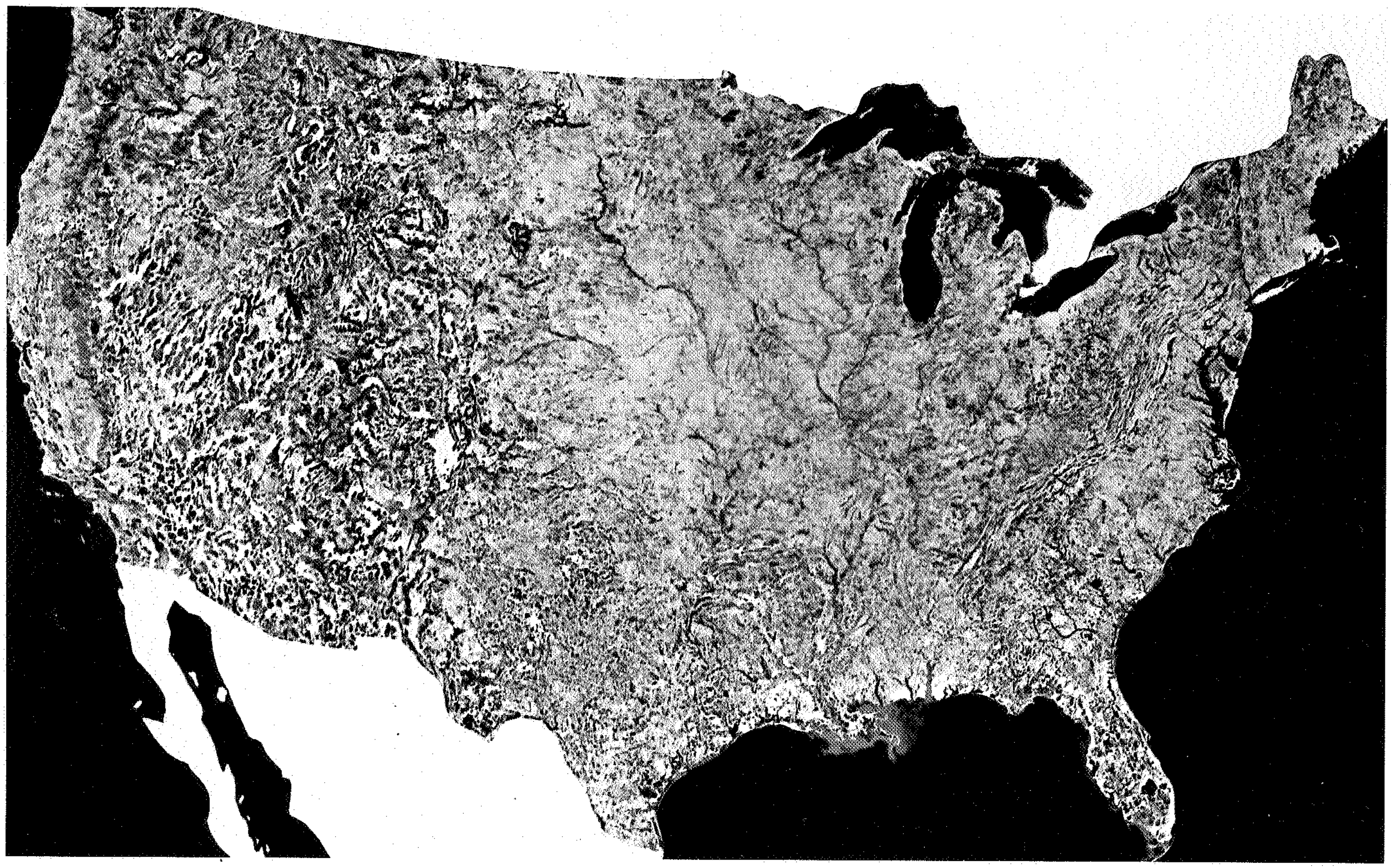
NASA SP-356



Two Band Color Mosaic of the conterminous 48 states constructed from black and white mosaics of bands 5 (0.6–0.7 μm) and 7 (0.8–1.1 μm) of ERTS-1 Multispectral Scanner imagery. The black and white mosaics were produced by the USDA Soil Conservation Service for the NASA Goddard Space Flight Center.

Volume II
SUMMARY OF RESULTS

THIRD EARTH RESOURCES TECHNOLOGY SATELLITE SYMPOSIUM

A symposium held by
GODDARD SPACE FLIGHT CENTER
'in Washington, D. C.
December 10 – 14, 1973

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA SP-356

THIRD EARTH RESOURCES TECHNOLOGY SATELLITE SYMPOSIUM

Volume 11
Summary of Results

Compiled and Edited by

Stanley C. Freden
Enrico P. Mercanti
Missions Utilization Office

and

*David **B.** Friedman*
Technical Information Division
Goddard Space Flight Center

May 1974

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

Scientific and Technical Information Office **1974**
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.G.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price $3.00 Stock Number 3300–00580

EDITOR'S NOTE

The papers of Volume II have been derived primarily from oral presentations made during the Thursday Summary Session of the Symposium. Because of this, and in order to achieve a uniform format, a considerable amount of editing was performed. Although contributors were afforded an opportunity to revise their oral transcripts, the time allotted them for this purpose was short in order to expedite the timely publication of this document. Therefore, while care was exercised not to alter **a** contributor's context, this may have happened inadvertently, in which case the editor assumes full responsibility.

PREFACE

The Third Symposium on Significant Results Obtained from the first Earth Resources Technology Satellite (ERTS-1) was held from December 10 to 14, 1973, at the Statler Hilton Hotel in Washington, D. C. The Symposium was sponsored by the National Aeronautics and Space Administration, Goddard Space Flight Center. The structure of this Symposium was similar to the one held from March **5** to 9, 1973. The Opening Plenary Session on Monday morning contained two papers of general interest to the entire audience, one on the status of the ERTS-1 system and a report on the Canadian ERTS program. The next two and one-half days were devoted to contributed papers in the various disciplines presented during three parallel sessions. These papers are contained in Volume I of the Proceedings.

The Thursday Summary Session, as before, was designed to highlight and summarize the significant results from the fiist three days and also to present some typical examples of the applications of ERTS data for solving resources management problems at the national, state, and local levels. This Session was highlighted by an introductory address by Dr. James C. Fletcher, NASA Administrator, and by a keynote address by Dr. John **C.** Whitaker, Under Secretary of the Interior, U. **S.** Department of the Interior. The presentations from this session are contained in Volume II of the Proceedings.

Volume III contains the Discipline Summary Reports. These were based on reports produced from a two-week long series of intensive interviews with the individual ERTS-1 Principal Investigators and then updated and extended from the material presented at the Third ERTS Symposium. The interviews were organized and directed by Dr. **O.** Glenn Smith of the Earth Resources Program Office at the Johnson Space Center and were held at the Goddard Space Flight Center from October **22** to November **2,** 1973. The Discipline Summary Reports were written by Working Groups in each of the disciplines which were convened on Friday, December 14. These Working Groups were chaired by the respective discipline session chairmen and were composed of selected specialists in the various disciplines. Opinions and recommendations expressed in these reports are those of the panel members and do not necessarily reflect an official position of NASA.

Stanley C. Freden
Symposium Chairman

TABLE OF CONTENTS

Volume II

Summary of Results

INTRODUCTION TO SUMMARY SESSION

Dr. James *C.* Fletcher
Admihistrator
National Aeronautics and Space Administration
Washington, D. C.

It gives me great pleasure to welcome you to the summary session of the Third Earth Resources Technology Satellite Symposium. Many significant papers have been presented so far, and although it is not possible to give justice to them in a summary session, it is useful to present a broad picture of this revolutionary new development. By now, many of our Principal Investigators have received data from a full year of operation of the ERTS-1 satellite. This period provides data covering a full growth cycle for agricultural crops in all parts of the world.

We are beginning to witness an increasing trend toward routine, almost operational use of ERTS data. **A** particular case is Florida, where imagery from ERTS and data from the ERTS Data Collection System are being used to manage water resources on a regular basis. The information is used to manage the flow of water and its distribution in the southern Florida drainage canal and impoundment system. It is used routinely in making decisions that are important to the water needs of agricultural and urban areas and national parks in Florida.

The number of applications of ERTS data having the potential of saving costs in solving current problems is growing. For example, I am told that Georgia has stated that an estimated 50 to 80 percent of the budget allocated to meet the requirements of the National Dam Inventory Act will be saved by using ERTS data for inventorying water impoundments of 60,000 cubic meters (50 acre-feet) or more. A spokesman for the U. S. Army Corps of Engineers will describe later today how ERTS data is being used to meet the requirements of this Act.

We are also discovering that an increasing number of applications of ERTS data have been undertaken by users on their own initiative. This we consider a good indicator of progress, and an example of one of these non-NASA supported investigations will also be discussed. It is most encouraging to witness the planning for the applications of ERTS and other remote sensing data by the other Federal departments—Interior, Agriculture, Commerce, and State—and by users at state and local levels of government to meet the requirements of forthcoming land use legislation. ERTS data are being used to develop and prepare base maps that will be used in anticipation of meeting both the initial requirements of this legislation and in conjunction with implementing the land use planning called for by the legislation.

We are encouraged that two countries, Brazil and Canada, have ERTS ground stations in full operation. Our foreign participants are especially welcome today since their presence confiis that **ERTS** data are available for applications on a global basis and not restricted by geographical boundaries.

I would like to cite one last example related to our pressing national energy problem. **ERTS** imagery has been particularly effective in mapping geologic structures, revealing for the first time faults and lineaments not previously identified. By using **ERTS** imagery of areas with known petroleum deposits and correlating these with **ERTS** imagery of geologic structures elsewhere, there is a good possibility that geologists will be able to determine where new petroleum deposits are located. For example, oil fields in southern Oklahoma appear to show up as tonal anomalies in **ERTS** imagery, suggesting that we may be able to see direct evidence of potentially productive structures as a guide in future petroleum exploration.

I sincerely trust that at the end of this day you will return home with pride that this group has, together, achieved a new plateau of accomplishment in the application of space-derived data to earthly problems and needs.

KEYNOTE ADDRESS

Hon. John C. Whitaker
Under Secretary of the Interior
U. S. Department of the Interior
Washington, D. C.

It is a pleasure to be here with you today at the Third ERTS-1 Principal Investigators Symposium.

I was almost late. With the energy shortages we are down to one Toyota per Department. That means Under Secretaries have to walk.

While each of us share no small satisfaction with the promise and the success of ERTS-1, all of us share an even larger challenge – the challenge to translate scientific promise into environmental and economic progress. Technology, in every age and nation, is a measure of its values, and most important, its aspirations. Before turning to the immediate challenge of ERTS, I would like to make a few observations regarding the relationship between the emergence of a new generation of technology and the ability of our people to absorb it.

In the mid-1880's one of the leading newspapers in New York City, in this case the New York Times, took a strong and impassioned stand against the disturbing and insidious threat of the technological aberrations being foisted on the community. Their warning began: "Plans to construct elevated electrical power lines along this city's streets shall threaten not only the well-being of our people, and the destruction of city commerce, but could even result in the electrocution of our horses." The Times, needless to say, has come around on electrical power lines. I should add, however, that at least in the view of some of us, they have yet to come around on a number of other issues. In either event, there is little question that the emergence of each new generation of technology, more often than not, follows economic and social needs rather than an ordered or reasoned application of scientific research.

What is most unique about ERTS-1 is that both human needs and purely scientific needs have merged. ERTS is a match of the earth scientist's quest for insight into the dimensions of the biosphere and our national needs to continue to meet human and economic needs without despoiling the integrity of the environment.

On a personal note, I would further like to acknowledge that it is one of the more effective technological programs any government has undertaken. While I refuse to suggest that "it could ever happen here," all of us at one time in our lives have had that disconcerting impression that government and scientific research are, at best, a star-crossed match. Or, as the Soviet physicist L. A. Artsimovitch said, "Scientific research is a method whereby private curiosity is satisfied at public expense." This is another way of expressing the layman's and the taxpayer's frustration with scientific research and development.

It reminds me of the story a wonderful human being, my predecessor as Under Secretary of Interior, Bill Pecora, used to tell. I think many of you know that Bill had been a strong, strong backer of this program and, as a matter of fact, he died within days of the launching of ERTS-1. Bill had the concern that Jim Fletcher just alluded to; that question of good communication between scientists and their lay administrators, who usually make the decisions. As a geologist, Bill Pecora used to tell a story to his young geologists to make the same point. A young geologist, just out of graduate school with a fresh PhD, was sitting on his first wildcat oil well and his client was a hard-crusted, bitter, tough guy who worried about the money and did not know much geology, and certainly no scientific nomenclature. At two o'clock in the morning he called his client and said, "We have just penetrated Miocene with a drill bit." The next night at three o'clock he called his client and said, "We just penetrated the Oligocene," and the following early morning he called his client and said, "We just penetrated Eocene." The old man responded, "Son, don't call me anymore until you reach kerosene.''

But ERTS has found the kerosene. ERTS' success has exceeded every level of expectation. ERTS' scientific promise has overtaken even the most optimistic view at its inception. ERTS' economic promise, while literally at the first step, has already begun to emerge. And while a few people suspect that the Federal Government willingly abides to the credo that indecision is the key to flexibility and higher spending is the key to perpetuity, it is worth noting that ERTS, in less than one decade, has literally brought the promise of space-age technology into the hands of everyone in the world.

On September 18, 1969, President Nixon formally announced that our earth resources program would be dedicated to provide information to all members of the world community. In the four years since then, the President's commitment has been fulfilled. Representatives from more than 50 nations have participated in ERTS conferences like this one. More than 70 countries and international organizations have visited the Karl E. Mundt EROS Data Center in Sioux Falls, South Dakota, and have taken part in education or orientation programs. In addition, we have received literally thousands of requests for ERTS data from abroad.

While ERTS holds overwhelming potential benefits for every nation, especially the underdeveloped nations, many of those benefits remain as yet ungrasped. Hopefully, there will be a broader scale of international participation(in the planning, design, and utilization, as well as the financing of new projects. While this is not a primary consideration facing this conference, it is one that ultimately must be confronted. ERTS' international implications cannot be overstated, As one recent visitor to the Goddard Center remarked: "My God, can you imagine how different things would be today if Moses had ERTS and went south to Kuwait instead of west towards Israel."

As principal investigators, each of you have had an opportunity to perform scientific and technological experiments examining the feasibility, and, indirectly, the hard economics of commercial applications for ERTS. You have probed the first layer of environmental and resource data, and, in anticipation of the expiration of ERTS-1's lifespan, all of you are looking toward the future. While any attempt to quantify the benefits of a satellite as vastly complex as ERTS is a difficult undertaking, a number of cost benefit studies of both ERTS and the Earth Resources Survey Program have been completed, and today another major evaluation of ERTS is in progress. Because of this, I cannot overstress the need for all of us – in the scientific community, in government, and in the private sector – to keep sight of the unimpassioned relationships of cost and application.

When I say application, I mean meeting both the need for environmental and other resource applications and the opportunities ERTS affords us in developing scientific capabilities. The long-term, continuing success of ERTS will depend not only on the fact that it works, but upon our ability to utilize photogeological and other data in a meaningful fashion. That will mean translating ERTS data into major resource decisions in mineral and agricultural development, in land use planning, and in the management of our water resources. The possibility for even greater applications in still other disciplines abound.

We have already been able to utilize ERTS data in targeting areas for mineral exploration. This has led to more efficient field programs in government and more profitable field exploration for the private sector. From the vantage point of nearly 580 miles above the earth's surface, ERTS is vastly superior to aircraft in locating and determining the features of ore deposits, potential geothermal areas, and ground-water distribution. We have been able to prepare thematic maps and charts of areas that simply could not have been described so easily with such speed and detail, and we have demonstrated potential applications in managing rangelands, forests, and agricultural areas with greater effectiveness.

One of the most promising applications for ERTS may well be in land use planning. As you know, the Congress is completing action on the President's proposed Land Use Planning and Assistance Act. This Act, if enacted into law – and we hope it will be – will provide incentives and assistance to the 50 states to develop land use plans. ERTS data can readily be utilized to provide baseline data on current levels of development and potential preservation and development areas. In fact, with automatic land classification technology we can reduce the time required for manual interpretation by a factor of ten or more.

Meteorologists have already found opportunities to rapidly develop weather analysis as well as to examine components of our weather mix, including rate and patterns of freezing and thawing in our lakes. Oceanographers and aquatic biologists have begun to trace the effects of currents on water conditions and even on the distribution of algae. The Geological Survey has demonstrated applications for ERTS in examining the impact of petroleum and mineral development. ERTS data indicate that, with few exceptions, all of the man-made scars resulting from exploration in northern Alaska in the late 1940's and early 1950's have healed or are in the process of healing. These scars are not spreading over the tundra like a cancer as some would report.

Each of these applications, however, as promising and rewarding as they may be, have still not touched the widest possible community of users. That task – the task of expanding the success of ERTS – is the challenge we all share. We must extend the discovery of potential uses for ERTS into still other areas. And we must maximize our efforts to refine existing applications. I have little doubt that we will eventually have a continuing and workable earth resources satellite system. The real question we face is when?

The unequivocal success of ERTS-1 and the EROS Program in the Department of Interior is a measure of the dedication and vision each of you have brought to our pursuit of applied scientific insight into our resources. Some years ago, Rene Dubow observed that, "One of the distressing oddities of the scientific era is its failure to apply the methods of science to the most important problems of human life." In my own view we can no more accept this position than we can Artsimovitch's chiding that "Scientific research is a method whereby private curiosity is satisfied at public expense." ERTS-1 has already developed an extraordinary record of achievement. The time has now come to extend those achievements into still another area. It is a matter of communications.

Parenthetically, I have my own communications story. I occasionally go to Nova Scotia; I go to a little community called Lake Annis. The summer population is nine; the winter population, two. The undisputed political leader is Miss Mildred Cossar, age 85, who has never been to Yarmouth, the county seat of 4,000 people, 18 miles away.

I checked in there last summer – you have to check in with Mildred, have a cup of coffee, and sniff the political climate before you go to the trout stream. In the privacy of Mildred's kitchen she said to me, "Johnnie" – I have known her since I was a little boy – "Johnnie, where did you come from today?" I said, "From Washington." She said, "I would not want you to mention this outside of my kitchen here, but I am embarrassed, Johnnie. Where is Washington?" She was serious so I could not laugh. I said, "It is about six or seven hundred miles south of here." I said, "That is where Mr. Nixon is, in Washington." She said, "How many people live there?" I said, "There must be about two million people there, if you consider all of greater Washington." She looked up at the ceiling and she said, "Think of that; two million people living so far away from everything."

So in essence – and I think this is the core of the problem – you do not have the luxury of isolation so that the lay people who basically make the decisions in government and industry are thinking of all those people living so far away from everything. Through aggressive communications by you, ERTS can make a lasting contribution to meeting our national goals for energy independence, environmental quality, and a higher quality of life. Whether it does in fact cross that threshold, however, will depend on you.

REPORT ON THE CANADIAN ERTS PROGRAM

Lawrence W. Morley
Canada Centre for Remote Sensing
Ottawa, Canada

INTRODUCTION

This report considers production statistics on Canadian ERTS imagery, a summary of several cost benefit case histories, and recommendations for the future of the international aspects of ERTS.

CANADIAN ERTS IMAGERY PRODUCTION

Under a four-year collaborative agreement between the United States and Canada, the Canada Centre for Remote Sensing (CCRS) reads out and distributes the ERTS data of Canada. The Canadian receiving station is at Prince Albert, Saskatchewan. Figure 1 shows the range circle of the station, with Prince Albert located in the center. The station covers most of Canada except for the East Coast.

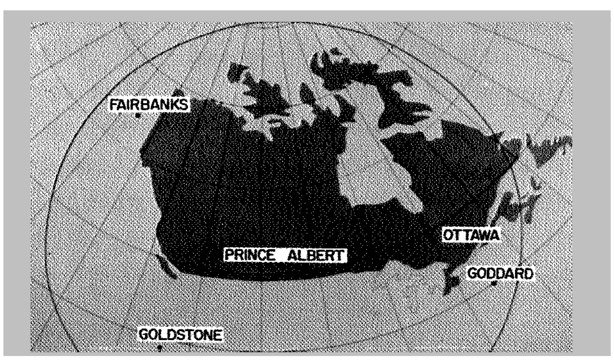


Figure 1. ERTS-1 Canadian coverage.

The multispectral scanner (MSS) data of Canada are recorded on high-density magnetic tape and then immediately played back through the "quick-look" cathode ray tube recorder where all the uncorrected images are photographed onto 70-millimeter black-and-white film. Enlargements of 23 by 23 centimeters (9 by 9 inches) are made from this film and are sold by Donald Fisher and Associates, a private contractor who was awarded the franchise. The photographic processing is done at the station in Prince Albert and the copies are mailed directly to customers from there within two days of the satellite pass.

Immediately after the quick-look information is extracted, the tapes are air-expressed to Ottawa where they are played through the ground data handling system onto electron beam recorders, providing all four bands and false color images for distribution by the National Air Photo Library. The Reproduction Center of the Library is located in the same building as the Canada

Centre for Remote Sensing, Ground Data Handling Center, and is fully equipped with automatic film-processing equipment for black-and-white and color reproduction in quantity.

Investigators in Canada are not centrally funded by the Canada Centre for Remote Sensing. Funds must be acquired from the appropriate mission-oriented agency, whether such agency is in the Federal Government, any of the provincial governments, the universities, or private industry. CCRS does carry out research in the methods of interpretation of remote sensing, both of the digital and analog varieties, but does not normally carry out routine interpretations of specific geographic areas.

The total number of ERTS products produced by the National Air Photo Library since launch is 272,800. That was in response to 1,159 orders for data. Total production of black-and-white quick-look images by Donald Fisher and Associates at Prince Albert is about 50,000. The company has been in operation since January 1973.

The quick-look images produced at Prince Albert utilize the full 2,400 lines of the NSS, but they have only about half the resolution of the images produced by the electron beam recorders in the ground data handling system at Ottawa. The big advantage of the quick-look is that there is no backlog; all orbits are processed immediately and the only limitation is the speed of the mail delivery. Facsimile service is available at Prince Albert with some considerable loss of resolution. It is used in a limited way by the ice-reconnaissance people. Plans for the future of the station call for upgrading the resolution of the quick-look system; installing automatic photo processing equipment; setting up a microfiche service on all ERTS imagery of Canada; and earth rotation correction. New higher resolution facsimile equipment may be installed if there is a demand for it,

To date, 14 data collection platforms units have been installed and tested at various locations across Canada. Reliable data retrieval from all units has been demonstrated. The Water Resources Branch of the Department of the Environment has nine units measuring river velocity, water level, precipitation, ice thickness, and ice movement. The Mackenzie River data is used by river boat traffic and the Columbia River data is used to forecast runoff for dam control. The Canada Centre for Inland Waters uses its platforms to monitor water quality in Lake Ontario. The Atmospheric Environment Service monitors precipitation, humidity, and air and water temperatures at its installations. Applications for six new units will be made soon.

Data are recorded at CCRS on magnetic tape from the Goddard telephone line in parallel with a hard-copy printout. Each morning the data are put into the PDP-10 computer at CCRS where they are sorted, converted into engineering units, and stored on a user disk file. The data may then be retrieved in hard copy through Telex from any location in Canada. The data retransmission system through CCRS has been operating since January 1973 to the complete satisfaction of all users, who are looking forward to expanding the number of units.

BENEFITS

Some demonstrated and potential economic benefits of the Canadian ERTS imagery are as follows. Seismic survey ships operating in the Arctic require information on ice conditions of the type provided by ERTS; that is, a broad enough coverage to show the general ice conditions in the area, but of high enough resolution to ensure that a ship's navigator can locate his position relative to the ice pack. This summer, because of ERTS imagery, one survey company operating in Norwegian Bay was able to survey an area it could not have otherwise. Quick-look ERTS imagery obtained two days after passage of the satellite showed the presence of open water beyond a large ice floe, and was useful for navigating within the floe. This information, which could not be obtained from helicopter support onboard the ship because of the extent of the floe, permitted survey of an additional 120 kilometers (75 miles). This represented over $100,000 additional revenue to the company. It is also known from ERTS imagery that at least an additional 400 kilometers (250 miles), representing close to $400,000, could have been surveyed with the one ship stationed in the area, had they been able to receive coverage in a more timely manner. The survey company is therefore examining the possibilities of relaying ERTS images directly to their ships from Prince Albert. This company expects that **ERTS** will also be valuable to them in their winter seismic studies. They have been studying ice floes moving down and consolidating, so they will have information on ice type and surface roughness. This will aid the company in deciding where to take contracts for winter surveys and what type of equipment to use.

Ice Forecasting Central, of the Department of the Environment, has recommended that April aircraft flights, which are used to determine ice conditions in the Arctic, be replaced by ERTS quick-look imagery. The flights utilize about 50 hours at a cost of approximately *$50,000*, compared to the ERTS imagery cost of $1,500. The imagery will permit an initial analysis of ice conditions for the seasonal outlook and permit the May aircraft flights to concentrate on key areas so defined. Ice Forecasting Central recommends that ERTS imagery be obtained from April through September to give increased information about ice conditions and to permit a better deployment of reconnaissance aircraft.

In 1972 a geophysical survey company spent six weeks in difficulty in ice-congested waters in and near Barrow Strait. Bellot Strait, an alternate route, was open for four days and navigable for some time beyond that with ice breaker support. In this region ERTS has five to six consecutive days of overlap out of eighteen. The probability of obtaining a useful ERTS photo showing the ice-free conditions of Bellot Strait, taking into account cloud cover, was then about 10 percent. Barrow Strait, which was closed in, would be covered by a different series of orbits, so that the probability of obtaining information that would have helped the ship was at least 20 percent. The company believes it could have saved $1.5 million with better information on ice conditions in this area alone.

ERTS imagery is being used in Saskatchewan to map 42 forest fire burns across the northern part of the province. In the past, helicopters had been used in the mapping of such burns. Using approximate values for helicopter time of one hour per burn for mapping and transit time, the cost at *$253* per hour would be over $10,000 for the helicopter. ERTS imagery costs less than $100, involves less manual time, and greatly improves the accuracy of the mapping.

A profitable application of ERTS imagery is in the mapping of large reservoirs in hydropower development projects. An accurate knowledge of reservoir storage is necessary to determine how much firm power can be generated. In one Northern Canada project, a reservoir was observed by aircraft three times when the reservoir was filling, at a cost on the order of one-quarter of a million dollars. During the course of one survey the water level changed *0.3* meter (1 foot) because of the time factor involved in covering the entire reservoir.

The reservoir could be covered by two ERTS images. Satellite data taken at one point in time would give a much less expensive and better volume estimate. This would result in a better estimate of firm power capability and would affect the contracts for power generation entered into by the company. In the project just mentioned, there are, at present, indications that the reservoir storage is several percent greater than expected. It is believed that this could be translated into about one percent extra power generation worth $1 million. ERTS will be used to try to assess the extra storage capacity. Although the project has entered into a long-term contract, it could still be made known to the customer that the company has the capability of generating this extra amount of power.

ERTS imagery is being considered in the mapping of Reindeer Lake in Saskatchewan, which will be used as a storage reservoir for a power development on the Churchill River. Reindeer Lake has been surveyed by aircraft at a cost of $46,000. A mosaic from which an area measurement could be made would cost $35,000. The reservoir can be covered by two ERTS frames, and several ERTS images taken at various lake water levels should give a better extrapolation to the final reservoir storage when the new dam is built.

E. A. Fleming of the Department of Energy, Mines, and Resources, investigating the utility of ERTS data for topographic mapping purposes, has concluded from a study of the reservoir formed by Kettle Rapids Dam in Manitoba, that the reservoir outline from ERTS for 1:250,000 mapping would be more accurate than could be obtained from 85 pictures at 2,000 feet/inch.

High benefit applications in Canada of ERTS imagery are predicted in land use mapping and in the selection of routes for pipelines, transmission lines, and highways. ERTS imagery is being used together with larger scale imagery in studies to select a route for the Polar Gas Pipeline. Preliminary estimates of updating the present land use mapping in Western Canada indicate cost savings of about 4:1 for high altitude photography over conventional aerial survey photography, and approximately 20:1 if satellite imagery is used. The satellite imagery would have to be used in digital form to give the required resolution.

INTERNATIONAL ASPECTS OF ERTS

ERTS satellites, operational resource satellites, EOS – Is there a real world need for such data? In spite of the fact that ERTS has been up for a year and a half, the international community has just begun to be aware of its importance.

ERTS is particularly useful to the developing nations, such as the nations in the Sahelian Zone of Africa where, because of drought and the absence of controlled grazing policies, the desert is slowly moving south and many people are dying. Dr. John Howard of the Food and Agricultural Organization (FAO) has said that FAO and the United Nations Development Program (UNDP) are mounting a crash program to map the vegetation in this zone to assess the damage and to point out areas that could still be productive. This must be done before any long-term viable program of population transfer could be undertaken. It could be done by sending 25 aircraft into the area for a year or so, but the resulting data would be fractionated, hard to handle, and would take five years to sort. ERTS can do the job now and can do it repetitively at a scale that will allow fast interpretation. In the past two years computer methods of using ERTS data have been devised that can categorize land use and vegetation in periods of days, rather than the years taken by conventional air photo techniques. The FAO and UNDP need these maps now and during the course of the next few years to begin their ground truth studies.

It takes time for the impact of a new technology to penetrate a technical and administrative infrastructure. It was two years ago when a group of remote sensor specialists from NASA, Interior, Agriculture, Purdue, and Canada were invited to FAO by the assistant director general, Dr. Frischnick, to make recommendations as to what FAO should do about remote sensing. Of all the international organizations that could benefit from ERTS, FAO would benefit most. It is responsible for world agriculture, forestry, and fisheries. It was recommended that four full-time workers be assigned, but because of shrinking budgets, only one man on a one-year contract could be assigned. Dr. Howard, an able and aggressive scientist, has recently been appointed on a permanent basis and will have three assistants; he is now receiving many letters from field parties requesting data and information.

ERTS is also important to India, where centuries of land cultivation compounded with population overgrowth have overtaxed the soils, and where some areas have not been mapped since the 1890's. After two or three years of uncertainty, India has taken a decisive step by assigning a budget and appointing a new coordinator for remote sensing, Mr. S. E. Roy of the Indian Department of Technology. A phased program has been designed and approved for remote sensing in the fields of agriculture and forestry, cartographic mapping, mineral exploration, water and oceans. More importantly, the budget has been approved. One interesting facet of the work in India is the water drilling program, funded by a most unlikely organization, UNICEF. They sent 130 drilling rigs into India and in the last year they have drilled 130,000 tube wells. In many cases the drillers are shooting blind. They desperately need ground water probability maps. ERTS could help significantly in this endeavor.

ERTS mapping is needed in Southeast Asia where the forces of war and threats of new wars are sapping the creative energies of the people, and where planning for a new life must begin quickly.

Dr. Murthy, the United Nations Special Consultant on Space, just returned from a remote sensing conference in Buenos Aires. Scientists from 17 Latin American countries attended the conference. Aside from Brazil and Mexico, who are already fully involved with remote sensing, these countries are just beginning to get interested, now that they have had time to translate and digest the first ERTS papers.

In conclusion, it should be remembered that there are two kinds of enemies to human survival. One includes the human factors of fear, jealousy, greed, lust for power, ignorance, and mere complacency, and the other, the forces of nature. The best way to fight the former is to uncover factual information on the subject and make it universally available. The forces of nature cannot be controlled, but with adequate and timely information, mankind can adapt more swiftly. ERTS-1 is one small step for mankind toward these goals. Let us hope that ERTS-B will follow soon.

ENVIRONMENTAL SURVEYS IN ALASKA BASED UPON ERTS DATA

John M. Miller
University of Alaska
Fairbanks, Alaska

Before reviewing the Alaskan applications of ERTS, three very significant events in recent years that have proven to be milestones in the management of Alaskan resources and land environment should be discussed. These are the 1968 discovery in northern Alaska of major oil and gas deposits to complement the existing petroleum production in the Cook Inlet Basin; the passage by Congress of the Alaska Native Claims Settlement Act of 1971 which allocated an unspecified 160,000 square kilometers (40,000,000 acres) of federal lands to Alaskan natives and authorized selection of 400,000 square kilometers (103,000,000 acres) by the State of Alaska; and the launch of the Earth Resources Technology Satellite in July 1972, which opened the door in an unprecedented way for up-to-date resource inventories and environmental surveys.

The basic data for informed resource management and land use planning in Alaska are sparse and often outdated. This fact is amply demonstrated by the national controversies surrounding the first two events mentioned. Environmental concern dictated that a need for marketing the North Slope oil be demonstrated and that the means for doing so presented a minimum threat to the land and to wildlife.

The current fuel shortage has amply answered the first consideration, but doubt has lingered much longer than usual about the environmental safety of the production and marketing of the North Slope petroleum. One reason for this doubt is that our present and urgent "need-to-know" has outstripped our detailed knowledge of the vast and complex Arctic environment.

Many areas remain unsurveyed. Resource maps were unavailable except at small scales, which limited their usefulness; conventional aerial photography generally is representative of World War II technology. A program to supplement and update the inadequate data base for this nearly 1,000,000-square kilometer region and 8,000-kilometer coastline by conventional means would require two decades and be economically unfeasible.

Not to force a simplistic answer, but to the extent that ERTS helps to bridge the environmental knowledge gap, it also aids the sound design of a transportation corridor to the mineral and petroleum resources in northern Alaska.

In consideration of the second significant event, the land selections to be made within the next two years by Alaskan natives and by the state of Alaska are of equal impact within Alaska to the oil discoveries. Figure 1 helps to put into proper perspective the importance of land use management in Alaska. The Federal Government is the land owner of 38 percent of Alaska. The state will have 28 percent; so-called national interests category land, 21 percent; native corporations will control 11 percent; and 2 percent will remain under private control. It is interesting to note that after the native corporations and the state have made their land selections, the Federal Government, with 59 percent, still will be a larger landowner than the others combined.

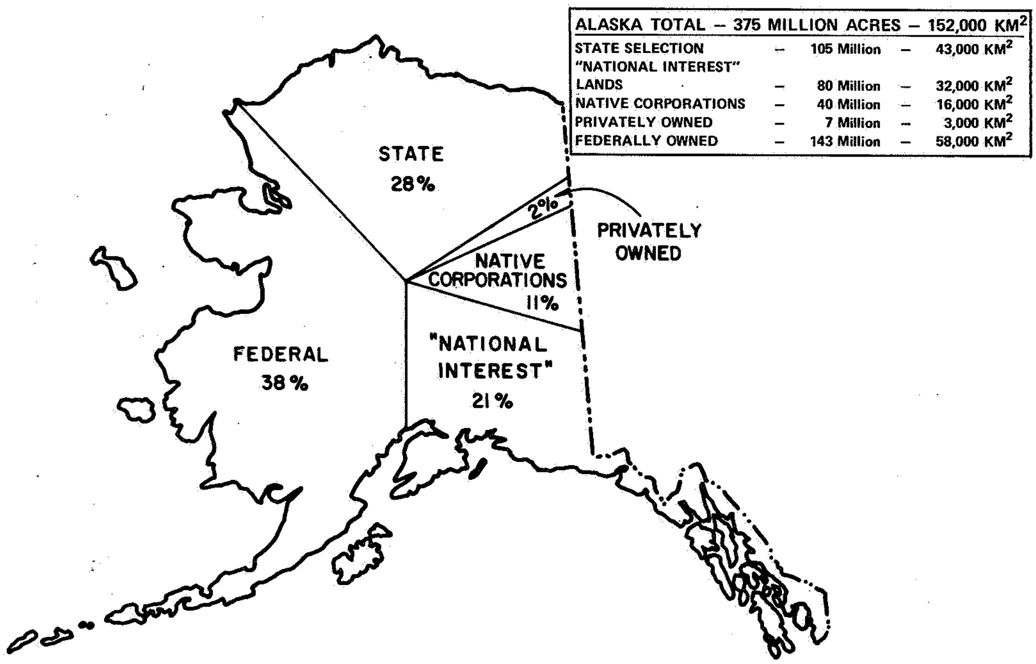


Figure 1. Status of land ownership in Alaska, 1973.

Since Figure 1 was prepared, the Department of Interior has recommended that additional acreage, totaling an area the size of the state of Connecticut, be added to the 320,000-square kilometer (80,000,000-acre) ceiling provided for by the Land Claims Act. If Congress approves this recommendation, this national interest figure would grow to 332,000 square kilometers (83,000,000 acres).

How do land managers make informed decisions, for example, of which acreage to select for native rights? For the best interests of the state? Or what lands should be included in the wild and scenic river category? Figure 2 shows the complexity of the land ownership status within Alaska. The heavy line marks the area within which one of the native land management corporations must make its land selections. Native leaders have asked for help in producing resource inventories of this area, which is threequarters of the size of Texas. In essence, their question is, "If we want to maximize commercial forestry and mineral potential, tell us what acreage to select." Obviously, the only way that answers to such questions as this will be timely is to utilize ERTS data.

