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UTILIZATION OF ERTS-1 DATA IN NORTH CAROLINA

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16. Abstract

ERTS-1 imagery has been used to study forested wetlands, dynamic processes off coastal North Carolina, and landuse patterns in the Wilmington, North Carolina area. The thrust of the investigation is still involvement of state and regional agencies in the use of ERTS-1 imagery in solving some of their day-to-day problems.

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1.0 Preface

The purpose of the investigation is to demonstrate the usefulness of ERTS-1 imagery in geological evaluation, regional planning, forest management, and water management in North Carolina. Visual analysis of the imagery as well as color additive viewing is to be utilized in interpreting the imagery.

During the period covered by this report both generalized and detailed study of the imagery have been undertaken, and agencies and persons probably interested in its use have continued to be contacted. There has been no general rush to use the imagery, but as the word of its availability spreads an increasing number of contacts are made. It is from these contacts that eventually will come systematic usage of the imagery.

It is generally recommended that the procedures outlined in the proposal continue to be followed.

2.0 Introduction

This report describes the work accomplished under ERTS-A Data Investigation Contract NAS5-21732 during the period June-November, 1973. As with the earlier stages of the investigation, the chief effort has been to acquaint the investigators further with the imagery, to develop the photographic techniques best suited for their situation, to bring to various local and state agencies the knowledge of the availability of the imagery and to continue the educational process in its use. We have found during the course of this investigation that use of the imagery on a routine basis by a regulatory or management agency requires that the agency make a conscious decision to use the imagery in its operations. The agency must be educated to the availability of the imagery and to its potential usefulness, and only through the educational effort does ERTS imagery become thought of as an important tool in resource management.

2.1 Discussion

During the first year of the investigation a considerable amount of the investigator's time has been spent acquainting state and regional agencies about the availability of the imagery and its potential for use in their missions. As a result of the educational efforts the investigators have obtained additional funding for specific projects and have worked cooperatively with the Region J Council of Governments to prepare a proposal for use of ERTS-1 imagery in a regional planning context. This proposal will be submitted sometime in January or early February to a suitable funding agency.

Discussions have been held with planners in the Charlotte area concerning use of the ERTS imagery in their planning program. This planning region has a computer-based municipal information system which if welded to ERTS-1 data would provide the planners with some tools that they do not now have. Discussions about a cooperative venture under the ERTS-1 program are underway.

Two graduate students are making use of the ERTS-1 data in conjunction with Master Degree programs. The first program is geologically related and is a continuing study of the soils and geomorphology of the North Carolina Coastal Plain. The second program is being carried on by a degree candidate in Landscape Architecture who is developing a methodology for application of ERTS-1 data and other data in the upcoming land use study and classification to be undertaken by the State of North Carolina. It is anticipated that a third graduate student will begin a study investigating the relationship between lineaments found on ERTS-1 imagery and groundwater yields in the crystalline rocks of the piedmont area.

Three papers relating to the circulation of suspended material in the sounds and offshore North Carolina have been prepared during the time covered by this report. Two of the papers were presented during the time period covered by this report, and a third is under preparation. Abstracts of the earlier papers have been submitted with this report. The third paper will be submitted to the journal, Photo-Interpretation, and the text and illustrations will be submitted with the next bi-monthly report.

Soil moisture studies in the Wilmington area were initiated, but because of the pressure of other work on the part of the cooperators, only a limited amount of data was collected during the summer. At this point in time the imagery has not been evaluated in terms of the soil moisture evidence. The soil moisture data from the several experimental stations scattered around the stateare being compiled for the last summer, and it is planned to make a study of the usefulness of this data in interpretation of the ERTS-1 imagery during the upcoming months.

During the spring semester 1974 a photogeology class will work with the ERTS-1 imagery, with available SKYLAB imagery, and with available aircraft imagery. Some of the class will work with land use problems, and others will attack geological problems. When the work is completed, there will be the opportunity to evaluate the various types of imagery in terms of its usefulness for various purposes. With the study which was undertaken by a photogeology class last spring available, we should obtain a good insight into the limits of the ERTS-1 data for various purposes, and some information about how well people can be trained to make satisfactory use of the imagery.

Conferences were held with personnel at the University's Mountain Horticultural Crops Research Station near Asheville to access the utility of the imagery in monitoring crops in the mountains of North Carolina. Further work needs to be done along this line, but the indications are that ERTS-1 imagery will probably have limited usefulness for this purpose. The problem is a matter of scale and the ability to differentiate in the mountain setting between the different types of horticultural crops and to differentiate them from the surrounding natural vegetation, especially forests.

Within the geological purposes of the investigation, Dr. Robert Butler, Geology Department, University of North Carolina, Chapel Hill, reports that he has used black and white 1:250,000 enlargements of ERTS-1 imagery to extend known lineaments in the western part of the state and to recognize several lineaments not previously known to him. He also reports that he was able to identify a major gabbro body but was unable to recognize another major gabbro body in the same image.

The work done to date indicates that recognition of previously unknown fracture patterns and recognition of new lineaments in the piedmont and mountain regions of North Carolina will be the most important geologic contribution of ERTS-1 imagery to understanding the geology of the state. Some presently unknown structures may be discovered when all of the images are studied in great detail, and modifications of the present understanding of the geology of the state may be made as a result.

The greatest usefulness, geologically for the imagery appears to lie in the coastal plain. Broad soil groups appear mappable, and the distribution of organic soils in areas of intensive agricultural development can probably be mapped at the series level. This fact has important implications in that parts of the northeastern area of the state have inadequate soils maps, and knowledge grained from the ERTS-1 imagery could play an important role in proper planning and management of the agricultural lands.

During the six months period covered by this report additional funding to support some of the ERTS-related studies have been obtained by the principal investigator. The Office of Earth Resources, one of the state agencies which contributed funding for the original proposal, made available another $1,000 to support a detailed investigation of the use of ERTS-1 imagery in interpretation of the geology, soils, and related matters in Region J (Raleigh area). On-going field work provides data for comparison with the imagery. The Region J study being conducted by the Office of Earth Resources is a pilot study in land use capability mapping and geologic mapping for planning and management purposes within each of the 17 regional planning areas. If the ERTS-1 data can be demonstrated to be capable of speeding up the basic mapping considerable economics will accrue to the state.

Attempts at getting planning personnel in the Winston-Salem Greensboro planning agency to study the ERTS imagery and to utilize it in their routine work have continued. It is expected that further discussions concerning their needs and their interests will be held in January. The planners have expressed considerable interest not only in the ERTS-1 data but also in the U-2 photography flown in September as groundtruth support. Discussions were held with planners from the Charlotte-Mecklenberg unit about cooperative programs using ERTS data, and a presentation was made to a group brought together by the planners in October. Preliminary discussions about use of ERTS-1 imagery in the Albemarle Sound area (Planning Region R) were held in October. It will take a period of time for these discussions to bear fruit, but the fact that the North Carolina State ERTS project is located in Raleigh at an educational institution would seem to have advantages. Among these is the education-orientation that we can take with respect to planning officials with little or no expertise in any type of remote sensing and its applications. Region R will provide an interesting experiment once the proper arrangements are made.

One of the important factors in use of ERTS-1 data for monitoring various phenomena is the incidence of cloud cover. To obtain some information on the control that cloud occurrence has on acquisition of data, a study was made of the imagery received through Spring of 1973. It was found that certain parts of the state statistically had a greater incidence of cloud cover than others. The detailed report is appended.

We have continued to issue the "ERTS-1 Newsletter" to keep potential ERTS data users informed of advances in the national as well as the North Carolina program. Issues summarize the availability of ERTS-1 images in the North Carolina State files and its quality. Also summaries of ERTS-1 reports and symposia have been presented through this medium. This endeavor has been at no cost to NASA. The technical and scientific monitors receive copies.

2.1.1 Significant Results

a. Mapping

During the period covered by this report a graduate student (landscape architecture - regional planning) not previously acquainted with the ERTS-1 imagery worked with selected images of North Carolina. He reproduced the imagery by making direct contact duplicates with Kodak SO-015 film from the 1:1,000,000 positive transparencies and cut the duplicates to fit 35 mm glass mounts. Projection of the scenes was then on to mylar supported on a 42-inch square glass plate mounted to be rigid. A suitable mount was made at a cost of about $40 for materials.

In the actual mapping an outline map showing the roads and cities was drawn on the mylar, and then the ERTS-1 imagery was projected onto the mylar at the scale desired.

It was found that the uninitiated should begin work with the imagery projected at a scale of 1:1,000,000 or 1:500,000 to familiarize himself with the imagery and the major features seen. Small areas with which the user is familiar should be studied at a scale of 1:250,000 or 1:125,000 for further familiarization.

For recognition of features smaller than 10 acres the user needs to understand how the imagery is obtained and the effects of the averaging of reflectances by the MSS.

One conclusion reached in the study was that when one is working at a scale of 1:125,000 or larger, he should not attempt to classify areas smaller than 25 acres; at this size shape is useful in identification.

