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LANDSAT-1 Imagery for Geologic Evaluation*

LANDSAT-1 imagery provides a synoptic view of the geomorphic features of the coastal plain of North Carolina.

Abstract: *LANDSAT-1 imagery shows many of the well-known geomorphic features of the coastal plain of North Carolina. Among these are the various scarps and ridges associated with former higher stands of sea level; variations of reflectivity within some of the larger high level swamps, possibly recording patterns of soil moisture differences and/or substrate differences; and the regional distribution of the Carolina Bays. The updip margin of the coastal plain is especially well marked on the imagery, appearing more intricate than the currently available maps show it to be. In parts of the coastal plain it is possible to trace boundaries between major stratigraphic units because of slightly different reflectances and patterns of land use.*

Compilations of various types of lineaments show two dominant trends, one northwest-southeast and one northeast-southwest. Recent regional subsurface studies suggest that these directions are significant in the tectonic development of the Atlantic Coastal Plain. At various times since the Triassic strain caused by shearing and tensional forces is believed to have developed in these directions. No direct evidence exists connecting the trends of the mostly short lineaments with the regional structural and stratigraphic trends of the post-Miocene coastal plain formations or with the directions arising from theoretical considerations of coastal plain tectonics.

Introduction

Geologic evaluation of the North Carolina coastal plain using LANDSAT-1 imagery has been attempted with three broad approaches in mind: (1) a general study of the geomorphology to assess the imagery as a tool for upgrading the understanding of the coastal plain; (2) more detailed studies aimed at recognition of geomorphic or geologic features not previously known or extension of those already known; and (3) studies concerned with recognition of linear features possibly related to subsurface structures. The general area of the study is shown on Figure 1.

Geomorphic Features

Among the more prominent features displayed on the LANDSAT imagery are the scarps and beach ridges associated with former positions of the shoreline. Prominent among these is the Suffolk Scarp—Sand Ridge, which can be traced more or less continuously from the Dismal Swamp area to the Neuse River and thence southeastward to the vicinity of Morehead City (Figure 1 and Plate 1). From the Pamlico River to the Neuse River it is topped by the Minnesott Sand Ridge (Daniels *et al.*, 1972; Figure 2).

Between Morehead City and Wilmington the Suffolk Scarp is less prominent than to

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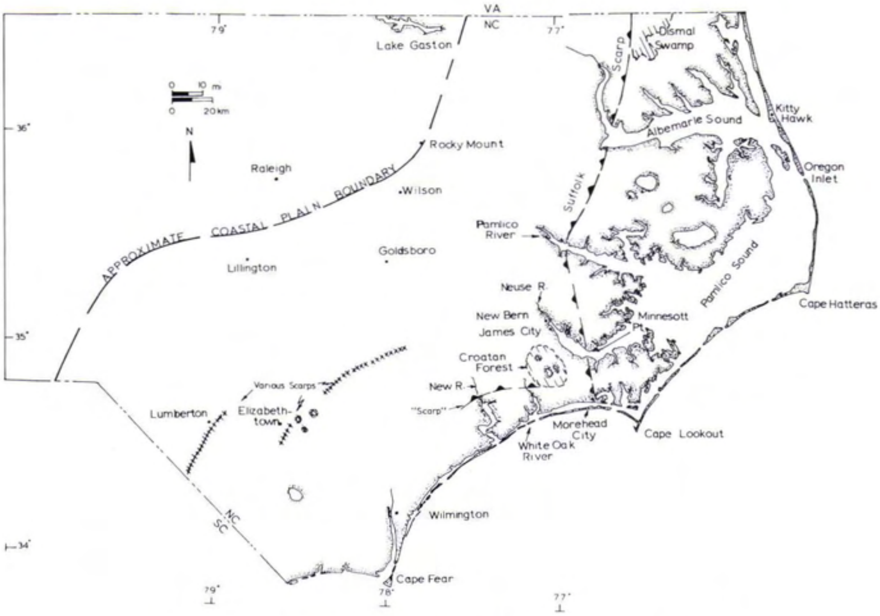

FIG. 1. General area of study, North Carolina Coastal Plain.

the north of the Neuse River. However, locally its presence can be detected on the LANDSAT imagery because of differences of reflectances on either side of the line marking the scarp. Examples are indicated in Figure 2. Near Wilmington the scarp occurs near the head of the several small streams between U.S. 17 and the coast (Plate 2). The presence of the Suffolk Scarp between Morehead City and Wilmington has been confirmed by field mapping and drilling (E. Gamble, personal communication, July 1975).