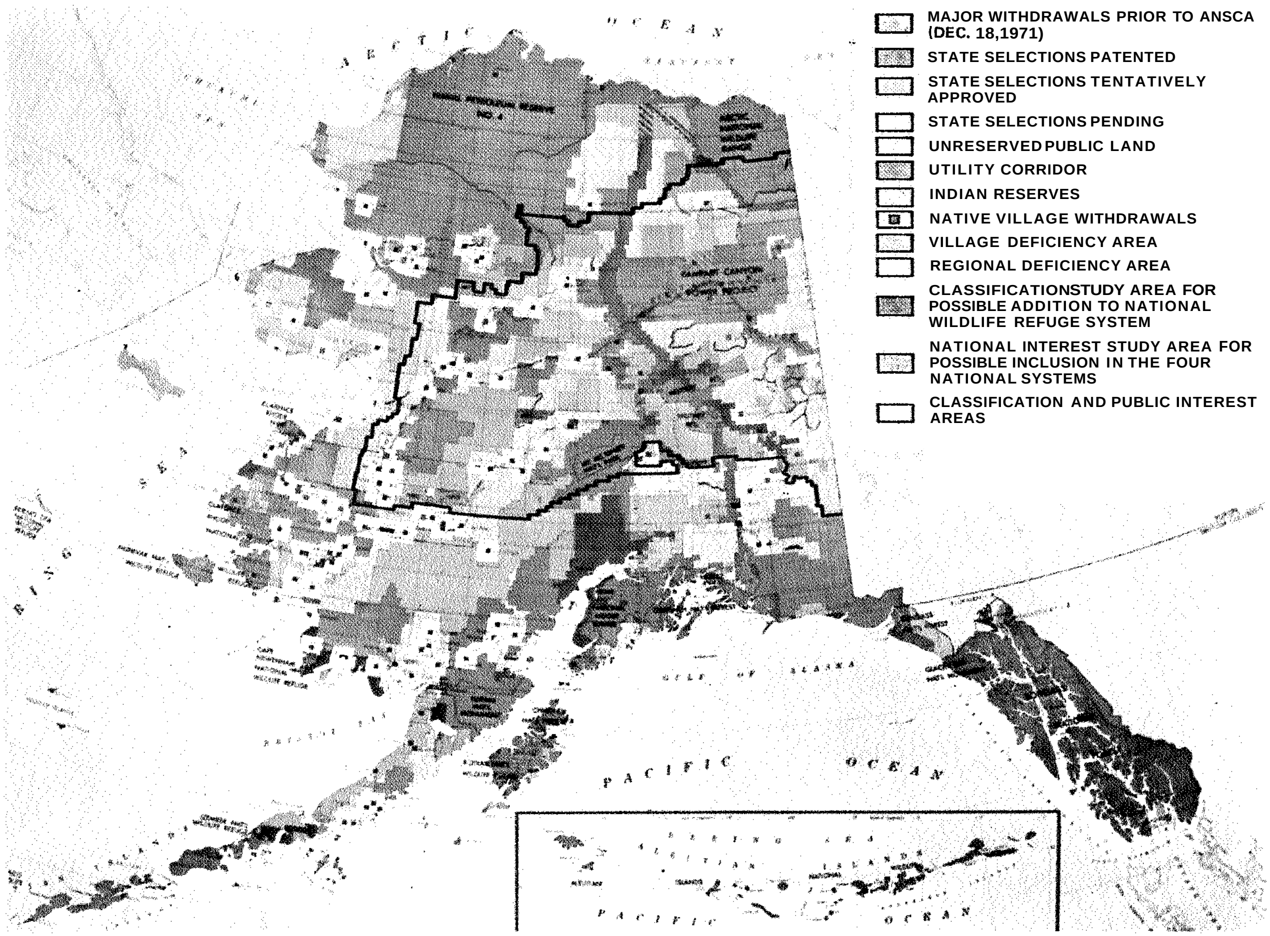


Figure 2. Proposed land use categories in Alaska, 1973.

The task of the Joint Federal-State Land Use Planning Commission must also be considered. The Commission had the task of recommending to the Secretary of the Interior, by August 1973, which of the 320,000 square kilometers (80,000,000 acres) should be placed in the national interest category. To generate a data base adequate for decisions of this magnitude, the Commission first produced the general ecosystems map of Alaska shown in Figure 3. The leader of the Commission's resources planning team estimated that use of ERTS data saved 100 man-years in the preparation of this map. In other words, if it were not for the availability of ERTS data, the Commission's decision-making process would have had to operate from an inadequate data base.

Land use planners believe there is a need to protect potentially prime agricultural lands from encroachment by urbanization in the Matanuska and Susitna Valleys near Anchorage. Many of the developed farms shown in Figure 4 are within commuting distance of Anchorage, where one-third of the population of Alaska lives. This fact, coupled with the fact that most non-farm land is federally owned and not available for development, means that land prices, along with the taxes, are inflated to levels beyond crop production protentials by pressure from the market for home sites – an altogether too familiar pattern in the lower 48 states. Because previous wasteful energy practices now give cause for regret, many planners believe that similar shortsightedness, causing waste of prime agricultural land, will also be regretted in the future.

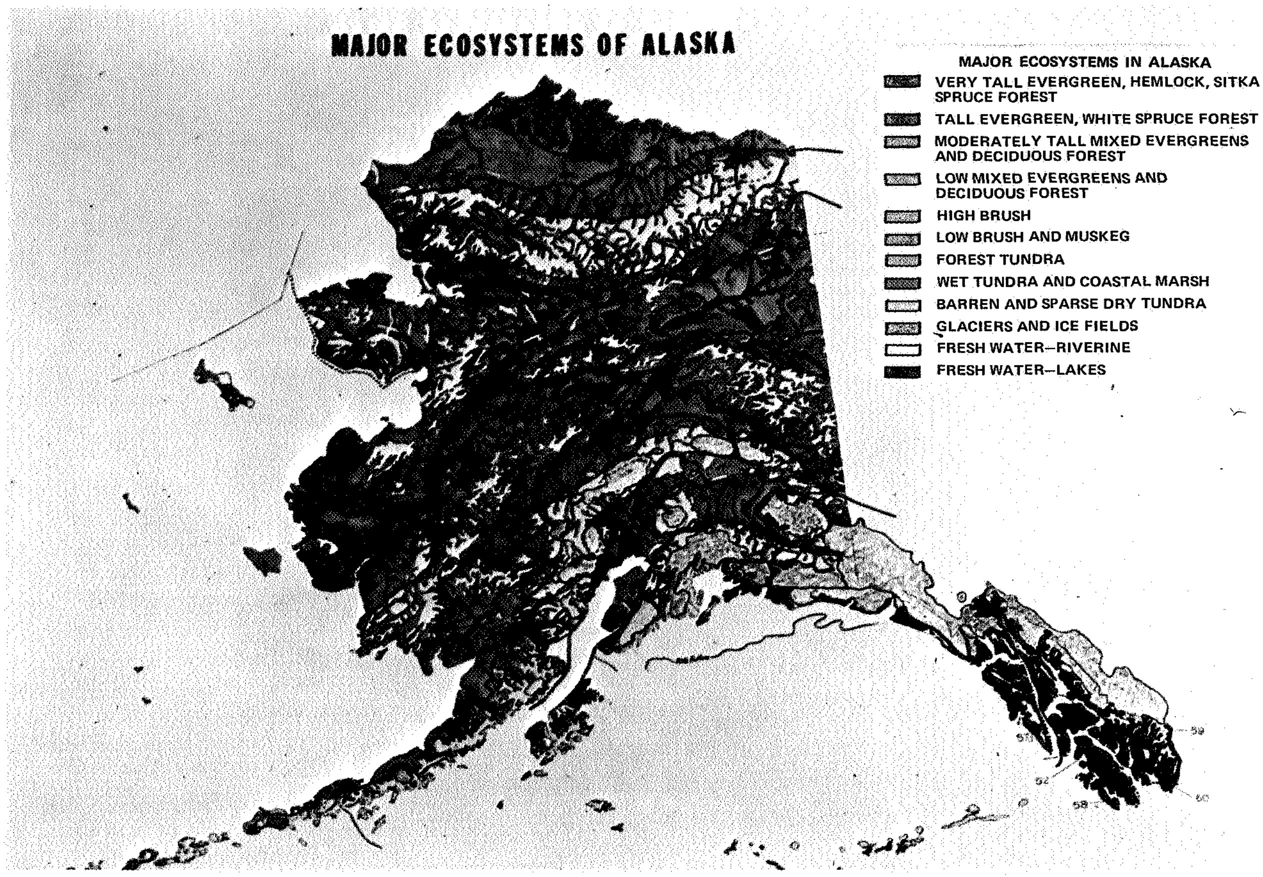


Figure 3. Varied terrain of Alaska is depicted by this ecosystems map prepared by the Federal-State Land Use Planning Commission.

Dr. McKendrik of the Institute of Agricultural Sciences in Palmer is using ERTS imagery to map native vegetation types to provide a guide to agricultural land inventories. Figure 5 depicts a computer classification of a suburban area north of Anchorage. The yellow is the silty water of Cook Inlet; green is spruce; and red is birch, which typically represents land with both agricultural and community development potentials. The black areas represent a haze, perhaps a heat island effect, from the urban Anchorage area. Note that the haze extends out into the inlet.

Figure 6 shows a similar classification map of the rural Big Lake area, which is currently under heavy pressure for home site development. Black in this figure primarily represents muskeg, while red is land that is suited both for home sites or agriculture. Planners must ask which would be the wisest and best use of specific parcels of land, and these planning tools provided by **ERTS** have about a 10:1 or 20:1 cost advantage over conventional aerial photography techniques.

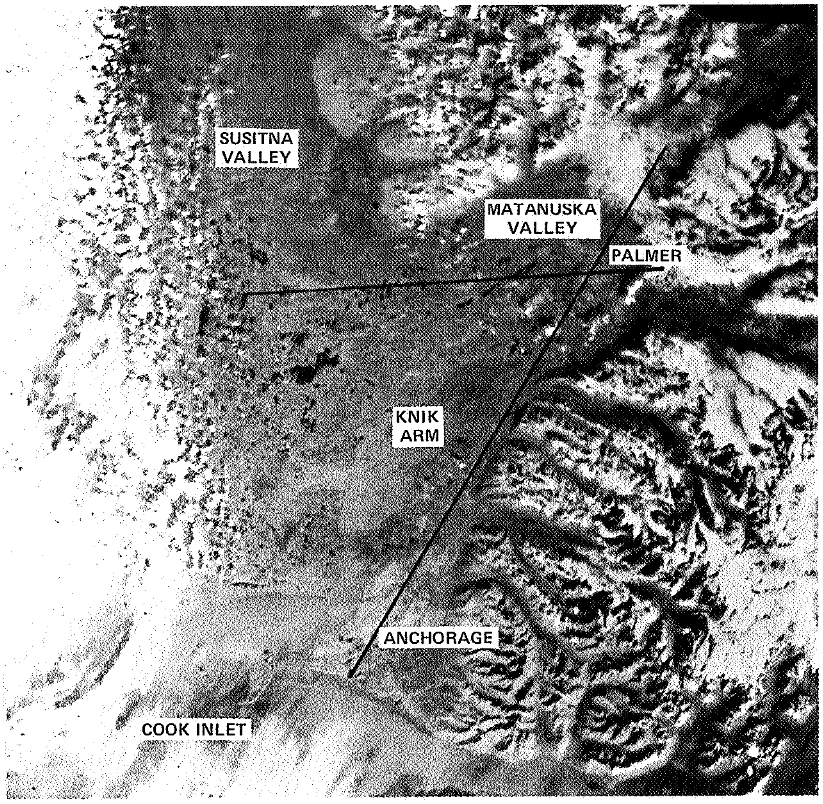


Figure 4. The Susitna and Matanuska Valleys in Alaska are two prime areas for both agriculture and homesite development. Flight lines mark 1972 aerial data acquisition used with ERTS to prepare land resource inventories.

Figure 5. A preliminary computer classification of developed land near Anchorage.

Figure 6. A computer classification of rural land subject to development pressure from the Anchorage population center.

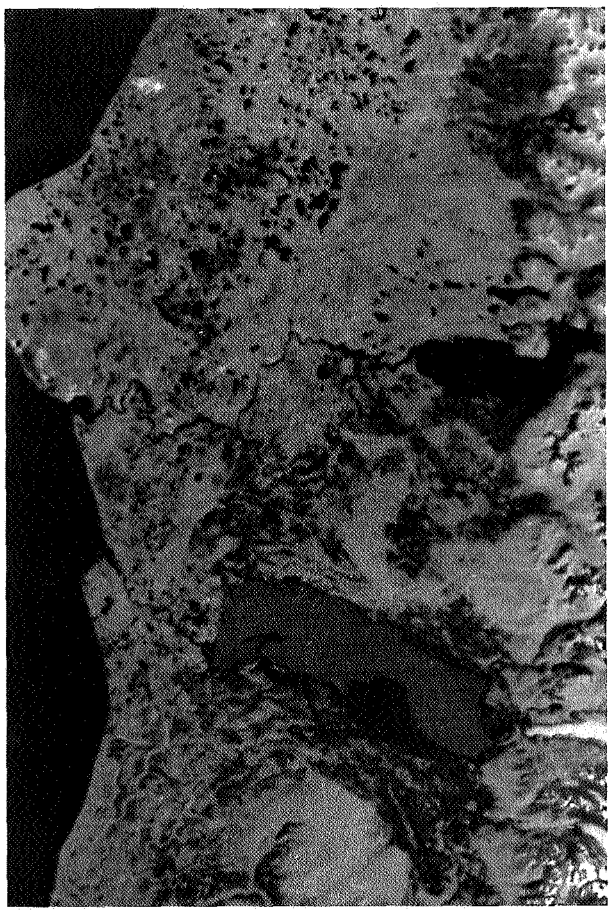


Figure 7. ERTS revealed an extensive grasslands,just north of Tustumena Lake in the lower center of this scene, that previously was mapped **as** upland brush.

Figure **8.** This computer-generated vegetation map of the lower Yukon River was used to define the spectral signature of abandoned village sites.

Sometimes sophisticated computer processing is not necessary to discover beneficial knowledge about remote areas. In Figure 7, a color composite scene of the Kenai Peninsula, an extensive rangeland that was previously unsuspected, has been located solely by interpretation of the color tones of the image. This is an important discovery because pioneering efforts were already underway to develop a red meat industry on the Kenai Peninsula. This new grassland region is presently inaccessible because it is 120 kilometers (75 miles) from the nearest road. Not only did ERTS provide the means for discovery of this potential grazing area, but it can also help to answer the question of whether it ought to be exploited or left to remain in its wilderness environment.

One of the more unusual projects of the University of Alaska is an archaeological study of the lower Yukon River. Its goal is to identify old native village sites using ERTS imagery. Groundbased studies have shown that such sites are often along river banks and are associated with areas of lush grass interspersed with unusually vigorous growths of willows.

Figure 8 is the vegetative-type map produced by Dr. Stringer on a computer display. He then isolated the spectral signatures for the special grass-willow growths typical of former habitation sites. The computer printout map shown in Figure 9 predicts the location of old Kaltag to be downriver, on the opposite shore, from the location of the present village of Kaltag. Verification that ERTS data have located an abandoned village site without prior knowledge of its location awaits further field work. Such techniques should have applications elsewhere in Alaska to protect the antiquities of man from unnecessary destruction as development proceeds in the state.

Figure 10 is a photo mosaic from ERTS scenes prepared by Cold Regions Research Engineering Laboratory (CRREL). It is an area located in north-central Alaska, about the size of Oregon, and from the information on the mosaic the CRREL was able to produce the permafrost map shown in Figure 11. Native vegetation is an important indicator of permafrost characteristics in the Arctic and sub-Arctic soils. The discontinuous permafrost zone is typically a complex mosaic of frozen and unfrozen ground, so the geographical distribution of permafrost generally is not well defined. Using vegetation and surficial geology features as indicators, Dr. Duwayne Anderson at CRREL mapped the area of this ERTS mosaic (Figure 11) at a scale of 1:1,000,000, showing four types of permafrost terrain with considerably greater detail than the earlier map.

Figure 9. Semicircles on the right bank of the river identify the computer-predicted former location of the village of Kaltag, Alaska.

A related Arctic phenomenon is that of stream icing. This occurs when subsurface ice forces water to flow on the top of the ice cover. Once on the surface, the water continues freezing and building thick layers of ice. Figure 12 is a summertime ERTS view of “aufeis,” as the icing is often called, which remained long after the spring breakup. Certain streams tend to generate aufeis seasonally, and frequently it will become so massive that it cannot completely melt in the summer. The summer ERTS scene of Demarcation Bay along the Arctic Coast near the Alaska-Canada border (Figure 13) shows many massive aufeis accumulations. The largest deposit is in the river delta and now has been monitored by ERTS for two years. It remained throughout the 1972 summer season and in 1973 appeared even larger in area. This winter ERTS image of Figure 14 also shows the larger streams, which in the winter are in the process of icing. The open water on this tributary near the pipeline route may indicate stream icing in progress. This is a potential application to monitoring the safety hazards of the pipeline and also to mapping sources of fresh water in the summer.

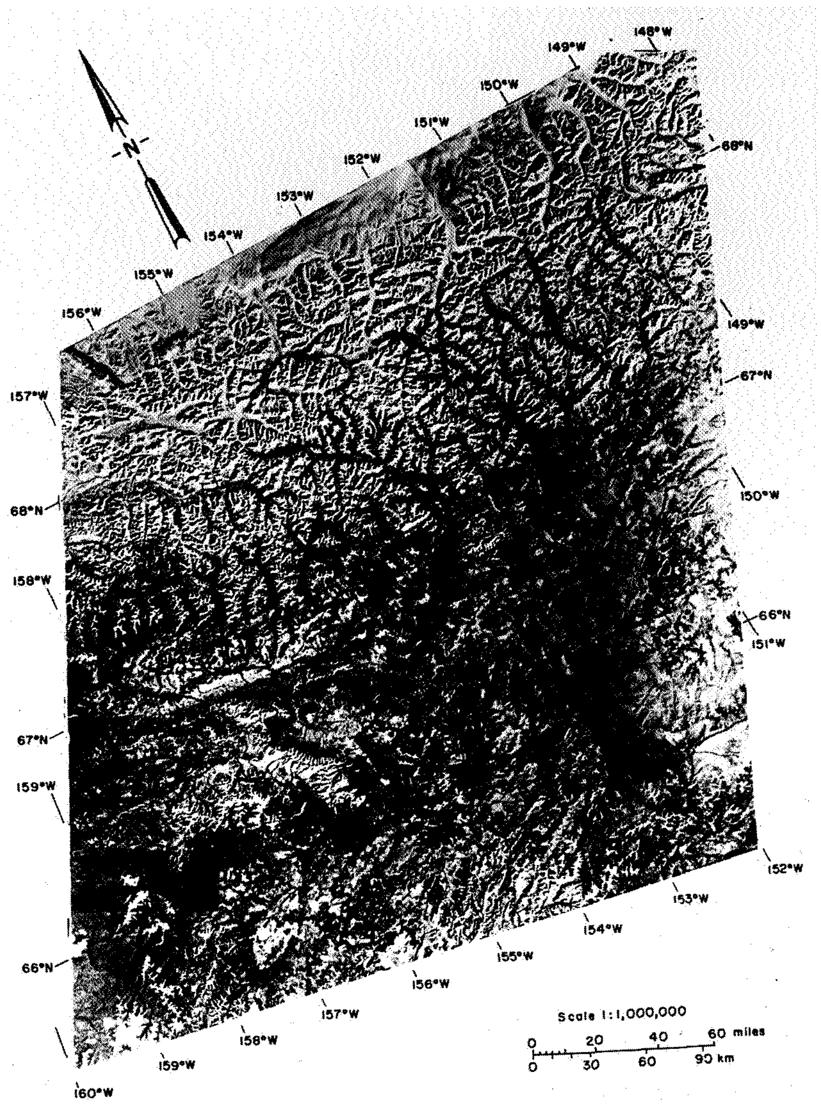


Figure 10. A photomosiac of **the north-central interior** of **Alaska prepared** by Cold **Regions Research** and **Engineering Laboratory.**

Another ERTS scene that expands our understanding of the Arctic climatic environment is shown in Figure 1.5, an enhanced May 27 image of the petroleum region of the North Slope. By this date, the Sagavanirktok River has open, running water, and the Prudhoe Bay roads are visible. This color-enhanced image shows melt plumes extending southwest from this road in the prevailing wind direction. These melt plumes are the result of winds picking up dust and depositing it downwind, thereby accelerating the melting process. Figure 16 is an aerial view of the road showing the effects of road building in the flat plains of the North Slope. The first result is the creation of extensive snow drifts paralleling the road, and the second is deposition of dust downwind onto the snow, which causes premature melting.

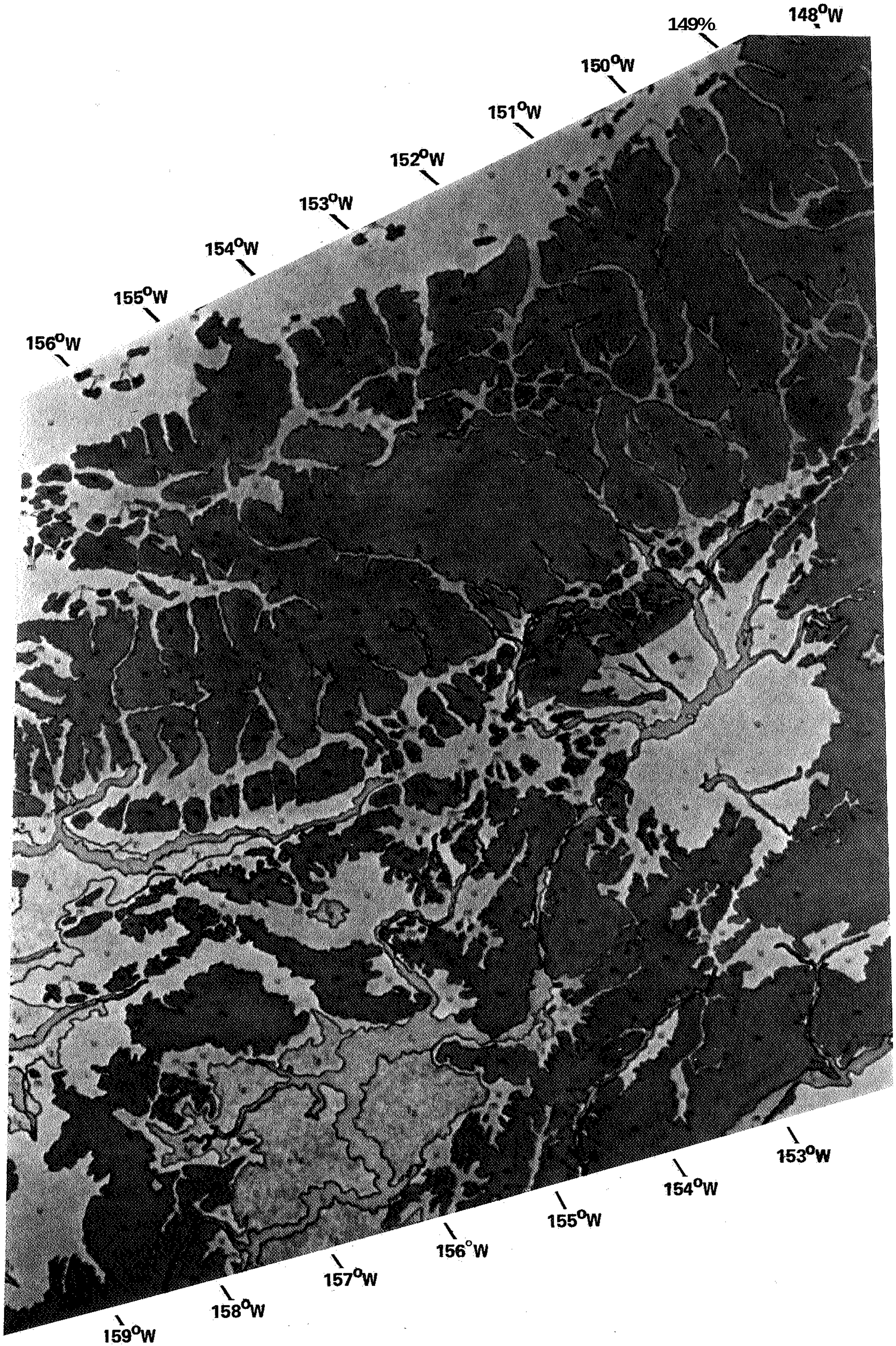


Figure 11. Permafrost terrain map prepared from the ERTS mosaic of Figure 10 of the north-central interior of Alaska.

Figure 12. An example of Alaskan aufeis, or stream icing.

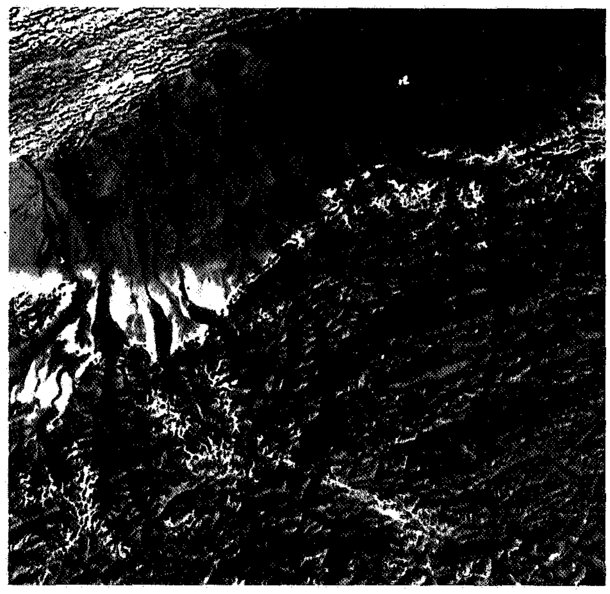


Figure **13. ERTS** image of the north coast of Alaska, showing many patches of aufeis along drainage channels near the shore as well as inland.

As oil production activities increase, they may have a significant influence on snow breakup patterns in the Arctic. Hydrological modeling of the Alaskan North Slope is an imperative need because clean water at certain seasons is a scarce commodity which will become more precious as man's activities increase.

ERTS has had an extremely significant geological impact on Alaska. Figure 17 is a composite color ERTS image of the Umiat oil field region in Naval Petroleum Reserve Number 4. The Umiat field contains some 50,000,000 barrels of oil, and Ernie Lathram of the USGS, through study of ERTS images, suggests that a closer look to the north and east of Umiat should be taken. The lineation in the region of the lakes should be noticed. Figure 18 also relates ground-truth data to the lineations visible in ERTS photos. Magnetic anomalies, gravity contours, and fold axes of the earth's crust are related to this ERTS image as shown by the overlay.

In Figure 19, the yellow area south of the lineated lakes is where the magnetic anomalies are sharply north-trending. The white area is the region of east-trending anomalies, which are exactly parallel to the lineations – an interesting coincidence. Seismic lines show folding in the seismic contours with the same trends as the surface lineations – another interesting coincidence. Next, the folds in the gravity contours in Figure 20 should be compared with the data of Figure 19. The adjacent bends in the gravity contours are parallel to the lineations. It should also be noticed that a plateau in the gravity contours overlays the circular lineation feature – another striking coincidence.. There is yet a fourth coincidence. Examination of ERTS imagery reveals that this lineation, shown as the shaded area in Figure 21, extends eastward to the Canning River and embraces the coastal plain from the foothills of the Brooks Range to the

Arctic Coast near Prudhoe Bay, and that Prudhoe Bay is located in similar geologic conditions. Here ERTS has revealed related comparisons between geologic **and** geophysical conditions which warrant further drilling.

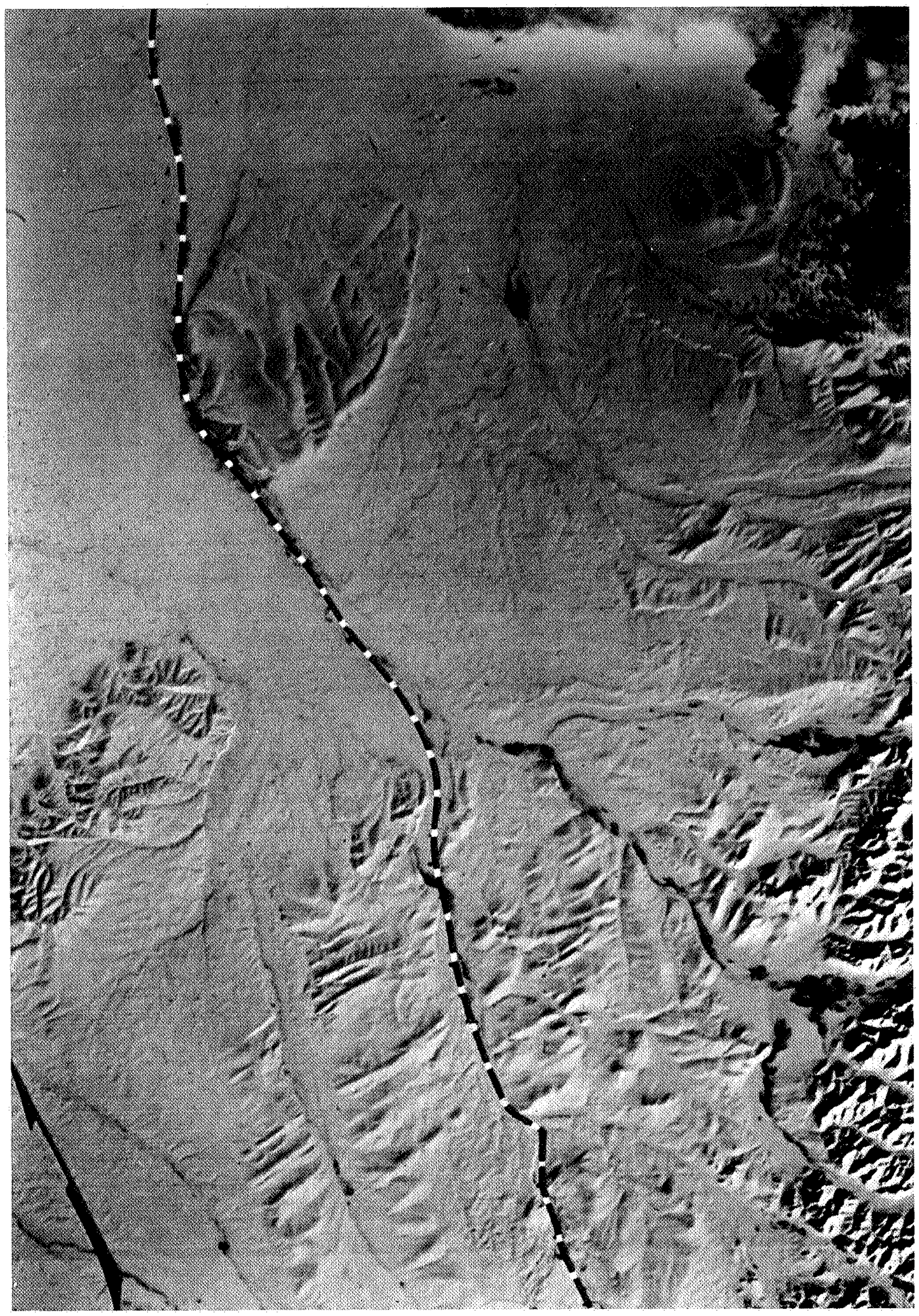


Figure **14.** Winter ERTS scene showing proximity of stream icing conditions (black patches along valleys) to the location of the oil pipeline (dashed line).

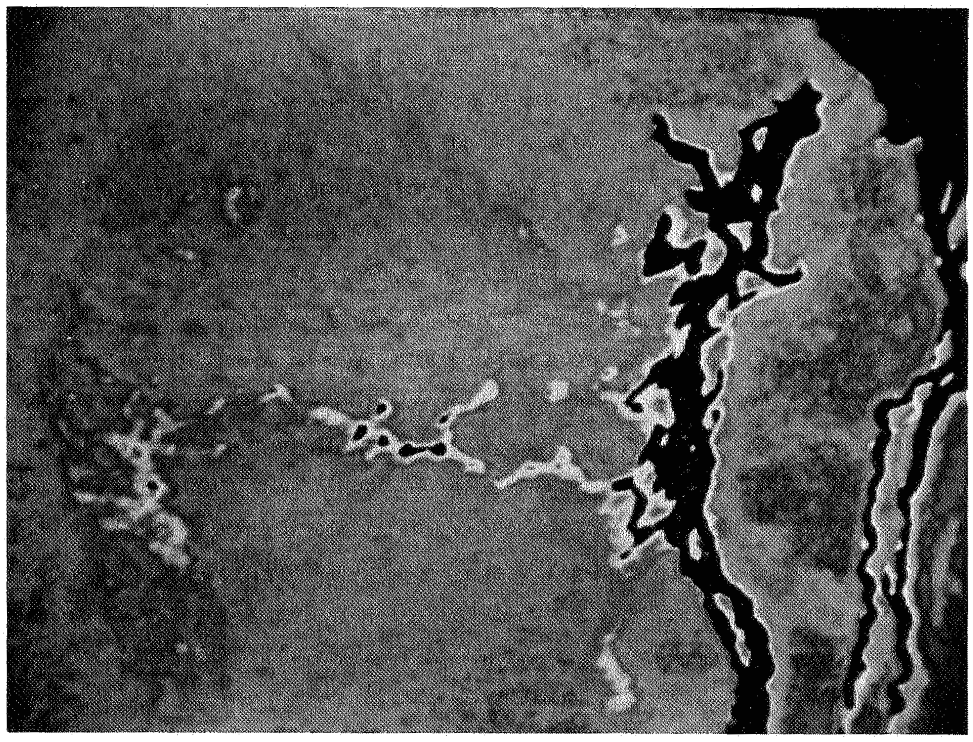


Figure 15. Color-enhanced enlargement of an ERTS scene showing raindrop-shaped dust plumes from Prudhoe Bay road network in the center of the photo. The tails point downwind from the prevailing wind direction.

Figure 16. Aerial view of a typical Nortli Slope gravel road showing enhanced snowmelt from dust blown downwind from the surface of the road.

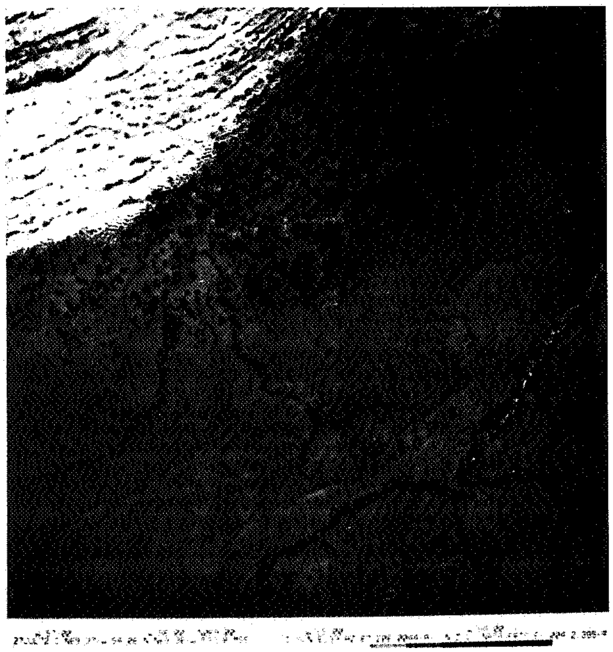


Figure 17. Color composite ERTS image of the Umiat, Alaska, area.

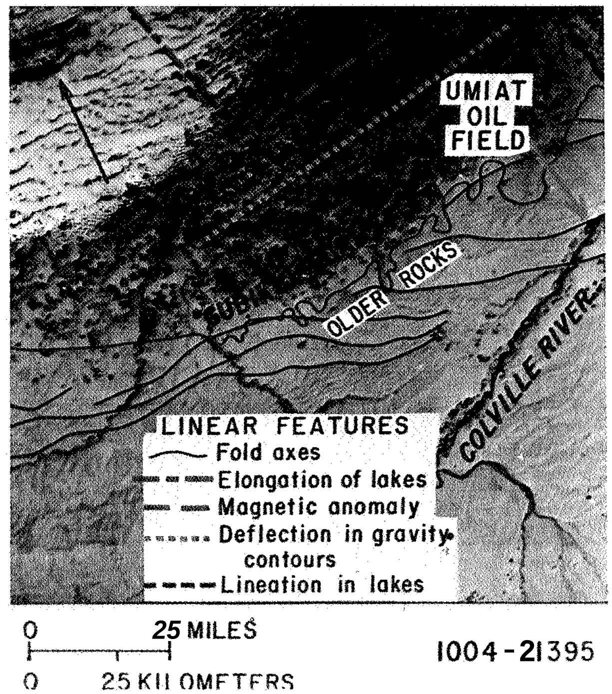


Figure 18. Relation of ground truth to lineations evident from ERTS.

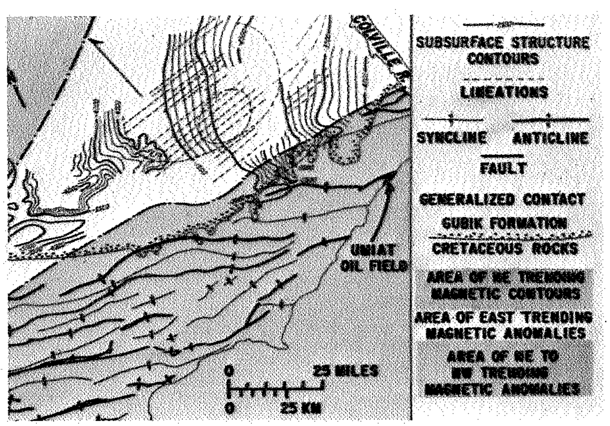


Figure 19. Relation of magnetic anomalies to surface lineations.