At scales larger than 1:125,000 the most important guides to interpretation are brightness in the gray level imagery and color and intensity of the color in color imagery derived from a color additive viewer together with alternate sources of information. Often areas can be interpreted in terms of the context in which they lie; e.g., a large vegetated area in a city may be a park, a golf course, or some other largely grassed area.

The mapping of variables can be done in several ways, from different bands of the same image or from imagery of different dates, or a combination. The most effective way to map a variable seemed to be to search the study area for each occurrence, circle the occurrence with a fine-pointed pencil, and later outline the boundaries of the occurrence. Once the more obvious occurrences have been outlined, the less obvious seem to become clearer.

Knowledge of an area as well as availability of supporting data aid the interpreter to utilize the imagery with the greatest effectiveness. The technique described here can be used by regional planners with a minimal amount of equipment and budget.

The discussions and notes on which this result is based will be formalized, printed, and circulated to appropriate planning personnel in the state within the next several months. It is an attempt to answer the oft-asked question, "But how can we use the imagery?"

b. Land Use Studies

Image 1080-15203 (October 11, 1972) of the Wilmington, North Carolina area was studied for land use patterns. Cloud cover over Wilmington made it difficult to distinguish open areas from clouds in the immediate area of the city. Major ponds and open areas are clearly discernible, as is the work being done at the Carolina Power and Light Company's Southport nuclear generating plant site. It was also discovered that the coastal islands appear to have different sizes and shapes from those shown on the 15' U.S.G.S. map available for the area.

The Lake Waccamaw area northwest of Wilmington was studied at a scale of 1:62,500 in black and white, using bands 5, 6, and 7. Composite color renditions of the scene were made with a color additive viewer. The area around Lake Waccamaw has swamps, forests, mixed farmland, and forested swamp. Tracts which have been recently harvested are readily recognized by the different red hues found on the color composite. It is believed possible to identify prime cypress stands in southeastern North Carolina from ERTS imagery.

A land use map was prepared for an area bounded by latitudes 34° 15' and 34° 22' 45" N and longitudes 78° 15' and 78° 35' W. The land uses mapped were forested, open, and water. Areas as small as 5 acres were separated, and a total of 175 square miles was mapped in about 8 hours.

Comparison of the ERTS-based map with a U.S.G.S. topographic sheet based on 1951 aerial photography showed a near-doubling of open land since 1951.

The effects of the different depths of penetration of the band 5 and band 7 energy affected the interpretation of the boundary of Lake Waccamaw. It was found that band 7 gave the correct dimensions of the lake, recording the existence of the very shallow edge portions of the lake. Band 5 showed a smaller water body.

Mapping of forested wetlands in eastern North Carolina is facilitated by the use of imagery which has been acquired when the foliage is off the deciduous trees. North of Albemarle Sound forested wetlands were mapped at a scale of 1:250,000 using ERTS images 1205-15150 (February 13, 1973), image 1133-15150 (December 3, 1972), bands 5 and 7. The presence of snow on the ground on February 13, 1973, and recorded on the image aided in the interpretation. Fields and open terrain showed white, water black, evergreens white, and deciduous trees showed gray. Comparison of the February image was made with the December 3, 1972, image which was taken a week after a period of moderate rainfall. Wet areas showed predominantly dark gray and black in the band 7 imagery.

Maps made by projecting 1:1,000,000 scale black and white imagery in a 35 mm format from each of the two images were overlain and the forested wetlands were then delineated.

The results of the investigation suggests that mapping at a scale of 1:62,500 is possible and that reductions from this scale to 1:125,000 or 1:250,000 will provide accurate maps for regional planning purposes. Based upon this experiment it is concluded that a person reasonably familiar with ERTS imagery and a region can prepare an accurate map of forested wetlands in a 5,000 square mile area of eastern North Carolina, or similar region, at a scale of 1:125,000 or 1:250,000 in a matter of two or three hours, and certainly within one working day, once the imagery is prepared for projection in a 35 mm format. Color additive viewing of 1:500,000 enlargements can also be used to map directly from the viewer screen at scales of 1:125,000 approximately. The exact scale depends upon the type of viewer used and the scale of the imagery placed into the optical system of the viewer.

c. Forestry and Urban Green Space

Use of information contained on the ERTS-1 imagery for mapping coastal wetlands has been described in (b). The utility of ERTS-1 imagery for work with urban green space including forested areas is being studied, and preliminary results will be described in a future report.

d. Geology

Preliminary evaluation of soils groundtruth and ERTS imagery in the southeastern part of North Carolina has suggested that it should be possible to recognize the histosols of the coastal plain from the ERTS imagery and to map them on the basis of their spectral responses. If the preliminary evaluation is correct, it should be possible to map the histosols in Beaufort and Washington counties and with sequential imagery already available and presumably coming in the future to study the effects of the large-scale clearing and drainage projects currently underway in these counties and adjacent Dare County.

A stream segment analysis along the Cape Fear Arch is in progress. Its purpose is to evaluate the geomorphology of the southeastern part of North Carolina (Wilmington test site) to determine if the Cape Fear Arch is reflected in the drainage patterns.

If the Arch has affected drainage patterns, then grounwater flow patterns may likewise be affected by jointing systems developed in the Castle Hayne Limestone, a major aquifer in this region. Space-acquired data on such jointing systems would aid in development of proper planning and management techniques for the aquifer by the Office of Water and Air Resources.

ERTS-1 imagery of the Wilmington test site has demonstrated the control old beach ridges and shorelines exert on coastal stream drainage patterns. Although this relationship is not unexpected and in a general way known, the ERTS imagery in its synoptic coverage permits recognition of the relationship on a regionwide basis rather than on a piecemeal basis associated with even U-2 imagery.

Recognition of lineaments and geologic structures on the imagery has been put aside somewhat as there were no pressing needs to re-demonstrate that such a use could be made of the imagery. However, geologic studies pertaining to western North Carolina are underway, and ERTS imagery is being supplied to the investigators. Some unsuspected lineaments have been recognized and known ones confirmed.

In the Hickory Nut Gorge area of the Bat Cove, North Carolina quadrangle a known fault has been extended on the basis of ERTS imagery. Three sets of good lineaments not previously known have been recognized in the South Mountain area of North Carolina. A gabbro outcrop south of Rock Hill, South Carolina is outlined best in band 7 imagery as the area is swampy. Along the Blue Ridge the Brevard Zone trend is well illustrated in the ERTS imagery, the low sun angle aiding in bringing out this feature from Wilkesboro northeastward.

Use of the imagery by a photogeology class in the Spring semester combined with the results of usage by a similar class in the Spring of 1973 will allow us to make a better evaluation of the imagery's usefulness for geologic interpretion in the mountain and piedmont areas of North Carolina by the end of the semester in May 1974.

e. Coastal Processes

As has long been recognized space-acquired data in its synotpic view gives the opportunity to study coastal and near-shore open ocean processes in a manner heretofore impossible. The repetitive nature of the ERTS-1 imagery allows development of an understanding of those processes even in the absence of extensive groundtruth. It is the capability to apply relatively inexpensive techniques to the imagery to acquire knowledge of these processes that makes the imagery so interesting and valuable.

To bring this capability of the satellite to a broader audience, the principal investigator presented a paper at the annual meeting of the Geological Society of America in Dallas, on November 14, 1973. The paper described some of the coastal processes of the North Carolina coast as seen from the ERTS imagery. A copy of the original manuscript is attached. Since the funds supporting this investigation are limited, copies of the slides used are not included with this report. However, the images utilized in the paper are indicated in the manuscript.

Coastal processes described from ERTS-1 imagery were discussed at the International Symposium on the Interrelationships of Estuarine and Coastal Sedimentation, Bordeaux, France, July 9-14, 1973. A copy of the manuscript for the Symposium publication is attached. An abstract of the publication was sent with an earlier report.

f. Water Resources

Sediment plumes going into major reservoirs have been described in previous reports, and the ability to monitor these features continues to be an important contribution of the ERTS imagery. Distribution of suspended matter in the estuaries and sounds have been described in the two papers mentioned in (d). It appears that movement of pollutants, thermal or suspended, can be predicted when the imagery is related to the meteorological conditions immediately preceding an overpass. Furthermore, the imagery can be used as a check against computer models of water circulation and be a useful tool in the design of models so that they accurately predict water mass behavior. A good application in which EPA and the AEC should be interested would be the case of the Carolina Power and Light Company's nuclear generating plant at Southport. This plant will discharge heated water about 700 meters offshore and a mile or so west of the mouth of the Cape Fear River.

Planning of water quality sampling programs in the Chowan River and Albemarle Sound should be guided by data obtained from ERTS imagery. In particular, an area in which little suspended material occurs is found at the eastern side of the mouth of the Chowan River rather consistently. This information was not available until the advent of the ERTS-1 data, and the information would seem to be important in development of an understanding of the eutrophication pattern of the river. Because of its location it is not currently being sampled. Efforts are being made to have this information along with other ERTS-1 data and related interpretations utilized by the Water Quality Division, Office of Water and Air Resources in the design of their water quality sampling program. This information and the resulting sampling design will contribute to a study of the Chowan River which is a cooperative venture on the part of the Office of Water and Air Resources, E.P.A., the U.S. Geological Survey, and the Water Resources Research Institute of the University of North Carolina.

g. Meteorological Evaluation

Since the repetitive nature of ERTS-1 imagery is an important aspect of the operation of the system for monitoring purposes and because the North Carolina investigation required the receipt of all imagery over the state with less than 50% cloud cover, a study was initiated to evaluate the reliability of the system in terms of the incidence of cloud cover. The investigation utilized the imagery available through August 1973, covering only about 9 months of imagery as the summer 1973 imagery had not all been received.