A scarp-like feature appears on the LANDSAT imagery and seems to cross the coastal plain from near the head of the White Oak River estuary to a short distance west of the head of the New River estuary (Figure 1). From topographic maps its toe elevation appears to be about 25 feet in contrast to the toe elevation of 20 feet for the Suffolk Scarp.

A series of beach ridges extending from a point west of Morehead City lies between the Suffolk Scarp and the scarp-like feature at the head of the White Oak estuary. The ridges appear to have been cut off sharply at their eastern ends and to have developed in a fan-like pattern from a point near the mouth of the White Oak River. The ridges are barely discernible on enlargements of the imagery, and they are best studied with negative transparencies (Figure 2). Figure 3 is a black and white print made from a color infrared photograph taken from 65,000 feet (19,700 m), and it illustrates their occurrence in more detail.

Little is known about the geology beneath the Croatan Forest area (Figures 1 and 3), but the LANDSAT imagery suggests one possible generalized interpretation for the Pleistocene events. The scarp-like feature may represent a stand of the Pleistocene sea above the present sea level. Conceivably, the shoreline could have extended eastward to a position somewhat inland from the beach ridges. At the same time a barrier bar complex could have existed, its presence being recorded by the beach ridges near Morehead City. The pattern of the ridges suggests two possibilities: (1) that a branch of the Neuse River estuary may have at one time extended southeastward approximately parallel to U.S. 70 through the Morehead City area or (2) that the eastern end of the beach ridges may mark the approximate position of an "ancestral Cape Lookout." Subsequent to the development of the beach ridges and the scarp-like feature in the White Oak River—New River area, the shoreline fell to the position recorded by the Suffolk Scarp, and the part of the Neuse River estuary draining through the Morehead City area was blocked off from the sea.

It is possible, of course, that the scarp-like feature and the beach ridges are records of events from different times in the Pleistocene history of this part of the North

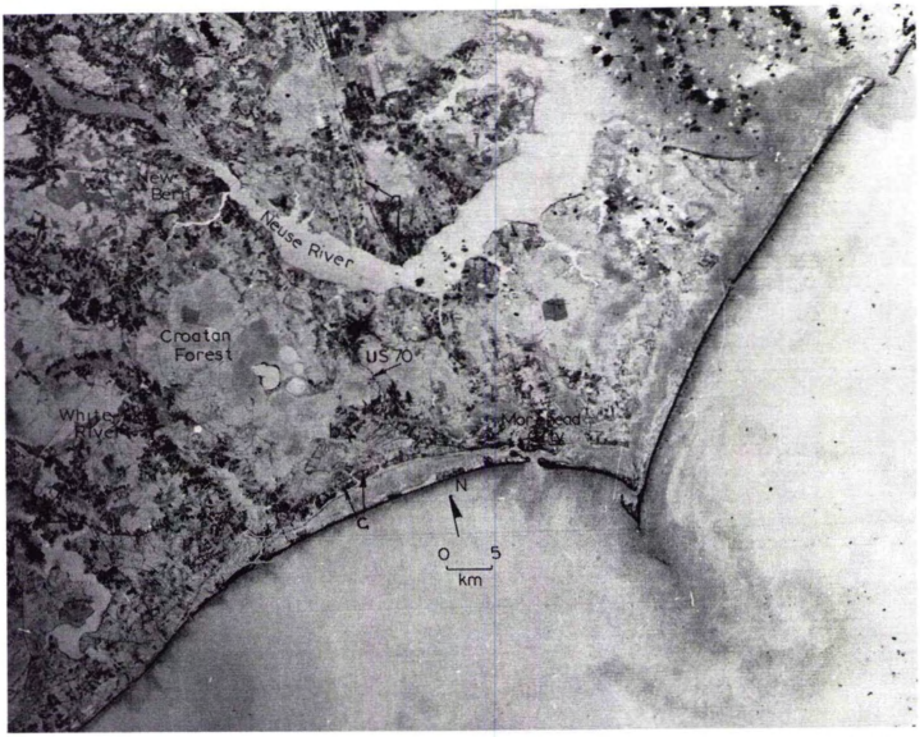

FIG. 2. Neuse River and Minnesott Ridge. Enlargement of LANDSAT-1 Image 1115-15152-5, 15 Nov. 1972. Negative print. (a) Minnesott Ridge; (b) beach ridges; (c) Suffolk Scarp.