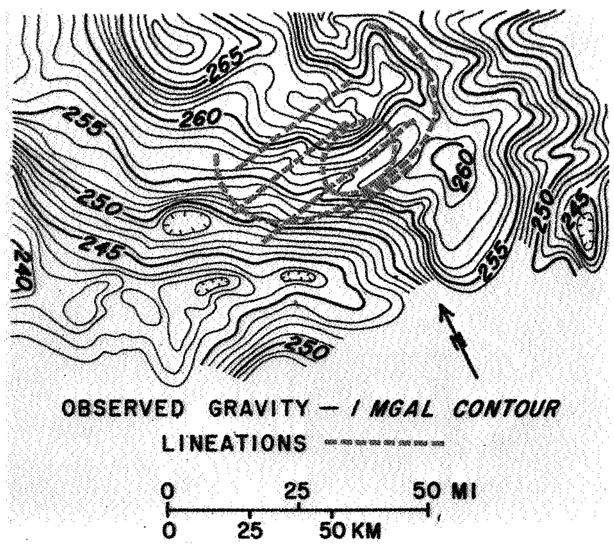


Figure 20. Relation of gravity contours to surface lineations,

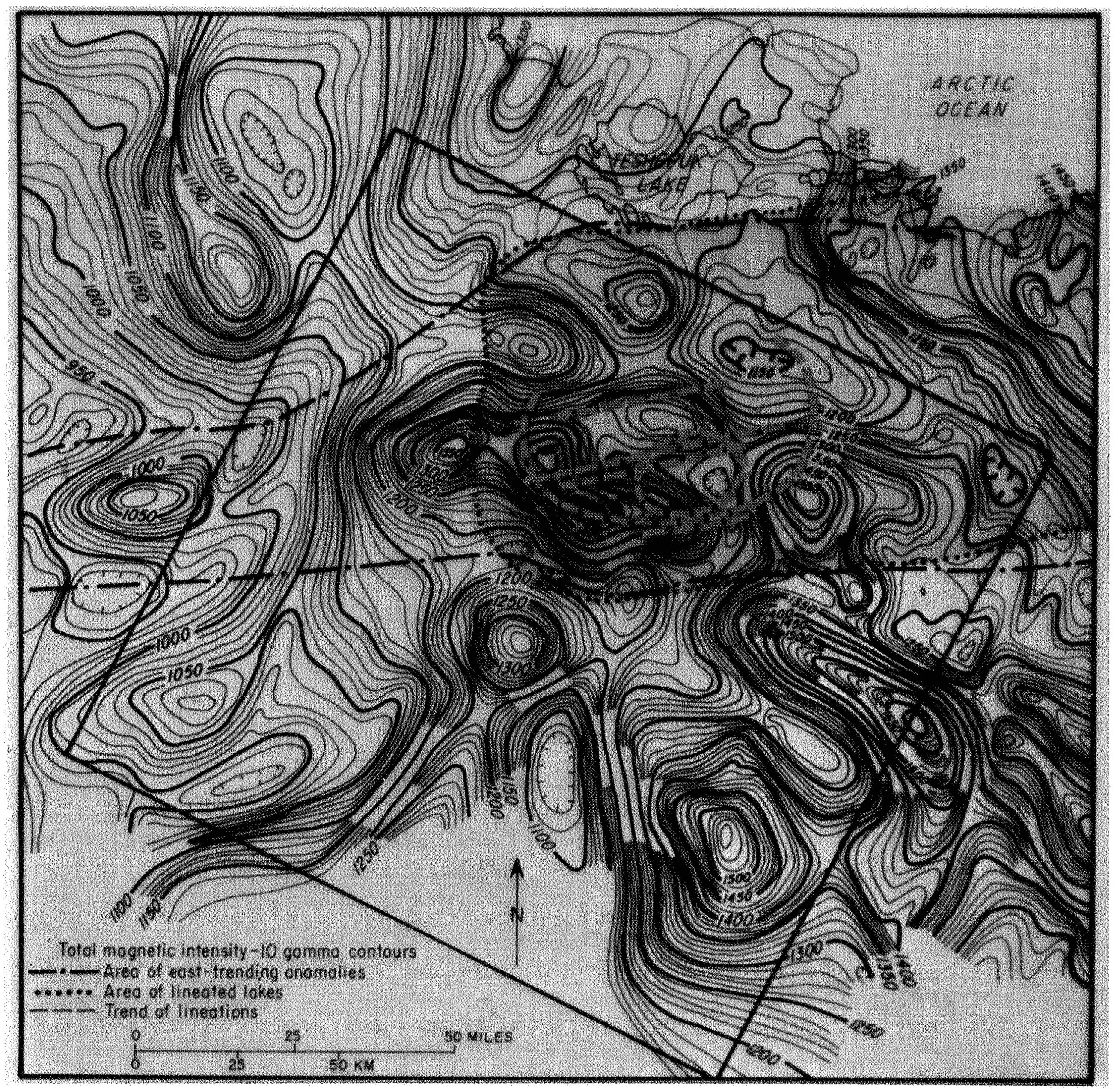


Figure 21. Shaded area is surface lineations that ERTS photo shows to extend to the coast near Prudhoe Bay. East-trending magnetic anomalies correlate well with trend of lineations.

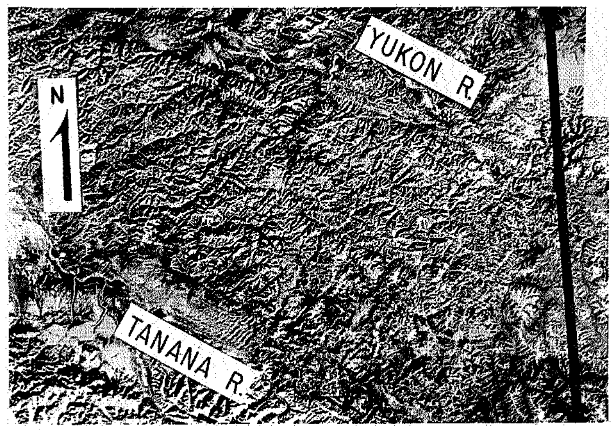
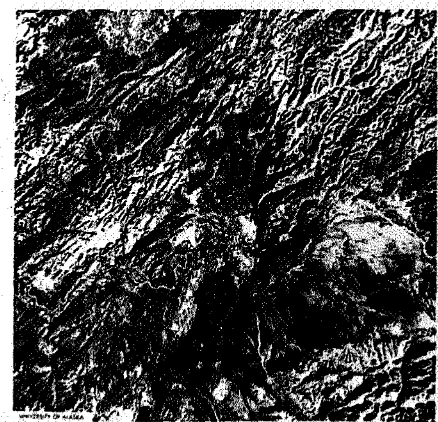


Figure 22. An ERTS mosaic of the eastern interior of Alaska showing a field of northeast-trending linear features that have good potential for porphyry ore deposits.

Mr. Lathram is also pleased with another ERTS product, a mosaic shown in Figure 22 of eastern interior Alaska. Fairbanks is just off the left edge of the picture and the heavy line marks the Canadian boundary. The significant feature is the overwhelming preponderance of northeast-trending linears. The new metallogenic concept of Alaskan geology, developed since spacecraft images became available, suggests that ore deposits should occur not only south of the Alaska Range, but also north of it at the intersection of crustal linears. This ERTS mosaic shows this concept. Further, this ERTS-supported new philosophy has been confirmed by the discovery of six copper molybdenum porphyries in the Tanacross area near the Canadian border, and two of them are being drilled by private industry.

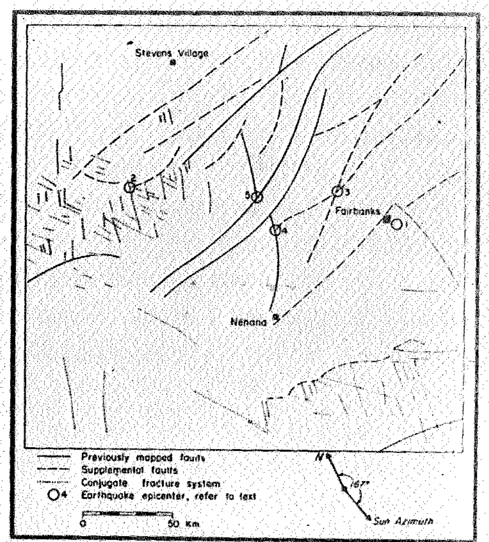
Figure *23* includes another ERTS mosaic filled with important geologic implications. The mosaic on the left was prepared from nine ERTS scenes acquired on November **3,** 4, and 5, 1972, and encompasses interior Alaska. The Tanana River is in the lower center and Fairbanks is in the right center. Experience with seismic data from the Geophysical Institute and the NOAA seismographic network in Alaska indicates that large earthquakes can occur almost randomly in the interior without prior warning. The data are insufficient, however, to indicate where such seismic zones might exist, although such knowledge would be valuable to earthquake engineering. On the right of Figure **23** is an overlay of lineaments evident in the ERTS mosaic, and it also locates the larger earthquakes that have occurred recently in the interior. Most of the epicenters fell on or near lineaments, and they especially tend to cluster near intersections of lineaments. The solid lines are those faults that had previously been mapped on the ground, and the dashed lines are large-scale faults not previously recognized. The dotted lines delineate a very sharp set of conjugate lineaments that suggest that stress lines radiate perpendicularly from the Alaska Range. Such stress is probably responsible for the broad area of shallow seismicity in the interior. Much of the region represented in this mosaic will be under development in succeeding years. In particular, the Alaskan pipeline will cross nearly every one of the major lineaments in the northeast section of the mosaic. Further, the pipeline and highway bridge across the Yukon River is planned at the end of the Minook Creek fault (location 2), which has long been suspected from seismic data as a fault, but which was first recognized on this ERTS image. The interpretation of ERTS and seismic data suggests these lineaments should be regarded as potential sites for sizable earthquakes.

In Figure 24 is a similar mosaic with overlay mapping lineaments and seismic events. This is the region south of the Alaska Range that includes Anchorage, the Kenai Peninsula, and Cook Inlet; the great Denali Fault crosses from the upper right to the left center. On the accompanying key



ERTS PHOTO-MOSAIC OF INTERIOR ALASKA

This photograph covers an area of interior Alaska measuring approximately 240 kilometers on a side. It is a reproduction of a mosaic produced from portions of 6 ERTS-1 images collected during two consecutive revolutions of the satellite during November, 1972. The Yukon River enters the scene at top, the Tanana River crosses from right to left, and the Alaska Range is at bottom right. Sun elevation over most of the area was around 9°, all streams and lakes were frozen, and there was a light cover of snow on the ground.



TECTONIC PATTERN DERIVED FROM PHOTO-MOSAIC AT LEFT
The inner margin of this figure is keyed to the boundary of the mosaic of interior Alaska. Three categories of lineaments are depicted. Those shown in solid lines represent faults previously mapped by geologists in the field. Lineaments represented by dashed lines are faults which appear to supplement the previously mapped set, while the dotted lines depict a previously unmapped conjugate fracture system which implies compressive stress in a NNE-SSW direction. Note that earthquakes tend to occur at intersections of these lineaments.

Figure 23. ERTS mosaic of central interior Alaska with accompanying overlay of faults, fracture zones, **and** earthquake epicenters.

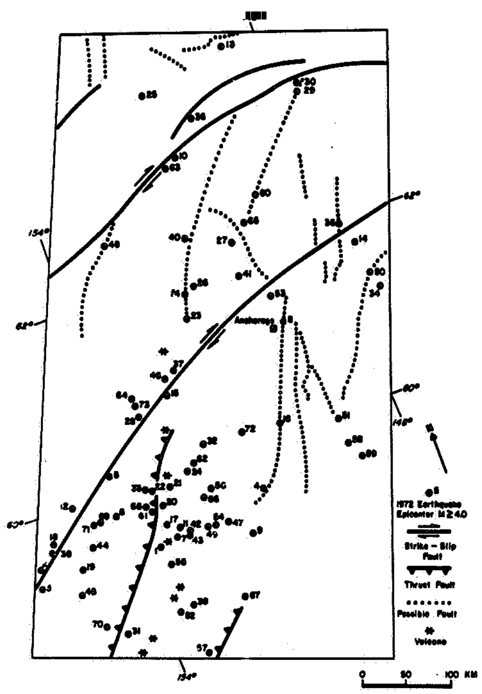


Figure 24. ERTS mosaic of southcentral Alaska with overlay of faults and earthquake epicenters.

diagram are located the epicenters for 1972 earthquakes of magnitude four or greater. It is evident that most of the earthquakes occur in Cook Inlet and are not related to surface lineaments. This agrees with current tectonic theory, which suggests that Cook Inlet is expected to have deep-seated seismic activity unrelated to surface features. However, there is an obvious clustering of earthquakes along the Lake Clark Fault and a few along the Denali Fault. Note the set of subparallel lineaments (dotted lines) first observed with ERTS, which trend off the Denali Fault, and the earthquakes associated with them. Also note those lineaments near Anchorage, especially the extremely sharp escarpment along the mountains just east of Anchorage. Last year there were three moderate quakes associated with this ERTS-discovered lineament which was not previously mapped as a fault. Clearly ERTS is proving to be a tool for the first crude attempts at predicting earthquake locations in Alaska.

Yet another regional ERTS mosaic of the Denali Fault in Alaska and Canada has provided corroborative evidence of a massive offset some 400 kilometers in length along the Denali Fault. In 1970, Forbes and Smith, as part of a cooperative effort of the University of Alaska and the Alaska Geological and Geophysical Survey, became aware of the striking structural and petrologic similarity of 'metamorphic terranes in the Coast Range and Maclaren metamorphic belts. This similarity was intensified by comparable K-Ar ages indicating that regional metamorphism had occurred in both belts between 60 and 70 million years ago. The dark blue area in Figure 25 shows the metamorphic rock belts, and the red area shows granitic types of rocks which are in sharp contrast to metamorphic rocks.

While discussing possible tectonic explanations for the similarity of the two belts, Forbes suggested that the Maclaren belt could be a segment of the Coast Range metamorphic belt, which had been offset by displacement along the Denali Fault. Most annoying, however, were some K-Ar ages older than the prevailing 60,000,000 years that had been obtained from rocks in the northwestern part of the Ruby Range adjacent to the Denali Fault. Later a similar zone of older dates on equivalent rocks was revealed by Turner's K-Ar age determinations along the margin of the Maclaren belt northwest of aprominent linear first recognized on the 1972 ERTS image and reported at the March ERTS Symposium. This prominent linear is now recognized as the Susitna Fault. At this point, Smith recognized that geologic field mapping indicates no significant lateral offset on the Susitna Fault structure, and he suggested that it should have a counterpart in the Kluane terrane in the Ruby Range, if indeed this interpretation of a Denali Fault offset was correct. Subsequent examination of these ERTS images in Figure 26 revealed the existence of a linear feature at Kluane that similarly divides older dates from younger dates in equivalent rocks. The ERTS mosaic helped to provide the breakthrough for those investigators to postulate that an ancient fault cuts through the Maclaren terrain, is truncated by the Denali Fault, and that the other end has been discovered near Kluane Lake, Yukon Territory. In reviewing Alaskan geologic applications of ERTS imagery, it might be said that the most common practice is to build a mosaic and then look for the intersections of lineaments. That is where the action is – ore bodies, or where it is going to be – earthquakes.

In considering hydrologic applications of ERTS imagery, Dr. Wendler of the University of Alaska has mapped the snowbelt breakup characteristics of the Chena River watershed near Fairbanks and generated a computer model of the runoff by use of ERTS imagery. Even in a small basin, snowmelt measurements on a pointwise basis are not very useful, owing to the complexity of the breakup process, and this is especially true in Alaska where precipitation gages are scarce. Furthermore, because of the colder climate, surface hydrology tends to dominate only four to six months per year.

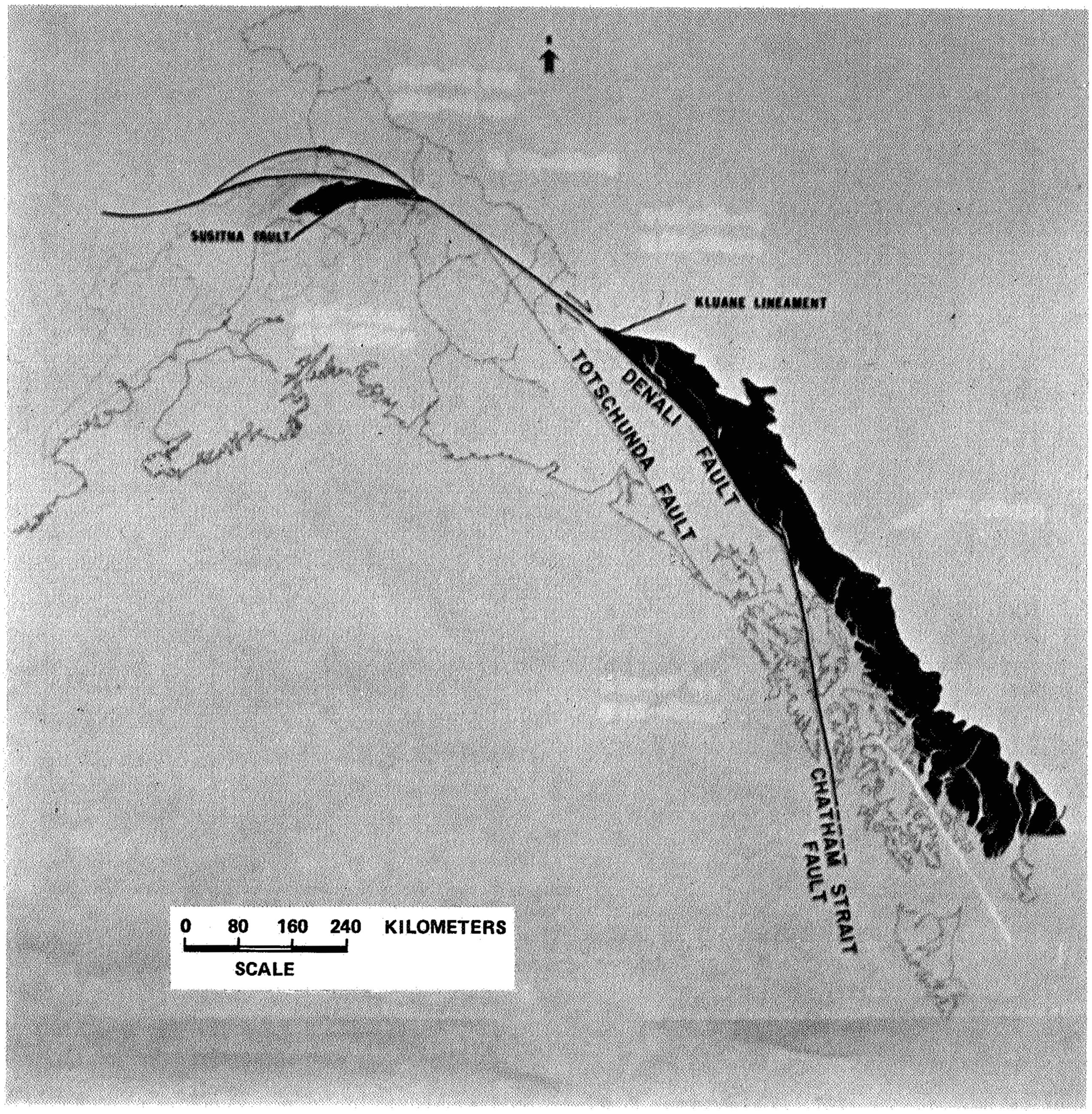


Figure 25. **A** postulated 400-km offset along the Denali Fault in Alaska and Canada. Susitna Fault and Kluane Lineament may have been colinear.

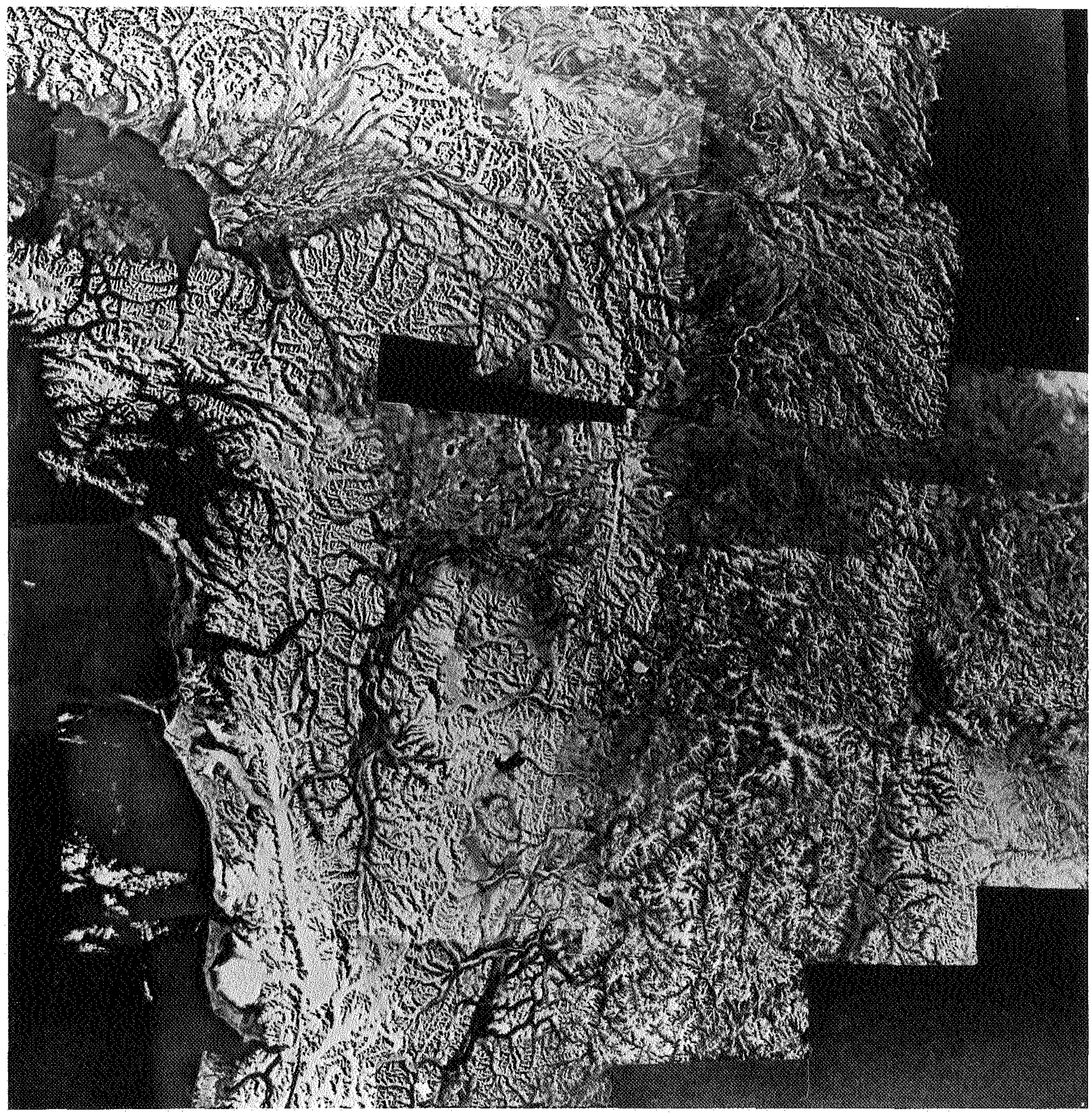


Figure *26. An* **ERTS** mosaic of the Denali Fault, which provided corroborative evidence for the newly-suggested offset.

Figures 27a and 27b compare the snow cover from ERTS scenes taken April 12 and May 2, 1973. By May, most of the snow in the lower lying areas had melted, represented by the yellow and orange colors. The percentage of area in the watershed that was snow-free was calculated throughout the spring breakup and the runoff model was found to agree with the actual runoff measurements provided by NOAA, as shown in Figure 28. ERTS should help improve hydrologic runoff predictions and aid water management practices. In the ERTS scene shown in Figure 29, a huge glacier is seen surging and threatens to dam off the Alsek River. The University of Alaska in a cooperative effort with Meier and Mayo of the **USGS** are using ERTS to monitor this glacier: another hydrological application.

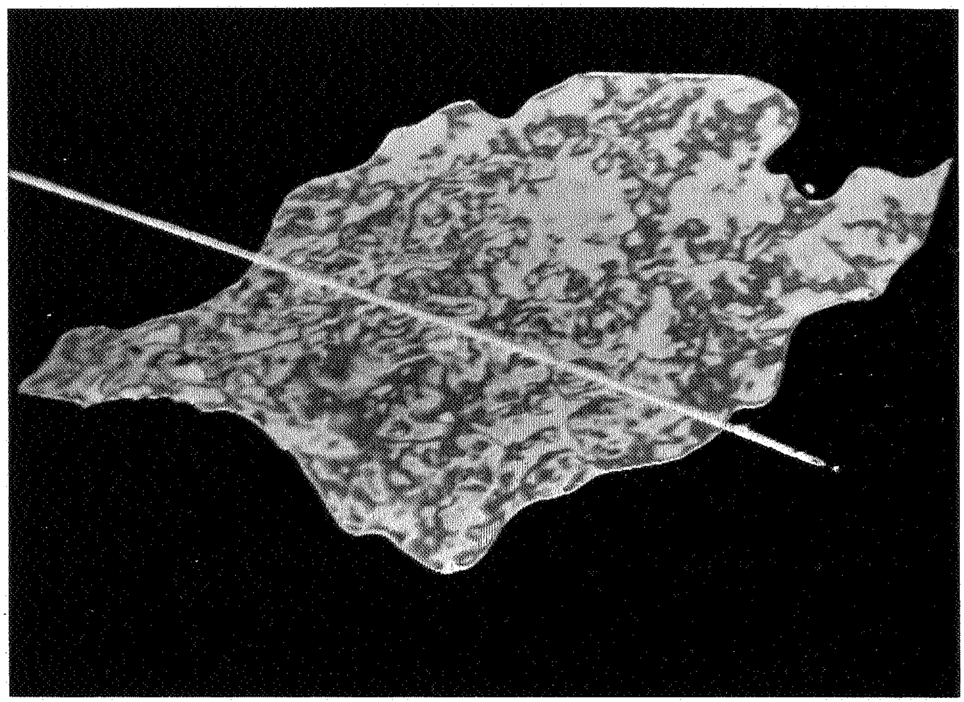


Figure 27a. Color-enhanced display of snow cover (orange and yellow indicate bare ground) of the Chena River watershed on April 12,1973.

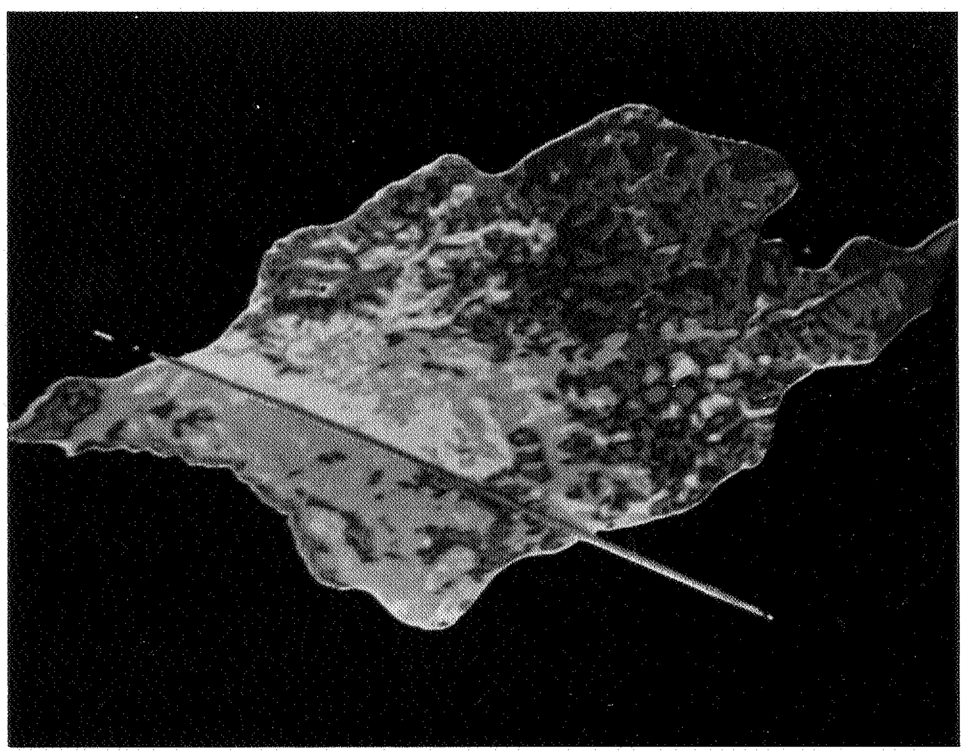


Figure 27b. Color-enhanced display of snow cover of the Chena River watershed on May 2,1973.

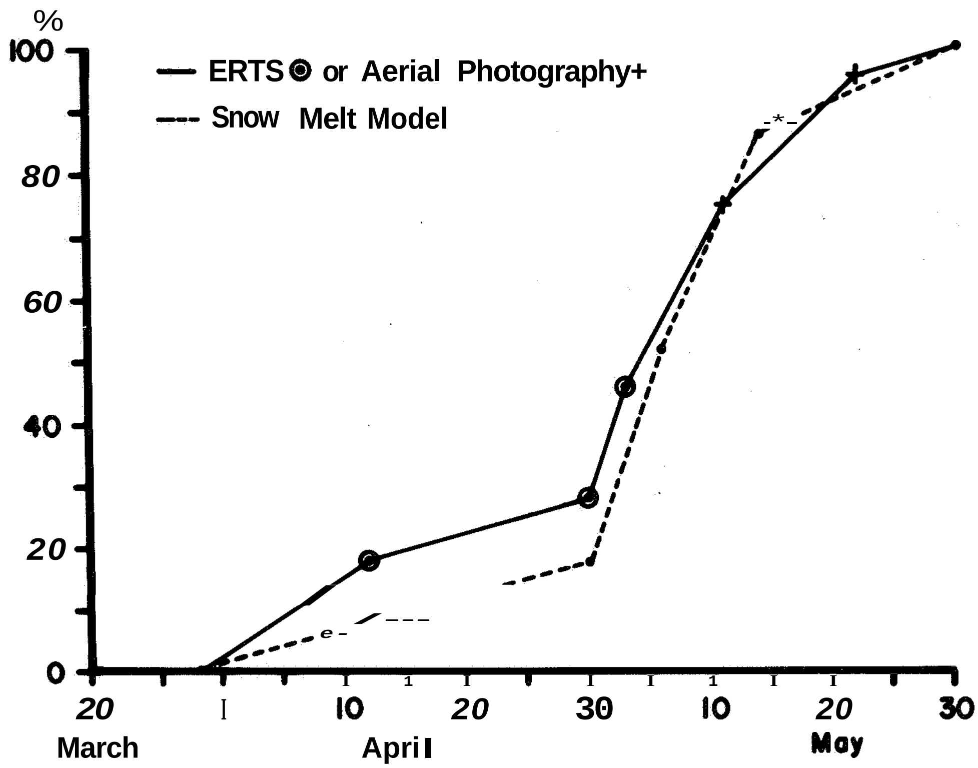


Figure 28. Agreement of ERTS interpretation with runoff measurements from stream gages.

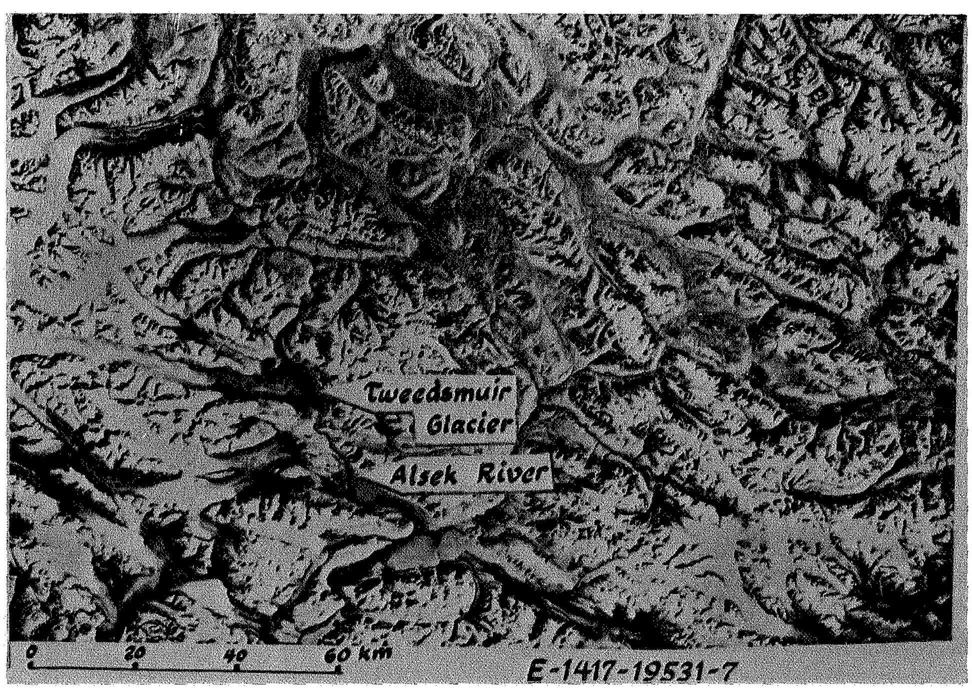


Figure 29. ERTS scene of Tweedsmuir Glacier, which is in the process of damming the Alsek River.

The Tweedsmuir Glacier is 70 kilometers in length and is 250 kilometers northwest of Juneau in British Columbia. This aerial view of Figure 30 shows how the large terminal lobe, 13 kilometers wide, spreads out in the Alsek River Valley and is encroaching along the river bed. For many years the lobe has blocked the main valley and has forced the river into a wild, narrow gorge along the glacier's eastern margin. The Tweedsmuir has not shown evidence of a surge in recent years, but in the fall of 1973 it became crevassed from end to end, as shown in the recent aerial view in Figure 31, and displays marked marginal shear: both occurrences are classical evidence of surging glaciers. After it became known that the glacier was surging, all cloud-free ERTS coverage of Tweedsmuir Glacier was retrieved from the ERTS library at the University of Alaska, Fairbanks. Seven photos, covering 12 months' elapsed time, were enlarged to a scale of 1:50,000 for a detailed, elapsed-time examination of glacier action. A shock wave was found to be progressing down the glacier, the margin expanding, the moraine pattern deforming, and the marginal valley deepening as the ice grew thicker. The results of the surge analysis from analysis of ERTS imagery are plotted in Figure 32. This is a particularly interesting application of ERTS imagery because the surge was nearly ended when it was first discovered, but the satellite had acquired the data automatically, and they were economically available on a timely basis.

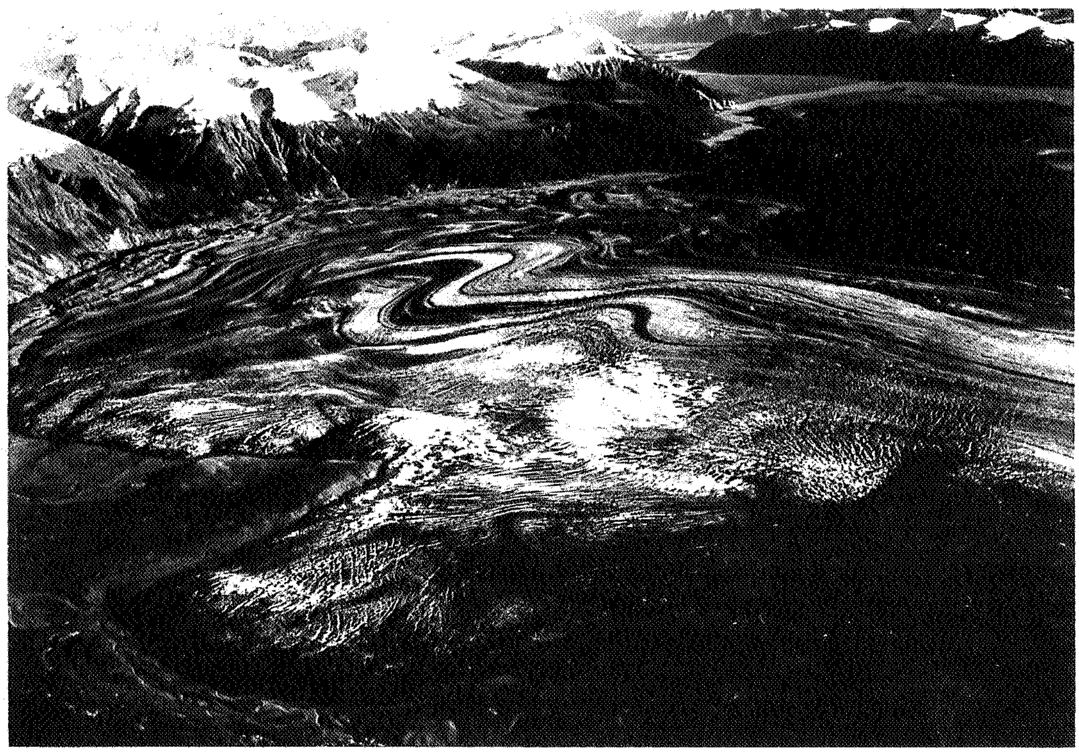


Figure 30. Aerial view of zigzag terminal moraine of the surging Tweedsmuir Glacier.

This glacier has started to dam the main river channel, and it may form a new lake upstream. There is evidence that gigantic floods have swept the Alsek Valley in the past when the glacier previously dammed the river in this canyon, creating a lake 20 kilometers long. Giant ripple marks in gravel bars, absence of mature forests, and denuded valley walls up to 100 meters above the valley floor attest to the magnitude of previous events. If this occurs again, there will be sudden and perhaps repeated massive releases of lake water once the ice dam fails during the summer runoff. This would cause serious flooding in the downstream channel and in Dry Bay, Alaska. From near-real-time ERTS images from the Canadian readout station at Prince Albert, Saskatchewan, the monitoring of the effects of this glacier advance on the Alsek River is continuing.

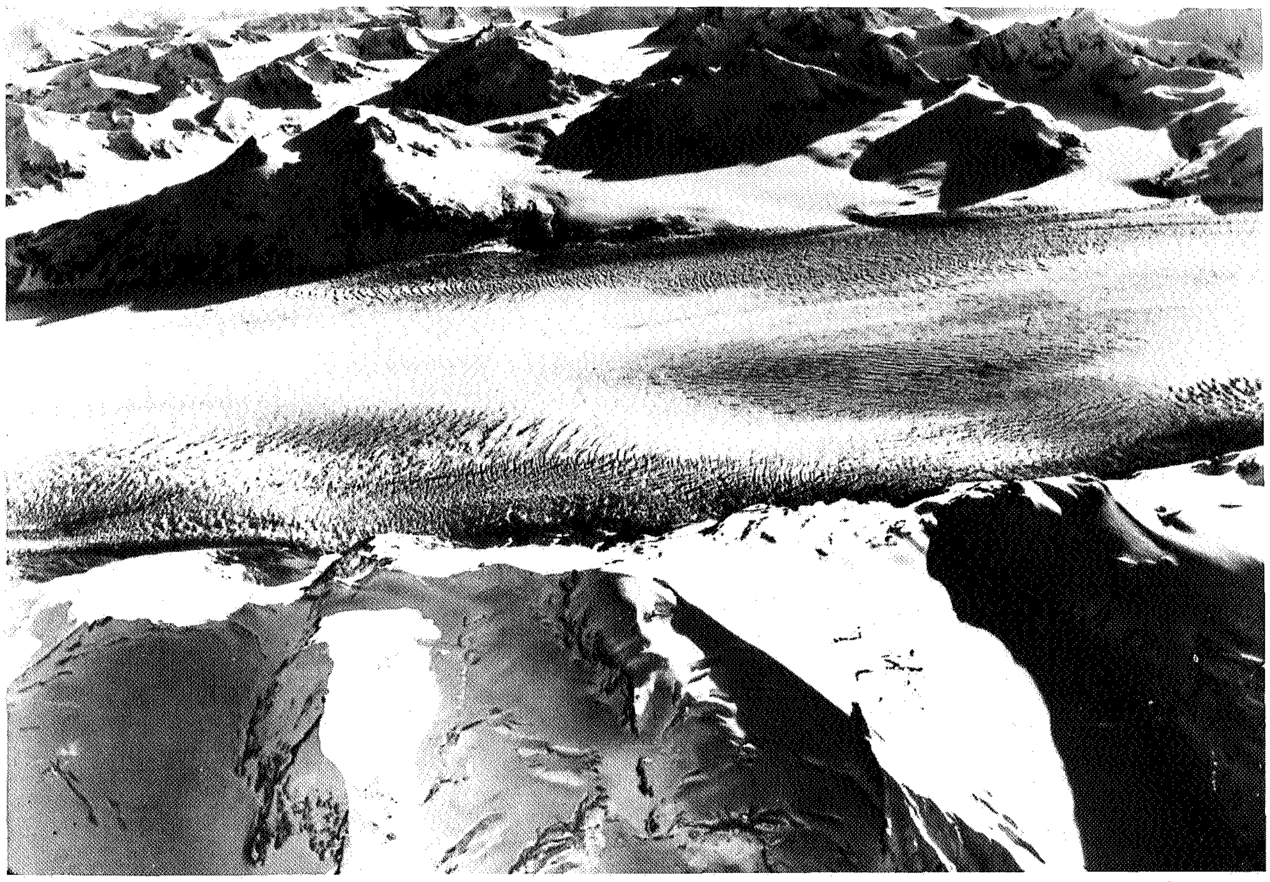


Figure 31. Aerial view of upper glacier showing extreme crevassing.