Two orbits appear to have the greatest probability of producing usable imagery: one passing over the Raleigh area and the next one west, over Winston-Salem. The orbital paths cross mainly the piedmont part of the state. The details of the study are attached to this report.

h. Cost-benefits

Cost-benefits are hard to assign in this investigation because of the manner in which it is being carried out. We cannot isolate specific benefits, nor can we isolate costs in detail beyond the initial NASA support, the support from individual agencies, and the matching funds of the University in terms of investigator's time. It is apparent to us at this point in time that the ERTS system has a great many potential benefits to North Carolina and that as the availability of the imagery becomes more widely known more use will be made of it. We have tried to address ourselves to helping people inexperienced in the use of the imagery to see the potential benefits in a regional planning context and to have them identify specific problems which they want and need to have solved. Once land use legislation now pending before the state legislature is enacted, planners and governmental representatives should prove more receptive to the use of the imagery on a routine basis as they will need the type of land use information that the imagery can provide and which is not available in any other form. The pressures of deadlines should have a very invigorating effect upon the interest in use of the imagery. It is at this time that the benefits will clearly begin to outweigh the costs.

One investigation begun with the support of the U. S. Army Corps of Engineers, Wilmington District during the report period concerns the mapping of the extent of Eurasian Watermilfoil in Currituck Sound. This study offers a good opportunity to make a cost-benefit evaluation within an operating format. The results of the investigation will be described in a future report, and the cost-benefit question will be addressed at that time.

We see broad uses for ERTS imagery. We have become acquainted with it and have begun to involve people with practical problems to solve in its use. There is even now a lot more educational work to be done before use of the imagery is more or less routine. We have attempted to get across the idea that the imagery is a new tool; we believe that the imagery should not looked upon as simply a high-level aerial photograph, although at times it is expressed in this format. Rather the imagery should be looked upon in terms of the synoptic coverage it gives and the ability to see relationships heretofore difficult to study. Its repetitive nature is of considerable value in some studies, and not so important in others. Yet even in the geological discipline the repetitive coverage allows recognition of features not seen in an earlier image because of differences in vegetative cover or differences in sun angle.

In our opinion the ERTS system is quasi-operational or could go operational with little additional effort for land use inventories, for delineating broad soil groups in the coastal plain, for study of water quality patterns in coastal regions, for study of circulation patterns in the sounds and estuaries of North Carolina, and for improving our understanding of coastal dynamics. The biggest problem at the moment is the time lag that exists between the pass of the satellite and the receipt of the imagery by a user with a practical problem. Delays in distribution of the imagery from NASA, let alone those that have been experienced by potential users from the EROS Data Center make for frustration and the turning away from the ERTS data to other sources more readily available although not necessarily more accurate or meaningful.

2.2 Future Program

The investigation will continue along the same general lines it has. An increasing amount of time will be spent on applying ERTS imagery to problems of particular interest to the investigators but which have been identified as of probable concern to various state and regional agencies. Efforts will continue, however, to get regional planning agencies directly involved as well as other agencies which the investigators see as capable of deriving benefit from the investigation.

3.0 Conclusions

Our conclusions about the usefulness of the imagery remain the same as in earlier reports. The chief problem remaining is that of education. Potential users are still reluctant to devote time, effort, and money to learn about the imagery in depth. It is a new tool which will gain acceptance slowly.

If it could be demonstrated that a sequence of ERTS-like satellites with improved resolution were to be launched in the forseeable future, the responses from potential uswers would in all probability be more positive.

4.0 Recommendations

It is generally recommended that the investigation be continued as in the past.

The extension of the contract by NASA in October to September 1974 will permit us to work with potential users on special problems and to seek further non-NASA funding. The effectiveness of our efforts can be enhanced by supplemental NASA funding, but successful conclusion of the investigation does not hinge on additional NASA funding.

Investigation Title: Utilization of ERTS-A Data in Geological Evaluation, Regional Planning, Forest Management and Water Management in North Carolina

Proposal No. 18

GSFC ID No. UN 281

Contract No. NAS5-21732

Principal Investigator: Charles W. Welby

1. Agricultural/Forestry/Range Resources

H. General

By combining images taken at two different times (1133-15150 and 1205-15150) it has been possible to map forested wetland in Chowan, Hertford, Pasquotank, Camden and Currituck Counties of North Carolina in a matter of a few hours. Adequate other types of imagery are not available for much of this area, and if they were, the time required to assemble them and interpret them for mapping at a 1:250,000 scale would be greater than that required to assemble the same data from ERTS imagery.

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3. Mineral Resources, Geological Structures, Landform Surveys

I. Landform Surveys

Study of ERTS-1 imagery of the southeastern part of North Carolina has demonstrated the control old beach ridges and Pleistocene shorelines have on coastal stream drainage patterns. This information can be utilized in the preparation of land capability maps.

Geomorphologic evidence of previously unsuspected lineaments is well displayed in parts of western North Carolina.

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5. Marine Resources and Ocean Surveys

B. Survey of Current and Ocean Dynamics

A sequence of 6 images covering a period from October 1972 through June 1973 show the effects of wind, tide, and current on the coastal waters in the region of Cape Fear of North Carolina. The information is important in understanding what may happen to a warm-water plume to be discharged near the mouth of the Cape Fear River from a nuclear generating plant located at Southport.

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7. Environment

C. Lake and River Pollution Surveys

Water quality sampling programs can be guided by ERTS imagery in the larger rivers of the coastal plain of North Carolina, and particularly where they spread into the estuaries and sounds. The imagery provides clues to the dynamics of the system. ERTS-1 information will be used to guide a study of the Chowan River.

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8. Interpretation Techniques Development

G. General

A relatively simple mapping procedure using 1:1,000,000 scale imagery mounted in 35 mm format has been demonstrated as being useful for many interpretations and mapping problems associated with landuse inventories. The technique consists of mounting a portion of a 1:1,000,000 positive transparency in a 35 mm glass slide and projecting the image onto a vertical glass plate with mylar mounted on it. The technique requires a minimum of readily accessible equipment and some acquaintance with the region of interest, ERTS-1 imagery, and its usefulness and limitations. Demonstration of the technique makes it possible to make ERTS-1 imagery useful at the organizational level of the multicounty North Carolina regional planning agencies. A minimal amount of training and equipment will enable planning personnel to make use of the ERTS-1 imagery.

NORTH CAROLINA ESTUARINE-SHELF COMPLEX -
PLEISTOCENE TO RECENT HISTORY

International Symposium on Interrelationships of
Estuarine and Continental Shelf Sedimentation

Bordeaux France July 9-14, 1973

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15-A

NORTH CAROLINA ESTUARINE-SHELF COMPLEX — PLEISTOCENE TO RECENT HISTORY

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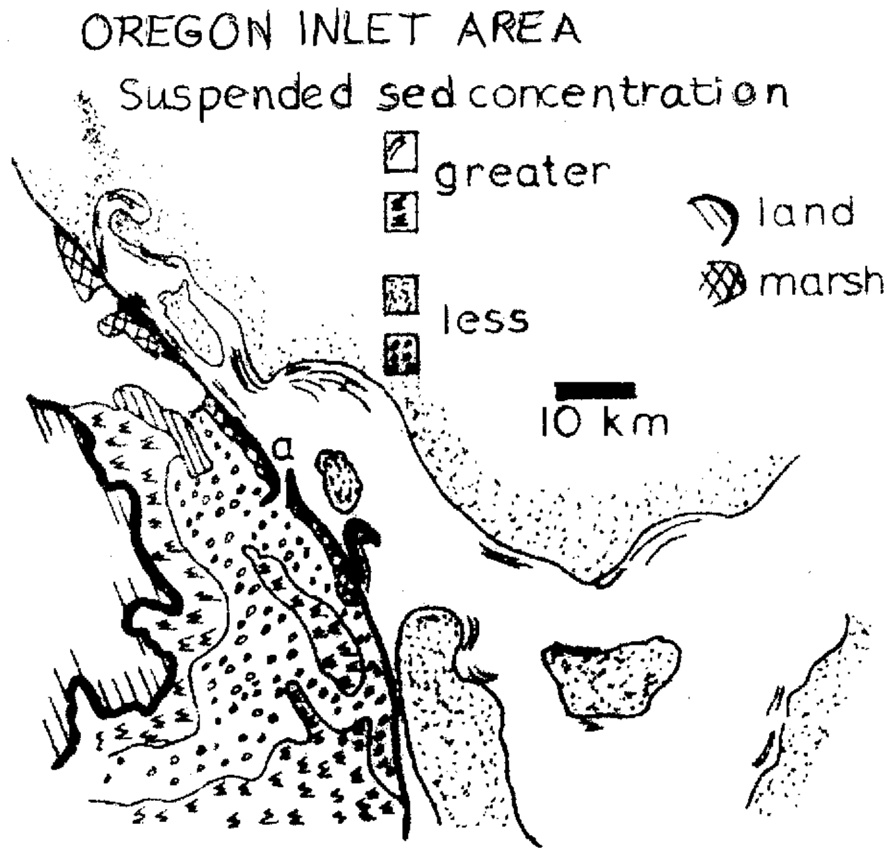
Like many coastal regions the North Carolina coast has a diverse geologic history. Its present form and the present processes are influenced by what has gone before. The following discussion addresses itself to two aspects of the development of an understanding of the North Carolina coastal region. The first aspect is that of the post-Miocene geologic history; the second is that of present-day processes and the relation of the estuarine areas to the continental shelf.

