deposits in Bay and Walton Counties, Florida: U.S. Geological Survey administrative report on black sands for the Bureau of Land Management, p. 46.

Liddell, D. M., 1917, A Florida rare-mineral deposit: Engineering Mining Journal, v. 104, no. 4, p. 153-155.

Lynd, L. E., 1978, United States dependence on foreign sources of heavy mineral concentrates: Society of Mining Engineers–American Institute of Mining, Metallurgical, and Petroleum Engineers meeting, Lake Buena Vista, Florida, SME-AIME preprint 78-H-366, 17 p.

Macdonald, E. H., 1983, Alluvial mining, the geology, technology and economics of placers: London and New York, Chapman and Hall, 508 p.

MacNeil, F. S., 1950, Pleistocene shorelines in Florida and Georgia, *in* Shorter contributions to geology: U.S. Geological Survey Professional Paper 221-F, p. F95-F106.

Mahdavi, Azizeh, 1964, The thorium, uranium, and potassium contents of Atlantic and Gulf Coast beach sands, *in* Adams, J. A. S., and Lowder, W. M., The natural radiation environment: Chicago, University of Chicago Press (for William Marsh Rice University), p. 87-114.

Mansfield, G. R., 1942, Phosphate resources of Florida: U.S. Geological Survey Bulletin 934, 82 p.

Markewicz, F. J., Parillo, D. G., and Johnson, M. E., 1958, The titanium sands of southern New Jersey: Society of Mining Engineers-American Institute of Mining, Metallurgical, and Petroleum Engineers meeting, New York, SME-AIME preprint 5818A5, 10 p.

Marsh, O. T., 1966, Geology of Escambia and Santa Rosa Counties, western Florida panhandle: Florida Geological Survey Bulletin 46, p. 140.

Martens, J. H. C., 1928, Beach deposits of ilmenite, zircon, and rutile in Florida: Florida State Geological Survey 19th annual report, p. 124-154.

——— 1935, Beach sands between Charleston, South Carolina, and Miami, Florida: Geological Society of America Bulletin, v. 46, no. 10, p. 1563-1596.

Matson, G. C., 1916, The Pliocene Citronelle Formation of the Gulf Coastal Plain: U.S. Geological Survey Professional Paper 98-L, p. L167-L192.

McGee, W. J., 1891, The Lafayette Formation: U.S. Geological Survey, 12th Annual Report, p. 322-521.

Moxham, R. M., 1953, Airborne radioactivity surveys for phosphate in Florida: U.S. Geological Survey Trace Elements Investigation Report 387, p. 16.

——— 1954, Airborne radioactivity surveys for phosphate in Florida: U.S. Geological Survey Circular 230, p. 4

Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal Province of North America: New York, Harper and Brothers.

Otvos, E. G., 1981, Tectonic lineaments or Pliocene and Quaternary shorelines, northeast Gulf Coast: Geology, v. 9, p. 398-404.

Overstreet, W. C., 1967, The geologic occurrence of monazite: U.S. Geological Survey Professional Paper 530, 327 p.

Pirkle, E. C., 1956, The Hawthorn and Alachua Formations of Alachua County, Florida: Florida Academy of Science Quarterly Journal, v. 19, p. 197-240.

Pirkle, E. C., Pirkle, W. A., and Yoho, W. H., 1974, The Green Cove Springs and Boulogne heavy-mineral sand deposits of Florida: Economic Geology, v. 69, no. 7, p. 1129-1137.

——— 1977, The highland heavy-mineral sand deposit on Trail Ridge in northern peninsular Florida: Florida Department of Natural Resources Report of Investigation 84, p. 50.

Pitkin, J. A., Neuschel, S. K., and Bates, R. G., 1964, Aeroradioactivity surveys and geologic mapping *in* Adams, J. A. S., and Lowder, W. M., eds., The natural radiation environment: Chicago, University of Chicago Press, p. 723-736.

Pressler, E. D., 1947, Geology and occurrence of oil in Florida: American Association of Petroleum Geologists Bulletin, v. 19.