Another important application of ERTS is the study of circulation patterns in Cook Inlet, which is an important transportation corridor to half of the state's population and includes both major petroleum production and commercial fishing activities. Figure **33** is a pre-ERTS model of the circulation pattern of the inlet. The clear sea water flows north along the eastern shore, while the heavily silt-laden water from the upper inlet comes down along the western shore. Figure **34** is a color-enhanced ERTS display of the lower inlet, with an overlay of sea truth sedimentation data acquired coincidentally with the satellite pass. The ERTS data verify the circulation model quite well in the lower inlet. The yellow and orange colors represent silty water, while the green, blue, and purple represent increasingly clear water. The model does not always describe conditions accurately, however. The November **3 ERTS** scene (Figure 35) of the upper inlet shows the sedimented inlet water appearing on the east side of the inlet as light blue and green, with the crossover between marine water shown as dark blue and black, and inlet water seen above the forelands rather than below as the model indicates. This suggests the possibility that the clear marine water flows under the sedimented water and then upwells to the north. Winter ice floes and opposing currents during flood tide in the lower inlet pose difficult navigation problems for ships while in this area above the forelands. In this crossover region a concentration of offshore oil platforms and oil terminal facilities are also located, so this circulation pattern information is valuable for design guidelines as well as navigation. There are also important implications for the fishing industry because salmon tend to congregate at the marine and fresh water boundaries before proceeding to their river spawning grounds.

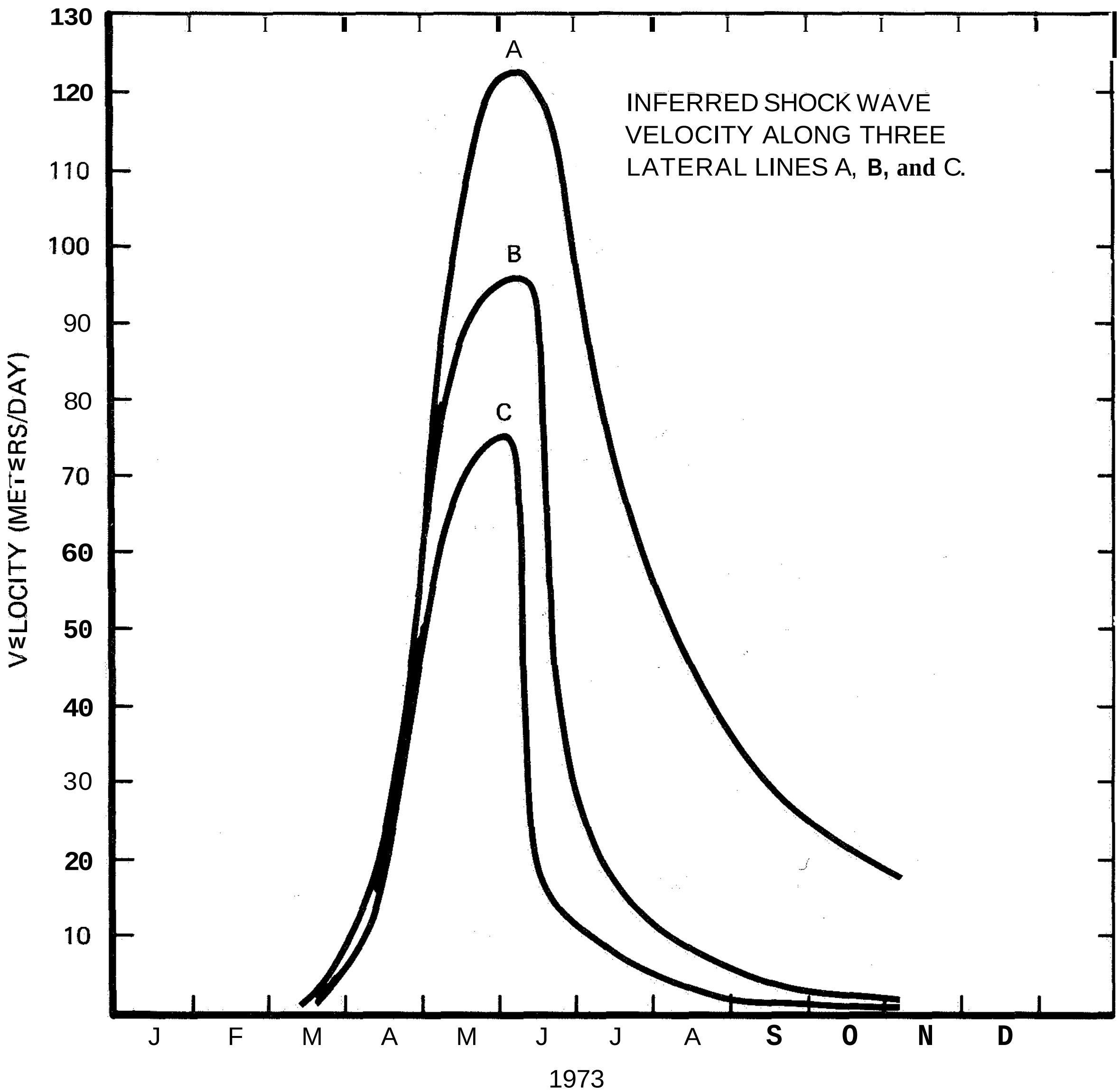


Figure 32. Shock wave velocity inferred from analysis of a sequence of seven ERTS images of Tweedsmuir Glacier during its surge.

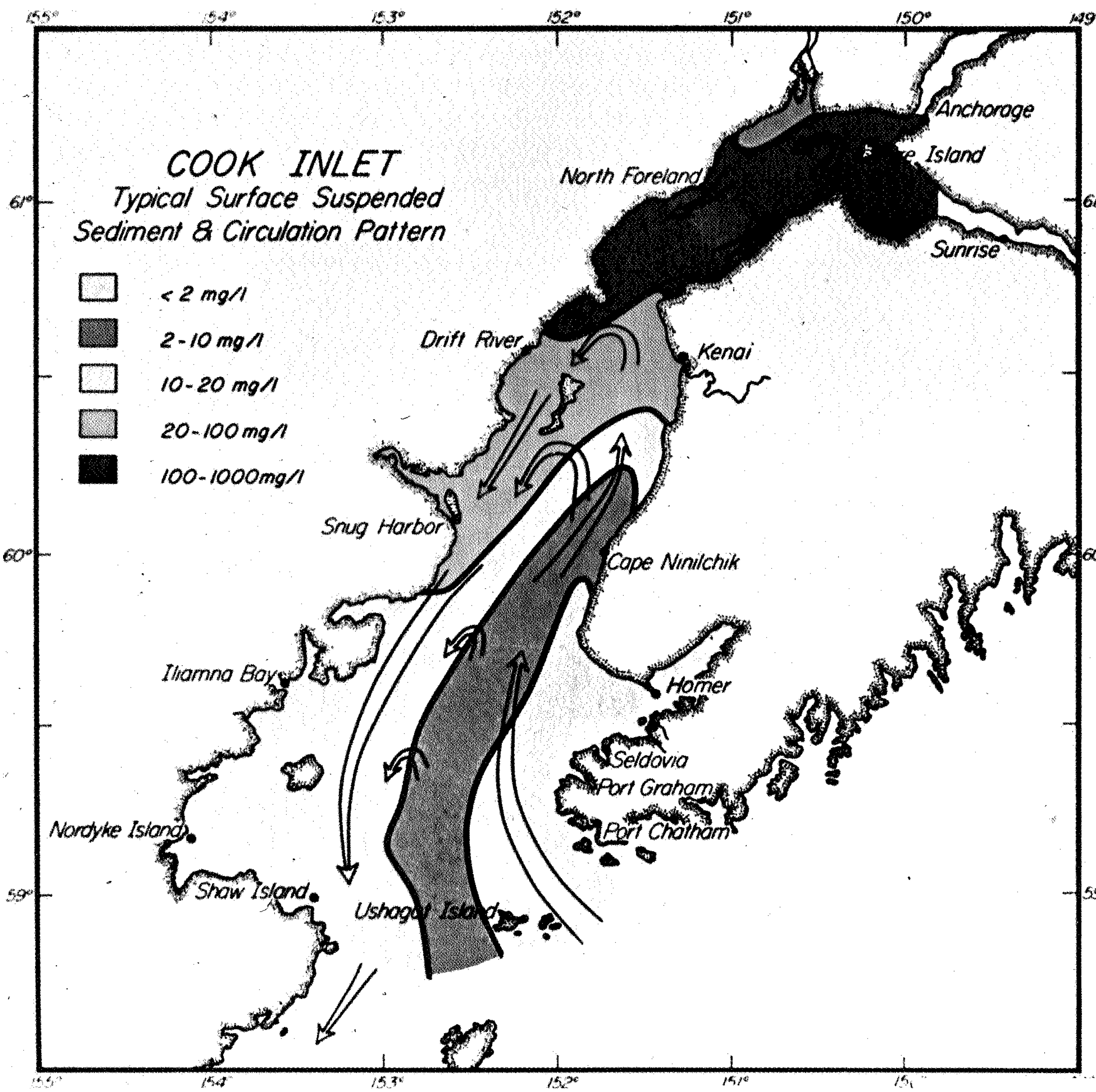


Figure 33. Pre-ERTS circulation model of Cook Inlet, Alaska.

Figure *36* shows a related study of sediment-borne circulation patterns in Cook Inlet. This figure shows how ERTS can help provide guidelines for initial planning steps in selecting optimum sites for small boat harbors. In this color enhancement of a portion of an ERTS image, the details of sediment load in the vicinity of Kenai, Alaska are depicted. It is evident from the blue colors that a region of clear marine water can be found close to the shore south of the Kenai River; but to the north, as shown by the red colors, the water is dominated by upper inlet water that is two to ten times as silty. From the ERTS data it is learned that further site selection studies should favor the southern rather than northern coast in order to avoid shoaling problems and to minimize dredging requirements. Discussions are currently underway with the

Corps of Engineers to determine the most effective way to apply remote sensing techniques to this troublesome design problem in Alaskan waters,

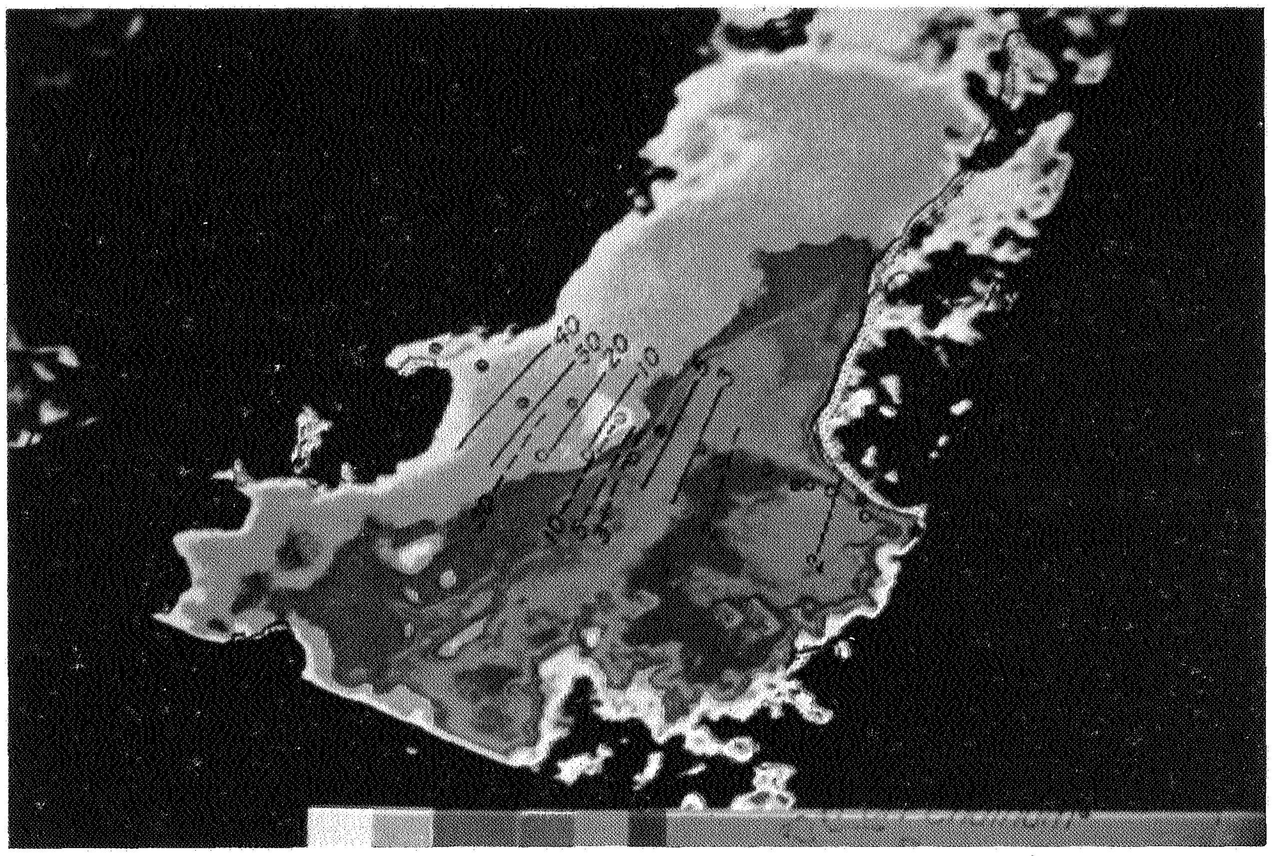


Figure **34.** Color-enhanced circulation pattern of lower Cook Inlet derived from an **ERTS** image. Sea truth data in mg/1 of sediment is included as an overlay.

A sea ice mosaic from ERTS of the Bering Sea on March 7 and **8,** provided unexpected payoffs in marine mammal management. From this mosaic it is possible to learn how prevailing winds direct the surface flow of water and ice southward into the North Pacific against the prevailing northward current into the Bering Sea. But, by mapping the open leads in the ice and from the clearly evident extent of the shore-fast ice, John Burns of the Alaska Department of Fish and Game used ERTS to map the previously unknown distribution of the habitat favored by certain marine mammals. Figure 37 shows the distribution of these mammals based upon the interpretation of the ice conditions over this region.

This map differentiates between the locations of walruses and of ringed, bearded, ribbon, and harbor seals. For the first time, the Fish and Game people can compete with the Alaskan Eskimo in knowledge of the whereabouts of these basic subsistence mammals.

Most of the previous examples involved sophisticated processing and interpretation techniques of ERTS data. The following use of ERTS data is an example of a do-it-yourself application to the man-in-the-street. Mr. Jim Movius, the winner of the 1973 Yukon River 1300-kilometer

(800-mile) boat race, attributes his success to the hour of time he spent studying our ERTS mosaic of interior Alaska, From this .he was able to improve his navigation through the meandering braided channels of the Yukon River, and thereby shaved ten minutes from his elapsed time. Since there were only two minutes separating the first and second place finishes, he calculates that his hour of study of the ERTS mosaic earned him an extra $1,200.

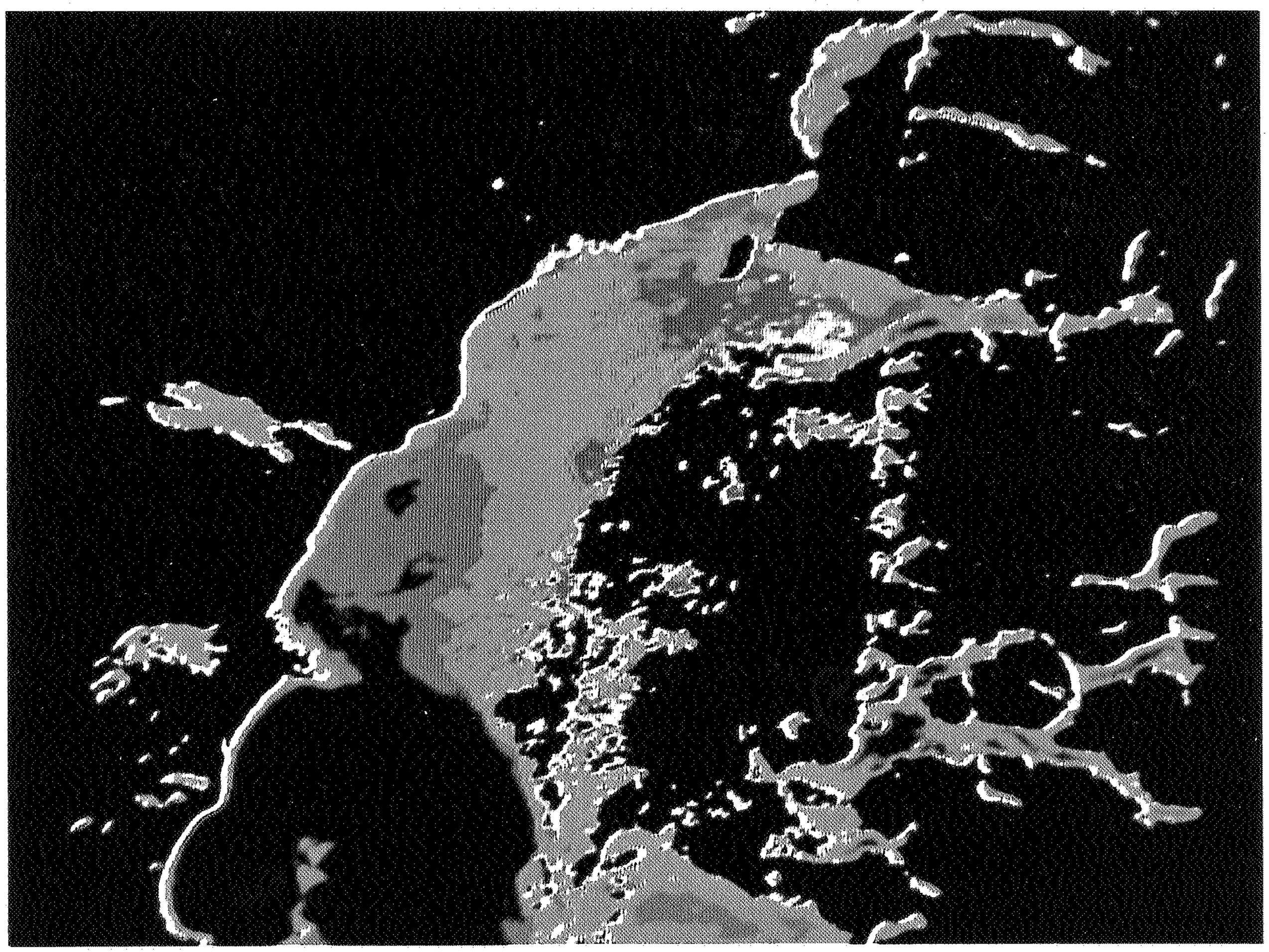


Figure 35. Color-coded circulation pattern of upper Cook Inlet shows that the existing circulation model breaks down. Dark blue and black sea water is on the left side of the inlet, with silty (light blue and green) water on the right.

Alaska's Senator Stevens, speaking in the Senate recently, explained why Alaskan officials are so enthusiastic about the ERTS program. Senator Stevens said, "ERTS sees things not possible with conventional methods of cataloging and observing the earth, such as aircraft and field study.

"First, ERTS collects more data faster and more accurately than any conventional means. Second, ERTS has provided data on remote and isolated areas, such as Alaska, where terrain, time, and money previously made exploration and mapping nearly impossible. Third, ERTS has the capability, by virtue of its position in space and path of orbit, to monitor ongoing and isolated phenomena on the earth's surface; for example, the changes of seasons, volcanic eruptions, floods, ice and water flow patterns,-and so forth." Senator Stevens went on to state, "ERTS can be a major tool in the quest for sound environmental policy. We are well on our way, but we have got a long way to go. I urge the Office of Management and Budget to respond to the future of the planet Earth by approving NASA's plan for launching ERTS-B next year."

In conclusion, it can be observed that four of the sixteen Alaskan applications summarized in this paper involve on-going and isolated phenomena. They will remain only feasibility studies if there is a hiatus between ERTS-1 and ERTS-B. Alaskan applications certainly warrant launching ERTS-B as soon as possible, and an operational system to follow.

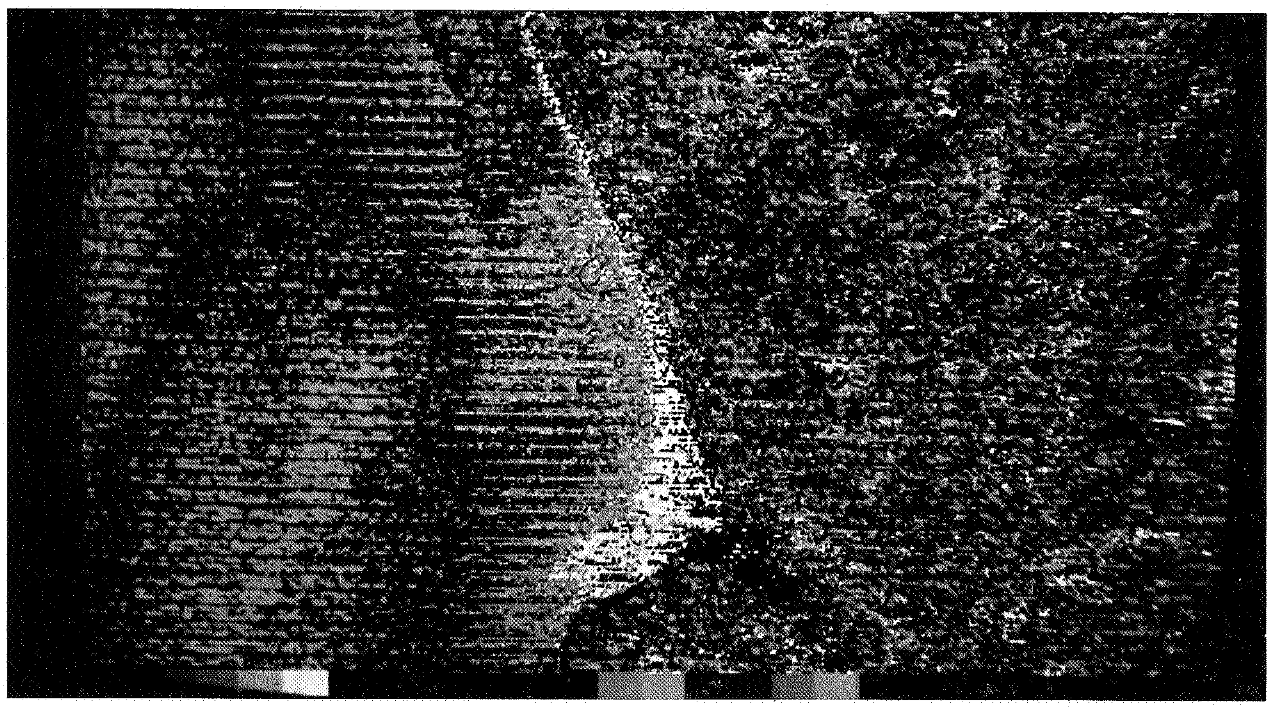


Figure *36.* Color-coded surface sediment near Kenai, Alaska. Mud flats along the shore are coded yellow, and the blue tones represent clear marine water surrounded by silty inlet water.

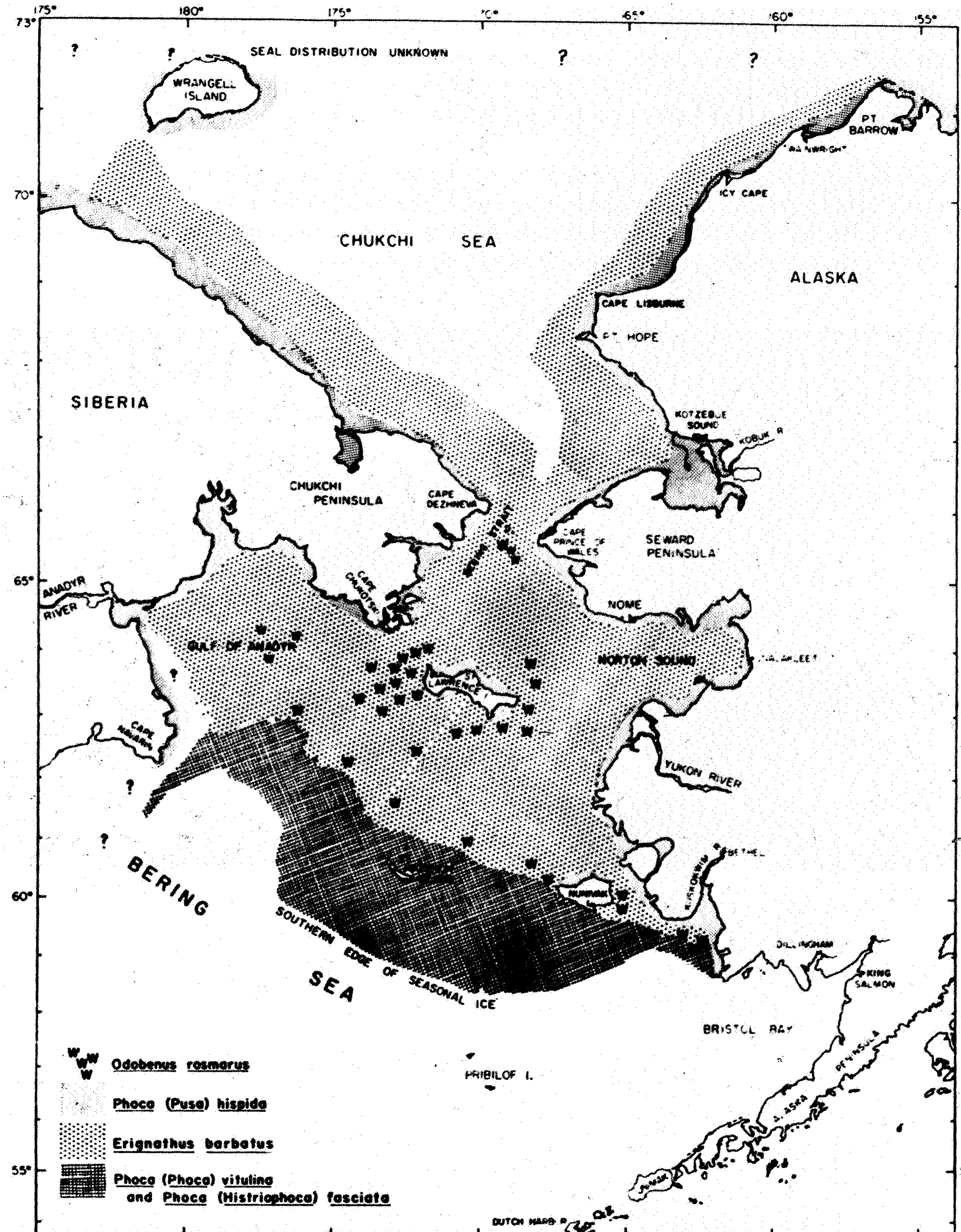


Figure 37. Distribution of sea mammals inferred from sea ice mosaic prepared from **ERTS** images of March 7 and 8,1973,

GEOLOGIC EVALUATION AND APPLICATIONS OF ERTS-1 IMAGERY OVER GEORGIA

S. M. Pickering and R. C. Jones
Georgia Geological Survey, Department of Natural Resources
Atlanta, Georgia

Since shortly after the launch of ERTS-1 in the summer of 1972, the Georgia Geological Survey has maintained a standing order for all clear-weather multispectral scanner (MSS) imagery of the state, which provides all 8:1 or better quality 70-millimeter and 9- by 9-inch negatives, from which prints at 1:500,000 and 1:250,000 scale are made. Each print is gridded with latitude and longitude and copies are provided to each field geologist for regional and local studies.

These black-and-white working products are supplemented with color-enhanced imagery derived by density slicing or a color additive viewer. Color products are useful in the recognition of particular features and for magazine articles or presentations of public interest. The Survey has also prepared state mosaics of bands 5, 6, and 7, and various regional interpretations which have been widely used by schools, universities, and state and local government for natural resource inventory and land use planning purposes. An ERTS interpretative atlas of the entire state for MSS bands 5 and 7 has been prepared and is currently in press.

Geologic mapping and mineral exploration by conventional methods are very difficult in Georgia. Thick soil cover and vegetation cause outcrops of bedrock to be small, rare, and obscure. ERTS imagery, and remote sensing in general, has helped delineate major tectonic boundaries, lithologic contacts, foliation trends, topographic lineaments, and faults. The ERTS-1 MSS imagery yields the greatest amount of geologic information on the Piedmont, Blue Ridge, Valley, and Ridge Provinces of Georgia where topography is strongly controlled by the bedrock geology. Band-7 imagery taken at low sun angle near the winter solstice (December 21) is greatly superior for discriminating lineations and landforms. Coastal plain geology from MSS imagery may be inferred from land use and drainage patterns. Imagery taken during wet, winter conditions seems best for southeastern coastal plain studies. Color enhancement analysis using band-5 and -7 negatives gives more visual contrast and allows the greatest amount of geologic discrimination.

Satellite imagery and other remote sensing tools and techniques have provided a powerful tool to assist geologic research; significantly increased the mapping efficiency of field geologists; shown new lineaments associated with known shear and fault zones; delineated new structural features; provided a tool to reevaluate tectonic history; helped to locate potential ground-water sources and areas of aquifer recharge; defined areas of geologic hazards; shown areas of heavy siltation in major reservoirs; and, by close interval repetition, aided in monitoring surface mine reclamation activities and the environmental protection of the intricate marshland system. For the past year the Georgia Geological Survey has been engaged in regional mapping for the new state geologic map. ERTS images enlarged to compatible mapping scales have increased field geologic mapping efficiency by at least *25* percent. There are a number of areas where data from ERTS imagery has allowed a notably higher level of precision than has been available with any amount of field work on the ground. The following examples demonstrate how the imagery is being used as a tool for solving geologic problems in Georgia.

Major faulting is commonly apparent on MSS band-5, *-6,* and -7 imagery in the form of topographic lineaments and zones of abrupt vegetation change. The Warwoman Shear (Figure 1) has been noted as a small structure in northeast Georgia, thought to be associated with the major Brevard Fault Zone. This band-7 frame shows that the shear is part of a major fault zone connecting the Ashland and Brevard Faults. This relationship was not previously known.

The Cartersville Fault, shown in Figure 2, is the prominent fault that separates the Paleozoic sediments from the crystalline rocks of the Piedmont. **As** such, it has been recognized and

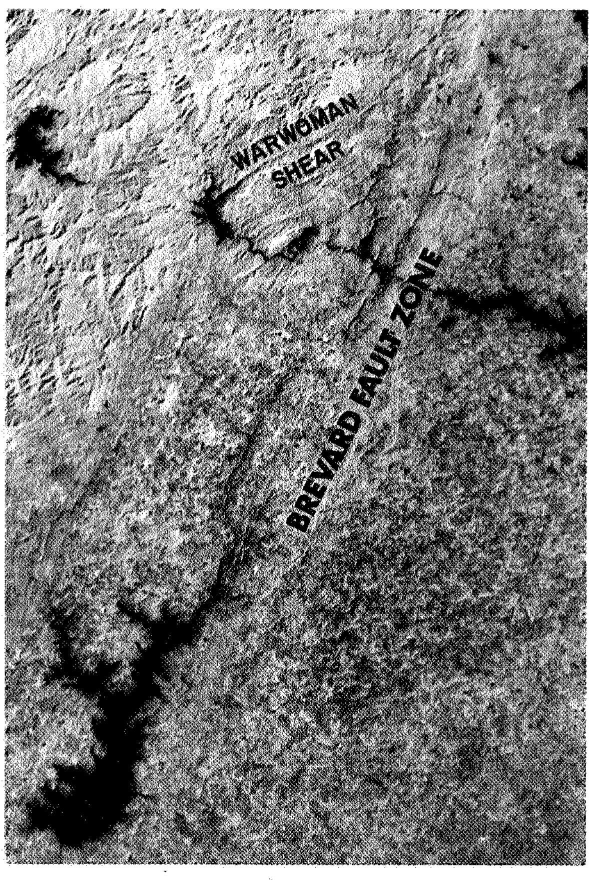


Figure **1.** ERTS-1 image of northeastern Georgia illustrating the relationship between the Warwoman Shear and the Brevard Fault Zone.

Figure 2. Image of northeast Georgia showing the Cartersville Fault, running from top to bottom in the right center of the image, and the Murphy syncline to the left of the image.

Figure 3. Lookout Mountain, Georgia, as seen from ERTS. The previously unmapped series of cross faults cut across Lookout Mountain from left to right.

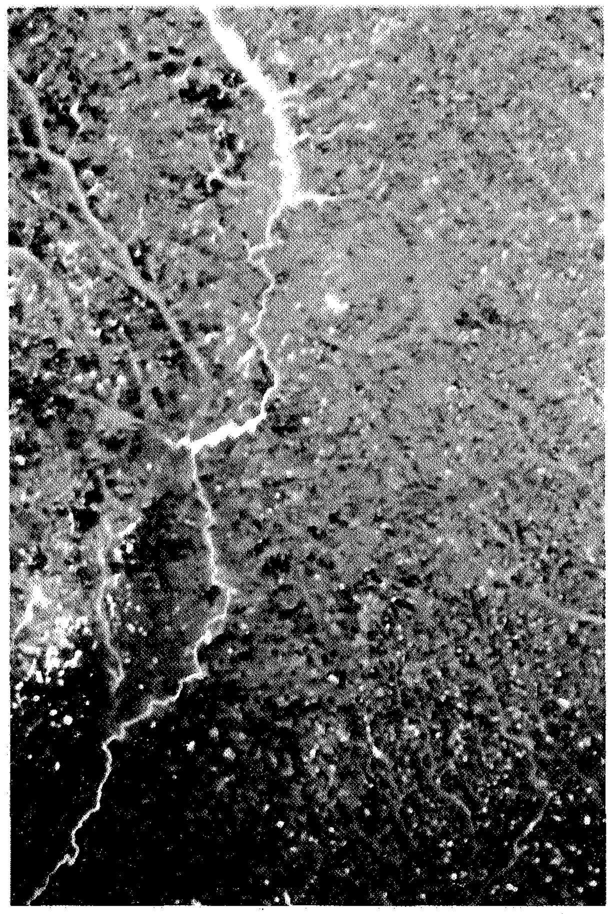


Figure 4. An example of ERTS MSS band-7 imagery that was used to make a limesink inventory map in the Lake Blackstrear area of Georgia.

mapped since the 1840's. ERTS images indicate that what was regarded as a single fault may be a series of overlapping thrust plates, and that there is at least one area where an abrupt fault does not exist. The figure also shows a tight elongate fold in high grade metamorphic rocks, the Murphy syncline. The pure marble deposits which allow Georgia to lead the nation in marble production are localized in the axial areas of cross-folds in this structure. This ERTS image is allowing a reevaluation of the tectonic history of the area, and is of great interest to marble exploration.

In Figure 3, the Red Mountain Formation, a Silurian sandstone in the Paleozoic area of northwest Georgia, is folded into a complex pattern of tight, plunging anticlines and synclines, which can for the first time be viewed as a structural unit, rather than as single folds. Pennsylvanian sandstone capping Lookout Mountain is cut by a series of cross faults that have never been mapped. This area of rapidly developing second homes has no extensive source of surface or ground water, and these faults may localize zones of aquifer recharge.

Large areas of southwest and northwest Georgia are troubled by the collapse of limestone caverns, which cause limesinks as much as 210 meters (700 feet) in diameter and **33** meters (100 feet) deep. These limesinks are of great concern if they occur in developed areas or are used as areas of refuse disposal, allowing pollutants a direct entry to the aquifer. Late winter, band-7 ERTS images (Figure 4) enabled the Geological Survey to make a limesink inventory map of these areas. Similar interpretative techniques were used to construct a farm pond inventory of Georgia, mapping all open water bodies as small as 16,000 square meters (4 acres).