Carolina coastal plain. Without detailed subsurface stratigraphic information, it is impossible to ascertain if the interpretation given above is reasonably near the truth or whether some other interpretation is more accurate.

The regional geomorphologic relationships recorded by the LANDSAT imagery suggest that the Pleistocene stratigraphic relations as they are presently understood (Dubar and Solliday, 1963; Daniels *et al.*, 1972) for the area south of the Neuse River should be studied in greater detail than they have been to date. In particular, the studies should show the relationship of beach ridge complex to the lagoonal-estuarine-marine sequence exposed at James City and a similar sequence exposed near the western end of the beach ridge complex. Also, it should clarify whether or not the Croatan Forest area is underlain by estuarine or open water sediments and whether or not the Neuse River had a connection to the sea through the Morehead City area. The LANDSAT imagery should aid the study by providing a regional view of the geomorphology which can then be tied to the subsurface information.

Inland, other scarps and beach features are recognizable in the vicinity of Lumberton and Elizabethtown (Figure 1). In the northeastern part of the state, the Hickory Ridge, the Pungo Ridge, as well as beach ridges near Kitty Hawk all are recognizable on the imagery (Plate 1). The Surry Scarp is also recognizable, although it falls outside the area covered in the photograph. In the Upper Coastal Plain the scarp complex lying in the triangle formed by Raleigh, Wilson, and Goldsboro (Figure 1) may be recognized although not in the detailed manner that larger scale aerial photography permits.

Formational boundaries have been distinguished in parts of the coastal plain (Marley *et al.*, 1973). The distinctions have been partly on the basis of reflectance differences and in part on the basis of land-use patterns. In particular, the contact between the Tuscaloosa Formation and the metamorphic rocks of the piedmont region as well as the contact between the Tuscaloosa Formation and the Black Creek Formation can be recognized in the southeastern part of the North Carolina coastal plain. Southeast of these contacts and trending northeasterly, the contact between the Pee Dee Formation and the Castle Hayne Formation can be traced in a general way.