Puri, H. S., 1957, Stratigraphy and zonation of the Ocala Group: Florida Geological Survey, Geological Bulletin no. 38.

Puri, H. S., and Vernon, R. O., 1964, Geologic map of Florida: State Board of Conservation, special publication no. 5, 312 p.

Robson, D. F., and Sampath, N., 1977, Geophysical response of heavy-mineral sand deposits at Jerusalem Creek, New South Wales: Bureau of Mineral Resources Journal of Australian Geology and Geophysics, v. 2, p. 149-154.

Rosen, N. C., 1969, Heavy minerals and size analysis of the Citronelle Formation of the Gulf Coastal Plain: Journal of Sedimentary Petrology, v. 39, p. 1552-1565.

Schmidt, Walter, 1978a, Environmental geology series, Pensacola sheet: Florida Bureau of Geology map series no. 78.

——— 1978b, Environmental geology series, Apalachicola sheet: Florida Bureau of Geology map series no. 84.

——— 1979, Environmental geology series, Tallahassee sheet: Florida Bureau of Geology map series no. 90.

Scott, T. M., 1978, Environmental geology series, Jacksonville sheet: Florida Bureau of Geology map series no. 89.

——— 1979, Environmental geology series, Daytona Beach sheet: Florida Bureau of Geology map series no. 93.

Sheldon, R. P., 1959, Geochemistry of uranium in phosphorites and black shales of the Phosphoria Formation: U.S. Geological Survey Bulletin 1084-D, p. D83-D115.

Spencer, R. V., 1948, Titanium minerals in Trail Ridge, Fla.: U.S. Bureau of Mines Report of Investigations 4208, 21 p.

Stockman, K. W., Pickering, S. M., Jr., Higgins, M. W., and Zietz, Isidore, 1976, Application of contoured aeroradioactivity maps for heavy-mineral exploration in Georgia's coastal area [abs.]: Geological Society of America, Abstracts with Programs, v. 8, no. 2, p. 277-278.

Stromswold, D. C., and Kosanke, K. L., 1978, Calibration and error analysis for spectral radiation detectors: Institute of Electrical and Electronics Engineers Transactions on Nuclear Science, v. NS-25, no. 1, p. 782-786.

Talibudeen, O., 1981, Cation exchange in soils, *in* Greenland, D. J., and Hayes, M. H. B., eds., The chemistry of soil processes: New York, John Wiley and Sons, Ltd., p. 115-177.

Thoenen, J. R., and Warne, J. D., 1949, Titanium minerals in central and northern Florida: U.S. Bureau of Mines Report of Investigations 4515, 62 p.

U.S. Bureau of Mines, 1943, Beach sands near Pensacola, Santa Rosa, Escambia, and Okaloosa Counties, Florida: War Minerals Report 141, 20 p.

U.S. Department of Agriculture, Soil Conservation Service, 1977, Important farmlands; Gadsden County, Florida: map.

U.S. Geological Survey, 1973a, Charlotte Harbor, Florida: Satellite image map, National Aeronautic and Space Administration Landsat-1, N2723W08143.

——— 1973b, Lake George, Florida: Satellite image map, National Aeronautic and Space Administration Landsat-1, N2849W08119.

——— 1973c, Lake Okeechobee, Florida: Satellite image map, National Aeronautic and Space Administration Landsat-1, N2723W08016.

——— 1973d, Lake Seminole, Florida-Georgia-Alabama: Satellite image map, National Aeronautic and Space Administration Landsat-1, N3015W08512.

——— 1973e, Pensacola Bay, Florida-Alabama: Satellite image map, National Aeronautic and Space Administration Landsat-1, N3015W08638.

——— 1973f, Sanibel Island, Florida: Satellite image map, National Aeronautic and Space Administration Landsat-1, N2557W08206.

——— 1974a, Gulf Hammock, Florida: Satellite image map, National Aeronautic and Space Administration Landsat-1, N2849W08245.