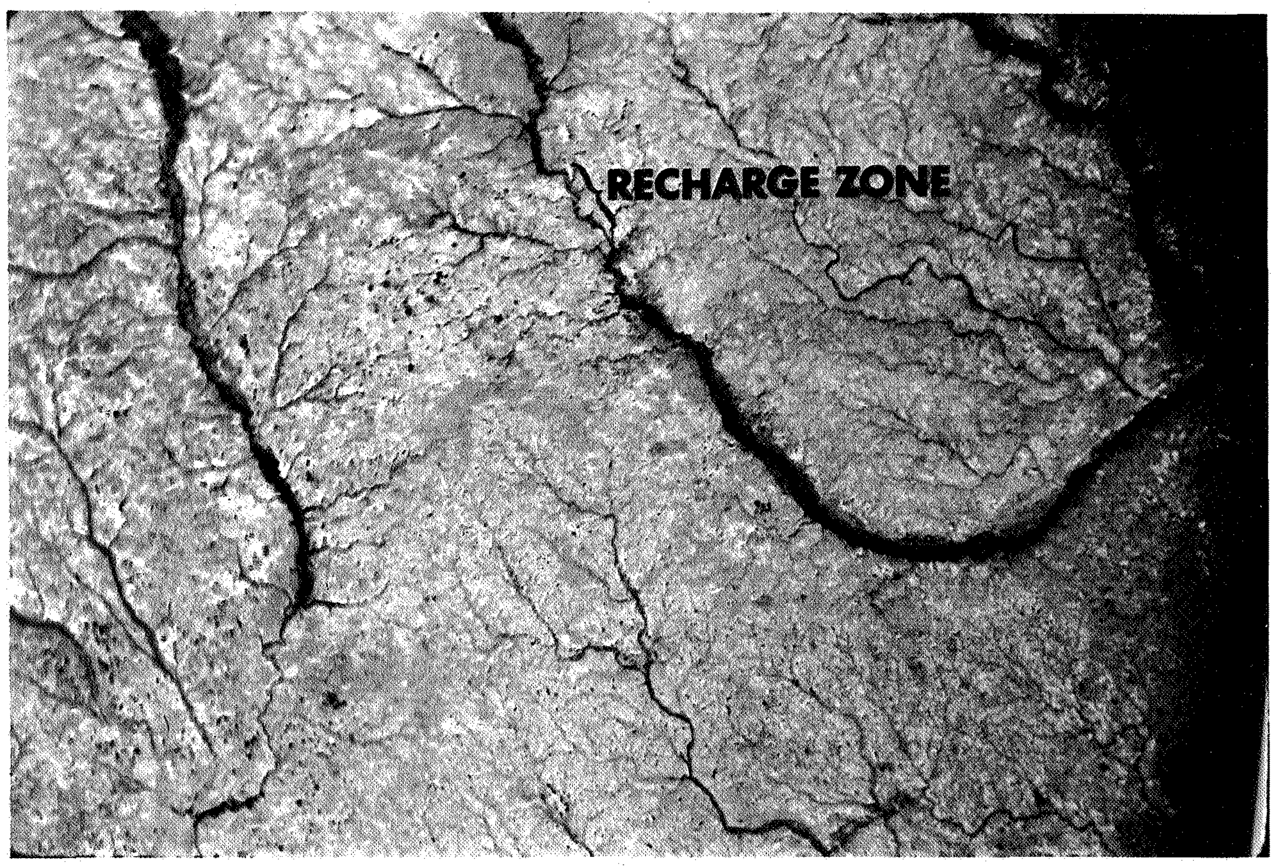


Figure 5. ERTS-1 image of the confluence of the Ocmulgee and Oconee Rivers in southwestern Georgia. Indicated on the image is an aquifer recharge zone on the Ocmulgee.

Aquifer recharge is evident in winter band-7 imagery (Figure 5) along rivers at areas where they cross permeable cavernous limestone. This ERTS image shows the water-saturated alluvial valleys of the major rivers clearly. Where the rivers cross aquifer recharge zones, the alluvium is well drained by underground recharging, and therefore light in tone. This image makes it possible to map both flood plain and areas of aquifer recharge along our rivers.

ERTS images of the Georgia Coast (Figure 6) offer spectacular definition of the Sea Island section and intervening marshland. These marshes have been recognized by biologists as among the most productive nutrient systems on earth. The 1971 session of Georgia's General Assembly

Figure 6. Marshland areas in the Sea Island section of the Georgia coast.

Figure 7. Detail of a small portion of ERTS-1 MSS band-5 imagery of the Georgia coastal marshland that has been used to classify and study tidal flow in the area.

passed a strict Marshlands Protection Act which limits filling, dredging, and development in this area. Without remote sensing techniques, it is very difficult to define a consistent boundary for salt marshes that will be legally acceptable.

The immense organic productivity of the coastal marshlands is a direct product of the complex network of tidal circulation and drainage. Detail of a small portion of band-5 imagery allows classification and study of the tidal flow (Figure 7). The rich suspended nutrient washed from the marsh is carried to the fishing and shrimping grounds of the open ocean by a system of currents not previously well known.

The Okefenokee Swamp is the largest elevated warm swamp on the North American continent and one of the most prolific of our nation's wildlife preserves. The origin of the swamp has never been well understood, The detailed band-7 image in Figure 8 gives a new perspective to the studies. It is evident that the swamp was a shallow Pleistocene marine bay during a time of higher sea level. **A** major longshore bar, Trail Ridge, developed along the east side of the bay and

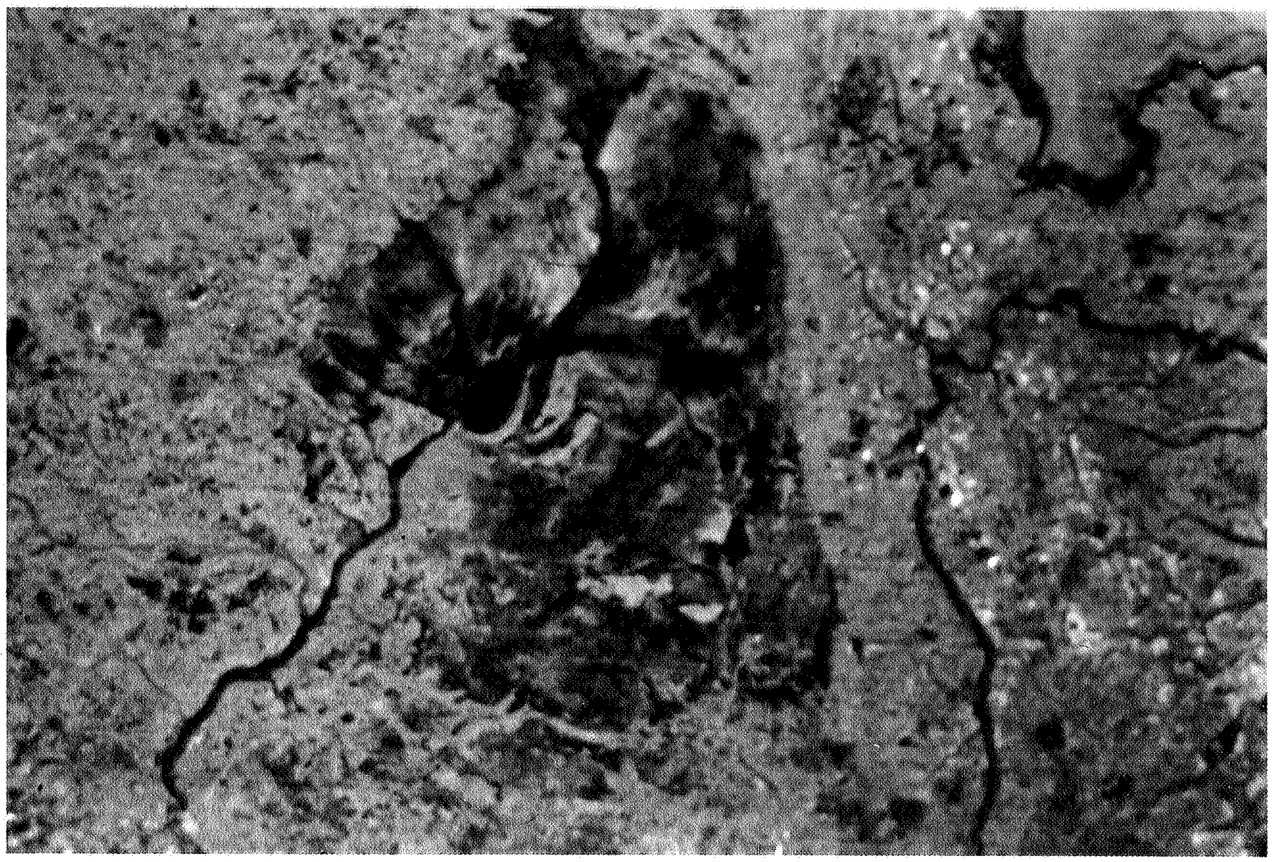


Figure 8. Okefenokee Swamp showing Trail Ridge to the right of the dark-toned swamp area. Imagery such as this enabled the scientific study of the gross morphology and drainage patterns of the swamp for the first time.

restricted drainage as sea level gradually lowered, thus impounding water behind the bar and forming the present day swamp. ERTS imagery allows, for the first time, a study of the gross morphology and drainage patterns of the swamp.

Wet weather, band-7 imagery has allowed a new survey of the shallow elliptical depressions known as “Carolina bays” (Figure **9).** ERTS data have tended to support speculation on the extraterrestrial origin of these features, which range in size from a few hundred feet (—100 meters) to 3 miles (~5 kilometers). It may be only coincidence that the bays are elongated toward the Georgia tektite strewn area. Five Carolina bayfields have been identified from ERTS imagery over Georgia.

Long trains of striking parabolic dunes as much as *6.5* kilometers (4 miles) in size have been identified along several rivers in southeast Georgia. Such windblown sand features have not been previously described in the humid Eastern United States (Figure 10).

Commonly, unusual land use by man can result in a feature apparent on ERTS imagery that resembles a major geologic structure (Figure 11). This large circular feature along the Georgia-South Carolina border resembles a major caldera or collapse structure. It is actually land

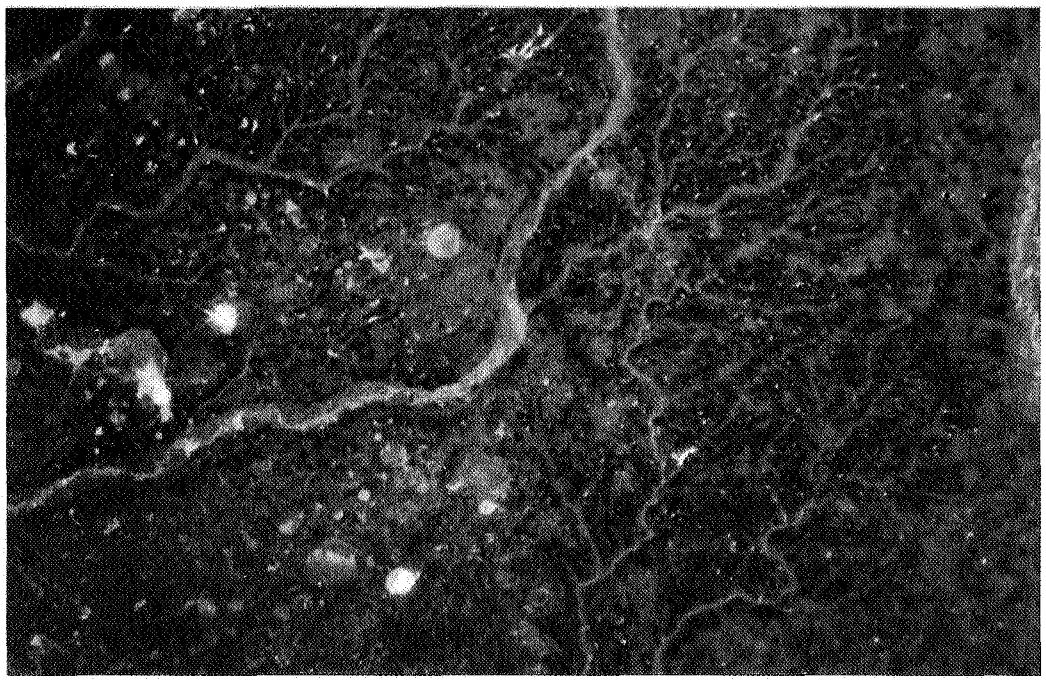


Figure 9. The light-toned, elliptical features apparent in this image are known as “Carolina bays.” **ERTS** data tend to support the theory that these depressions are of extraterrestrial origin.

Figure 10. In this **ERTS-1** image of southeastern Georgia, the unique parabolic dunes described in the text can be seen on the right-hand banks of the two rivers in the center and right-center of the image.

Figure 11. The large circular feature in the center of this image was at first thought to be a caldera or collapse structure. Further investigation showed it to be land under Federal ownership at the Savannah River Nuclear Plant which had been allowed to grow up in forest cover, in contrast to the cultivated farmland surrounding the Federal facility.

under Federal ownership at the Savannah River Nuclear Plant. Since the Atomic Energy Commission's only concern is plutonium production rather than farming, their land has grown up in forest, in contrast to the surrounding cultivated area.

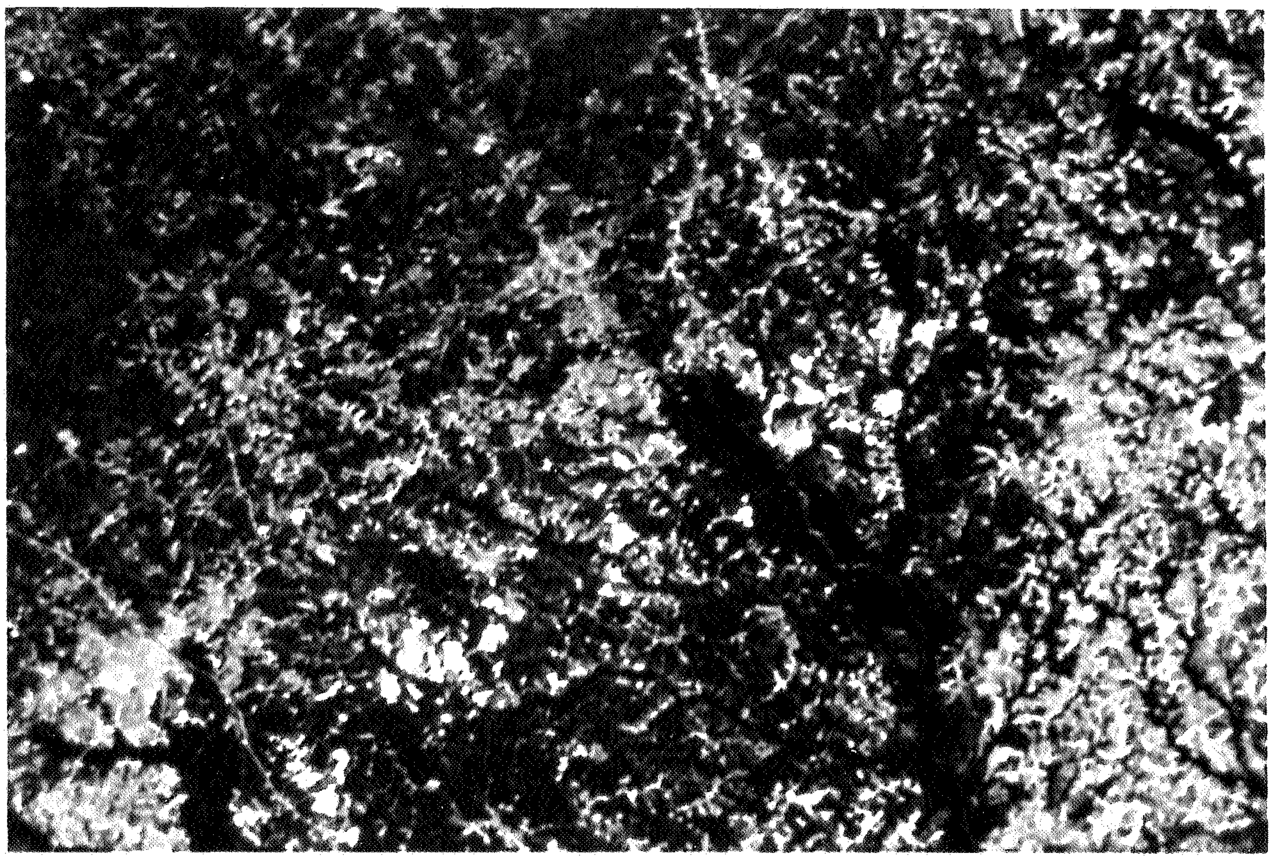


Figure 12. ERTS-1 image of Georgia's kaolin mining district. Each pit is clearly discernible as a white spot, and state-required reclamation efforts may be readily evaluated.

The Department of Natural Resources of the State of Georgia requires reclamation of all mined land in the state within one year of completion of mining. The monitoring of this industry, which produces over one-quarter billion dollars each year, is a major task. Figure 12 shows the extent of Georgia's kaolin mining district, which produces over $150 million in industrial clays yearly. Each pit is clearly discernible as a white spot, and reclamation efforts may be readily evaluated. This ability results in considerable savings in enforcement costs and provides an inexpensive, impartial referee in disputes.

No NASA or other Federal funds are involved in the Georgia Geological Survey's remote sensing program. However, the EROS Mississippi Test Facility has assisted in simplifying the Survey's standing order with the National Data Center and in encouraging use of their imagery enhancement equipment, and this assistance is gratefully acknowledged.

The ERTS system has provided a valuable tool and a new perspective for natural resources research in Georgia. It would be a considerable setback to Georgia's remote sensing program if continuous satellite coverage of this part of the United States was interrupted.

AN EVALUATION OF THE SUITABILITY OF ERTS DATA FOR THE PURPOSES OF PETROLEUM EXPLORATION

John R. Everett
Earth Satellite Corporation
Washington,D. C.

Gerald Petzel
Eason Oil Company
Oklahoma City, Oklahoma

INTRODUCTION

The overall objective of this experiment is to determine the types and amounts of information valuable to petroleum exploration that are extractable from ERTS data and to determine the cost of obtaining the information from **ERTS** relative to costs using traditional or conventional means. In particular, the objective is to evaluate this new petroleum exploration tool in a geologically well-known area in order to assess its potential usefulness in an unknown area. In light of the current energy situation, it is felt that such an evaluation is important in order to best utilize technical efforts with customary exploration tools, by rapidly focusing attention on the most promising areas in order to reduce the time required to go through the exploration cycle and to maximize cost savings.

TEST SITE

The Anadarko Basin lies in western Oklahoma and the panhandle of Texas (Figure 1). It was chosen as a test site because there is a great deal of published information available on the surface and subsurface geology of the area, there are many known structures that act as traps for hydrocarbons, and it is similar to several other large epicontinental sedimentary basins. Eason Oil Company's geologists know the area well, and it is convenient to its offices in Oklahoma City.

As a result of a climatic variation across the site, native vegetation ranges from scrub *oak* in the east to short prairie grass and sage in the west. The entire area is extensively farmed and ranched and is divided along township and range survey lines. This imposes a north-south and east-west cultural and vegetation pattern over the area. The eastern part of the area is characterized by gently rolling hills with a local relief of 60 meters. In the west, the topography consists of mesas and undissected uplands with sharply incised canyons producing local relief of up to 400 meters.

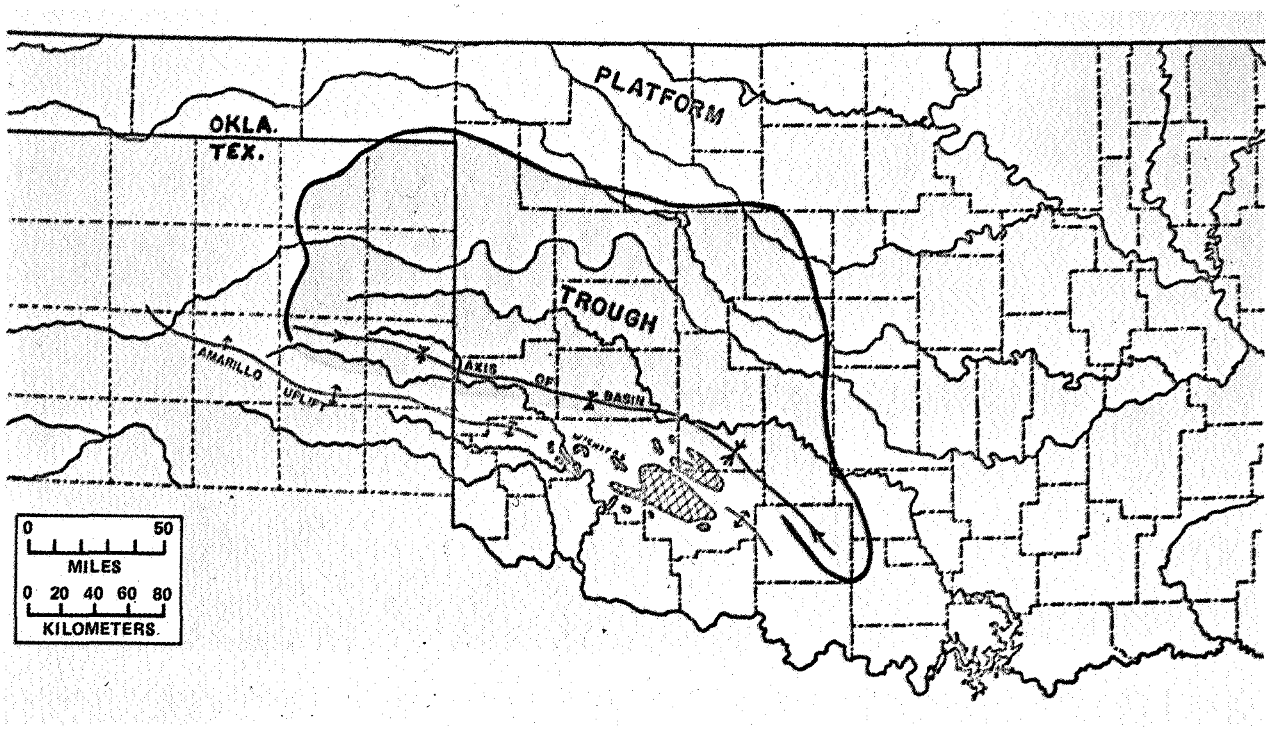


Figure 1. Location map showing the Anadarko Basin in pink with the structural axis of the basin lying close to the Amarillo-Wichita Mountain Uplift. Outcrops of early Cambrian crystalline rocks are cross-hatched.

GEOLOGY

The basin is a large west-northwest-trending asymmetrical syncline with the south flank much steeper than the north flank (Figure 1). The axis of the basin, where Figure **2** was taken, lies about 40 kilometers north of the Wichita Mountains, seen in the distance, which expose early Cambrian crystalline rocks.

Figure 3 is a diagramatic stratigraphic section of the basin. The basin is filled with approximately 7,000 meters of late pre-Cambrian and early Cambrian sedimentary and layered igneous rocks. The Paleozoic rocks include approximately 5,000 meters **of** pre-Pennsylvanian limestone, shale and sandstone, approximately 5,000 meters of Pennsylvanian clastic sedimentary rocks deposited during rapid subsidence and orogenic deformation, and approximately 1,000 meters of Permian rocks, mostly red beds and evaporites accumulated during late gentle subsidence marked by periods of restricted circulation.

Rocks exposed at the surface include gently dipping Permian red beds and evaporites in the eastern half of the area (Figure 4). Tertiary continental clastic rocks of the Ogallala formation cover the western part. Quaternary deposits occur along major rivers and in large areas of windborne sand on the uplands.

Most of the structures that trap hydrocarbons – marked by black dots in Figure 5 – were created during the intermittent tectonism that began in earliest Pennsylvanian time and continued into earliest Permian time. Many of these traps are located in the highly deformed frontal zone north of the Amarillo-Wichita Mountain trend.

Figure 2. View of the Wichita Mountains, which expose early Cambrian rocks at the surface, looking southward from the axis of the Anadarko Basin near Cordell, Oklahoma. The mountains are about 40 kilometers distant.

Exploration for structurally trapped hydrocarbons in the basin is exceedingly difficult because the important structures are buried by 300 to 1,000 meters of essentially undeformed Permian and younger rocks. Surface features that reflect the deeply buried structures are extremely subtle and may be interrupted by much younger solution collapse structures. The guiding hypothesis was that the synoptic view provided by ERTS imagery might allow integration of a sufficient number of these subtle features to, in effect, see the deeply buried structures through the overlying rocks.

Intensive petroleum exploration in the basin began in 1917. However, it is only during the past five years that the deeper portions of the basin have received extensive exploration attention. The deepest well in the world, the Lone Star Number 1, Baden, with a total depth of 9,000 meters (30,050 feet), completed drilling last year west of the Elk City field. It is a $5 million dry hole.

TECHNICAL ANALYSIS

From a total of 49 ERTS scenes received, 16 scenes were interpreted in black-and-white and color composite form. The remaining 33 scenes are of limited use because they are peripheral to the test site or contain a high percentage of cloud cover. Paper prints, transparencies, mosaics, and digitally-enhanced imagery were interpreted. Figure 6 is an optical color enhancement combining bands 5, 6, and 7 which brings out closed anomalies and linears.

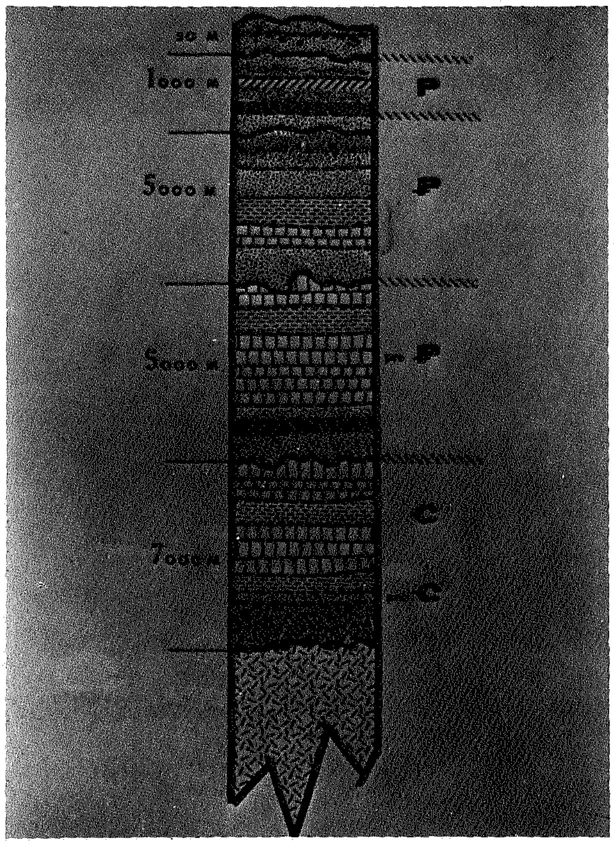


Figure 3. Simplified stratigraphic section of layered rocks in the Anadarko Basin: 7000 meters of Precambrian (preC) and early Cambrian (C) layered sedimentary and igneous rock, 5000 meters of pre-Pennsylvanian (preP) sedimentary rocks, 5000 meters of Pennsylvanian and early Permian (P) rocks deposited during orogenic episode, 1000 meters of post-orogenic Permian (P) rocks, and 50 meters of surficial deposits.

The multispectral scanner (MSS) imagery was interpreted for a variety of features, including linear features (Figure 7); lithology; tonal, textural, and closed anomalies; and a variety of other features such as drainage and topography.

Interpretation of the four **MSS** bands and color composites resulted in more than 120 individual interpretations. From these frame-by-frame studies, two directions were taken. One approach was to focus attention on small areas selected during ERTS interpretation on the basis of known oil and gas exploration interest. The second approach was to compile the various interpretations into regional overlays. The regional compilations, selected site studies, and interpretations of individual frames were analyzed and compared to existing information. The information included published maps and reports, auxiliary imagery, and interviews with geologists in Oklahoma.

RESULTS AND CONCLUSIONS

Bands 5 and 7 together have the greatest versatility and widest range of easily extractable information. These bands are generally of high overall contrast and, in fact, the contrasts are frequently reversed between the two. However, all bands must be carefully interpreted in order to derive the maximum amount and kinds of geologic information. Each band contains different features that are more easily detectable than on the other bands. Figure **8** shows linears interpreted from band 7 of the scene as solid lines. Combining this successively with interpretations of bands 5 and 4, band-5 linears can be seen in dashed lines **A** and B that were added to the interpretation previously done from band 7. Linears C and D (dotted lines) were visible on band 4 but not on bands 5 or 7.

Seasonal differences increase the amount of information available from ERTS. Imagery of extremes of vegetation growth, that is, maximum vigor and maximum die-back, appear to be the most useful. However, so many subtle but important differences appear throughout the year that study of imagery from an entire year or even several years is necessary for optimum results.

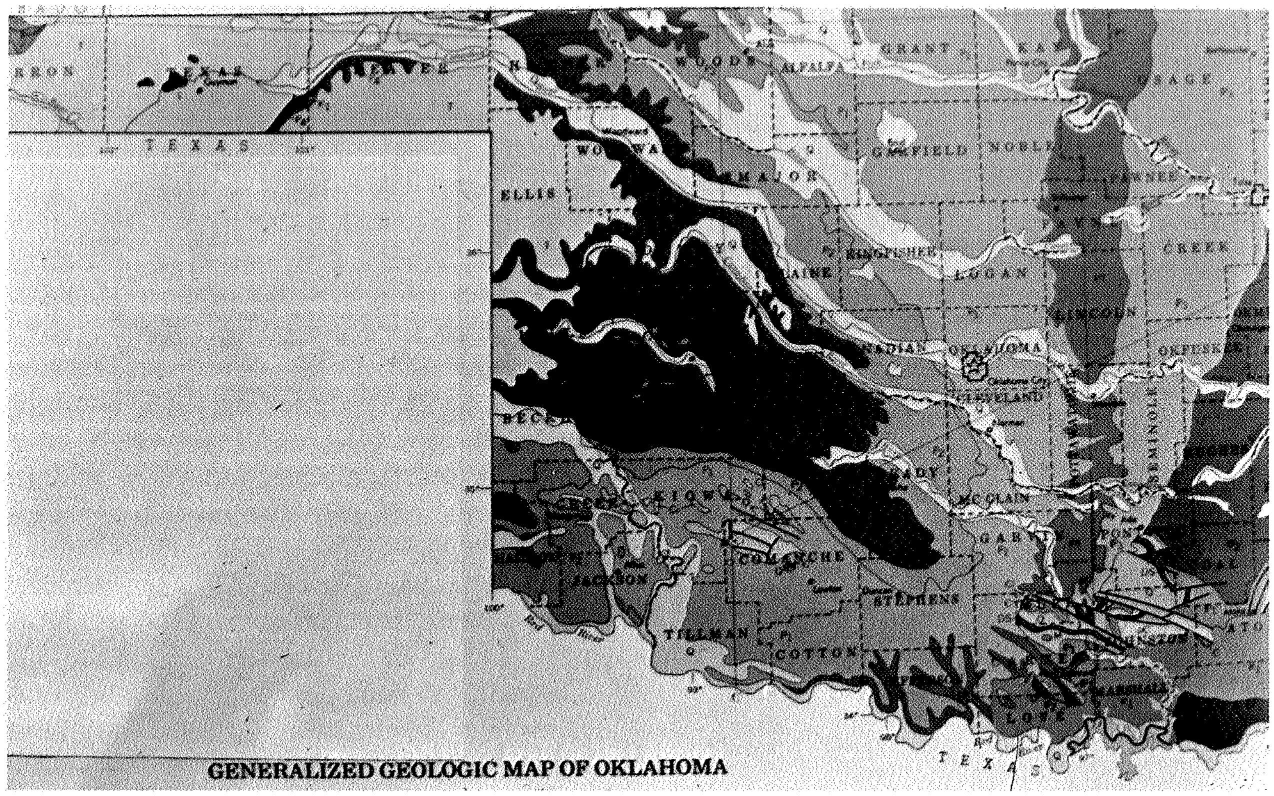


Figure 4. Simplified geologic map of Oklahoma compiled by Ken Johnson of the Oklahoma Geological Survey, showing surface geology. Lower Paleozoic units are in pink and purple, Permian (P_1, P_2, P_3, and P_4) units of the Anadarko Basin are in shades of blue, the flat-lying Ogallala **(T)** is in light brown, and Quaternary deposits are in yellow. Taken from *Geology and Earth Resources of Oklahoma,* Oklahoma Geological Survey, 1972.

Figure 9 compares the interpretation of inferred lithologies made from spring and fall imagery of the areas shown in Figures 10a and 10b. Area A demonstrates the great amount of detail frequently obtained from spring imagery that is nearly absent in the fall. Points **B** and C locate boundaries interpreted from fall imagery not seen in the spring. At D there is a more detailed and precise location of a lithologic boundary on spring coverage. Boundary **E,** while noted on both images, is more confidently drawn from fall imagery.

Interpretation of ERTS imagery defined the major features of the Anadarko Basin and refined the understanding of many smaller areas within the test site. The general features of the basin can be inferred from analysis of the interpreted lithologic distribution. Figure 11 was compiled from interpretation of **ERTS** band-7 imagery without reference to existing maps. Figure 4 shows a generalized geologic map for comparison. Outcrop pattern indicates a gentle south dip on the north flank of the basin, Moving eastward, the dip becomes southwesterly, indicating a plunging syncline. The narrow outcrop on the south side of the basin shows asymmetry, with the south side having the steeper dip. Horizontal rocks cover the west end of the basin unconformably, and basement rock outcrops and alignments define the Amarillo-Wichita Uplift on the south.

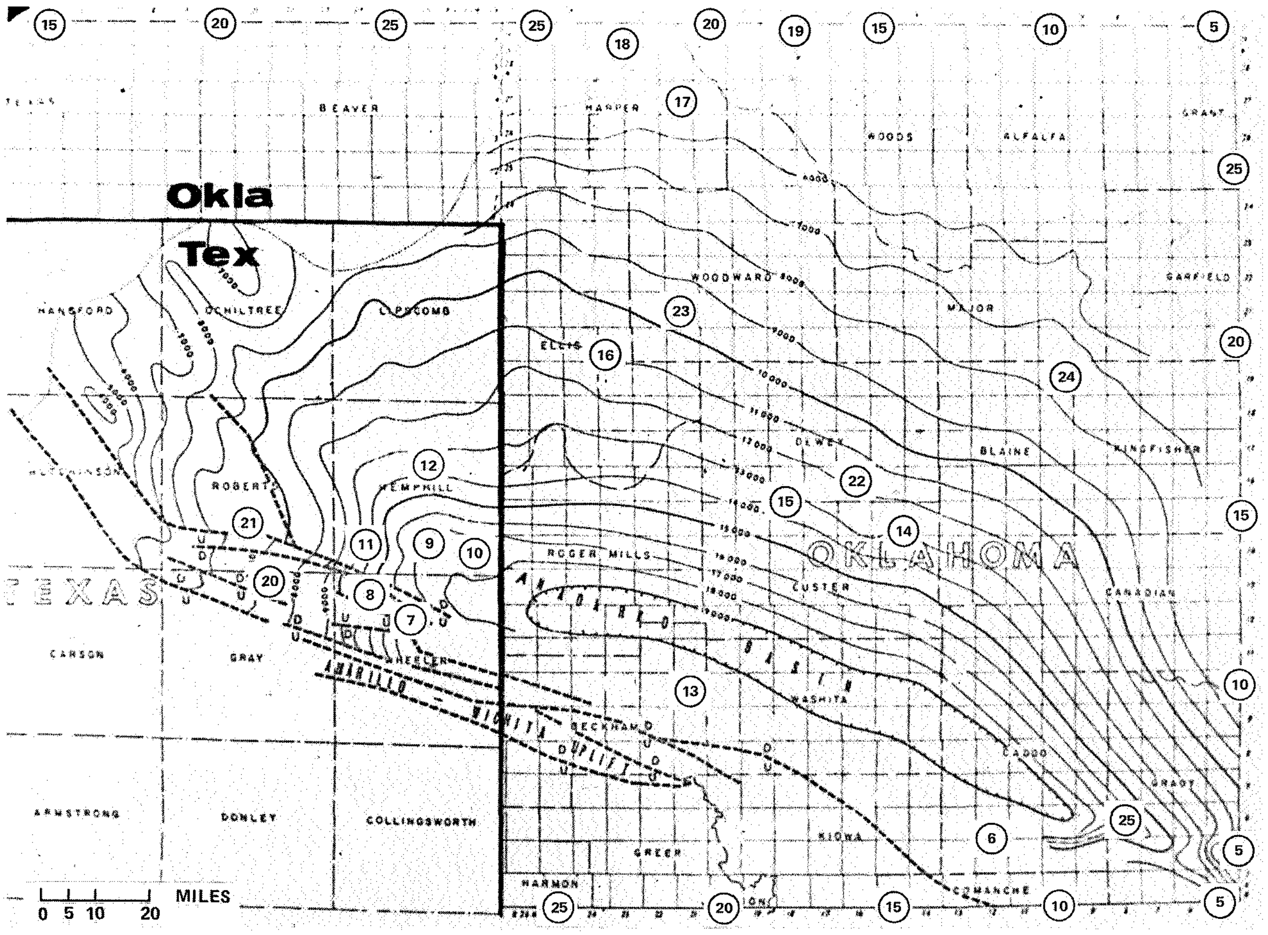


Figure 5. Structural contour map of the Anadarko Basin contoured on the Mississippian **(C. I.** 300 meters (1000 feet)). Shaded dots indicate structurally controlled oil and **gas** fields.

The study defined several regional sets of linears (Figure 12). Field checks indicate that these linears represent fractures. The sets trending approximately N 40" W (yellow) and N 80° W (green), in particular, are associated with or control many of the structural hydrocarbon fields. **A** few such fields are located by the brown dots. The N 30" E set (blue) coincides with the edges of solution collapse areas and with the edges of a large thin area shown on a thickness map of Middle-Pennsylvanian rocks of the north flank of the basin. The N to N 10" W set of linears (brown) is associated with the Amarillo-Wichita Uplift on the south side of the site and is clearly displayed in outcrops of the crystalline rocks. Observations suggest that the regional linears are either faults or fault-related features that have been active in the past and control the location of many structural hydrocarbon traps.

The heavy green dotted lines in Figure 13 mark known and hypothesized regional faults and linears within the basin as presented in the literature. The base map consists of the working interpretation of linears interpreted from fall imagery. Places where the interpretation matches or extends the previously mapped linears are marked in red.

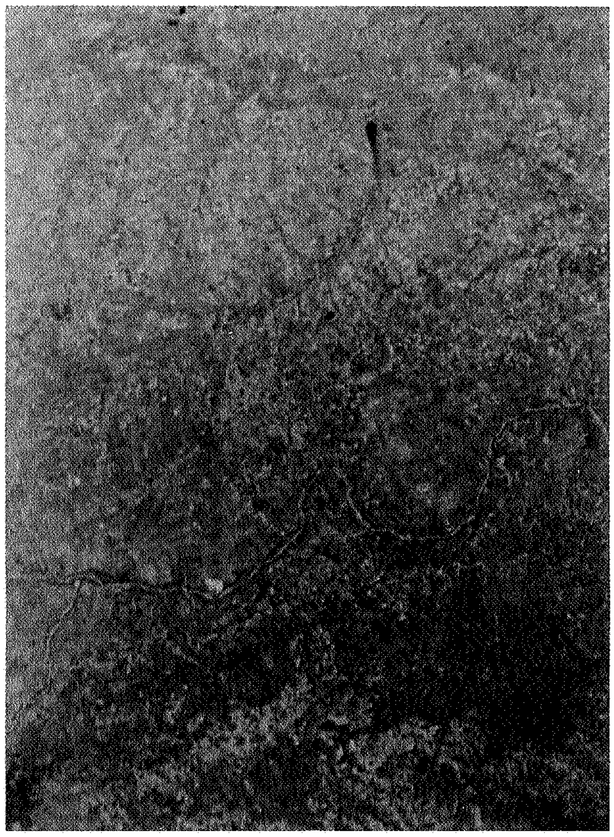


Figure **6.** Color-enhanced ERTS frame produced using an I^2S MiniAdcol using bands 5, **6,** and **7.** This enhancement emphasizes closed anomalous features (note the large circular feature in the northwest) and linear features.