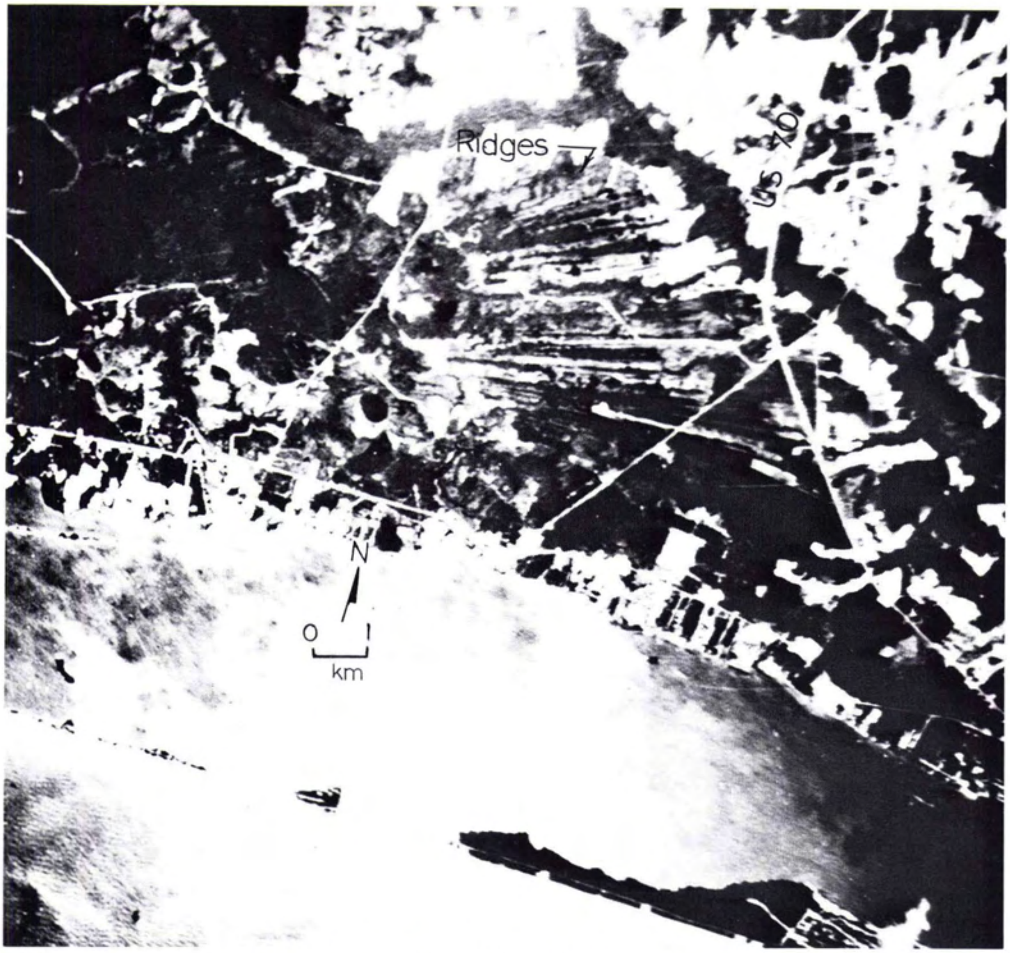

FIG. 3. Photograph from 65,000 feet (19,700 m) of Morehead City area, showing beach ridges west of Morehead City. Black and white print from color infrared transparency (EK2443 film). Source: NASA, Flight No. 73-062, 28 April 1973. UAG 1046-153.30, frame 9310. Original scale 1:130,000.

Green Swamp, a roughly circular vegetated depression (Plate 2), may be interpreted from the LANDSAT imagery as a Pleistocene lake which was breached by the Waccamaw River and drained. Carolina Bays, southeasterly oriented elliptical lakes and depressions, are prominent features on all aerial photographs and images of the North Carolina coastal plain. Their southeasterly trend and concentration between the South River and the Cape Fear River are brought out in LANDSAT image 1080-15203 (Plate 2).

The intricate nature of the updip limit of the coastal plain can be demonstrated especially well with LANDSAT imagery. Figure 4 illustrates the Piedmont-Coastal Plain boundary as found near Raleigh, and this contact is much more intricate than is shown on currently existing maps of a scale similar to that of the LANDSAT imagery.

Two large sand and gravel pits are recorded south of Raleigh, near Lillington. One is located on a high-level terrace of the Cape Fear River and the other is located about 50 feet (15 m) above the floodplain of the Little River, a tributary of the Cape Fear and about 5 km upstream from their juncture. Study of the imagery suggests its possible usefulness in exploration for similar deposits near the westward margin of the coastal plain.

Experience has shown that in coastal North Carolina, as well as in the piedmont region of the state, the differentiation of soils is a difficult task. In fact, in most instances it is impossible to map even soil associations. However, in northeastern North Carolina