——— 1974b, Okefenokee Swamp, Georgia-Florida: Satellite image map, National Aeronautic and Space Administration Landsat-1, N3015W08220.

——— 1974c, Apalachee Bay (Florida-Georgia): Satellite image map, National Aeronautic and Space Administration Landsat-1, N3015W08346.

——— 1976a, Land use and land cover, 1972-73, Apalachicola, Florida: Open-File Report 76-001-1 land use series.

——— 1976b, Supplemental land use, 1972-73, Apalachicola, Florida: Open-File Report 76-001-7 land use series.

——— 1976c, Land use and land cover, 1972, Gainesville, Florida: Open-File Report 76-004-1 land use series.

——— 1976d, Land use and land cover, 1973, Pensacola, Florida: Open-File Report 76-009-1 land use series.

——— 1976e, Land use and land cover, 1972, Plant City, Florida: Open-File Report 76-010-1 land use series.

——— 1976f, Land use and land cover, 1972–73, Tallahassee, Florida: Open-File Report 76-011-1 land use series.

——— 1976g, Land use and land cover, 1972–74, Tallahassee, Florida, Georgia, Alabama: Open-File Report 76-029-1 land use series.

——— 1976h, Land use and land cover, 1972–74, Valdosta, Georgia, Florida: Open-File Report 76-023-1 land use series.

——— 1978a, Aeroradioactivity map of part of the Pensacola 1° x 2° quadrangle Florida: Open-File Report 78-717.

——— 1978b, Aeroradioactivity map of northern Florida: Open-File Report 78-760, 2 sheets.

——— 1978c, Aeroradioactivity map of northern Florida: Open-File Report 78-760.

——— 1978d, Aeroradioactivity map of north-central Florida: Open-File Report 78-763.

Veatch, Otto, and Stephenson, L. W., 1911, Preliminary report on the geology of the coastal plain of Georgia: Georgia Geological Survey, Bulletin 26.

Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geological Survey Bulletin 33, p. 256.

Vernon, R. O., and Puri, H. S., 1965, Geologic map of Florida: Florida Bureau of Geology, map series 18.

White, W. A., 1970, Geomorphology of the Florida peninsula: Florida Bureau of Geology, Bulletin 51, 164 p.

Winkler, C. D., and Howard, J. D., 1977, Plio-Pleistocene paleogeography of the Florida Gulf coast interpreted from relict shorelines: Transactions of the Gulf Coast Association of Geological Societies, v. 27, p. 409–420.

Young, Edward, and Altschuler, Z. S., 1958, Uranium distribution in pseudowollastonite slag: Industrial and Engineering Chemistry, v. 50, p. 793–796.

Zellars-Williams Inc., 1978, Evaluation of the phosphate deposits of Florida using minerals availability system: U.S. Bureau of Mines Open-File Report 112-78, p. 106.