Figure 1 shows the area being described. An important element in the discussion of the relations between the shelf and estuarine deposition is the presence of the well-known barrier islands, the "Outer Banks."

Post-Miocene History

Generalizing about the history of the North Carolina coast, it appears that during Late Pliocene to Early Pleistocene erosion took place. Streams incised themselves into the Late Miocene formations, and many of the major streams still follow the sites of this downcutting. Erosion developed an undulose surface on the Miocene and older beds.

As sea level rose during the Pleistocene, marine water crept up the stream valleys, and as the coastal area was inundated, sediment accumulated to greater thicknesses in the lower areas than in the topographically



a. Oregon Inlet and tidal delta
Fig. 5 ERTS-1 1222-15093
Mar. 2, 1973

higher ones. Some of the best records of Pleistocene events appear to lie beneath the waters of Pamlico Sound and adjacent areas. In general there is a seaward thickening of the post-Miocene section.

The Pleistocene sediments exposed on land record a mixture of marine and nearshore environments in an as yet incompletely deciphered pattern. So in a general way we see the Pleistocene recorded not too differently from what we find today, except that the margin of the sea lay farther inland than at the present.

A high resolution boomer study of the Pamlico Sound area has shown the presence of three post-Miocene unconformities in addition to the unconformity existing between the Late Miocene and Pleistocene sediments. Shideler and Swift (1972) describe a basal boundary reflector off the North Carolina and Virginia coasts at depths of 40 to 80 meters. The contours shown on their map can be interpreted as extension of the structural contours presented by Brown, Miller, and Swain (1972) for the top of the Late Miocene. The geophysical work in Pamlico Sound generally agrees with the subsurface interpretations of these authors. It thus appears that for much of the eastern one-half of Pamlico Sound that the top of the Miocene is between 50 and 60 meters below sea level.

The unconformities found beneath Pamlico Sound are best defined in the geophysical records on the basis of the edges of channels, but inclined bedding and locally cross-bedding also assist in their recognition. Swift and Shideler (1972) recognize in the Cape Hatteras to Cape Henry stretch of the shelf a set of unconformities which appear to correlate with those described in this report. They attribute the sedimentation in the lowermost post-Miocene sequence to fluvial processes and recognize the middle unit as nearshore in origin. O'Connor and Riggs (1971) describe extensive channeling perpendicular to the coast in what appears to be the upper part of the Sequence discussed here. They suggest fluvial and/or tidal activity as the cause of the channels.

One drill hole near Swanquarter on the northern shore of Pamlico Sound (Welby, 1971) clearly cut through the lower post-Miocene unconformity into the Miocene beds. The macrofossil assemblage in the beds immediately above the Miocene suggests a marine environment of at least 10 meters water depth. Other drill holes along the northern shore of Pamlico Sound indicate that much of the post-Miocene interval is marine with the exception of the upper 3 meters or so. The channeling, which is very prominent in many places, is believed to represent erosional events during periods of lowered sea level. The back-filling in the channels in the western part of Pamlico Sound can apparently be connected to deposits under present land areas, implying that much of the back-filling took place as sea level rose to cover the higher areas. In some places the bedding is suggestive of a deltaic environment.

No clear channel pattern throughout the sound has been discovered. However, near Ocracoke Inlet a pattern suggests that during each break in sedimentation channelized water flowed out onto the shelf area near the western end of the present Ocracoke Island (Fig. 1). Tidal channels in Ocracoke Inlet are an extension of this pattern.

In summary it appears that the Pamlico Sound area experienced at least three marine invasions prior to being shut off from the sea and developing its present configuration. The landward margins of these transgressions lay west of the present sound. One of these invasions is recorded by the Suffolk Scarp which is well shown in several satellite images of the area (Fig. 1).

It appears from drilling elsewhere in the North Carolina Coastal Plain that the oldest post-Miocene beds extend west of the Suffolk Scarp (Daniels and Gambel, *personal communication*, May, 1973) and that much of the post-Miocene record is pre-Wisconsin in age.

Present-Day Processes

Although today's shoreline activities do not necessarily duplicate those of the past exactly, we can get some appreciation of the energy relations and sediment transport patterns from today's circumstances. In recent years considerable study of coastal erosion has been undertaken and some long-term patterns of coastwise sand movement developed (Langfelder, et al, 1968). One recently completed study (Masterson, 1973) suggests that the net sediment movement through the inlets is associated with the ebb tide. Thus far, however, the coastal system has been studied piecemeal, and not all of the pieces have been fitted together. Repetitive satellite imagery has provided an opportunity to study some of the coastal processes synoptically.

ERTS-1 Imagery

Any number of air photographs exist which show sediment movement along the North Carolina coast and which show sediment plumes off Cape Hatteras, Cape Lookout, and Cape Fear. With the advent of the ERTS-1 satellite operating on its eighteen-day cycle, it has been possible to obtain imagery over a large area for different wind and tide conditions. Study of the ERTS-1 images taken since the fall of 1972 shows the strong influence that wind conditions have on sediment behavior in the estuaries as well as offshore. Only a few examples can be presented here.

Wind and tidal conditions associated with the November 15, 1972, ERTS-1 pass over coastal North Carolina as well as the interpretation of the sediment patterns seen on ERTS-1 image 1115-15152 are found in Fig. 2. The patterns taken from a density slice of the .5 to .6 micron band show the decrease in suspended material away from the Cape. The original image suggests not only a mushroom-like plume but also a southward drift at some depth below the surface.

Cape Hatteras and the sediment plumes adjacent to it are generally well known from the Apollo IX photographs. ERTS-1 has provided some interesting imagery of this area, including information on the behavior and migration of the Gulf Stream.

On December 2, 1972, January 25, and March 2, 1973, the Hatteras area was imaged. Figure 3 illustrates the tidal and wind data for the area on these dates, and Figure 4 is an interpretation of the ERTS-1 images. A southward drift from Oregon Inlet toward Cape Hatteras is suggested for the nearshore region in the original imagery. Sometime before the image was made local conditions caused the development of a northward arching of the Hatteras plume just offshore. The sediment is strung northeastward and apparently sharply sheared off by the west side of the Gulf Stream.

In the January 25, 1973, image of the area north of Cape Hatteras the sediment load is diffused. A faint northward arching pattern about 20 km offshore and in the same approximate position as for the December 2 image is present. A two-pronged pattern of sediment distribution lies about 50 km offshore.

The March 2 image shows the stretching of the Hatteras plume to the northeast, and interestingly enough, it shows the presence of at least two layers of suspended sediment. The long, finger-like northeastern part of the plume seems to be deeper in the water (a in Fig. 4) than the parts closer to the shore. The image is interpreted as showing at least two periods of sediment injection into the system. The arching seen in the December and January images just north of Cape Hatteras does not seem to be present at this time. Figure 4 illustrates the several positions of the Hatteras plume at the different times. Shifting of the plume undoubtedly has had an effect upon the distribution of suspended material.

Details of the sediment distribution pattern in the Oregon Inlet area on March 2, 1973, is shown in Fig. 5. The flood tide delta at the inlet is visible as is the pattern of sediment concentration along the shore and offshore. It seems probable that the sediment concentration in the lower right hand corner of the figure represents a plume extending northward from Cape Hatteras.

Conclusion

In studying estuarine-shelf sedimentation, we often cannot pinpoint the dynamics of the system. Looking through drill holes and studying seismic information, we see the results of a complex matrix of events, the end result of the geologic events. Usually we look at only a small portion of a region.

ERTS-1 imagery gives an opportunity to see synoptically and repetitively the events that are going on over a large area and the dynamics of the system. In studying sediment transport from behind the barriers, we cannot ignore the fact that currents offshore act both longshore, toward land, as well as seaward. Our interpretation of geologic history must take these facts into account.