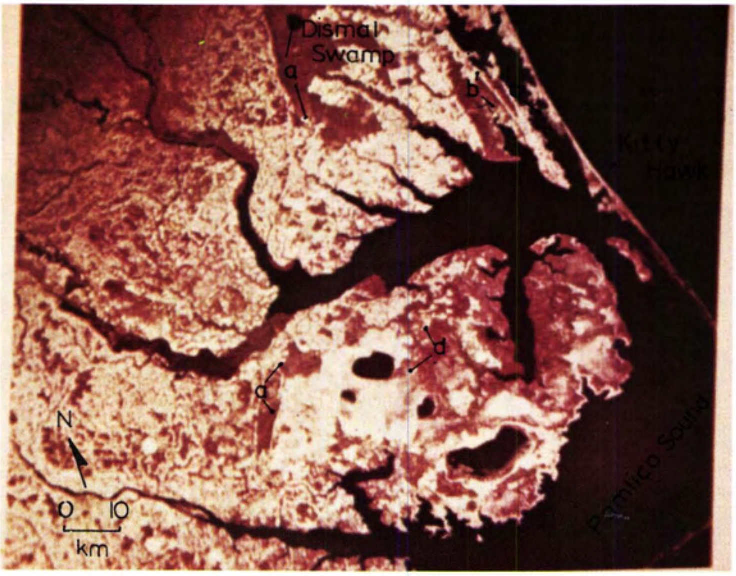

PLATE 1. Coastal Plain of Northeastern North Carolina, showing ridges and scarps. LANDSAT-1 Image 1205-15150, 13 Feb. 1973. False color composite made with color additive viewer. Band 4—blue; band 5—green; band 7—red. (a) Suffolk Scarp; (b) Hickory Ridge; (c) Pungo Ridge; (d) clearing and drainage.

where large-scale agricultural developments are taking place in an area of organic soils, LANDSAT imagery may prove useful in two ways. The first is that patterns of vegetation may possibly indicate differences in soils, thereby showing the distribution of the organic and mineral soils in areas that are difficult of access. Vegetational differences are shown by the reflectances from the Green Swamp area (Plate 2). They are believed to be due in part to substrate differences. Similarily, reflectance differences in the vegetated areas east of the drained areas of northeastern North Carolina (Plate 1) are believed to record substrate differences. The particular false color rendition used to make Plate 1 does not bring out these differences as sharply as other color combinations.

The second is that as clearing and drainage takes place (Plate 1), patterns of relatively wet and dry soils may be monitored. Combinations of bands 4, 5, and 6 are useful in this type of study.

TECTONICS

Because one of the early demonstrated uses of LANDSAT imagery was the mapping of linear features and lineaments, LANDSAT imagery of the North Carolina coastal plain has been studied to see if any regionally important lineaments which might provide clues to structures beneath the coastal plain exist. Aside from those which mark scarps and ridges such as the Suffolk Scarp, most of the recognizable linear features are associated with streams and subtle abrupt changes in shades of gray on the black-and-white LANDSAT photographic products. Patterns of stream bends and stream segments provide many of the clues. The question always arises, of course, "Are we seeing two points which make a straight line?" This question cannot be easily answered in every case.

As an example of this type of study, a LANDSAT-1 image of the upper and middle coastal plain centered near Rocky Mount (Figure 1) shows a number of lineaments. Figure 5 is the interpretation made from Band 5 of image 1314-15204. The study was undertaken to evaluate the imagery as an exploration tool for quarry sites. The Fountain Quarry of the Southeast Division, Martin-Marietta Aggregates is located as indicated on Figure 5. One notable feature arising from this study is found in dominance of two general trends: (1) northwest-southeast and (2) northeast-southwest.

Members of two photogeology classes were given an assignment to interpret LANDSAT-1 imagery of the coastal region with special emphasis upon recognition of

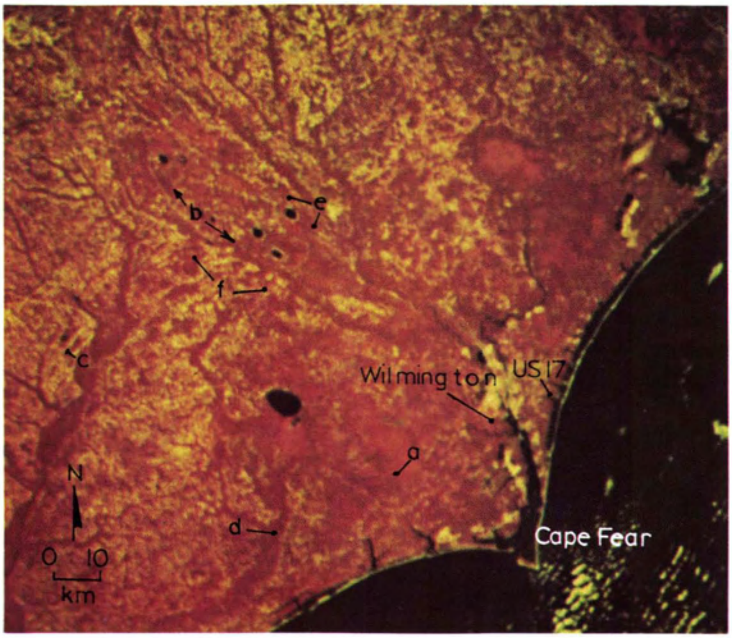

PLATE 2. Cape Fear area. LANDSAT-1 Image 1080-15203, 11 Oct. 1972. False color composite made with color additive viewer. Band 5—green; band 6—red. (a) Green Swamp; (b) Carolina Bays; (c) Surry Scarp; (d) Waccamaw River; (e) South River; (f) Cape Fear River.