APPENDIX

CHARACTERISTICS OF THE PRINCIPAL AERORADIOMETRIC ANOMALIES IN THE STUDY AREA

Aeroradiometric anomaly No.[1]	Geologic setting[2]	Elevation zone[3]	Surficial geology[4]	County	Land use and land cover[5]
J1[6]	R and P	10	MFSS	Nassau	1
J2	do	10	SSC	do	1
J3	do	10	do	do	1
J4	do	10	do	do	1,4
J5	do	10	do	Nassau/Duval	7
J6	do	10	do	Duval	4
J7	do	10	do	do	4,1
J8	do	10	do	do	6,1,4
J9	do	10	do	do	7,6
J10	do	10	do	do	1
J11	do	10	do	St. Johns	1
J12	do	10	do	do	4
J13	do	10	do	do	4
J14	do	30	do	do	4,6
J15	do	10–30	do	do	4,6
J16	do	10–30	do	do	4,6,2
J17	do	10	do	do	4,1,6
J18	do	10	do	do	4,6,1
J19	do	10	do	do	6,5
J20	do	10–30	do	Nassau	4
J21	do	30	MFSS	do	4,6
J22	do	30	SSC	do	4,1
J23	do	30	MFSS	do	4,6
J24	do	30	SSC	do	1,4
J25	do	30	do	do	4
J26	do	30	do	do	4,7
J27	do	30	do	do	4,6
J28	do	30	do	do	4,6,1
J29	do	30	do	do	4,2,1,6
J30	do	30	do	do	4,6
J31	do	30	do	do	4,2,1,6
J32	do	30	do	do	4,6
J33	do	30	do	do	1,4
J34	do	30–80	CS,SSC	Duval/Nassau	4,2,6
J35	do	30	SSC	Duval	2,4,6,1
J36	do	30	do	do	4,6
J37	do	30	do	do	4,2
J38	do	30	do	do	1,4,2
J39	do	30	do	do	4,5,6
J40	do	30	MFSS	do	1,4,5,7
J41	do	30	SSC	do	1
J42	do	30	do	do	1,5,6
J43	do	30	MFSS	do	4,1,2,5,6
J44	do	10–30	do	do	4,6
J45	do	30	SSC,MFSS	St. Johns	4,6
J46	do	30	SSC	do	4,5
J47	do	30	do	do	4,1,6
J48	do	30	do	Clay	4,7,1
J49	do	30	do	do	4,2,1,6
J50	do	100–150	CS	do	4

CHARACTERISTICS OF THE PRINCIPAL AERORADIOMETRIC ANOMALIES IN THE STUDY AREA—CONTINUED

Aeroradiometric anomaly No.[1]	Geologic setting[2]	Elevation zone[3]	Surficial geology[4]	County	Land use and land cover[5]
J51	Mjb	80–90	do	Duval/Clay	4
J52	R and P	80	do	Duval	1,4
J53	do	80–90	do	do	1,4
J54	do	80	do	Nassau/Duval	4,2,6,1
J55	M"c"	80	do	Nassau	4,2,6
A1[7]	R and P	10–30	MFSS	Franklin	4
A2	do	10–30	do	do	4
A3	do	10	MFSS,CS	Gulf	4
A4	do	10–30	CS	do	4
A5	do	10–30	do	do	7,4
A6	do	10–30	MFSS	do	4
A7	do	10	CS,MFSS	do	4
A8	do	10–30	MFSS	Franklin	4
A9	do	10	do	do	4
A10	do	0–10	do	do	7,4
A11	do	0–10	do	do	7,4
A12	do	0–10	do	do	7,4
A13	do	0–10	do	do	7,4
P1[8]	do	10–30	do	Walton	4,7,6
P2	do	10–30	do	do	4,2
P3	Mrb	150	SC and C	do	1,2
P4	Mc/Odc	---	do	Walton/Holmes	4,2
P5	Odc	---	do	Holmes	4,1,2
P6	Mc	---	do	Walton	4,6,2
P7	do	---	do	do	2,1
P8	R and P	10–30	MFSS	do	4
P9	Mc	---	SC and C	do	4,2
P10	Msr/?PPc	---	do	do	4,2
P11	Mc/?PPc	---	do	Okaloosa	4,2,7
P12	Msr/?PPc	---	MFSS,SC and C	do	2,1,6,4
P13	?PPc	---	G and CS	do	2
P14	do	---	do	do	2,1
P15	do	---	G and CS, SC and C	Okaloosa/Santa Rosa	2,4
P16	do	---	SC and C, G and CS	Santa Rosa	2,4
P17	do	High terrace	G and CS, SC and C	do	2,4,1
P18	do	100–150	G and CS	do	2,4,6
P19	R and P	150–High terrace	do	do	2,4,1
P20	?PPc	High terrace	do	do	2
P21	do	do	do	do	2,4,6
P22	do	do	do	Escambia	2,1,4
P23	do	do	do	do	2,4,1
P24	do	do	do	do	2
P25	do	do	do	do	2,4
P26	do	do	do	do	2
P27	do	80–150	do	do	1,4
P28	R and P	100–150	do	Santa Rosa	1,2,4
PC1[9]	Ei	80–100	?	Citrus	4,2
PC2	Ew	80–100	?	do	7,4,1
PC3	Ma	80–100	?	do	1,4
PC4	Os/Mh	100	?	do	7,2,4
PC5	Ma	80–100	?	do	2