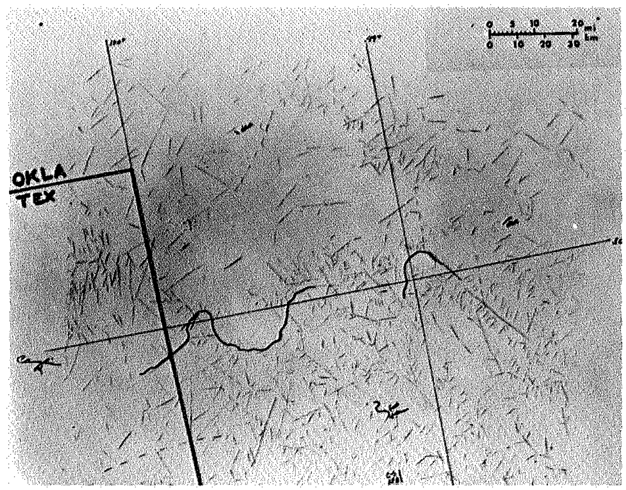


Figure **7.** Interpretation of linear features made from band 5 of frame **1131-16465** (December **1972).** This working map is an example of one of the three interpretations (linears, lithology, and closed anomalies) made for bands 5 and **7** of each frame interpreted.

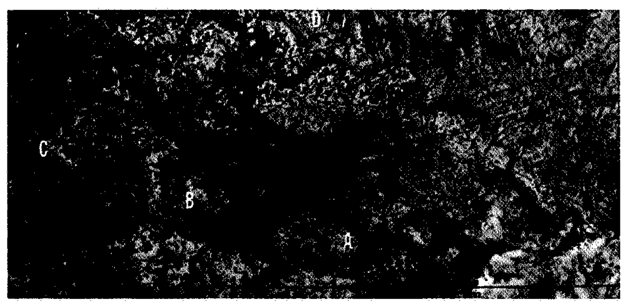


Figure **8.** Linear interpretation overlaid on a December **1972** color composite image. Solid lines are linears interpreted from band **7,** dashed lines such as A and B are linears added by an interpretation of band 5, and dotted lines (C and **D)** are linears added by band **4.**

The regional compilation map of anomalies was also compared to existing pertinent information. Most known structures of interest were located on ERTS imagery prior to referring to existing data. One composite overlay of fall imagery contained 76 anomalous features. These were classified as geomorphic, tonal, and hazy areas. The hazy areas appear on the imagery as if imagery detail had been smudged or partially erased. They are not artifacts. Of 76 anomalies, 59 correlate with producing oil and gas fields, 11 are known but nonproducing structures, and the remaining 6 could not be correlated with known features. Of 35 hazy anomalies, ***33*** correlate with producing fields or drilled structures. On a recent compilation, 42 of a total of 57 hazy areas occur where producing fields exist. Six additional areas correlate with known but nonproductive structures. Several hazy anomalies **(H)** are shown in Figure 14 along with a few textural (Tx) and geomorphic anomalies ***(G*** and **S).** Figure 15 is a color infrared photo of the hazy anomalies near the center of Figure 14 taken from 18,000 meters (60,000 feet). The hazy area seen on ERTS is outlined. Study of this and other air photographs taken over the hazy areas indicate that they cannot be recognized except on ERTS imagery.

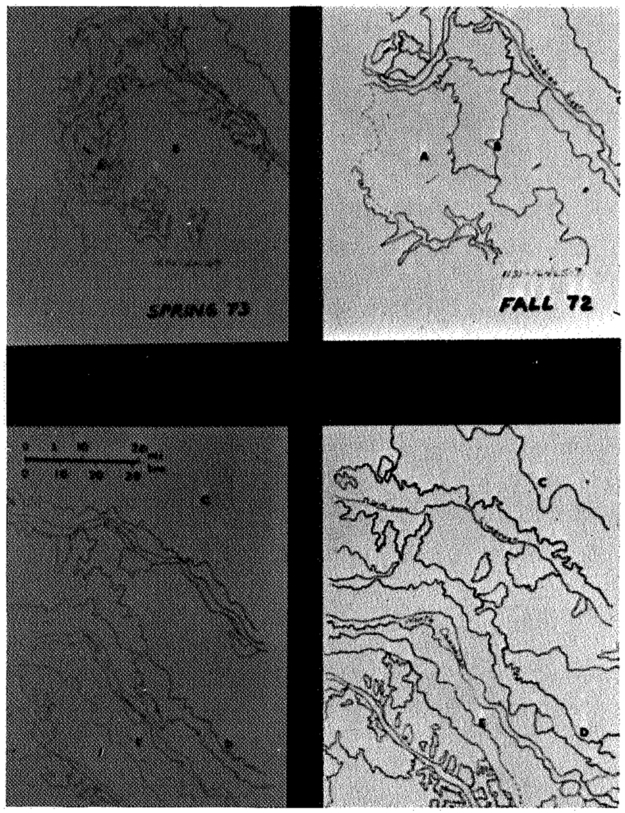


Figure 9. Comparison of interpretation of inferred lithology made from spring 1973 and fall 1972 imagery. Some areas such as **A** in spring imagery provide more information than fall imagery. In other areas **(B** and C), fall imagery is better. In still other areas (D and **E),** boundaries are visible on both coverages but are more interpretable on one than on the other.

Small areas selected from the anomaly maps and published reports, at the suggestion of petroleum geologists, have been studied. In every instance, attention focused in this fashion increases the detail perceived in an area. The interpretations that are produced differ occasionally from suggested or published analyses. In a few instances, notably over the Cement-Chickasha fields, details can be added to the known structure, but the structures themselves, which are fairly shallow, strongly folded and faulted, were not visible in the ERTS imagery.

Some of the interpretations closely match conventional interpretations as at the Mobeetie field. Its closed structure and faulted nature can be seen in Figure 16a, as well as in the ERTS interpretation (Figure 16b). In summary, interpretation of ERTS imagery makes it possible to locate areas for more detailed analysis by ERTS and for aerial photographic and geophysical studies.

Auxiliary imagery, particularly high altitude aerial photography, is exceedingly valuable to studies of ERTS data. The side-looking, airborne radar and thermal infrared imagery that is used, despite their generally poor quality, prove of value in defining, locating, and understanding linear and geomorphic features. High altitude, small-scale, multiband, aerial photography provides a means of understanding local image responses and patterns seen on ERTS imagery. It provides a means of verifying and refining interpretations and relating field observations to ERTS imagery. The photography provides details about large features that are best interpreted in the regional context provided by ERTS. In short, photography provides a cognitive bridge between space imagery and ground reality.

APPLICATION TO PETROLEUM EXPLORATION AND COSTS

ERTS imagery is an excellent tool for reconnaissance exploration of large sedimentary basins or new exploration provinces. The imagery allows rapid interpretation of large features and quickly focuses attention on anomalous areas. For the first time, small and medium size oil companies can rapidly and effectively analyze exploration provinces as a whole. Specific types of information derived from ERTS that are useful for petroleum exploration are as follows:

- There is a vast quantity of information on linear features, much more than is generally available even on large-scale maps.
- Many of the general lithologic relationships that are known to exist in the basin are visible on the imagery.
- A large number of closed anomalies of various types appear on the imagery; the majority of these correlated with known structural features or oil and gas fields.
- Many of the details of the structures controlling hydrocarbon accumulation are visible in the imagery, once attention is directed to a particular area.
- The overall structure of the basin and many of the major internal structures are visible on the imagery.
- The imagery provides overall geologic context of the exploration province.

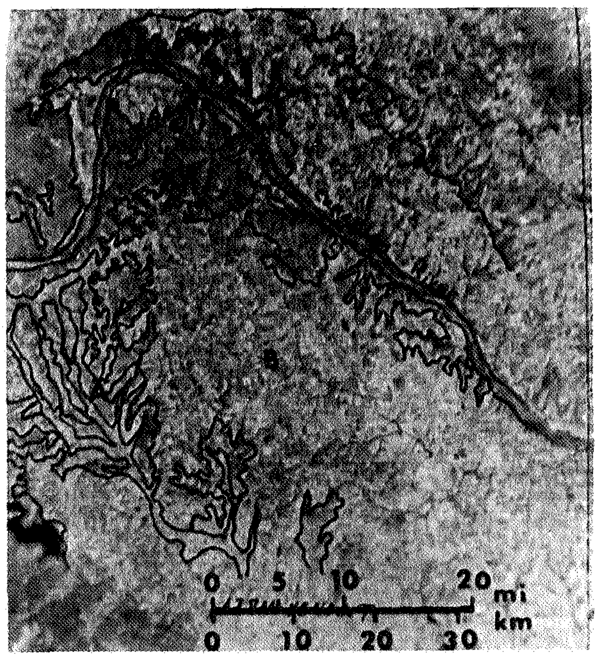


Figure 10a.

Interpretations of inferred lithology overlaid on a color composite ERTS image of Oklahoma. Figure 10a is an enlargement of the area covered by Figure 10b. From south to north the rivers visible in 10b are the Canadian, North Canadian, and Cimarron. The letters indicate areas discussed in Figure 9.

Figure 10b.

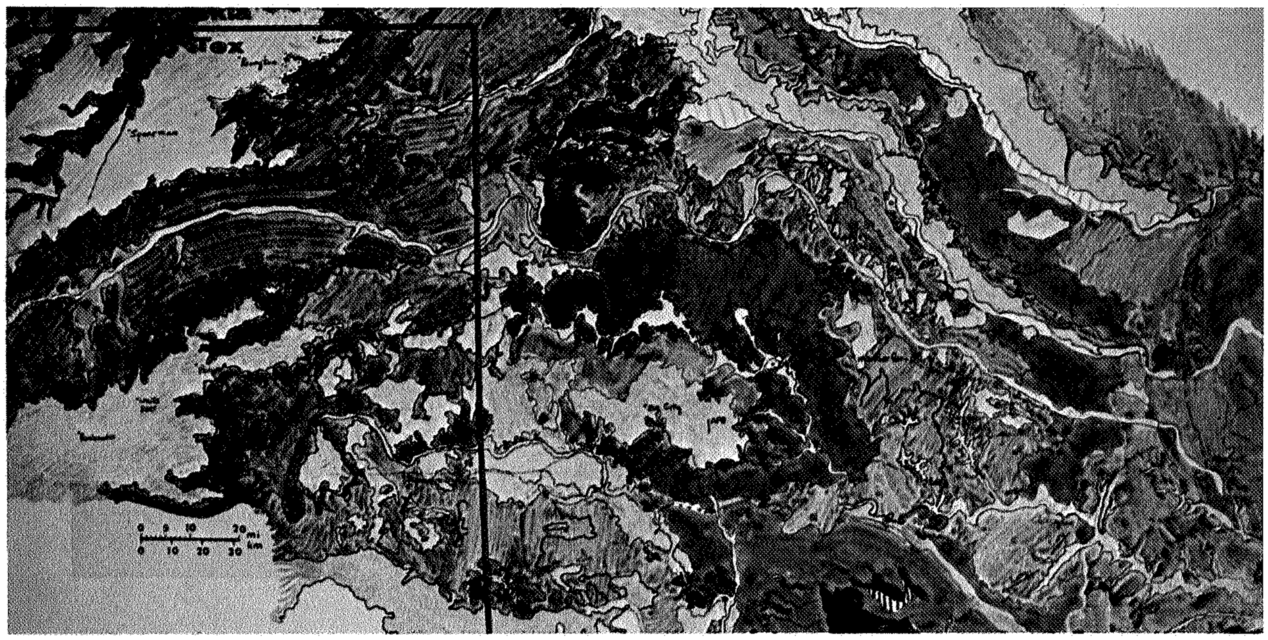


Figure 11. Inferred lithologic map of the Anadarko Basin made using band 7 of fall imagery without reference to existing maps (cf. Figure 4). Black, areas of Cambrian crystalline and lower Paleozoic crystalline rocks at the surface; lavender and blue, Permian rocks of the Anadarko Basin; brown, Tertiary rocks which unconformably cover the western part of the basin; yellow and light brown, Quarternary sand and gravel along major streams and on uplands. The map depicts the major features of the basin including its asymmetrical synclinal nature with basement rocks exposed on the south fork.

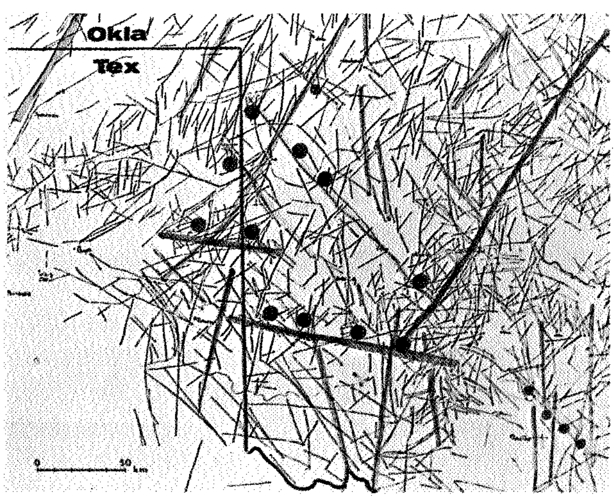


Figure **12.** Regional compilation of linear features interpreted from fall ERTS imagery. The various colored lines indicate major direction and are discussed in the text. Brown circles indicate major oil and gas fields associated with particular sets of linears.

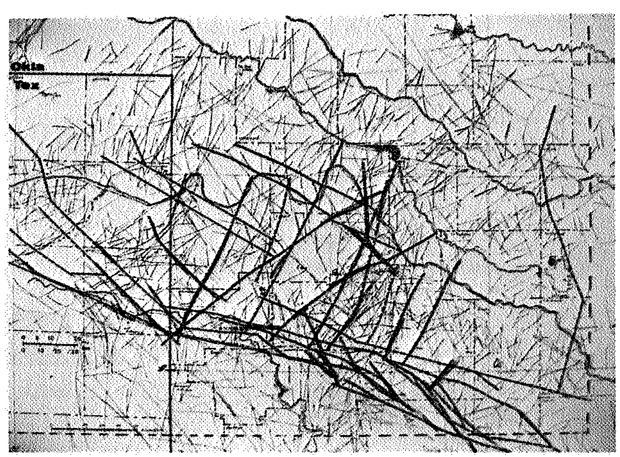


Figure **13.** Comparison of previously mapped regional fractures and linears interpreted from ERTS imagery. Heavy green dashed lines indicate mapped or inferred fractures discussed in existing literature. Red lines indicate where these fractures coincide with or are extended by linears mapped from ERTS imagery.

How does the cost of a petroleum exploration program employing ERTS compare to a standard program? Because of a variety of options available for obtaining reconnaissance geological and geophysical data, cost comparisons are difficult. Moreover, the types of data obtained by the two approaches are not precisely comparable. Based on preliminary analysis: savings produced by incorporating ERTS into an exploration program might be 20 to 50 percent of the cost of a standard survey. The savings would be made primarily by reducing the amount of seismic and other geophysical surveys needed. The ERTS approach would also greatly reduce the time required for regional reconnaissance and analysis of the basin and would conserve technical manpower. It is difficult to assign a dollar figure to either of these types of savings.

This study has raised several questions that require more study. There is the need to determine the exact nature and source of several anomaly types, particularly hazy areas. Are the anomalies manmade or man-induced? Are they geochemically induced soil or vegetation effects, or merely fortuitous? Are the hazy anomalies characteristic of hydrocarbon provinces, unique, or ubiquitous? What anomalies are related to stratigraphic oil and gas traps? Which to structural traps? What aspects of this study apply to other deformed sedimentary basins? And, finally, what savings will result from incorporation of Earth Resources Satellite data into an actual exploration program?

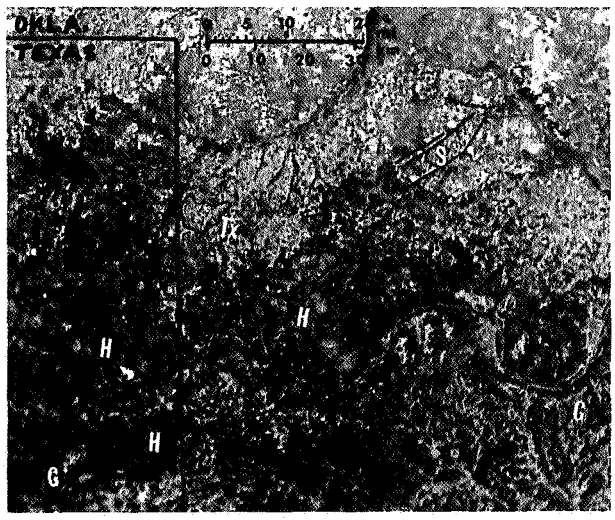


Figure **14.** Several types of closed anomalies interpreted from ERTS imagery overlaid on a color composite image. ***G*** and ***S*** indicate geomorphic or structural anomalies, **H** hazy anomalies, and Tx textural anomalies. Figure 15 shows details of the **H** anomalies near the center of the figure.

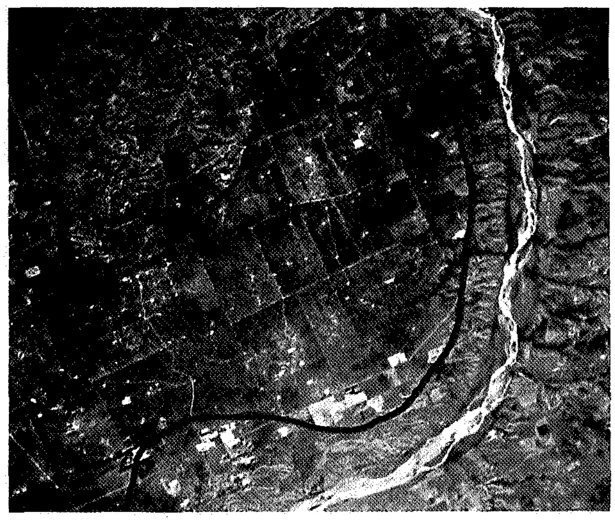


Figure 15. High altitude color infrared picture of the area occupied by the H anomalies seen near the center of Figure **14.** The anomalous area **is** outlined in black. In aerial photography this area does not appear significantly different from adjacent areas along the flight line.

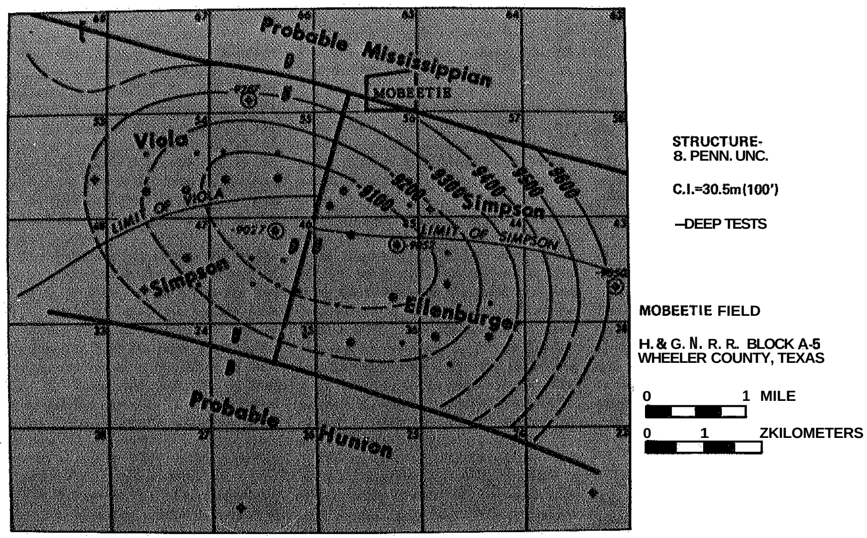


Figure 16a.

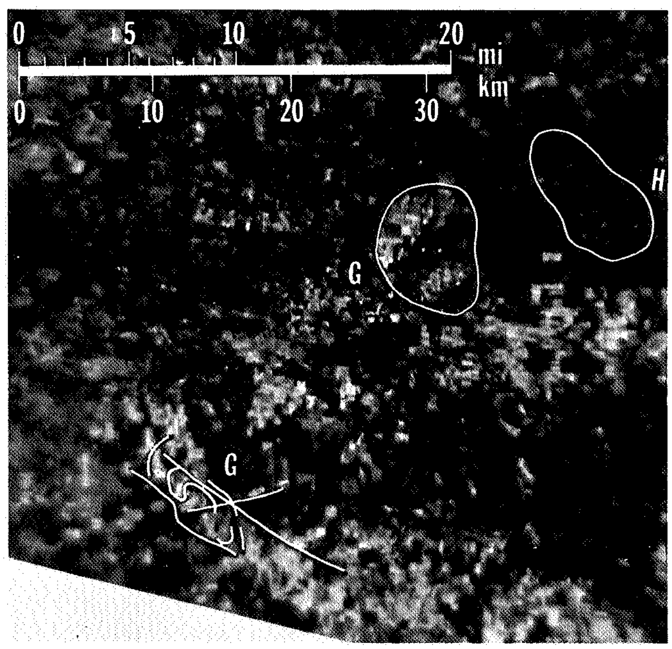


Figure 16b.

Figure 16. Comparison of interpretations of the Mobeetie Oil Field as made from subsurface information and **ERTS** imagery. Figure 16a, showing structural contours and faults, **is** from "Oil **is** Black and Beautiful," by **H.** L. Sahl, which appeared in the February 1970 ***Shale Shaker,*** Oklahoma City, Oklahoma, page 111. The area designated G in the lower part of Figure 16b **is** the preliminary interpretation of the Mobeetie Field made from a color composite of **ERTS** imagery.

ERTS PROGRAM OF THE U. S. ARMY CORPS OF ENGINEERS

Jack W. Jarman
U. S. Army Corps of Engineers
Washington, D. C.

The Army Corps of Engineers is in many senses rather unique in the research and development (R&D) efforts associated with the ERTS Program. First of all, it is oriented more to software products, which contribute to the design, specification, construction processes, and techniques involved in water resource development, while the majority of the industrial, academic, and governmental R&D establishements in the ERTS Program tend to be hardware-oreiented. Secondly, the Corps is doing the ERTS R&D efforts for its own applications. It is hoped that the work done will contribute to other efforts, but basically the Corps is addressing its own needs. Thirdly, the Corps has a great deal of difficulty separating R&D from Engineering. An exploratory effort on a problem area such as waste water disposal is frequently considered R&D when the literature seems to indicate that all of the R&D has been done on the problem. It has been found to be a rather long step between the scientific verification of the technology and the use of this technology by field personnel.

Another area in which the Corps is unique is that most of its R&D effort seems to go into the area of extending its data base. The problem of collecting data is not necessarily regarded in scientific circles as a professional R&D job, but as a job that is somehow subprofessional. So the Corps' R&D activities primarily fall in the middle, between the rather liberal world of the scientist and the extremely conservative world of the engineer. Some of the Corps' efforts in trying to apply the ERTS-1 capabilities to applications will follow. These are considered R&D efforts, but with heavy use of applications developed. Because this report concerns the Civil Works' activities, the applications discussed are strictly the applications to investigation, design, construction, operation, and maintenance of water resource projects. Military applications are not involved.

When the Corps of Engineers entered the ERTS Program, it evaluated the areas where it felt ERTS capabilities would assist in collecting data. The program was categorized in several ways, as shown in Table 1. NASA generously funded most of these Corps of Engineers' R&D efforts.

When ERTS-1 was first launched, there were some feelings that data communications was a proven capability and therefore should not be considered an R&D effort. The Corps felt that data communications by satellite was important and that R&D had to be done to find out how the people in the field could actually use it. The final ERTS Program did have a communications capability, and the Corps installed a system in the Northeastern United States that used approximately 30 data collection platforms to provide data such as river stage, tide

Table 1

Corps of Engineer Investigations

Problem	Region	Bay	Reservoir	Lake	River	Coast
Resource Inventory	D. Anderson* Dornbush†				Grabau* Christian†	Gagliano†
Environmental Impact			Jain*		Miller?	
Pollution Monitoring				Haugen†		
Water Circulation Sediment Transport		Grabau* Gatto†	Scheps-f			Berg* Pirie*
Data Collection System	Cooper*					
Engineering			Vogel† Ray† Fisher† Gelnet-f			
Model Verification		Herrmann†				

*R&D funded for ERTS investigations
†Aircraft imagery and Skylab

information, water quality, and precipitation for various river basins in that area (Figure 1). Seven of the stations were connected in parallel with a microwave system that was in the area at the time, and the parallel operation was used to verify the accuracy and the reliability of the ERTS data relay system. The reliability has been found in many cases to be higher than landline communication or microwave communication, and the Corps is on record now as stating that when an operational satellite is available for data communications, the Corps will be a user. It is, as far as the Corps is concerned, a proven operational system.

In conjunction with that program, the use of imagery to augment the type of data that was being obtained from the data communications system was investigated. The data communications system provided only point sources. Information was needed that would allow

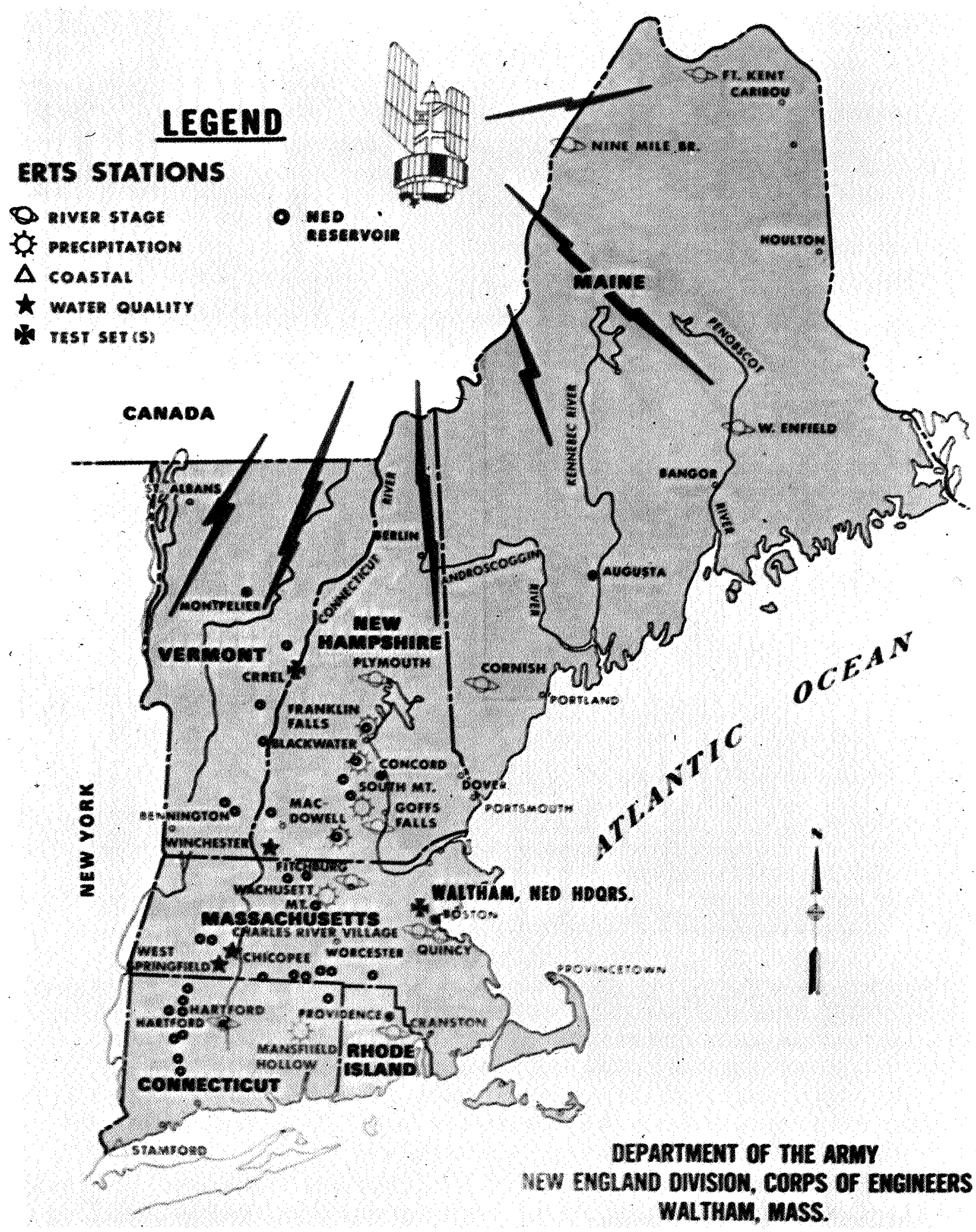


Figure 1. ERTS-1 data reporting stations in Northeastern United States.

the interpolation or extrapolation of the point sources into predictive capabilities for runoff. Figure 2 is an example of work that is being done by Dr. Paul Bock of the University of Connecticut in coordination with the Corps of Engineers. Because of the location of the test area and the overlap from ERTS, coverage can be obtained periodically on successive days. The figure shows the difference in snow cover on successive days. The dark outlines are areas where there was no snow on either April *6* or **7,** 1973. The wine color shows the snow that existed on April ***6*****,** and was not there on April **7;** the yellow is the area that was covered by snow on both days. This type of information can be quantified for input to models. Connecting this information with the point data that is accumulated from the data collection system gives a much better idea of the potential runoff within the basins in the New England region. It is hoped to eventually extend this to other basins of the country as well.

Figure ***2*****.** Composite **of** repetitive **ERTS** coverage to map snow ablation.

The next area to be discussed is, actually, an area that was not a funded ERTS experiment. It is an area in which ERTS imagery was available and proved to be extremely useful. Basically, it is an attempt to provide a data input for the Corps' environmental impact statements. The Corps of Engineers has a tremendous workload in preparing environmental impact statements which are required by our mission. The environmental impact statements are prepared not only on those projects that require construction, but also where dredging is involved for maintenance of facilities. Impact statements are also required from a private citizen or a state or local entity who decides to build a structure on navigable waters. Again, the data requirement is extremely large.

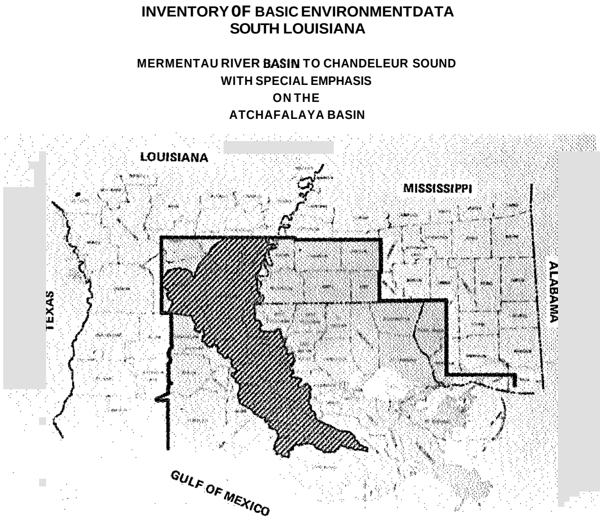


Figure 3a. Coverage of Atchafalaya Environmental Atlas.

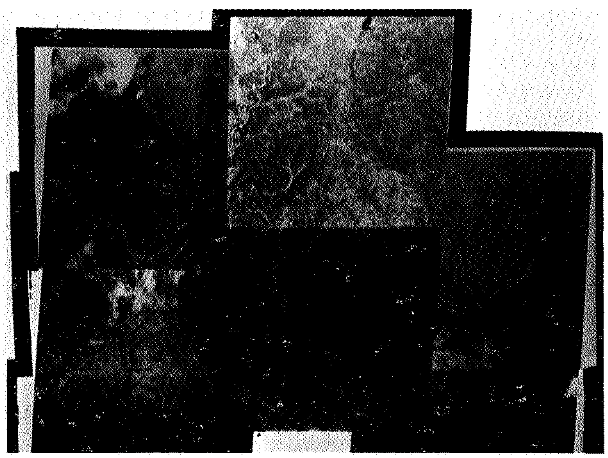


Figure 3b. ERTS mosaic (bands 4, 5, and 7) of southern Louisiana

Figure 3a illustrates coverage of an atlas that was compiled as an inventory of basic environmental data for the Atchafalaya area in southern Louisiana. Environmental impact statements will be required for a number of projects in this area and the atlas attempts to provide a single overall inventory that permits a systematic approach to the impact statements rather than separate inventories for each project. The study area covers approximately 62,500 square kilometers (25,000 square miles). Figure 3b is an ERTS mosiac of the New Orleans area. The study area is on the left-hand side of the mosiac. ERTS imagery was used extensively for mapping of land use and vegetative cover, at a scale of 1:250,000. Figures 3c and 3d are photographs of pages from the atlas and are extremely detailed. From the ERTS data it was possible to acquire accuracy that is probably much greater than could be obtained by traditional methods. The work involved 20 man-weeks of effort, and would probably have been twice that if it had not been for the ERTS data.

In a NASA-funded study of the Chesapeake Bay area, an attempt was made to delineate the sediment content of five test areas that flowed into the Chesapeake Bay (Figure 4a). By using this information, more will be learned about the dynamics of the Bay system, through the use of the sediment traces as natural dye to show the currents and movements of the water in the Bay. Figure 4b shows comparisons of radiance areas in bands 4, 5, and 6. By comparison of the spectrum and the sediments in the various rivers, it is found that from ERTS imagery a level of sediment can be mapped and the sediment of various rivers can be differentiated. Figure 4c shows the computer printout of the radiance values that are assembled for a specific area. Figure 4d gives a film overlay that classifies the suspended material concentration in an area.

Work in the Waterways Experiment Station resulted in the use of the digital techniques described above for the inventory of dams. When the Buffalo Creek disaster occurred in 1972, the Federal Government became aware of the potential disasters of the many small dams and impoundments that exist throughout the country, and legislation was passed requiring an inventory and inspection of any impoundment that was 1.8 meters (6 feet) in height or that

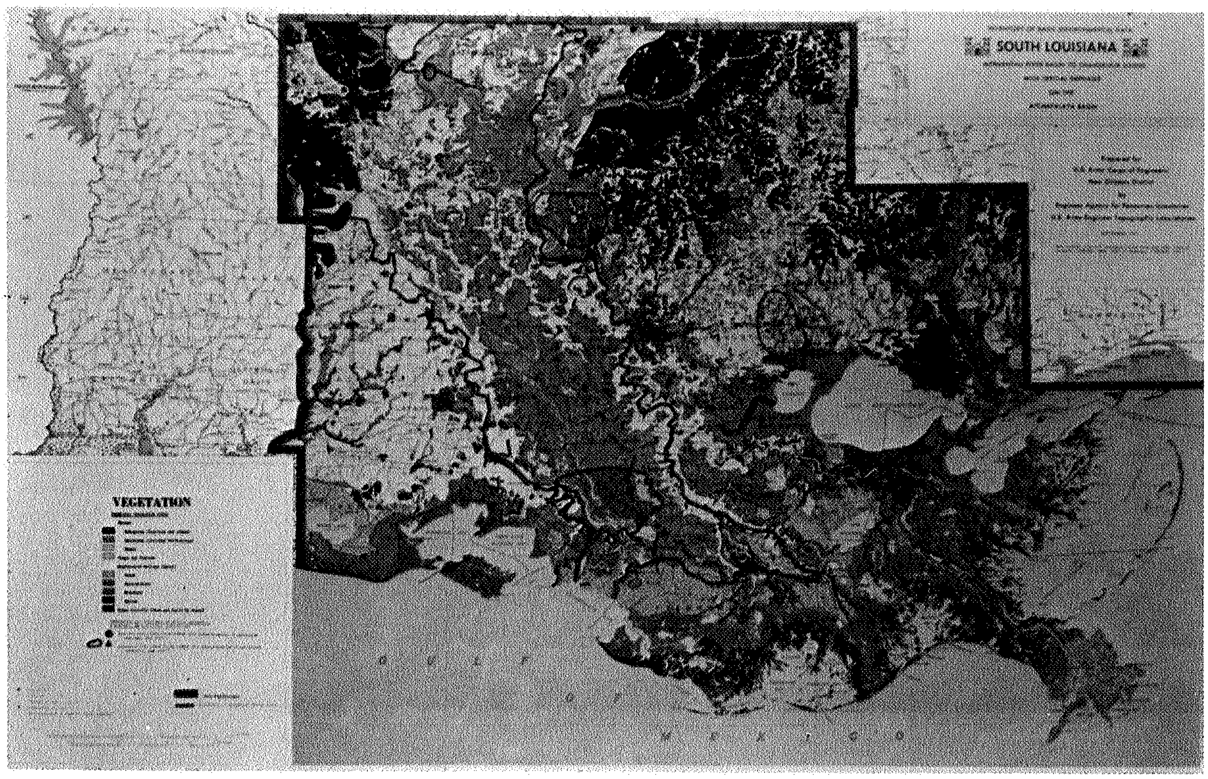


Figure 3c. Vegetation map partially derived from ERTS imagery.

Figure **3d.** Land use map partially derived from ERTS imagery.