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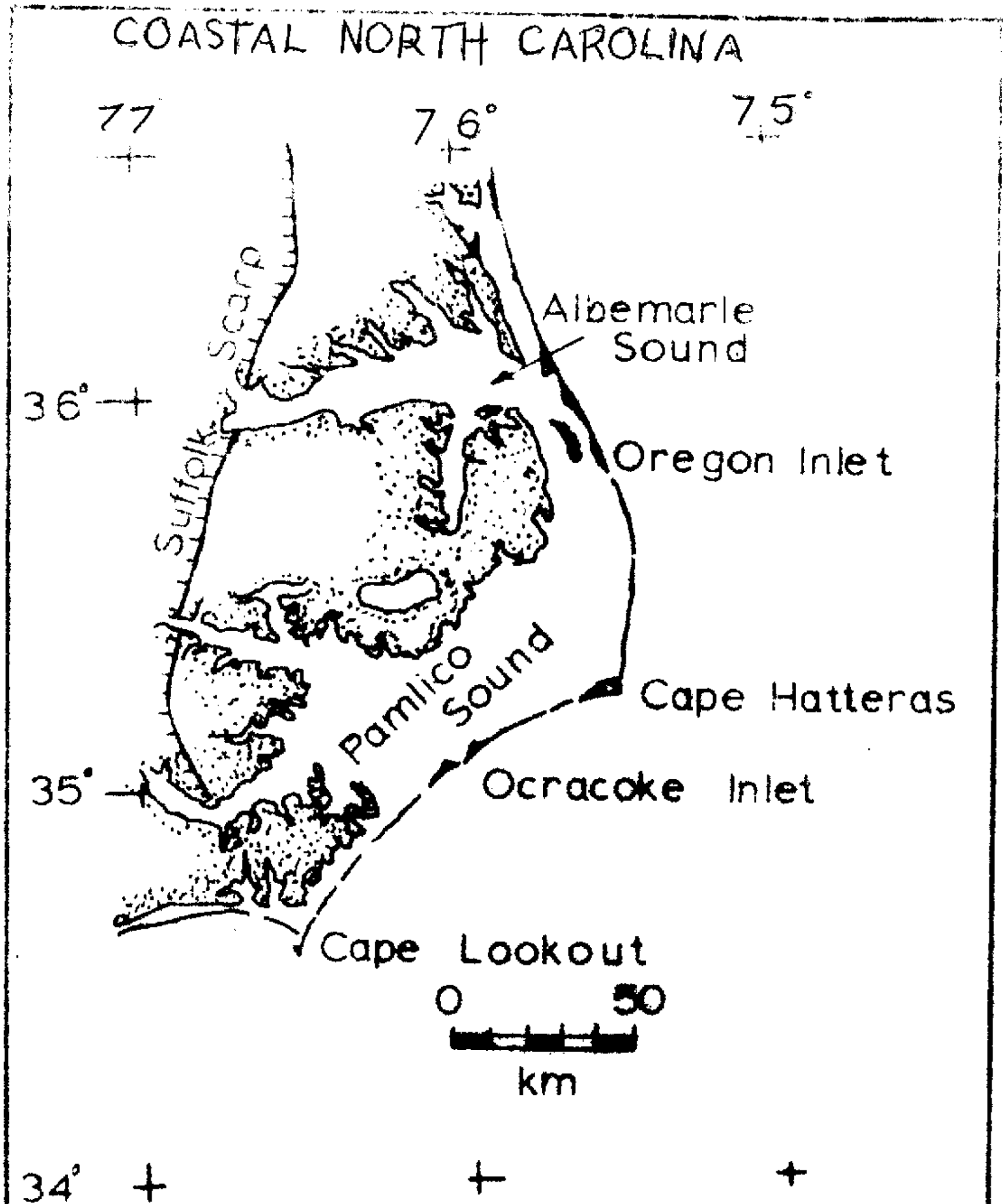

COASTAL NORTH CAROLINA
77
76°
75°
36°
35°
34°
Suffolk Scarp
Albemarle Sound
Oregon Inlet
Pamlico Sound
Cape Hatteras
Ocracoke Inlet
Cape Lookout
0
50
km