lineaments. The study was under the general direction of R. J. Carson III. Most of the work was done with 1:250,000-scale black-and-white prints, although some used the 1:1,000,000-scale positive transparencies and color additive viewing techniques. Man-made linear features were eliminated as were linear features attributable to the known scarps. The preponderance of the lineaments mapped had either northwest-southeast strikes or northeast-southwest strikes. No information was provided the students about the expected results, and thus they had no bias concerning the directions found. Since different interpreters found a similar pattern in different parts of the coastal plain as well as on the same parts, and since images from different times of the year were used, it is believed that the two prominent lineament directions are present.

The dominant linear trend directions of northwest-southeast and northeast-southwest were first noted by Hobbs (1904, 1911). He described two sets of lineaments of the Atlantic border region which had these orientations, and he noted that the lineaments were composite in nature, consisting of crests of ridges, drainage lines, boundaries of formations, or lines of outcrops. The LANDSAT imagery has added to this list notable changes in reflectances.

Brown *et al.* (1972), in an argument based upon regional stratigraphic studies, as well as the work of Hobbs suggest that in these two directions lie two of the critical structural trends of the Atlantic Coastal Plain. The north-south structural trend which also plays an important role in their theory of the development of the Atlantic Coastal Plain is not well represented by linear features on the LANDSAT imagery.

In the case of the Rocky Mount area imagery (Figure 5), most of the Coastal Plain Province is underlain by Upper Miocene sediments, the Yorktown Formation, topped by Pleistocene sediments. According to Brown *et al.* (1972), the depositional environments and patterns for Late Miocene time were controlled structurally by two sets of shears: (1) a master shear direction in an northwest-southeast direction and (2) a complementary shear set in a northeast-southwest direction. Subsequently, in post-Miocene time, the important tectonic directions were a shear in a north-south direction and tensional forces acting in a northeast-southwest direction to open up fractures trending in a northwest-southeast direction.

With our present state of knowledge of the geology of the Atlantic Coastal Plain of North Carolina, one cannot hope to correlate a particular lineament identified on a