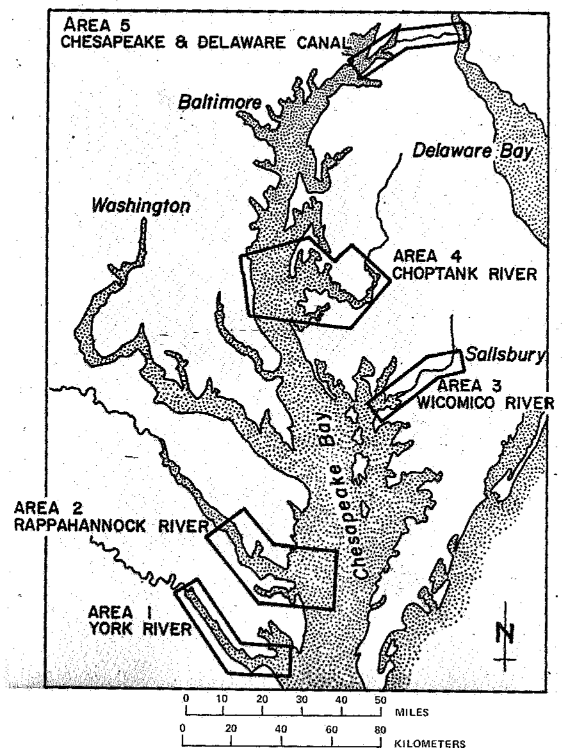


Figure 4a. Chesapeake Bay sediment content study areas.

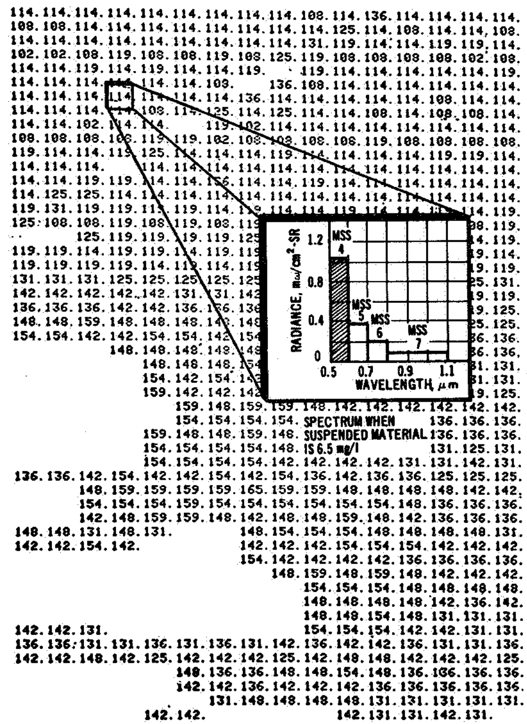


Figure 4c. Computer printout of radiance values assembled for a specific area.

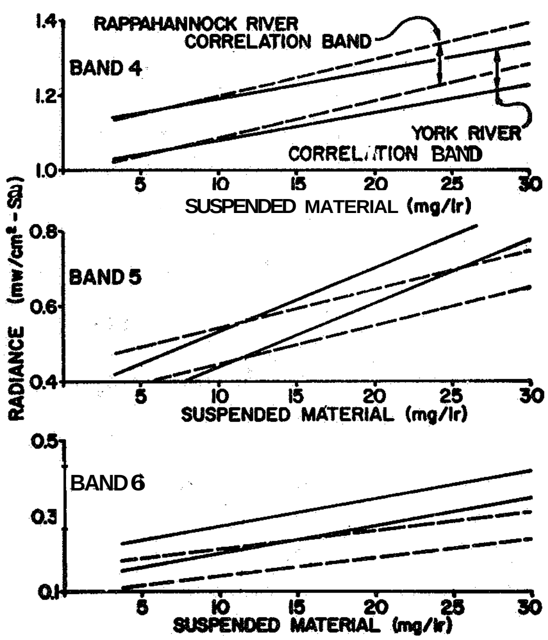


Figure 4b. Comparison **of** radiance signatures of York and Rappahannock Rivers.

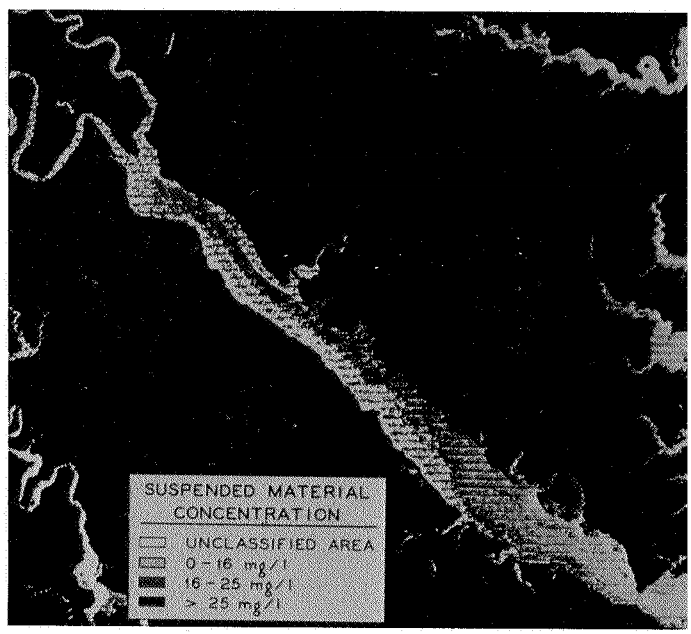


Figure 4d. Computer classification of suspended material concentrations.

contained 60,000 cubic meters (50 acre-feet) of storage. These are extremely small impoundments and it was rather difficult to determine how all of the impoundments in the country would be located.

It was found that by visual inspection of the ERTS imagery, water bodies that were less than 40,000 square meters (10 acres) in surface area could be located on band 7. It was assumed that just about all of the impoundments containing 60,000 cubic meters (50 acre-feet) of storage would have a surface area of 40,000 square meters (10 acres). So the *Corps* of Engineers published a pamphlet that explained the use of ERTS 70-millimeter imagery, band 7, enlarged to approximately 1:1,000,000 scale, for identifying water bodies. These water bodies could then be checked to determine whether or not they were, in fact, natural water bodies or impoundments.

Figure 5a gives an indication of the way the water stands out on band 7. The water, because it absorbs the infared response, is quite black and makes it fairly easy to do a general assessment of an area. Figure 5b is a film overlay that is merely the result of computer processing of band 7 to delineate those water bodies.

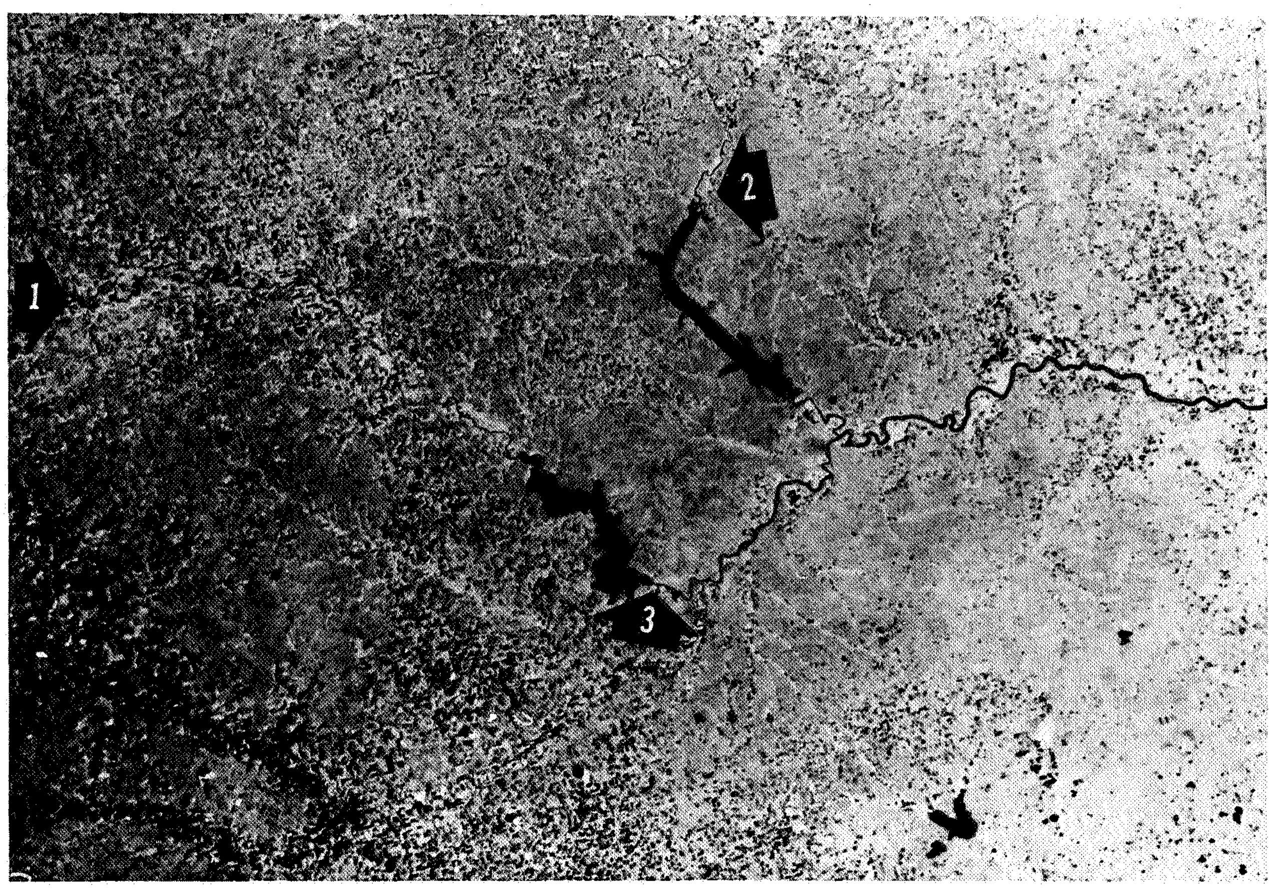


Figure 5a. Band 7 is most useful for identification of water bodies. There is a large contrast between water bodies and the surrounding land features. The course of the Republican River **(1)** extends from the left center of the image, entering the upper corner of Milfred Reservoir. The Blue River (2) enters the upper portion of Tuttle Creek Reservoir. The Kansas River **(3)** begins at the base of Milfred Reservoir and flows in an easterly direction toward the Missouri River.

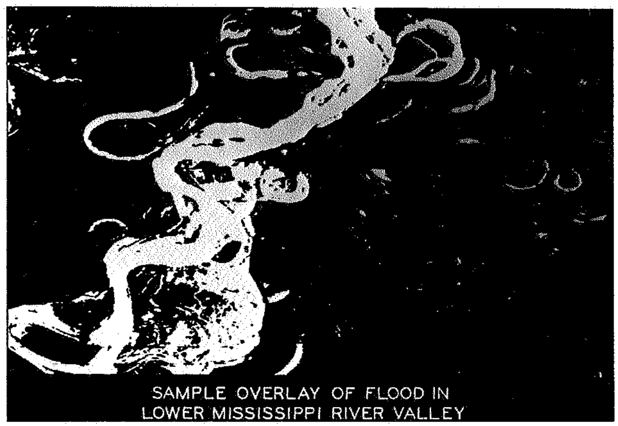


Figure 5b. Computer-mapped water bodies.

LATITUDE DEG MIN	LONGITUDE DEC MIN	PIXEL COUNT	EST. SURFACE ACRES
N35- 9.6	W 82-21.4	45.	50
N35- 7.0	W 82- 4.8	1.	1.
N35- 9.2	W 82-18.9	2.	2.
N35- 9.6	W 82-21.7	1.	1.
Y35- 9.6	W 82-21.9	3.	3.
N35- 6.3	W 82- 1.1	1.	1.
N35- 6.2	W 82- 1.0	1.	1.
N35- 9.5	W 82-21.9	1.	1.
N35- 8.8	W 82-17.6	2.	2.
N35- 6.2	W 82- 0.8	19.	21.
N35- 9.4	W 82-21.9	6.	7.
N35- 6.2	W 82- 1.6	2.	2.
N35- 6.1	W 82- 1.3	27.	30.
N35- 9.4	W 82-22.1	1.	1.
N35- 6.0	W 82- 0.7	10	11.
N35- 6.7	W 82- 5.3	1	1

Figure 5c. Sample computer printout of inventory of surface water bodies.

Computer processing of the digital information from ERTS provides other products (Figure 5c). It is possible to compute latitude, longitude, and pixel counts; since each pixel is approximately 5,000 square meters (1.25 acres) it is possible to indicate the estimated surface area. The accuracy is not map accuracy, but it provides information that allows the determination of the location of water bodies to within approximately 1 kilometer.

NASA-funded work has also been done in the Arctic areas, the test site being Alaska. The objective of the research was the testing of ERTS imagery to delineate sediment concentrations in an Arctic inlet. Cook Inlet was chosen, the reason being the high tidal range. It was felt that, given the tidal flow in these inlets, a good opportunity was available to evaluate the capability and then extrapolate this capability to other areas in the country.

Permafrost mapping, snowpack, and icing were also investigated. This led to spinoffs, the major one being the permafrost mapping in support of the pipeline work that is now getting underway. Figure 6a is a sample of the ERTS imagery that was used for mapping the permafrost in North Central Alaska and Figure 6b shows the permafrost map. Completion of this map would have been virtually impossible if the ERTS imagery had not been available.

The next experiment is one being conducted by the Corps' San Francisco District. A contract was made with North American Rockwell to do digital processing and enhancement. The results of this work have proven the worth of the ERTS data in the investigation of coastal processes. With ERTS it is possible to map the gross patterns of the coastal sedimentation, the littoral processes, the way the suspended solids are carried along the coast, where they are deposited, and where these solids come from. It is also possible to do some work in determining where dredging will be required.

The next figures show some of the enhancement techniques that have been used by North American Rockwell to show the density of sediment. Figure 7a, the normal band 4, gives some evidence of the sediment. It is rather difficult, however, to delineate the sediment patterns. By using a flying spot scanner (Figure 7b), and by narrowing the spectral range being investigated, it is possible to enhance the sediment patterns. This is the San Francisco area and it is obvious that the current patterns, the sedimentation in the water, and some bottom features can be delineated. Figure 7c is a sample of computer enhancement techniques which provide even more information.

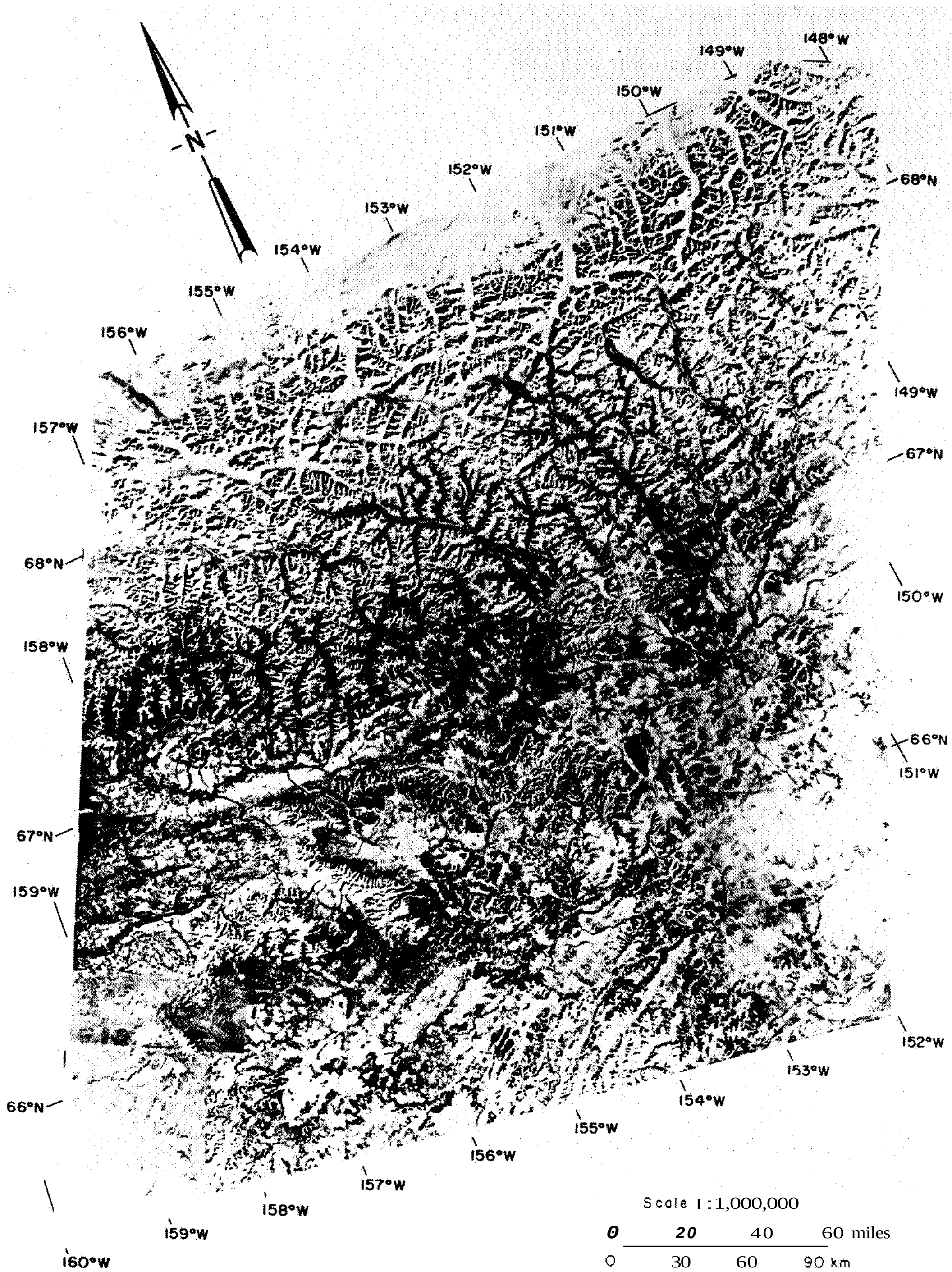


Figure 6a. Uncontrolled ERTS mosaic of North Central Alaska.

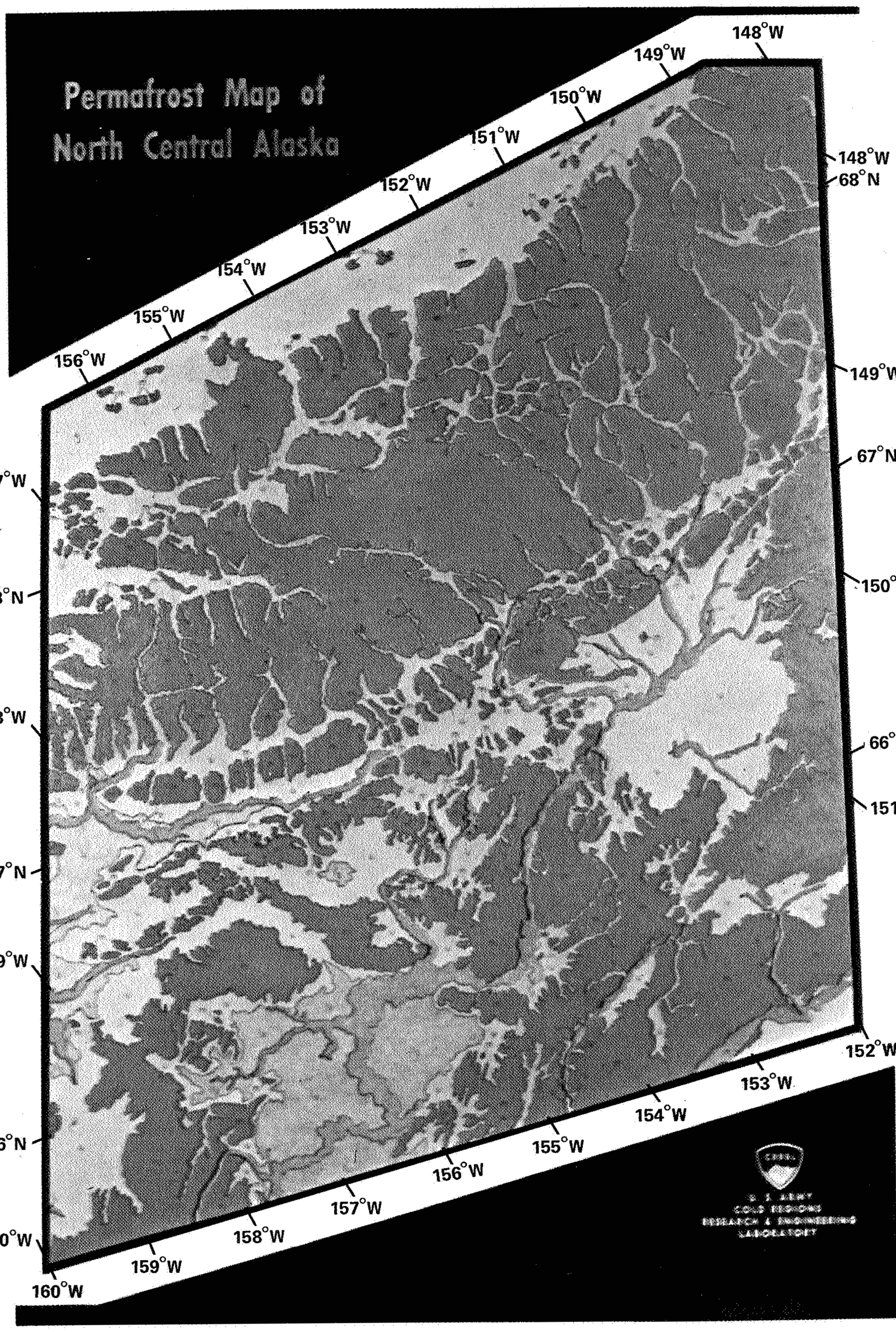


Figure 6b. Permafrost map of North Central Alaska compiled using ERTS imagery.

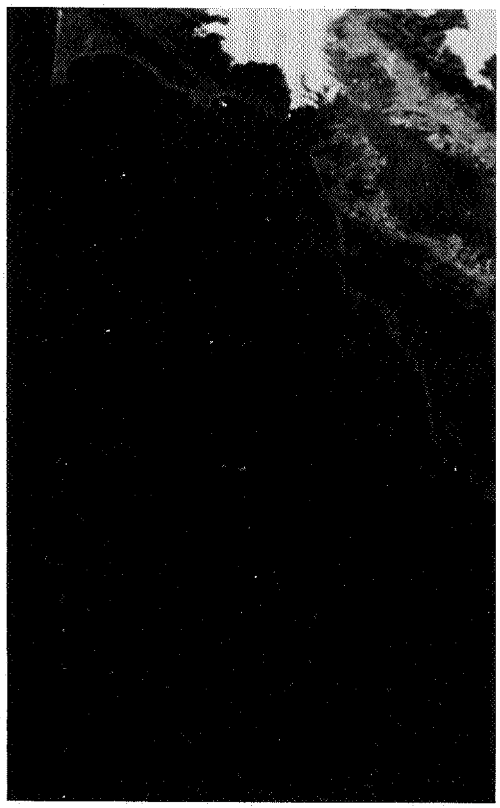


Figure 7a. San Francisco coastal area, band 4.

Figure 7b. San Francisco coastal area, band 4. Flying spot scanner enhancement of sediment.

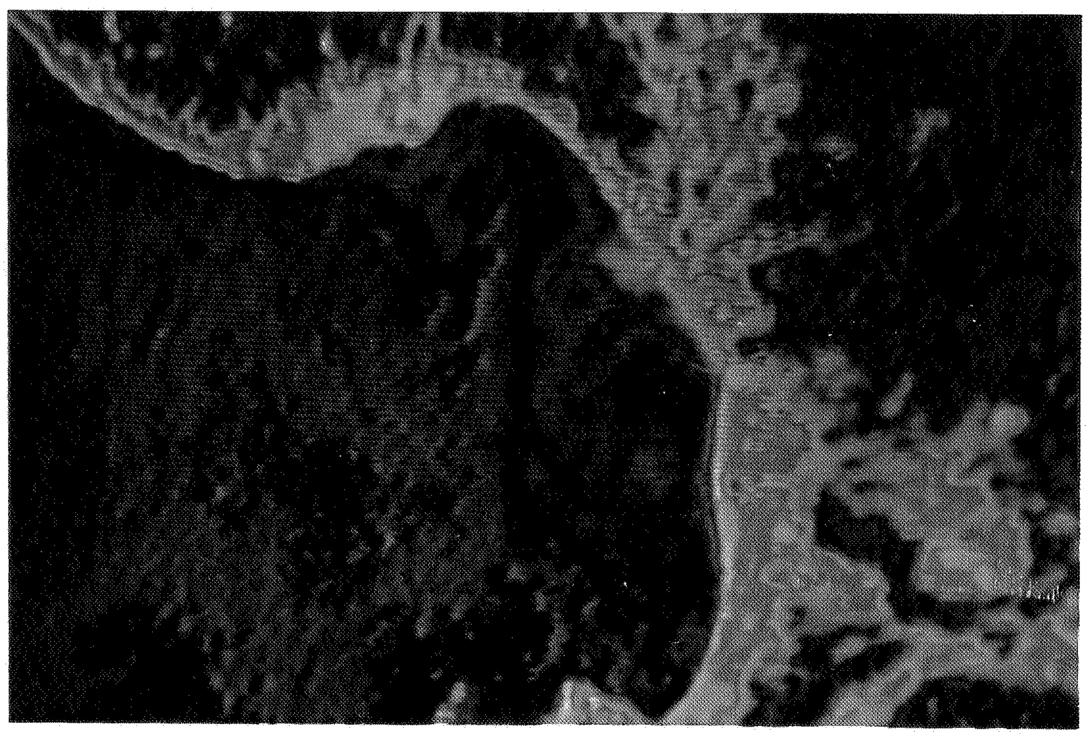


Figure 7c. Data color enhancement of Monterey Bay.

As a result of this work on the coast, the Corps has been in contact with several foreign governments. For example, the Hydrographer of the Navy for Great Britain contacted the Corps of Engineers concerning hydrographic surveys in the Fiji Islands and asked the Corps to provide some ERTS imagery and some suggestions on the use of this imagery. Figure 8a is a band-5 image and Figure 8b is a band-7 image of a Fiji scene. On band 5, the subsurface reefs are easily distinguishable, but it is difficult to delineate the islands. Conversely, band 7 shows only the above-water features. The value of this imagery is evident from the following excerpt of a letter from the Hydrographer of the Navy:

"Indications are that many coral atolls are out of relationship with neighboring atolls and islands. Largest discrepancy found to date is an atoll two miles out of its charted position."

The point that the Corps wants to make is that ERTS imagery has been extremely valuable in developing techniques and is now being used in everyday applications. As more imagery is available, as more work is done with it, and as people get more training, ERTS imagery will be a necessary resource in the Corps' work.

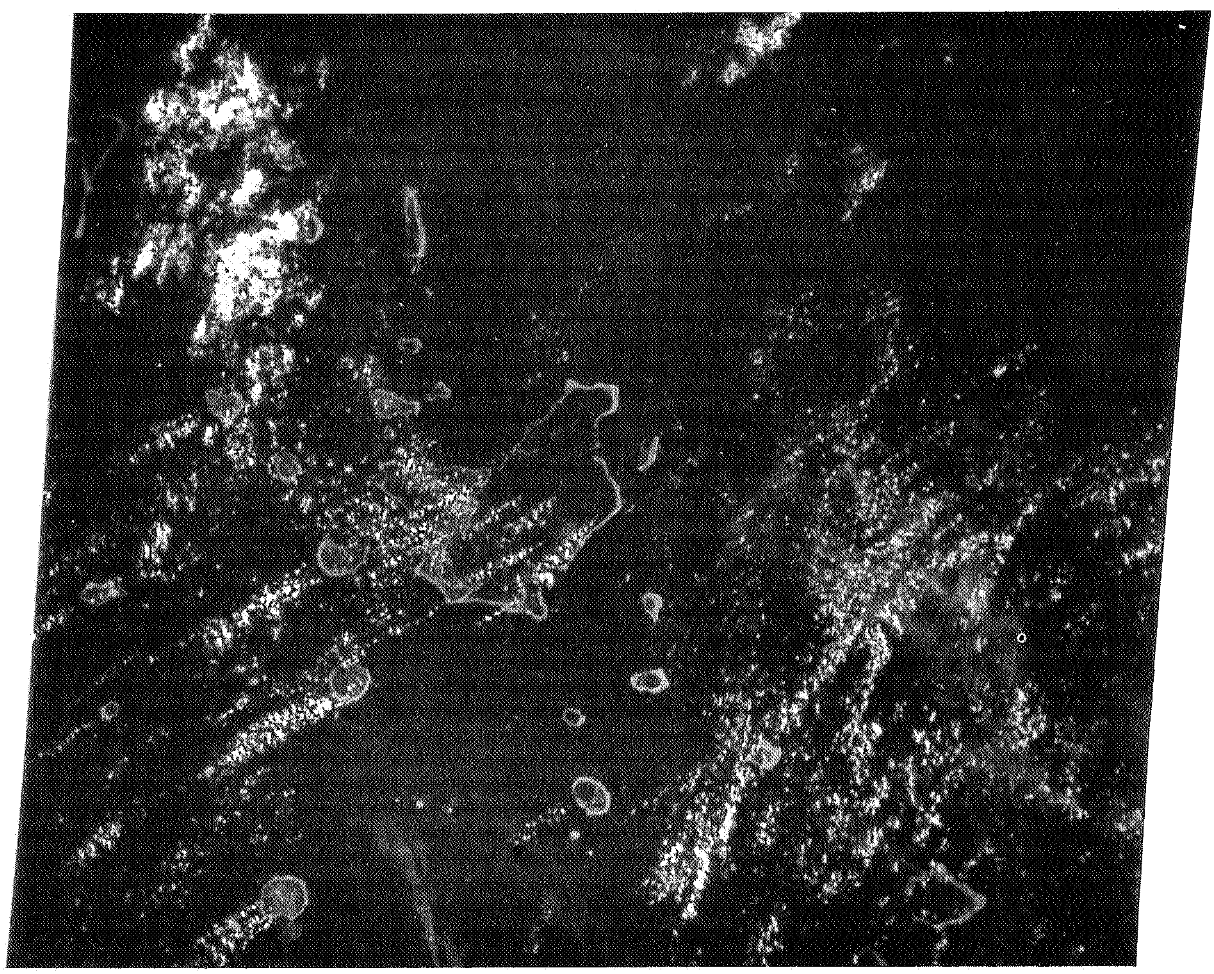


Figure 8a. Fiji Islands, band 5.

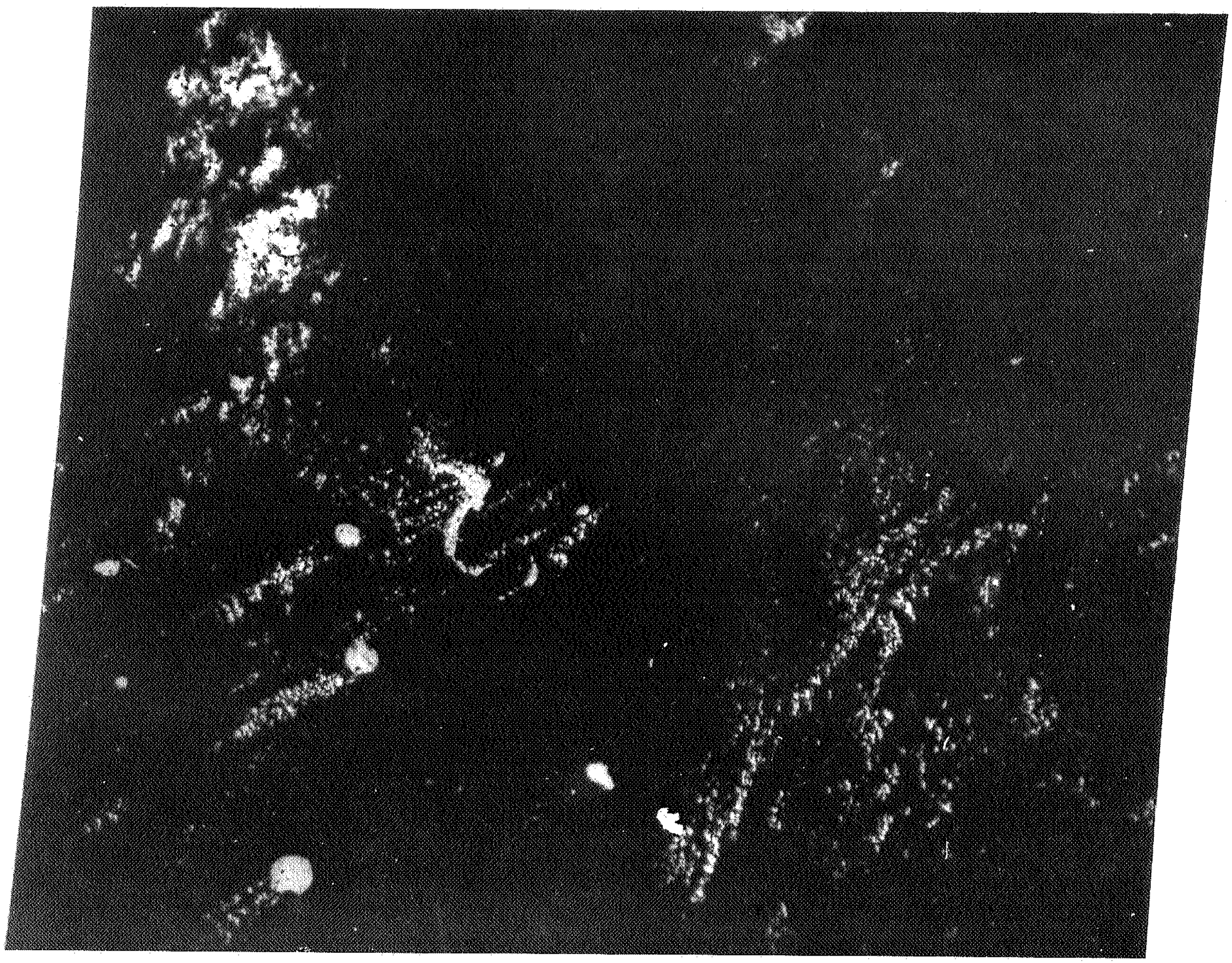


Figure 8b. Fiji Islands, band 7.

A REVIEW OF INITIAL INVESTIGATIONS TO UTILIZE ERTS-1 DATA IN DETERMINING THE AVAILABILITY AND DISTRIBUTION OF LIVING MARINE RESOURCES

William H. Stevenson
NOAA, National Marine Fisheries Service
Bay St. Louis, Mississippi

Andrew J. Kemmerer
NOAA, National Marine Fisheries Service
Washington, D. C.

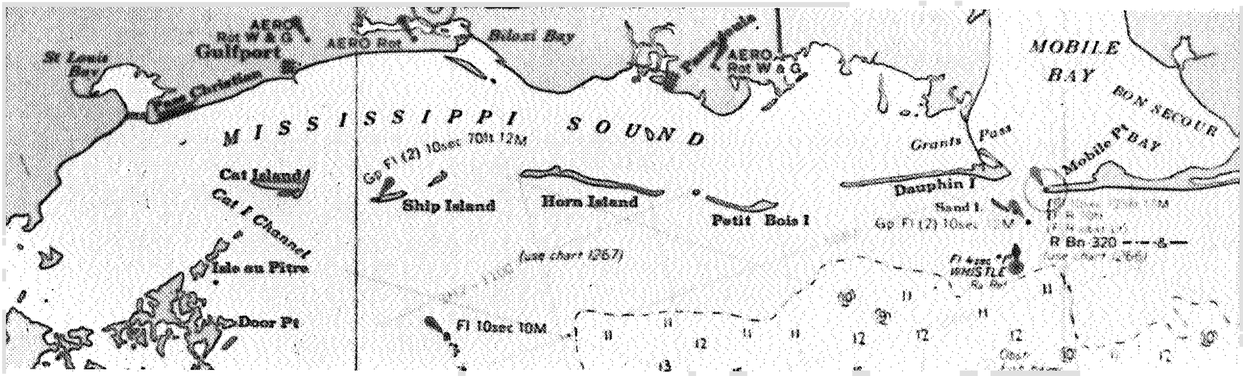
Buddy H. Atwell
NASA, Earth Resources Laboratory
Bay St. Louis, Mississippi

Paul M. Maughan
Earth Satellite Corporation
Washington, D. C.

INTRODUCTION

The National Marine Fisheries Service has been studying the application of aerospace remote sensing to fisheries management and utilization for many years. The 15-month study that is the subject of this report began in July 1972. Its objectives were to: (a) determine the reliability of satellite and high altitude sensors to provide oceanographic parameters in coastal waters; (b) demonstrate the use of remotelysensed oceanographic information to predict the distribution and abundance of adult menhaden; and (c) demonstrate the potential use of satellites like ERTS for acquiring information for improving the harvest and management of fisheries resources. The study focused on a coastal area in the north-central portion of the Gulf of Mexico, including parts of Alabama, Mississippi, and Louisiana (Figure 1). The test area used in the final analysis was the Mississippi Sound and the area outside the barrier islands to approximately the 18-meter (10-fathom) curve.

A small industrial fish, commonly called menhaden, was selected as the target species (Figure 2). This fish supports the largest volume commercial fishing industry in the United States and is a major source of protein for animal food, as well as for solubles and oils for several hundred other uses. The menhaden is a surface schooling species. It is located on the surface and can be



TEST SITE COORDINATES

	LATITUDE	LONGITUDE
A)	30°27'N	89°30'W
B)	30°27'N	87°45'W
C)	30°00'N	87°45'W
D)	30°00'N	89°30'W

SCALE 1:875,000

N.MI. 10 20

KM. 10 20 30 40

TEST SITE DIMENSIONS

LENGTH: 170 KM
WIDTH: 51 KM
AREA: 8685 SQ.KM.

Figure 1. Test Site.

Figure 2. Adult menhaden, *brevoortia patronus.*

easily observed from aircraft. Figure **3** shows two different schools of menhaden that were located in the test area during the test period.