Fig. 1

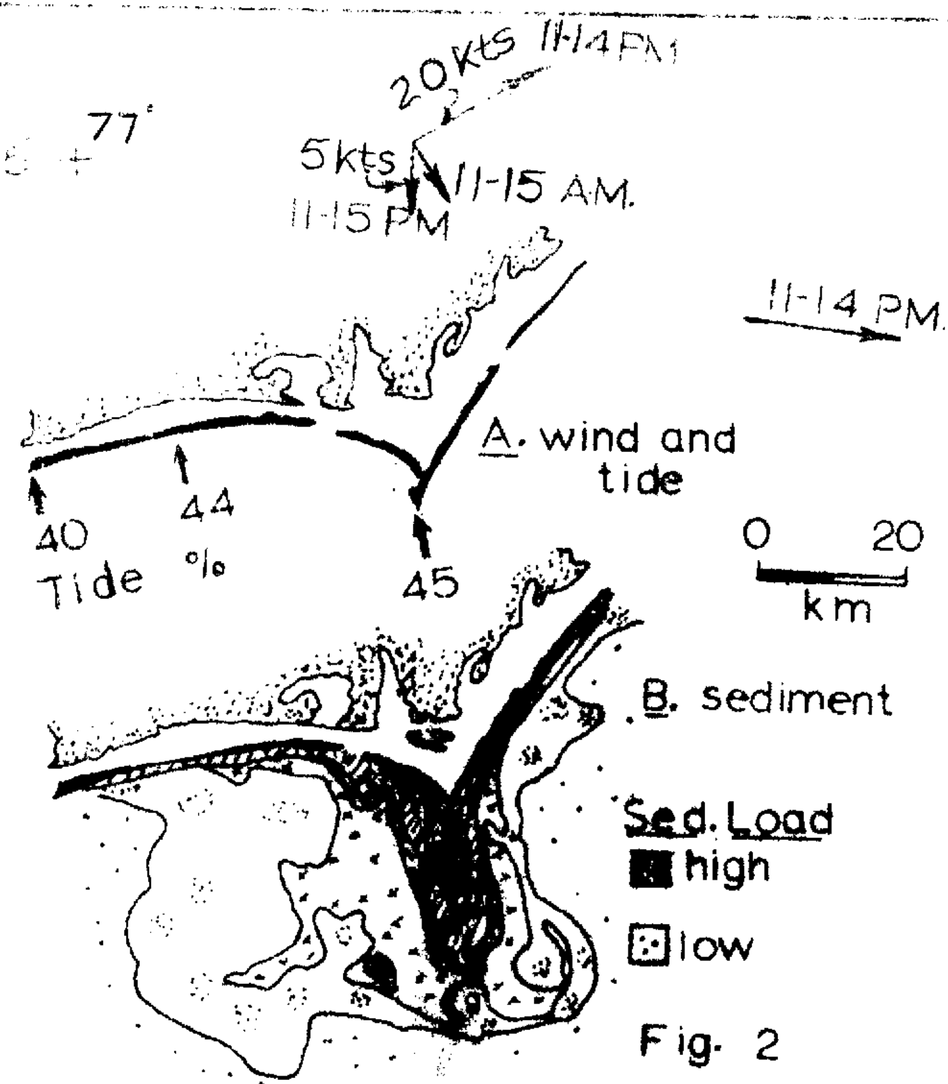


Fig. 2

CAPE LOOKOUT
from ERTS-1 Image 1115-15152, Nov. 15

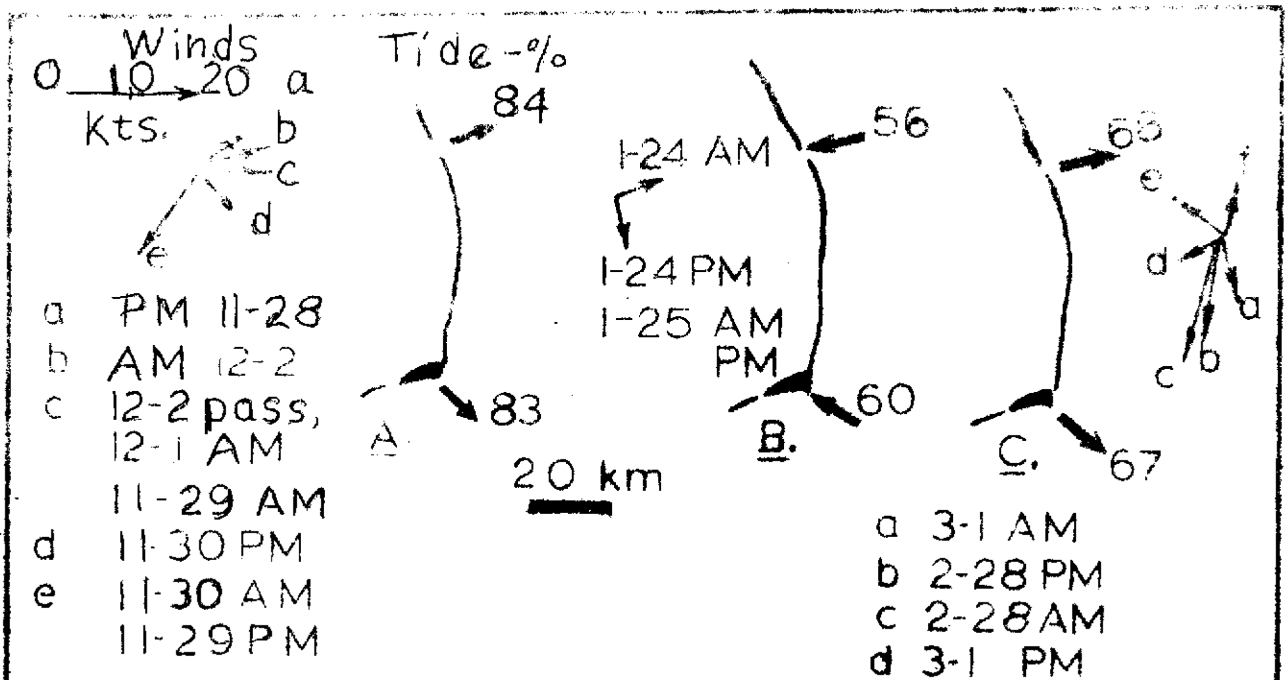
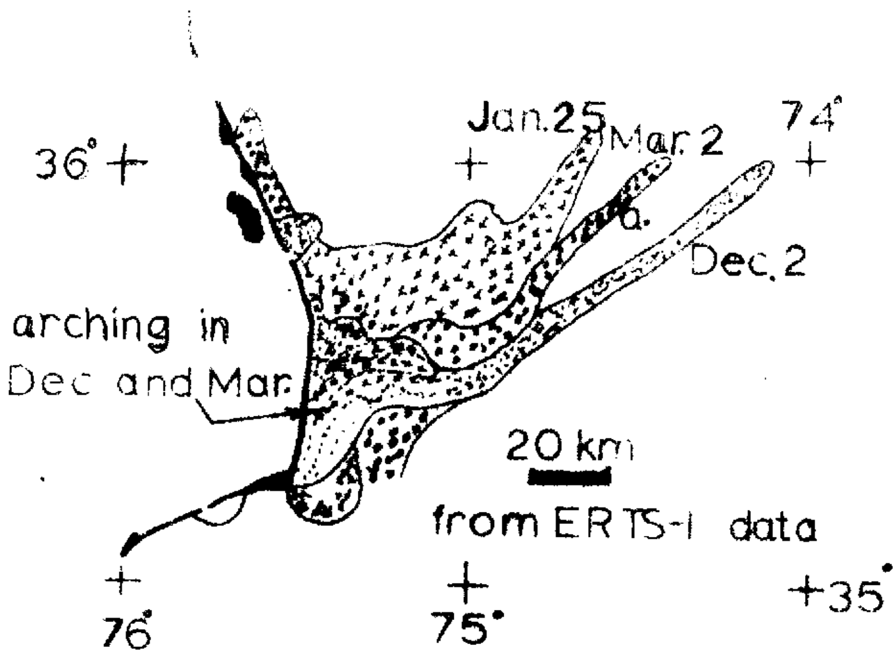


Fig. 3 Winds and Tides
Cape Hatteras



CAPE HATTERAS PLUMES
a. Boundary between upper
and lower layer Mar 2
Sed concentration decreases
seaward

Fig. 4

SEDIMENT TRANSPORT IN NORTH CAROLINA SOUNDS AND OFFSHORE - A USE OF SPACE IMAGERY

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Presented at Annual Meeting
Geological Society of America
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Introduction:

This presentation is an effort to describe some sediment transport phenomena and coastal processes using ERTS-1 imagery. Detailed studies may require collection of a considerable amount of groundtruth; still the "big picture" provided by ERTS-1 imagery can give considerable information and can lead to better sampling programs. Probably automatic data processing techniques will assist greatly in detailed interpretations.

Within the coastal waters of North Carolina the effects of wind are important in stirring up water and in causing water masses to move. Not always is it possible to find a direct correlation between meteorological events, the tide, and a given apparent water mass movement as seen on the imagery. On the other hand, broad correlations do seem possible. Manheim, Meade, and Bond in 1970 described the distribution of suspended sediment in the surface waters of the Atlantic. Rudolfo, Buss and Pilkey in 1971 described the effects of a hurricane on suspended sediment load in the Cape Lookout area, noting the stirring of the bottom. Investigations have shown that except for the nearshore areas much of the suspended matter at the surface of the Atlantic is organic. Variations in color of the water appear to be a useful tool for estimating concentrations of suspended matter. Reflective boundaries can be correlated with sharp changes in suspended matter.

This discussion is a description of three areas: the Cape Fear, Albemarle Sound and the Cape Hatteras regions. Time will permit only a brief discussion of some of the phenomena; in this case a picture is better than the proverbial "one thousand words." The general location is shown by the small inset map of the first slide.

Cape Fear

Six images of the Cape Fear area are available from October 1972 to July 1973. They show the changing face of the Cape Fear area. In each instance we can perhaps hypothesize about the details of the coastal processes, and from such thoughts expend our investigations of sediment transport and pollutant dispersion.

Image No. 1080-15203, 11 October 1972

The first good image of the Cape Fear area was made on Oct. 11, 1972. It shows suspended matter in a narrow band close to shore north of Cape Fear as well as some irregularly distributed patches along the westward-trending coast west of the Cape. Areas of suspended material are indicated by the darker colors in the slide made from a negative. At the time this image was made the tide was about one-tenth of the way toward flood and currents were about 1.9 knots in the ebb direction. The wind had been blowing at 5 to 10 knots from the northeast to southwest for at least 12 hours. Water flow in the Cape Fear River about 65 miles upstream was 4,270 cfs on Oct. 10 and somewhat less on October 11.

Two relatively clear-water bands are indicated by the arrows. A more diffuse mass of suspended material is located between the westerly band and an area of relatively clear water south of Yaupon Beach, to the west of the river, two to three miles offshore. A density slice brings out the larger of the two bands.

Image No. 1134-15211, 4 December 1973

Two things seem striking about the Dec. 4 image. The first is the general bulbous appearance of the plume off Cape Fear, along with the apparent rather diffuse distribution of the suspended material. The second feature is the apparently greater concentration of suspended sediment in the Cape Fear River than either off-shore or in the river at the time of the Oct. 11 image. River flow at the gaging station 65 miles upstream was 8,600 cfs in a decreasing flow pattern on Dec. 3. In late November major rains had caused flooding along the Cape Fear River upstream.

Tidal and weather data are as follows. At Cape Fear the tide had just turned from flood to ebb, and the currents were about 0.6 knots in the ebb direction. The winds had been variable at less than 5 knots. At the time of the pass they were blowing southeasterly or offshore at 5 knots. The arrow indicates the position of a band of water with less suspended material in it.

Image No. 1188-15210, 27 January 1973

At the time this image was made winds were blowing at 10 to 25 knots from the west. Up to about 0700 the winds had been blowing from the south. The tidal stage at Cape Fear was about one-third toward flood with a current velocity of 0.03 knots upstream. Some 13,000 cfs of water had passed the gaging station 65 miles upstream the day before, and the flow was decreasing. Presumably the flow through the mouth of the Cape Fear was of this order of magnitude at the time of the imaging.

The suspended sediment cloud is anchored at the south end by Frying Pan Shoals. A less dense cloud exists between Smith Island and the shoals. Two areas of relatively clear water are discernible on the original imagery: the broader band between the short dotted lines and a narrower band indicated by the arrow. A very thin band of suspended material parallels the shore west of Cape Fear, showing probable longshore transport. A density slice of band 5 emphasizes the regional pattern.

Image No. 1278-15212, 27 April 1973

The April 27 image illustrates the general diffusion of suspended material north of Cape Fear. Unfortunately, the original image did not pick up Cape Fear. The black dots mark the edge of the concentrations of suspended material, both in the Cape Fear River and offshore. The suspended sediment boundary is between 2.5 and 3 kilometers offshore. Tidal and wind conditions were as follows: winds at 10-15 knots in an easterly direction (offshore) north of the Cape and parallel to the shore toward the Cape to the west or left of the mouth of the river. At Cape Fear the tide was about a quarter of the way to high tide and current velocities were 0.1 knot. Upstream at Wilmington low tide had not yet been reached, and current velocities were downstream at about 0.6 knot. Noteworthy in this image is the path of relatively clear water near the west edge of the Cape Fear River. Approximately 4,200 cfs of water is flowing from upstream into the Wilmington area at this time. An April 29 image of the southeast coast taken from the NOAA-2 satellite shows the regional context for this image, and appears on the cover of the 2 November issue of Science.

U-2 Imagery, 28 April 1973

A color infrared photograph made at about 11:15 AM EST shows the most recent ebb tidal plume and its structure. For scale the distance parallel to the coast of Smith Island is about 3.5 miles. The winds have been blowing at about 15 knots parallel to the coast and slightly offshore in an easterly and southeasterly direction toward the tip of the Cape. At the time of this photograph the tidal cycle was about 23 percent of the way toward flood tide, and slack water had occurred within the previous 30 minutes. Thus, the currents were in the early stages of upstream movement. Approximately 4,500 cfs of water was flowing down the Cape Fear River. The photograph also shows a diffuse cloud of suspended sediment, probably from an earlier tidal cycle, beneath the most recent plume. Again, though, the interpretation is that most of the earlier plume moved eastward toward the tip of the Cape.