CHARACTERISTICS OF THE PRINCIPAL AERORADIOMETRIC ANOMALIES IN THE STUDY AREA—CONTINUED

Aeroradiometric anomaly No.[1]	Geologic setting[2]	Elevation zone[3]	Surficial geology[4]	County	Land use and land cover[5]
PC6	do	80–100	?	do	2,1
PC7	do	80–100	?	do	2
PC8	do	100	?	Hernando	4
PC9	do	80–100	?	do	4
PC10	Os/Ma	150	?	do	2
PC11	Mh	150	?	do	2,4
PC12	Os	100–150	?	do	1,2
PC13	Mh	150	?	do	2
PC14	Os	100	?	do	1,7,6
PC15	Ei	0–30	?	Citrus	1,6
PC16	Ecr	0–30	?	Sumter	2
PC17	Os	0–30	?	Hernando	6,1
V1[10]	Os/Mh	80–100	L,CS	Hamilton	4
V2	Os	80–100	do	do	4
V3	do	100	CS	Suwannee	2,4
V4	do	80–100	L,CS	Hamilton/Suwannee	4
V5	do	80–100	D,CS	Hamilton	4,2
V6	do	80–100	L	Madison	4
V7	Os/Ecr	80–100	do	do	4
V8	Mh	80–100	CS,MFSS	Columbia/Union	4,2,6
V9	R and P	100–150	CS	Hamilton	7,4,6
V10	Mh	150	MFSS,CS	Suwannee	4,2,6,1
V11	do	100–150	CS	do	2,4,1
V12	do	100–150	do	do	2,4
V13	Mh/Os	100	do	do	2,4
V14	Mh	80–100	do	do	2,4
V15	R and P	80–100	CS,MFSS	do	4,2,6
V16	Os	80–100	L	Columbia	4,2
V17	R and P	100–150	CS	do	2,4,1
V18	do	100–150	CS,MFSS	do	1,2,4,5
V19	do	100–150	CS	Baker	4,2,6
V20	Mh	100–150	CS,MFSS	do	4,6,1,7
V21	R and P/Mh	100–150	do	do	4,6
V22	R and P	100–150	MFSS	Charlton (Ga.)	4,6
V23	do	80–100	do	do	4
V24	Ecr	80–100	L	Lafayette/Suwannee	4,2
V25	do	80–100	do	Lafayette	2,4
V26	do	80–100	do	Lafayette/Suwannee	2,4
V27	Os	100	CS	Suwannee	2,4
V28	do	80–100	L	Suwannee/Lafayette	2,4
V29	do	100–150	CS	Madison	2
V30	Mh/Os	100–150	do	do	2,4,1,6
V31	Mm	150	do	do	2,4
V32	do	80–150	do	do	4,2,6,1
V33	do	100–150	do	Jefferson	2
V34	Mh	30–100	CS,MFSS	do	4,2,7
V35	Os	10–30	L/D	Perry	4,6
V36	do	30–100	do	do	1,2,4
T1[11]	do	---	L	Jefferson	6,4
T2	Mm	---	CS	do	2,4
T3	do	---	do	Jefferson/Leon	4,2
T4	Mm/Mm	---	do	Leon	2,4