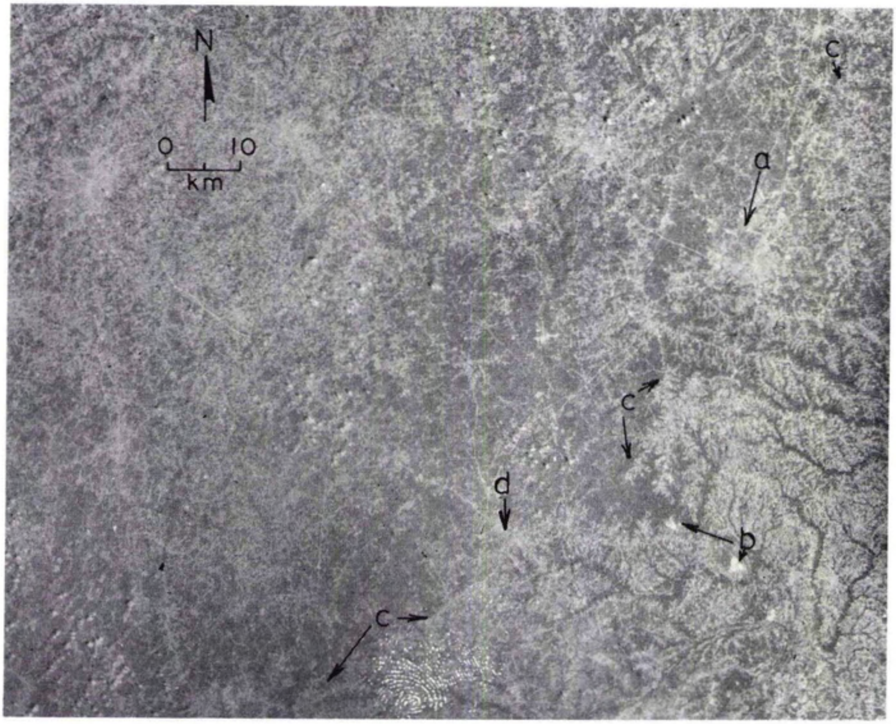

FIG. 4. Coastal Plain—Piedmont boundary near Raleigh. LANDSAT-1 Image 1045-15254-5, 6 Sept. 1972. (a) Raleigh; (b) Gravel pits near Lillington; (c) Edge of coastal plain; (d) Sanford; (e) Lillington.

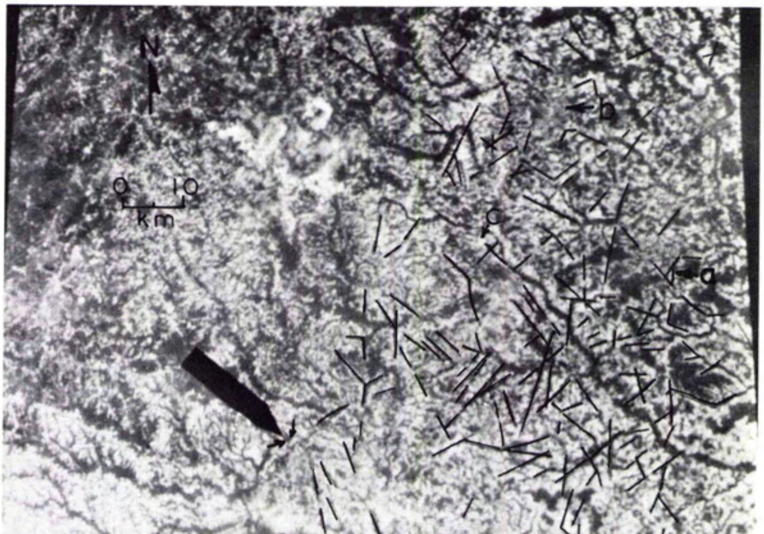

FIG. 5. Lineaments, North Carolina coastal plain. (a) Fountain Quarry; (b) Rocky Mount with several quarries nearby; (c) Wilson. Large arrow points to general location of Coats Scarp, and smaller arrows show its approximate extent. LANDSAT-1 Image 1314-15204-5, 2 June 1973. Picture made using 1:1,000,000-scale transparency, transmitted daylight and Ektachrome ASA 64 film.

LANDSAT image with a particular zone of weakness in the basement or a particular set of crustal forces. Also, if the zones of movement or hinge lines are as suggested by Brown *et al.* (1972), the mechanical situation could well cause development of many small, subsidiary weak zones in the surficial material which would be reflected in a number of ways. The chief reflection would presumably be in the drainage nets of the streams which cross the coastal plain. Weak zones caused either by the tectonic activity directly or by depositional patterns associated with the structural control on the stratigraphy would be preferentially eroded, and streams developing on the sediments within these zones of weakness would reflect the geometry of the structural control. If one looks at the imagery of the North Carolina coastal plain, one is quickly struck by the realization that a number of angular bends in adjacent streams fall along a straight line and that in many cases subtle differences in the tone of the images fall along this same trend. The alignment of bends also can be recognized on topographic maps.

Examination of a map of the barrier islands along the North Carolina Coast ("Outer Banks") discloses that this string of islands is concave seaward except in the stretch north from Cape Hatteras to Oregon Inlet. This part of the island chain is convex seaward (Figure 1). Examination of shallow subsurface data indicates that the Miocene surface is higher along a general east-west axis passing approximately through the point of maximum curvature than on either side. In the Pamlico River and Pamlico Sound erosion had cut well down into the Miocene beds prior to deposition of the post-Miocene beds (Welby, 1971). Directions of the tributaries to the Pamlico River are dominated by the northeast-southwest and northwest-southeast trends.

The path of the Neuse River below New Bern has a northwest-southeast trend in its upper reaches and a northeast-southwest trend in its lower part. Other instances of the dominance of these directions in the drainage patterns can be cited, such as in the area shown along the northern edge of Plate 2.