Image No. 1314-15210, 2 June 1973

Wind and Tidal Data for Cape Fear are as follows:

The tide is about 31 percent toward full ebb with current velocities of 0.02 knot. The sea is calm and the winds have been variable in direction at 0 to 5 knot for the preceding 9 hours; these weather conditions were generally true for the preceding several days. At Wilmington the tide is near flood peak, and current velocities are 0.5 knot upstream. On June 1 the Cape Fear River had a flow of 11,800 cfs at the nearest gaging station 65 miles upstream. Flow at this same station at the time of the image was 8,900 cfs.

The general easterly and northerly concentration of sediment seen in the April 27 image appears to be true of June 2 image. Of particular interest are the clear-water bands within the suspended sediment mass. They are not bottom channels alone, for they appear in the infrared bands also. So we are looking at a near-surface phenonmenon as well as one that may occur deeper. Again a density slice provides clues to the relative concentrations of the suspended matter.

Albemarle Sound Area

Four images of the Albemarle Sound area illustrate the usefulness of ERTS-1 imagery in studying the effects of various weather conditions on a shallow-water body with wind-controlled tides.

Image No. 1133-15150, 3 December 1972

With the wind from the southwest at about 10 to 15 knots the water mass is shoved northward against the margin of the sound, and suspended materials are concentrated against the northern shore. Water from the Alligator River extends northward as a tongue into Albemarle Sound. The tide at Oregon Inlet, south of Roanoke Island, was about two-thirds of the way into the ebb part of the cycle. This image suggests an area in Croatan Sound where suspended material is less prominent.

A density slice of Band 5 points to the concentration of suspended sediment against the northern shore. The black band suggests the presence of a relatively sharp boundary with the less turbid water to the south.

Image No. 1205-15150, 13 February 1973

An image taken two days after a major snow storm in February with the wind still blowing out of the northeast illustrates a different response of the area.

Fingers of less turbid water extend southward into the sound, and suspended matter extends into the Alligator River. Part of the red coloration is thought to be related to a phytoplankton bloom which was at its height about this time. The density slice of the red band (Band 5) serves to emphasize the relationships. The blue fingers represent the southward extension of less turbid water from the rivers draining into Albemarle Sound. Also the blue area at the mouth of the Chowan River is a feature present in other images. The density slice of the December 3 image showed a similar area of less turbid water.

Image 1403-15134, 30 August 1973

Finally, on Aug. 30, 1973, the waters of Albemarle Sound have less suspended material than at the times of the earlier images. This is also true for a July 24 image. The next slides illustrate this point. The first is a false color rendition, and the second is a density slice of Band 5.

Cape Hatteras-Manteo

Two views of the area north of Cape Hatteras and 60 or 70 kilometers seaward show extension of a plume swinging off Cape Hatteras and extending northeastward. Close to shore the material is spread from north of Oregon Inlet to Cape Hatteras, but seaward a finger-like extension is present.

The first slide shows a northward arching in the plume, presumably caused by northward drift north of the Cape. The southeastern edge of the finger-like extension is apparently sheared off by the Gulf Stream. At the instant of this image made on Dec. 2 (1132-15092) the winds were blowing easterly, offshore, at 10 to 15 knots, and this situation had existed for two days before the pass. The tide was in the late stages of the ebb phase.

On January 25, 1973, the wind had been blowing to the southeast for several days. Image number 1186-15090 shows only the nearshore arching, and no finger-like extension. The hooking of the plume off the southside of Cape Hatteras is seen in the images for January.

On March 2, 1973, the finger-like extension is once again present. Image 1222-15093 illustrates the relationship. The tide is in the late stages of the ebb cycle at Oregon Inlet. The winds had been blowing both north and south during the two days preceding the pass. At the time of the pass the wind was blowing to the northeast.

Close inspection of the imagery shows that about halfway out on the finger the plume seems to be composed of two layers, a higher one extending back to the Outer Banks and a deeper, more narrow one, extending northeastward. Also, of interest is the distribution pattern within the base of the plume.

The December, January, and March imagery implies that the northward moving coastal water masses south of Cape Hatteras is deflected at Cape Hatteras to the northeast. Southward moving currents appear to be deflected in a broad U-shaped pattern to the northeast also. The Gulf Stream controls the southward movement.

In contrast to the plumes described already, is the general diffusion pattern found in the August 29, 1973, image (1402-15080) of the area north of Cape Hatteras. Absence of a concentration of suspended material in the water makes it virtually impossible to detect a current pattern. There is a general lack of suspended material in the sounds also.

The question arises in considering the sediment transport along this portion of the coast, "Do the currents ever get north of Cape Hatteras?" An early ERTS-1 image gives some information about this matter. Image 1024-15082 made on August 16, 1972, shows fingers of suspended matter moving northward more or less parallel to the coast in the nearshore area. A Sept. 16, 1973, image (1420-15074) also shows northward moving plumes and fingers.

Close to shore, north and south of Oregon Inlet, the sediment movement appears to be southward. However, about 5 miles offshore a finger-like extension from the broader mass of water with suspended matter together with the general pattern within the mass suggests a northward movement. It appears that the water containing the suspended matter is bouncing off the nearshore area about at the southern margin of the image.

Conclusion

ERTS-1 images from various times of the year and for different tidal and meteorological conditions provide an excellent means for guiding sampling programs in coastal waters. Although time has not permitted the necessary detailed analyses of the imagery *vis-a-vis* all the parameters that might be affecting the phenomena seen, it is clear that attempts to model the coastal circulation, the coastal erosion, and the sediment transport must take into account what the imagery is telling us about the dynamics of the system. Perhaps the imagery raises more questions than it answers, but therein lies the challenge of what we do.

Cloud Cover Analysis of ERTS Imagery Received Through August, 1973

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Department of Geosciences
October 1973

Cloud cover data for each image was obtained from the ERTS U. S. Standard Catalog for areas from which the user has consistently received imagery. The lowest number of images received was 8 from the Rocky Mount area, while the largest number received was 15 from the Raleigh-Greensboro group. The mean number of images received for each area was 12.

We have arbitrarily assigned the following quality ratings to ERTS imagery as a result of the work with the imagery. Imagery with 0 to 20 percent cloud cover is excellent for regional analysis and mapping. At approximately 30 percent cloud cover the imagery is of only marginal value. Almost invariably cloud cover of 40 percent or greater prevents any detailed work with the imagery. Of course, the limits of usefulness will vary from user to user. Their applicability depends on:

(1) the areal extent of the region in which the user is interested
(2) the "type" of cloud cover; that is, are the clouds scattered haze which obscures fine detail, or are they isolated, distinct clouds which leave significant areas of the image clear, although the total cloud cover may be as much as 50 percent.

Compilation of the cloud cover data has yielded the following trends:

(1) The coastal zone imagery has a higher percentage of cloud cover than other regions. Examination of the last column of Table 1 shows relatively high values for the percentage of inner coastal plain and piedmont imagery that have 0 to 20 percent cloud cover. This fact could guide research to areas in which clear, numerous sequential images are needed.
(2) During each three-month period the satellite makes five passes over each target area. Of these five passes, only 50 to 60 percent are processed and eventually received by the user.
(3) Comparison of Tables 2 and 3 show that while the average number of images received from each area increases from Fall 1972 to Spring 1973, the average cloud cover is lowest in the winter. Data for the summer of 1973 was omitted because all imagery had not been received at the time of the compilation and analysis of the data.