CHARACTERISTICS OF THE PRINCIPAL AERORADIOMETRIC ANOMALIES IN THE STUDY AREA—CONTINUED

Aeroradiometric anomaly No.[1]	Geologic setting[2]	Elevation zone[3]	Surficial geology[4]	County	Land use and land cover[5]
T5	Mm	---	do	do	2,4
T6	Mm/Mh	---	do	do	2,4,1
T7	do	80–150	do	do	1
T8	Mst. M	---	L	do	4,2,1
T9	do	30–80	MFSS	do	4
T10	do	---	L	Wakulla	4,6
T11	do	---	do	do	6,5,4
T12	Mjb	10–30	MFSS	do	4,2,6
T13	Mm	---	SC and C,CS	Gadsden	2,4
T14	Mfp	---	CS	do	4,1,7
T15	Mh	150	CS,SC and C	do	2,4,1
T16	Mfp	---	do	do	2,4
T17	do	---	CS	do	2,4,6
T18	R and P	30–80	MFSS	Liberty	4,6
T19	do	100	CS	do	4,6
T20	do	30	do	do	4,6
T21	do	---	do	do	4
T22	do	---	do	do	4,2,6,7
T23	do	---	do	do	2,4,6
T24	R and P/Mjb	150	do	do	2,1
T25	Mh	150	MFSS	do	4
T26	do	---	MFSS,CS	Gadsden	4,2
T27	Mch	---	CS	Jackson	2,4
T28	Mfp	---	do	Calhoun	2,4
T29	Mfp/R and P	---	do	do	2,4,1
T30	do	80–100	do	do	2,4
T31	R and P	80–100	do	do	4,2
T32	do	80–100	do	do	4,6
T33	do	30–80	do	Gulf	4,2,1
T34	do	30	do	do	4,2,6
T35	do	30	CS,MFSS	Bay/Gulf	4
T36	do	80	CS	Calhoun	4,6
T37	do	30–80	MFSS	Bay	1,4,7
T38	do	30	do	do	1,4,7,6
T39	do	10	do	do	1,4
T40	do	0–30	do	do	4,5
T41	do	30–80	do	do	4,2,6,7
T42	Om/Odc	---	L	Jackson	2,4,6
T43	Ecr	---	CS	Holmes	2,4
T44	Odc/Mch	---	do	Washington	2,4
T45	Ocr/Mc/Mch	---	CS,MFSS	do	4,2
T46	Mc/Mch	---	CS,MFSS	do	4,2,6
T47	Ecr	---	G and CS,CS	Holmes	4,2,7
T48	do	---	MFSS,G and CS	do	4,2
T49	Mc/Mrb	---	SC and C	Walton	4,2,7
T50	R and P	10–30	MFSS	Walton/Washington	4,6
T51	do	---	CS	Calhoun	4,2,6
T52	do	30	do	do	4,6
T53	do	10–30	do	Gulf	4,2
G1[12]	Ecr	30	L/D	Dixie/Taylor	4,6