It would seem that the dominance of these two directions in the drainage patterns of the North Carolina Coastal Plain must be caused by some factor common to the geological history of these streams. On the basis of the stratigraphic evidence cited by Brown *et al.* (1972), one must look carefully at the possibility of a basic structural control to many of the geomorphic features of the coastal plain. If the control exists, it is well reflected in the drainage patterns, and the satellite imagery serves to emphasize the regional nature of these trends.

Conclusion

Many of the geomorphic features of the North Carolina coastal plain are well displayed in the LANDSAT imagery. The synoptic view recorded by the satellite allows a perspective that aids geologic studies of this part of the Atlantic Coastal Plain. Features known, but seemingly unrelated, can be viewed in a context which promotes a synthesizing of ideas and facts to develop new hypotheses to be explored and evaluated in turn. Regional lineament patterns can be determined and evaluated in the light of other geologic evidence, or they may be used for corroboration of interpretations and conclusions arrived at from other lines of evidence. Whether the Neuse River once drained from New Bern southward to near Morehead City, or not, can be proved only by careful stratigraphic studies in the Croatan Forest area. Similarly, the dominance of the northwest-southeast and northeast-southwest trends of the lineaments is a fact which must be taken into account in consideration of coastal plain geology. These features, in fact, may be subtle support for the tectonic and stratigraphic concepts of Brown *et al.* (1972). In the final analysis, the ultimate meaning of the linear features seen on the satellite imagery can be proved only by extensive subsurface geological investigations.

Acknowledgments

Several graduate students aided in the interpretation of the LANDSAT imagery. Walter Marley did much of the initial evaluation of the imagery of the Cape Fear area, and Michael Anderson studied the area around the Fountain Quarry. Robert W. Edwards of the Southeast Division, Martin-Marietta Aggregates granted permission for use of Figure 7 and the related interpretations. Robert J. Carson III supervised the work of students in two photogeology classes who did lineament mapping exercises on LANDSAT imagery. Past discussions with R. B. Daniels and E. E. Gamble concerning the several scarps of the coastal plain and related stratigraphic problems have been drawn upon in the interpretation of the imagery. The continued encouragement of C. F. Withington, U.S. Geological Survey, is especially appreciated. It is a pleasure to acknowledge the contributions of these friends and colleagues.

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BOOK REVIEWS

Manual de Fotografía Aérea, Carl H. Strandberg, Published originally in English by John Wiley & Sons, Inc., N. Y. and the Spanish version by Ediciones Omega, S. A., Casanova, 220, Barcelona, 1975, 9″ × 12″ flexible paper cover, spiral hinge, heavily illustrated, 268 pages, translated from English to Spanish by David Serrat Congost. Price: 1,000 pesetas ($17).

Having had personal experience in translating photogrammetric material from English to Spanish, I can appreciate Sr. Congost's trials and tribulations. Having been a fellow employee with him at Photogrammetry, Inc., I can vouch for the author's (Strandberg's) competence. The title of the English version is *Aerial Discovery Manual* which one must admit is a romantic way to describe a photointerpretation treatise which is slanted toward geology and hydrology. It appears the author had used this book to do some teaching of the subject. The manual is broken up into 18 chapters and also includes a glossary and an alphabetic index. The book is more than a manual; it is a worthwhile textbook. I wish I had had such a book when I was teaching Spanish-speaking students from Latin America in my former Coast & Geodetic Survey (now National Ocean Survey) days in this very subject.

All chapters of the book end with summaries and practical exercises except for Chapter 18, which ends with a summary only. The first part of the book deals with aerial photographic interpretation. Its seven chapters cover material such as aerial reconnaissance, taking of aerial photography, instrumentation, preliminary interpretation, measurements, and comparative analysis. The second part deals with photogeology. Its five chapters cover material such as basic concepts, relief, networks, soils, and terrain analysis (a step-by-step procedure). The last part of the book deals with photohydrology. Its seven chapters cover material such as subterranian water, rivers, lakes, water pollution, algae and water vegetation, and fish.

For anyone who is interested in elementary photogrammetry and its application to geology and hydrology, the English version is a must for his or her library. Those who are more at home with Spanish may wish to acquire the subject book.

—Bernard J. Colner
Bureau of the Census