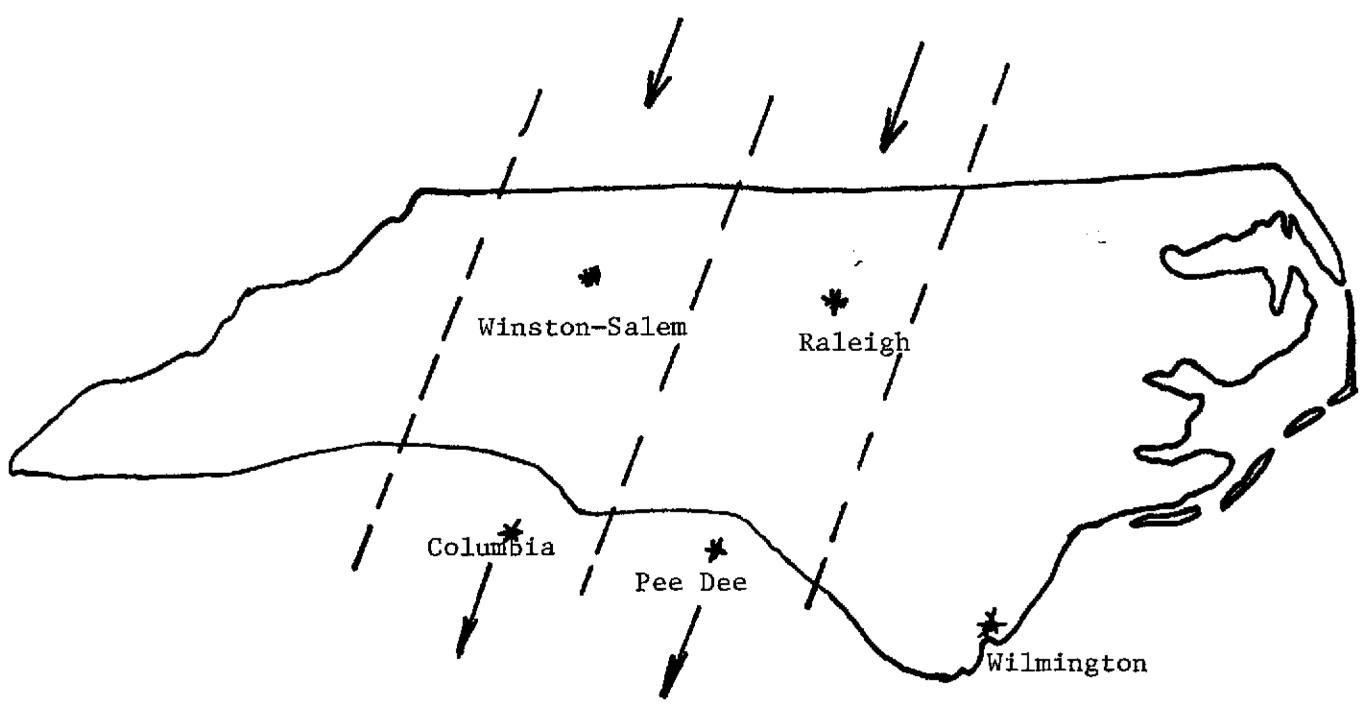

Figure 1. Orbital paths over North Carolina from which the clearest imagery has been obtained most consistently, October 1972 - June 1973.

TABLE 1

Centers	Number of Images Received	Average Cloud Cover	Number of Images with 0-20% Cloud Cover	Number With Cloud Cover > 20%	% of Images Received W/ Cover 0-20%
Asheville	9	20	7	2	78
Cape Lookout	14	29	5	9	36
Hatteras	9	28	4	5	44
Manteo	13	29	5	8	38
Mattamuskeet	12	30	4	8	33
Pee Dee	14	17	9	5	64
Raleigh- Durham-Greensboro	15	25	6	9	40
Rocky Mount	8	23	4	4	50
Wilmington	11	26	6	5	55
Winston-Salem	11	18	8	3	73
Knoxville	11	31	4	7	36
Crossville	12	25	5	7	42
Columbia	14	14	11	3	79
Greenville	11	27	4	7	36
Dawsonville	12	30	6	6	50
Total	176		88	88	

TABLE 2

SEASON*	NUMBER OF IMAGES RECEIVED
Fall 1972	37
Winter 1973	40
Spring 1973	47

SEASON*	AVERAGE NUMER OF IMAGES RECEIVED FOR EACH CENTER EVERY 3 MONTHS
Fall 1972	2.5
Winter 1973	2.7
Spring 1973	3.1

*1. Data was not included for Summer of 1973 because all imagery had not been received or evaluated.

2. Fall: October, November, December

3. Winter: January, February, March

4. Spring: April, May, June

5. Summer: July, August, September

TABLE 3

SEASON	AVG. CLOUD COVER OF IMAGERY
Fall 1972	30%
Winter 1973	19%
Spring 1973	25%

TABLE 4

Image Quality Tabulation by Image Center

ASHEVILLE	% CLOUD COVER	
1101-15374	40	Fall 1972
1137-15380	10	
1173-15373	20	Winter 1973
1191-15375	20	
1209-15380	0	
1281-15381	50	Spring 1973
1299-15380	10	
1317-15375	20	
1371-15371	10	Summer 1973

CAPE HATTERAS	% CLOUD COVER	
1078-15090	30	Fall 1972
1132-15094	10	
1150-15094	50	
1186-15093	10	Winter 1973
1222-15100	40	
1240-15100	20	
1294-15095	30	Spring 1973
1330-15092	50	
1402-15083	10	Summer 1973

CAPE LOOKOUT	% CLOUD COVER	
1007-15142	10	
1025-15144	30	Summer 1972
1061-15143	50	
1079-15145	40	Fall 1972
1115-15152	10	
1187-15151	40	
1205-15153	10	Winter 1973
1241-15155	30	
1259-15155	30	
1277-15155	30	Spring 1973
1295-15153	50	
1349-15150	40	
1385-15143	20	Summer 1973
1403-15141	10	

MANTEO	% CLOUD COVER	
1024-15082	30	Summer 1972
1078-15084	20	
1096-15090	50	Fall 1972
1132-15092	0	
1150-15091	50	
1186-15090	20	
1222-15093	20	Winter 1973
1240-15094	30	
1294-15092	50	Spring 1973
1312-15091	40	
1348-15085	30	
1366-15083	30	Summer 1973
1402-15080	10	

MATTAMUSCKEET	% CLOUD COVER	
1007-15140	50	Summer 1972
1079-15142	30	Fall 1972
1097-15144	50	
1115-15150	50	
1133-15150	30	
1187-15145	10	Winter 1973
1205-15150	0	
1295-15151	50	Spring 1973
1313-15150	30	
1349-15143	30	Summer 1973
1385-15140	20	
1403-15134	10	

PEE DEE	% CLOUD COVER	
1027-15260	0	Summer 1972
1045-15261	30	
1063-15260	10	
1081-15262	0	Fall 1972
1099-15264	0	
1135-15265	40	
1243-15271	0	Winter 1973
1261-15271	10	Spring 1973
1279-15271	10	
1297015270	0	
1315-15265	10	
1333-15263	50	
1351-15262	30	Summer 1973
1369-15261	50	

RALEIGH-GREENSBORO	% CLOUD COVER	
1027-15254	50	
1045-15254	10	Summer 1972
1063-15254	30	
1081-15255	30	
1099-15261	10	Fall 1972
1135-15263	50	
1243-15265	0	Winter 1973
1261-15265	30	
1279-15264	30	
1297-15263	0	Spring 1973
1315-15262	10	
1333-15261	40	
1351-15260	10	
1369-15254	40	Summer 1973
1405-15251	40	

ROCKY MOUNT	% CLOUD COVER	
1062-15195	50	Summer 1972
1080-15201	0	Fall 1972
1134-15204	10	
1170-15202	0	Winter 1973
1242-15211	30	
1260-15210	50	Spring 1973
1314-15204	0	
1350-15201	40	Summer 1973

WILMINGTON	% CLOUD COVER	
1080-15203	10	
1098-15205	50	Fall 1972
1134-15211	10	
1170-15205	20	
1188-15210	20	Winter 1973
1242-15213	20	
1260-15213	40	
1278-15212	30	Spring 1973
1296-15211	30	
1314-15210	10	
1350-15204	50	Summer 1973

WINSTON-SALEM	% CLOUD COVER	
1046-15313	0	Summer 1972
1064-15312	20	
1082-15314	50	Fall 1972
1172-15315	0	
1190-15320	30	Winter 1973
1208-15322	20	
1244-15323	10	
1280-15323	10	Spring 1973
1316-15321	30	
1352-15314	10	Summer 1973
1370-15313	20	

KNOXVILLE, TENN.	% CLOUD COVER	
1030-15430	40	Summer 1972
1084-15431	10	Fall 1972
1192-15433	40	
1210-15435	30	Winter 1973
1228-15440	40	
1264-15440	20	
1300-15434	50	Spring 1973
1282-15435	10	
1336-15432	40	
1354-15431	10	Summer 1973
1372-15425	50	

DAWSONVILLE, GA.	% CLOUD COVER	
1030-15432	20	
1048-15432	20	Summer 1972
1066-15431	40	
1084-15433	0	Fall 1972
1102-15435	50	
1192-15440	50	Winter 1973
1210-15441	50	
1264-15443	10	
1282-15442	20	Spring 1973
1336-15434	40	
1354-15433	30	Summer 1973
1372-15432	20	

COLUMBIA, S. C.	% CLOUD COVER	
1010-15315	10	
1028-15320	50	Summer 1972
1046-15315	0	
1064-15315	20	
1118-15323	40	Fall 1972
1172-15321	0	
1190-15323	20	Winter 1973
1208-15324	10	
1244-15330	10	
1262-15330	0	
1280-15325	0	Spring 1973
1298-15324	30	
1352-15320	0	Summer 1973
1388-15314	10	

GREENVILLE, S. C.	% CLOUD COVER	
1047-15371	40	Summer 1972
1083-15375	50	Fall 1972
1101-15381	50	
1137-15382	50	
1191-15381	0	Winter 1973
1209-15382	0	
1263-15384	30	Spring 1973
1281-15383	30	
1299-15383	0	
1317-15381	40	
1371-15373	10	Summer 1973

CROSSVILLE, TENN.	% CLOUD COVER	
1121-15492	40	Fall 1972
1103-15491	40	
1157-15491	40	
1175-15490	10	Winter 1973
1211-15493	10	
1229-15494	40	
1247-15495	30	
1265-15494	0	Spring 1973
1319-15492	30	
1337-15490	10	
1355-15485	20	Summer 1973
1391-15482	30	