CHARACTERISTICS OF THE PRINCIPAL AERORADIOMETRIC ANOMALIES IN THE STUDY AREA—CONTINUTED

Aeroradiometric anomaly No.[1]	Geologic setting[2]	Elevation zone[3]	Surficial geology[4]	County	Land use and land cover[5]
G2	Ma	30	do	Lafayette	3,6
G3	Mh	30–100	CS	Alachua	2
G4	Eap	30–100	L/D,MFSS	Marion	7
G5	Ecr	30–100	L	Columbia	4
G6	do	30–100	CS	Alachua	2
G7	Ma	30–100	do	Gilchrist	4,2
G8	do	30–100	MFSS	Levy/Alachua	4
G9	Ecr	30–100	L,CS	do	4,2
G10	Ew/Ecr	100	CS,L	Marion/Levy	2,4
G11	Ecr/Mh	100	L	do	7
G12	Mh	100	do	do	2
G13	Ecr	100	do	do	2
G14	Ecr/Mh	100	do	do	2,4
G15	Ew	80–100	do	do	4
G16	Ecr/Ew	100	L,CS	do	2,4
G17	Ew	80–100	L,MFSS	do	2,4
G18	Ma	100	MFSS	do	4
G19	Ei	100	do	do	4,2
G20	do	80–100	do	Citrus	4,1,2
G21	do	80–100	L/D	Marion	7
G22	Mh	80–100	CS	Alachua	2
G23	do	80–100	MFSS,CS	Bradford	1,2,4
G24	do	80–100	MFSS	Alachua	2
G25	do	80–100	CS	do	2
G26	do	150	do	do	2,4
G27	Ecr	100–150	do	do	2,4
G28	Ecr/Mh	100–150	do	do	2
G29	Mh/Ecr	150	do	do	2
G30	Mh	150	do	do	2,1
G31	Mh/Ecr	100–150	do	do	4,2,6
G32	Mh	150	do	do	2,4
G33	do	100–150	do	do	7,4,2
G34	do	80–100	do	do	1,4
G35	do	100–150	do	Alachua/Marion	2,4
G36	do	100–150	do	Marion	4,1
G37	do	150	do	do	2,4
G38	Ecr	80–100	L	do	2
G39	do	80–100	MFSS	do	4
G40	do	100–150	CS	do	2
G41	do	100–150	do	do	2,4
G42	do	100	L	do	2,4
G43	do	80–100	do	do	2,4
G44	do	80–100	do	do	2,4
G45	do	80–100	do	do	2
G46	do	80–100	do	do	4,2
G47	do	100	CS,L	do	7,2,4,1
G48	do	100	CS	do	7,4
G49	do	80–100	do	do	1,2,4
G50	Mh	100	L	do	7
G51	Eap	10–30	D/L,S	Levy	4,6

CHARACTERISTICS OF THE PRINCIPAL AERORADIOMETRIC ANOMALIES IN THE STUDY AREA—CONTINUED

Aeroradiometric anomaly No.[1]	Geologic setting[2]	Elevation zone[3]	Surficial geology[4]	County	Land use and land cover[5]
G52	Eap/Ei	10–30	L/D	do	4,6,2
G53	Ew	10–30	L	do	4,6
G54	R and P	10–30	L/D	Dixie	4,6
G55	Ecr	30	L	do	6,4
G56	do	30–100	do	Lafayette	4,2
G57	do	30–100	do	Gilchrist	2,4
G58	do	10–30	do	do	7,4
G59	R and P	100–150	CS	Alachua	4,2
G60	MFP	150	MFSS	Clay	1,7
G61	R and P	150	CS	do	4
G62	do	80–90	do	do	1,7
G63	do	30–80	SSC	do	7,2
G64	do	10–30	do	St. Johns	2,4
G65	do	30	MFSS	do	4
G66	do	0–10	do	do	6
G67	Pa	10–30	do	do	7
G68	do	0–10	do	do	1,4
G69	do	10–30	do	do	6
G70	do	10–30	do	Flagler	4,6
G71	do	10–30	do	do	4,6
G72	do	10–30	do	do	7
G73	do	30	do	Volusia	6
G74	R and P	10–30	do	Flagler	6,2,4
G75	Ecr	30–100	do	Marion	4,2,6
G76	R and P	10–30	SSC	Putnam	4,1,6,2
G77	Ecr	30–100	L	Suwannee	4,2
G78	Ei	0–30	L/D,D	Levy	4,6
G79	do	0–30	do	do	6,4

[1]May include several discrete rad anomalies.
[2]Modified from Vernon and Puri (1964) and Cooke (1945), explanation on plate 1.
[3]Modified from MacNeil (1950), in feet.
[4]Modified from Scott (1978, 1979), Schmidt (1978a, b), and Knapp (1978a, b), explanation on plate 5.
[5]Modified from U.S. Geological Survey (1976a-h)
1—Urban or built-up land 2—Agricultural land 3—Rangeland
4—Forest land 5—Water 6—Wetland 7—Barren land
[6]J—Jacksonville 1° × 2° quadrangle.
[7]A—Apalachicola 1° × 2° quadrangle.
[8]P—Pensacola 1° × 2° quadrangle.
[9]PC—Plant City 1° × 2° quadrangle.
[10]V—Valdosta 1° × 2° quadrangle.
[11]T—Tallahassee 1° × 2° quadrangle.
[12]G—Gainesville 1° × 2° quadrangle.