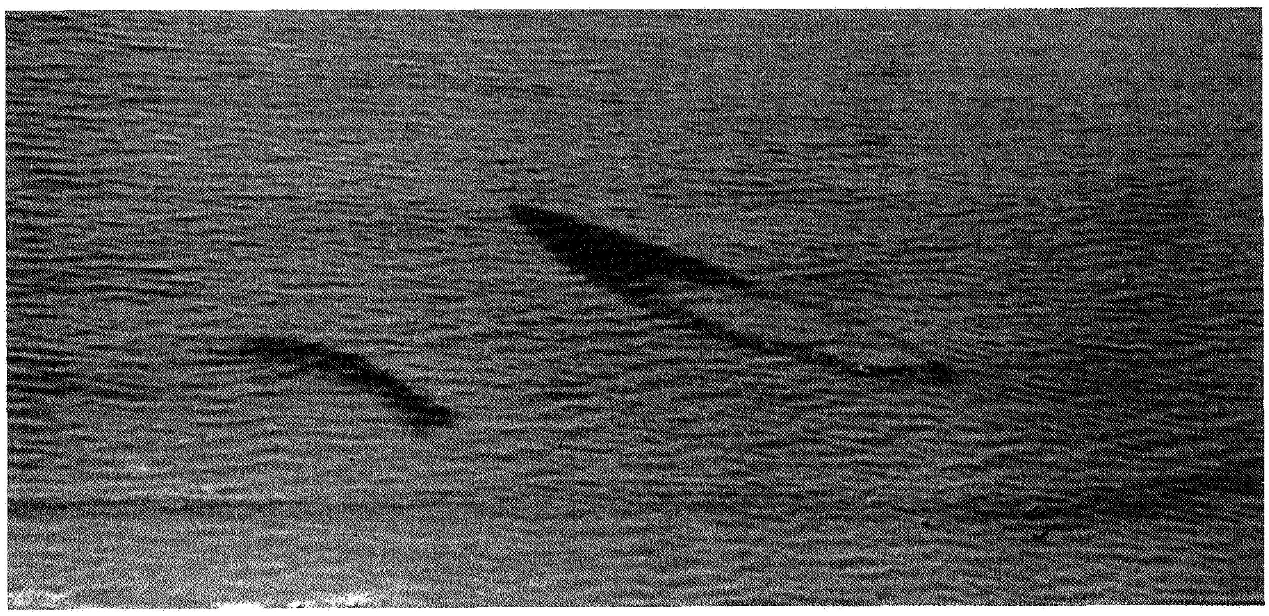


Figure **3. Aerial photograph** of **menhaden fish schools.**

The menhaden are harvested by fishing vessels operating in concert with low-flying, fish-spotter aircraft flown by trained professional fish spotters. They are captured in fence-like nets called purse seines. Figure 4 shows the top cork line of a purse seine surrounding a school of fish. The net is set from the two vessels shown. The fish are carried to processing plants, such as the one shown in Figure 5, aboard large transport ships. The fish are transferred to the transport ships by bringing the small boats and the net alongside and then pumping the fish aboard ship by a series of pumps (Figure 6).

PROJECT MANAGEMENT RATIONALE

The multiple discipline project was organized along technical disciplines: remote sensing, oceanography, fisheries biology, and resources utilization. Management responsibilities for each discipline were assigned to one or more of the Government or industry groups who participated in the project as co-investigators. One example is the National Fish Meal and Oil Association, which represents seven of the major fish meal producers of the United States. In addition, state and Federal agencies, and private fishing companies provided resources or data to the project. These various groups have access to the extensive data base located at the Mississippi Test Facility that has accumulated from the project.

DATA ACQUISITION SUMMARY

Data acquisition activities were also divided into four discipline groups: remote sensing, oceanography, resource biology, and utilization (Table 1). Remotesensing data were obtained by both ERTS-1 and by high- and low-altitude aircraft. Oceanographic data were taken at 95 stations within the Mississippi Sound area and at 45 stations outside the area to provide an overall sampling density of one station per 29 square kilometers. Fisheries resources distribution and abundance data were provided primarily by lowaltitude, aerial photography, augmented by nighttime, low-level, low-light television surveys and daytime commercial fish spotters' reports. Utilization (or harvest) data were obtained from commercial fishing vessels throughout most of the fishing season. Measurements were taken at the time and location of the capture, or attempted capture, of a school of menhaden. The data acquisition system was designed to obtain similar data from more than one source. This provided the redundancy necessary to compare data obtained from one discipline with that obtained from a different discipline technique.

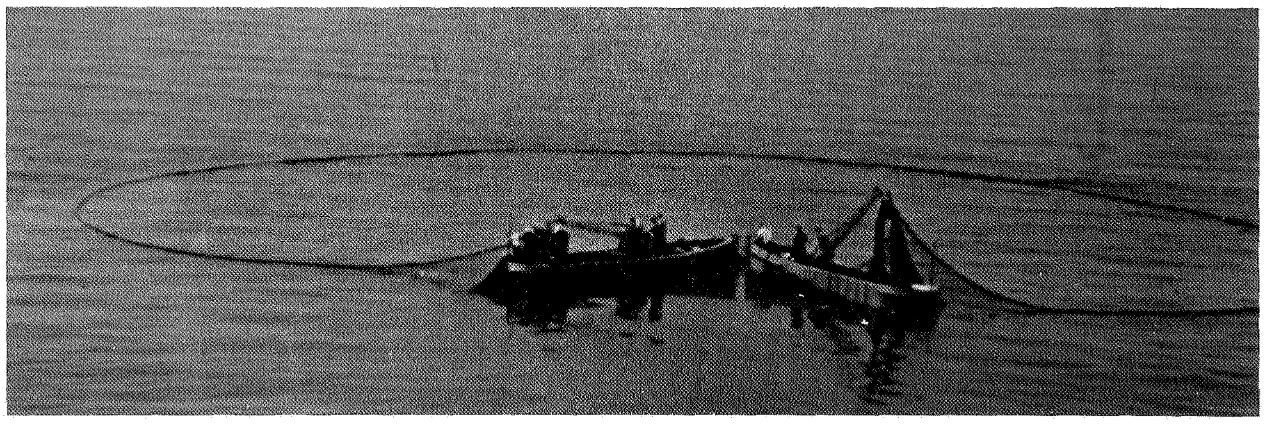


Figure 4. Typical menhaden purse seine operation.

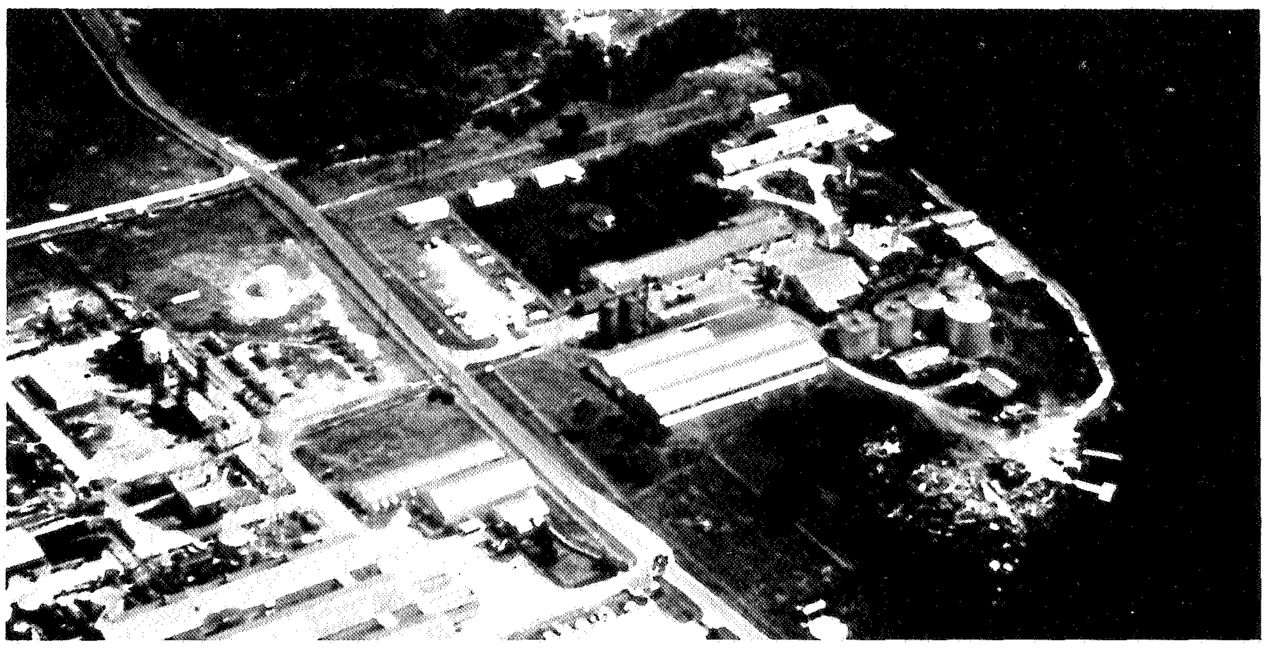


Figure 5. Menhaden processing plant, Moss Point, Mississippi.

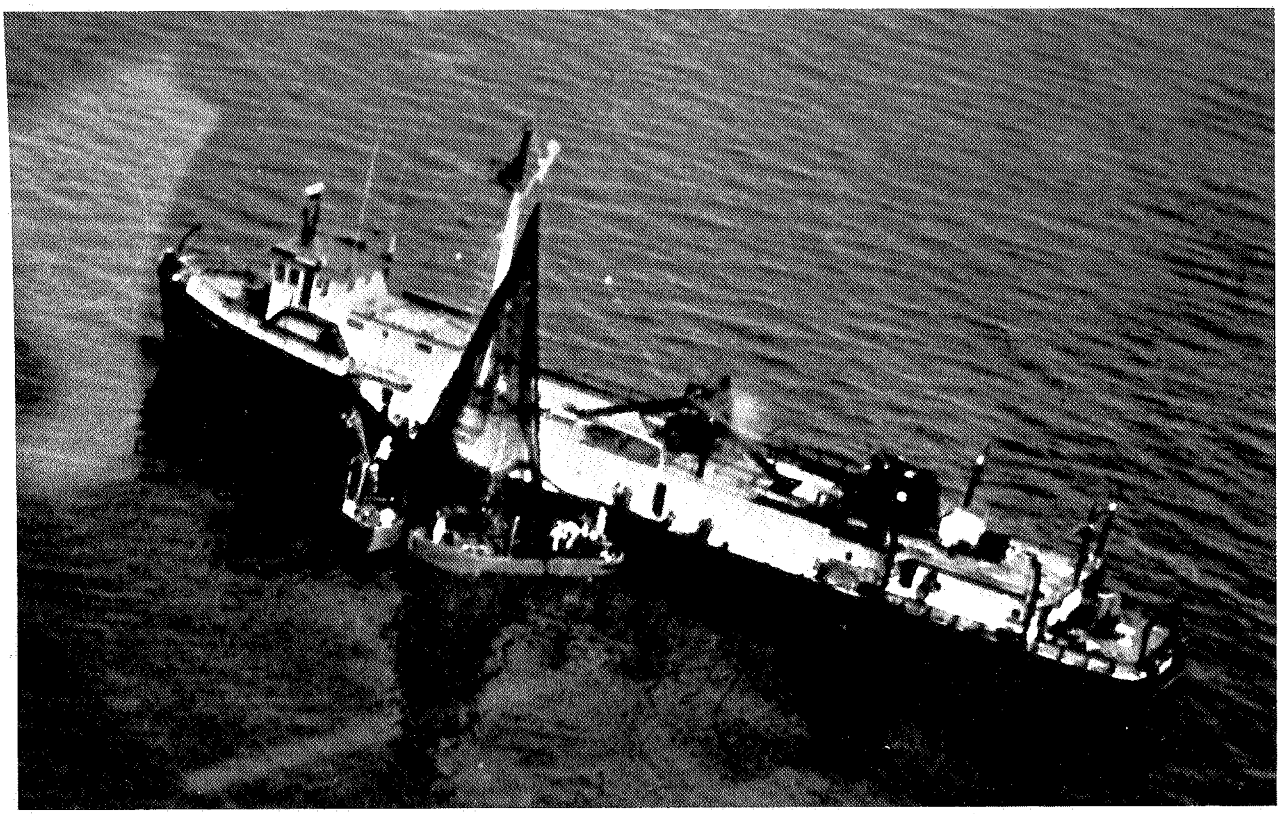


Figure 6. Transport ship with purse seine boats alongside.

Table 1
Data Acquisition by Discipline

Remote Sensing Surface Characteristics	Oceanographic	Resource Biology	Utilization
Water Color	Water Color		Water Color
Turbidity	Turbidity		Turbidity
Temperature	Temperature		Temperature
Current Patterns	Currents		
Salinity	Salinity		Salinity
	Chlorophyll-a		
	Sea State		
	Water Depth		
		School Location	Catch Location
		Species	Species
		School Size	Catch Size
		School Number	Number of Catches

DATA ANALYSIS AND RESULTS SUMMARY

Analysis of the data followed two distinct avenues. Intradiscipline analysis was made to provide an internal check on validity of information within each discipline. Interdisciplinary data analysis was carried on concurrently to determine if correlations existed between the remotely-sensed environmental data and the surface water environment, between the environment and menhaden distribution and availability, and between fish distribution and commercial fishing activities, or utilization.

Results of the analyses clearly demonstrate the feasibility of using data from environmental sensors aboard satellites to predict fish distribution under at least one set of conditions. It must be emphasized that the results presented in this report should be considered as a first attempt, the first step. Additional tests are needed to confirm these results and their applicability in other geographical areas for the species of menhaden, for other species of coastal pelagic animals that exist throughout the coastal regions of the United States and most other countries of the world, and for the different changes that take place in the biological conditions of the animal throughout the season.

The ERTS multispectral scanner **(MSS)** band-5 imagery of August 7, 1972, was correlated with the menhaden distribution patterns (Figure 7). **A** portion of this imagery, which is outlined in Figure 7, was analyzed, based on surface measurements obtained on the same date. The imagery was analyzed by superimposing on it the location of 23 photographically detected menhaden schools. The menhaden schools are identified by small dots in Figure 8, which is a false-color enhancement of the test area outlined in Figure 7. In Figure 8, water imagery density was divided into two density ranges, which are depicted by the yellow-orange and the green. All of the menhaden schools indicated were found to lie in the less dense ranges of the imagery, the yellow-orange. In statistical analysis, these density levels were further shown to correlate significantly with measurements of water transparency and depth. These same parameters were also shown to correlate with menhaden distribution. Two other parameters that correlate with menhaden distribution are water color and salinity. Independent tests of these relationships, using oceanographic and biological data collected at the surface by commercial fishing vessels at the site or near the site of the capture of fish schools, further corroborated this relationship.

Another interesting result of the same analysis was the fact that there was a correlation between chlorophyll-*a* and menhaden distribution. However, we do not feel that the data base is significant enough to say definitely that this correlation is positive. There is an additional correlation, which was in a negative direction; that is, there appeared to be little or no correlation between sea surface temperature and menhaden distribution. We do, however, recognize that temperature is an important factor or environmental parameter for many other species of fish besides menhaden. It is not desirable to rule out temperature as an important environmental parameter based upon the results of this particular project.

Based upon the surface data and supported by the remote-sensing information, both from aircraft and ERTS, eight different relationships were established between the distribution of menhaden in the test area and the four environmental parameters of water depth, surface transparency or turbidity, salinity, and water color. These models provide a capability of predicting'distribution of animals based upon environmental conditions.

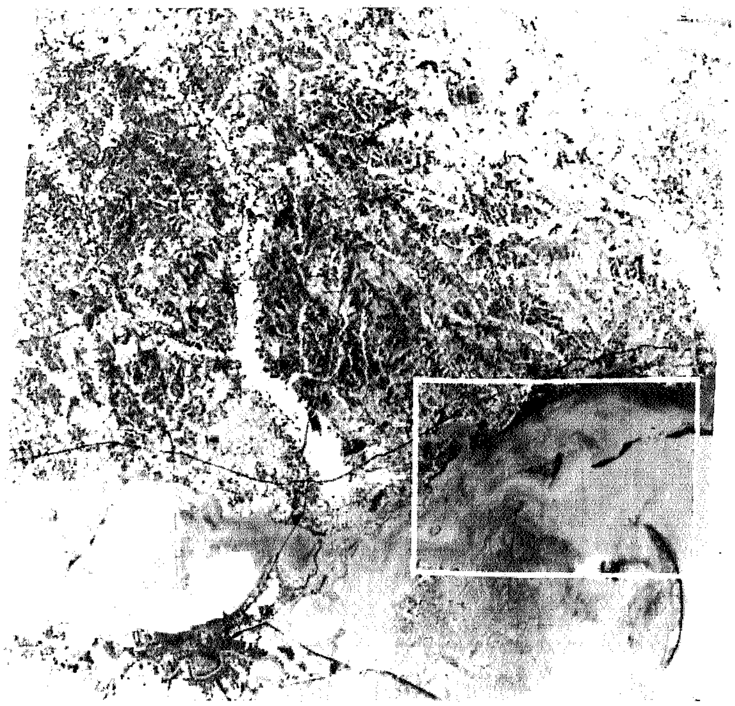


Figure 7. ERTS-1 image with test area outlined.

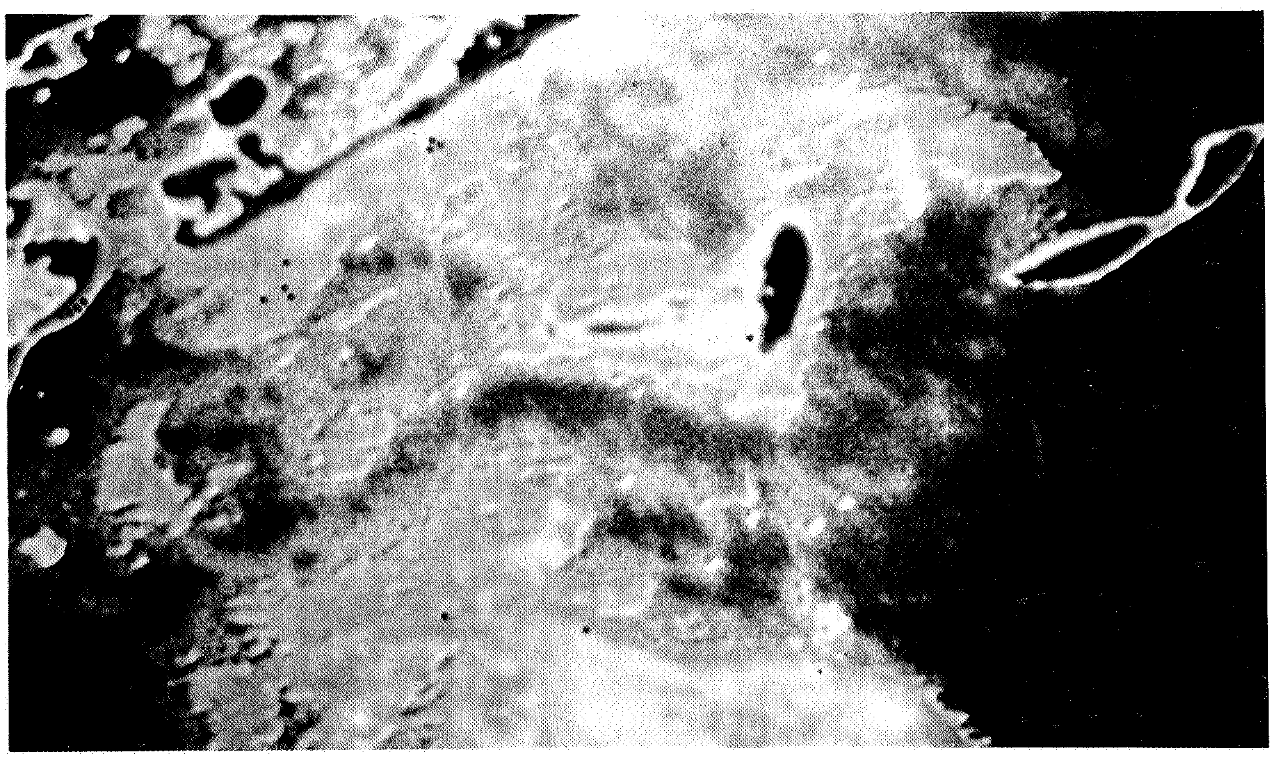


Figure 8. False color enhancement of area outlined in ERTS-1 image, Figure 7.
Dots indicate location of fish schools.

A representation of one of the eight models, shown in Figure 9, indicates high probability, moderate probability, and low probability areas, or potential areas, in which menhaden are likely to be found. The importance of the models is not that they are an end in themselves, but that they demonstrate a potential means or direction through which remotely-sensed oceanographic information can be used to provide menhaden distribution information on a real-time basis.

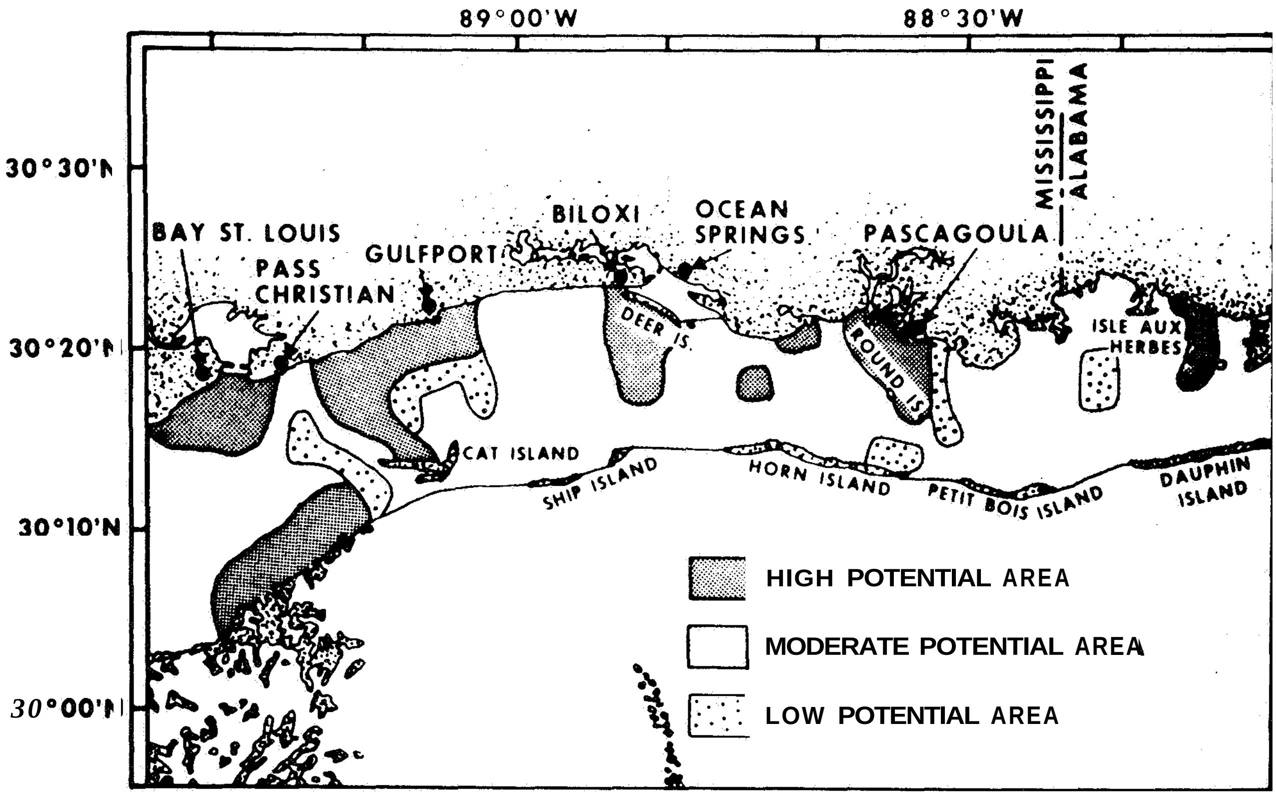


Figure 9. Model prediction **of** menhaden distribution on August 7,1972.

POTENTIAL APPLICATIONS

Potential applications of the results of this study cannot be completely identified at the present time. However, three areas are recognized as having good potential: commercial fishing, resources assessment, and environmental monitoring (Table 2).

Identification of good fishing areas for commercial operations may very well be possible using ERTS imagery and menhaden models of the type just discussed. This includes using linear models obtained directly from ERTS MSS band-5 digital data as input to the menhaden distribution prediction models. If it is realized that the menhaden are distributed over roughly 40,000 square kilometers (12,000 square nautical miles) in the Gulf of Mexico alone, and that the species has a biological range from Maine to Florida on the East Coast of the United States as well, the importance of being able to sort out those areas that have a high probability of successful fishing is fairly obvious. At this time it is impossible to put a dollar value on this, because it is an entirely new approach to the management of tactical fishing.

Table 2
Potential Applications of Satellite Remote Sensing to Menhaden Fishery

- Prediction of potential areas for menhaden appearance in commercial concentrations thus reducing industry operations time.
- More efficient resource assessment operations by predicting high potential areas of fisheries resources.
- Measure oceanographic parameters remotely with sufficient synopticity to meet fishery-oceanography requirements.

Another potential use of menhaden distribution prediction models appears to be in the aid of developing efficient sampling designs for resource assessment purposes. It is seldom practical to sample 100 percent of an area because of time and budgetary constraints. Instead, sampling designs in fisheries resources are often predicated on a prior knowledge about the resource itself. Field operations are then conducted to have the greatest amount of sampling done in areas where most of the fish are expected to be located. To be reasonably cautious, an area five times larger than is estimated for the distribution of the animal during standard survey procedures is covered. As mentioned previously, this is usually a decision based on prior knowledge. However, using predictions of high potential areas such as the type developed under this project, it is believed that the survey effort could be reduced up to 60 percent. This estimate in the reduction of survey effort will change, depending on how well the models perform and whether or not their predictive capability can be improved through additional data inputs.

Another potential application is in the area of environmental monitoring. It has been shown that relationships exist between certain oceanographic parameters and the distribution of menhaden, and that these relationships may have a potential application for commercial fishing and resource assessment. Conventional methods of obtaining oceanographic measurements synoptically over an area the size of the Mississippi Sound, which is approximately 2,500 square kilometers (1,000 square miles), are prohibitive. For these measurements to satisfy the needs of the prediction model found to be necessary in this project, the measurements would have to be obtained within a two-hour time frame of each other and, because of the spatial dynamics of the Mississippi Sound, would be needed on a 0.6-kilometer (0.5 mile) wide basis to accurately describe the conditions within the Sound. An estimate was made of the number of boats required to obtain these data by conventional methods. Typical vessels used in this type of operation travel at about 19 kilometers per hour (10 knots); it takes about 15 minutes on station to acquire the type of information required in this project. Under these conditions, at least 660 vessels in a two-hour time frame would be required to collect enough raw data to satisfy the oceanographic requirements identified during the course of the project. The alternative is to measure the oceanographic parameters remotely from satellites like ERTS-1 or from aircraft.

The present state-of-the-art in remote-sensing water parameters, based on research done by many others as well as **NOAA,** indicates that measurement of surface water temperature from aircraft and satellites is an operational technique. Methods to measure salinity, chlorophyll, and turbidity remotely from aircraft are being developed and improved continuously. Enough work is being done to offer encouragement regarding the continued development of methods for increasing accuracy and for extending all or some of the methods to a satellite-sensing capability. Although remote techniques for measurement of all oceanographic and biological parameters are not completely developed, the advantages of a synoptic coverage of large areas make remote sensing from systems like ERTS-1 the only realistic method for acquiring the data for fishery models of the type that were developed in this project.

Future applications will be identified by continued studies like the ERTS-1 project, but only if they are carried out in close active participation with the commercial and scientific personnel who have the ultimate responsibility to manage and utilize marine fisheries resources.

SOURCES

Atwell, B. H., 1973, Mississippi Sound Remote Sensing Study, Report 11.

Atwell, B. H., 1973, NASA Earth Resources Laboratory, Report No. 091.

Kemmerer, A. J., and J. A. Benigno, 1973, "Relationships between Remotely-Sensed Fisheries Distribution Information and Selected Oceanographic Parameters in the Mississippi Sound," Symposium on Significant Results Obtained from ERTS-1, Greenbelt, Maryland.

Kemmerer, A. J., J. A. Benigno, G. B. Reese, and F. C. Minkler, 1974, "A Summary of Selected Early Results from the ERTS-1 Menhaden Experiment," *Fishery Bulletin, U. S. Department of Commerce* (in press).

Maughan, P. M., A. D. Marmelstein, and O. R. Temple, 1973, "Application of ERTS-1 Imagery to the Harvest Model of the U. S. Menhaden Fishery," Symposium on Significant Results Obtained from ERTS-1, Greenbelt, Maryland.

Stevenson, W. H., and E. J. Pastula, Jr., 1973, "Investigations Using Data from ERTS-1 to Develop and Implement Utilization of Living Marine Resources," Final Report, NASA Project 240, No. CO 321.

Stevenson, W. H., and T. M. Vanselous, 1973, "Remote Sensing Data Management from a User's Viewpoint," American Astronomy Society, 19th Annual Meeting, International Congress Space Benefits, AAS Paper No. 73-152.

Thomann, G. C., 1973, "Remote Measurements of Salinity in an Estuarine Environment," *Remote Sensing of Environment,* 2, No. 4.

Weldon, J. W., 1973, "Remote Measurements of Water Color in Coastal Waters," NASA/Earth Resources Laboratory/MTF Internal Report No. 083.

AUTOMATED STRIP MINE AND RECLAMATION MAPPING FROM ERTS

Wayne A. Pettyjohn
Ohio State University
Columbus, Ohio

Robert H. Rogers and Larry E. Reed
Bendix Aerospace Systems Division
Ann Arbor, Michigan

INTRODUCTION

The area encompassed by this investigation includes five counties in eastern Ohio that comprise nearly 7,500 square kilometers (3,000 square miles) (Figure 1). The counties (Muskingum, Coshocton, Guernsey, Tuscarawas, and Belmont) have been disrupted by coal mining since the early 1800's. Strip mining, which generally began before the 1920's, has been practiced in all of them. The total area of stripping operations in each county was quite large from 1914 to 1947, but is insignificant when compared to the area stripped from 1948 to the present.

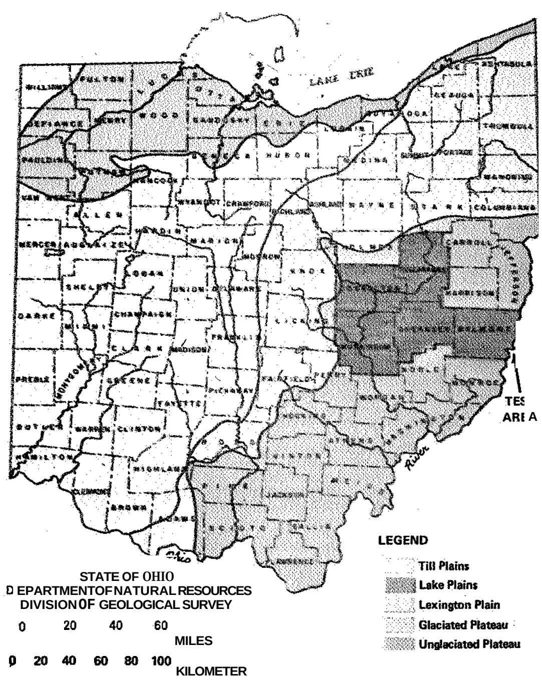


Figure 1. Index map showing location of study area in east-central Ohio.

Strip-mined areas are well illustrated on ERTS imagery where they generally appear as light areas on color composites, such as shown in Figure 2. This scene, representing the August 21, 1972, overpass, encompasses the east central part of Ohio and adjoining areas in West Virginia. The major water course is the southwest-flowing Ohio River. The northwest part of the image includes most of the area covered by this investigation (Figures 1 and 2). This report, however, will deal almost entirely with a single large strip mine that appears in the northwest part of Figure 2, and due west of the large man-made lake, Senecaville Reservoir. This mine is owned and operated by the Ohio Power Company.

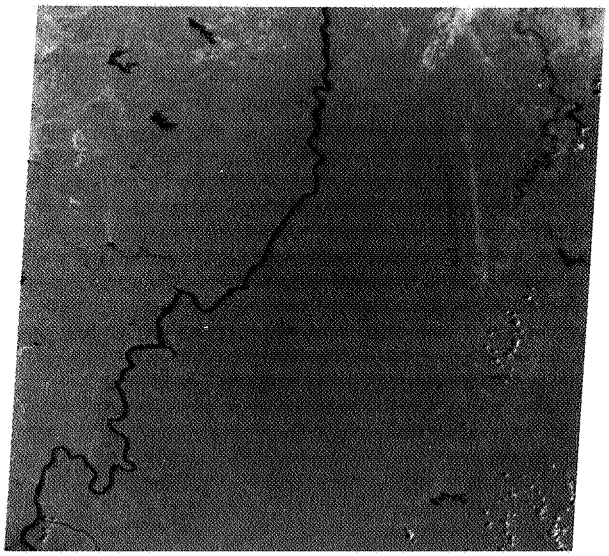


Figure 2. ERTS-1 color composite of the August 21, 1972, overpass showing east-central Ohio and adjacent regions in West Virginia.

Figure 3. Abandoned strip mine in east-central Ohio that was partially reclaimed.

On-site examination of individual mines, and particularly older mines, is hindered by a lack of adequate mine map coverage; deeply eroded, nonexistent, or blocked access roads; lack of accurate or adequate records; the great total size of the stripped area; strip mine reclamation planting along roads that obscures adjacent barren land; and dated aerial photographic coverage.

From the earliest days of mining until 1948, little thought was given to the detrimental effects of coal mining on the environment (Figure 3). However, reclamation techniques required by the 1948 Ohio strip mine legislation resulted in some grading and planting of trees and forage on soil banks (Figure 4) although, in some areas, the soil was too toxic for replanting (Figure 5). In view of the stricter laws passed by the state legislature in 1972, reclamation is proceeding, not only more rapidly, but also much more effectively. Various agencies within the Ohio state government collect certain types of coal mining data. There is, however, little or no coordination between agencies; automatic data processing is nonexistent and various filing systems approach the chaotic. Consequently, reports available to the public are severely dated, commonly inaccurate, and difficult to acquire.

ENVIRONMENTAL EFFECTS OF STRIP MINING

In addition to large areas that are disrupted to such an extent that they are no longer productive, strip mining has caused severe ecologic effects. These include the erosion of bare or sparsely vegetated spoil banks (Figure 5) and the discharge of highly mineralized water (Figure 6). Sediment eroded from mined areas tends to fill streams and reservoirs which, in turn, leads to flooding, decreased storage area, and the choking of vegetation

(Figure **7).** Water that discharges from spoil banks and underground mines generally has a low ph (acid) and is highly mineralized.

Figure 4. Strip mine reclaimed under terms of **1948** laws—some grading of spoil banks and planting.

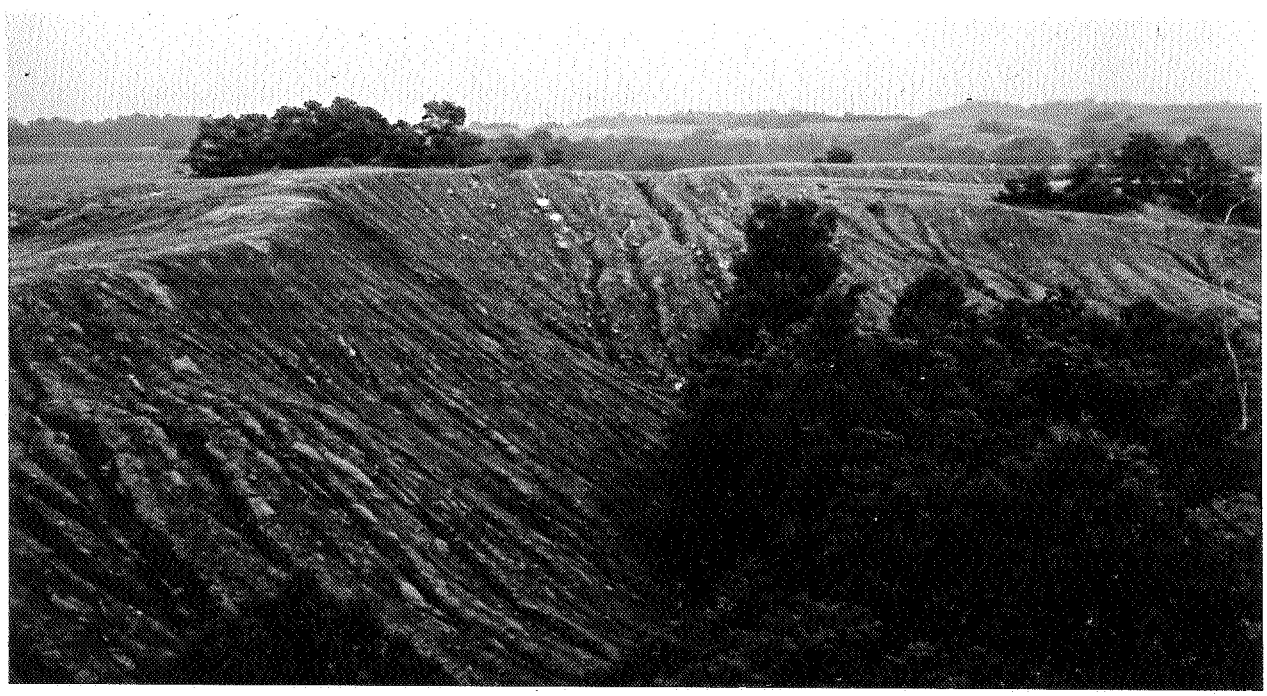


Figure *5.* Although this area was reclaimed, the soil was too toxic for adequate growth. The lack of vegetation on the steep slopes has led to active erosion. Most of the vegetation shown here is growing on unmined land.

Figure *6*. Water seeping from spoil banks in an abandoned strip mine area. The **water** is acidic, corrosive, and highly mineralized.

MAJQR TARGET AREA

Although several specific areas have been examined, a very large mine in southeastern Muskingum County, owned and operated by the Ohio Power Company, was chosen for detailed examination. The mine, although very irregular, is nearly 14 kilometers (9 miles) long and as much as 8 kilometers (5 miles) wide (Figures 8 and 9). Mining and reclamation at this mine are proceeding at a very rapid rate. Air photographs indicate that there was no stripping in the area in 1950. By 1965, however, about 16 square kilometers (4,000 acres) had been disrupted and by 1971, strip mining had devastated close to 44 square kilometers (11,000 acres) in a single mining area (Figures 10, 11, and 12). A similar pattern occurred in several other Ohio counties. Because of the more stringent 1972 Ohio strip mine bill, reclamation now proceeds, in **many** areas, at the same rate as the mining (Figure 13). In fact, grading equipment may be operating just behind the giant mining machinery (Figure 14).

Aerial photographs of the northern part of the Ohio Power Company area were taken in May of 1972. The area was examined in the course of field work in June of 1973. In several parts of the mine, there is no comparison between the landscapes that appear on the 1972 photography and the condition that existed only 13 months later (Figure 15). Many of the strip mine lakes had been filled, graded, and planted as a part of the reclamation program.

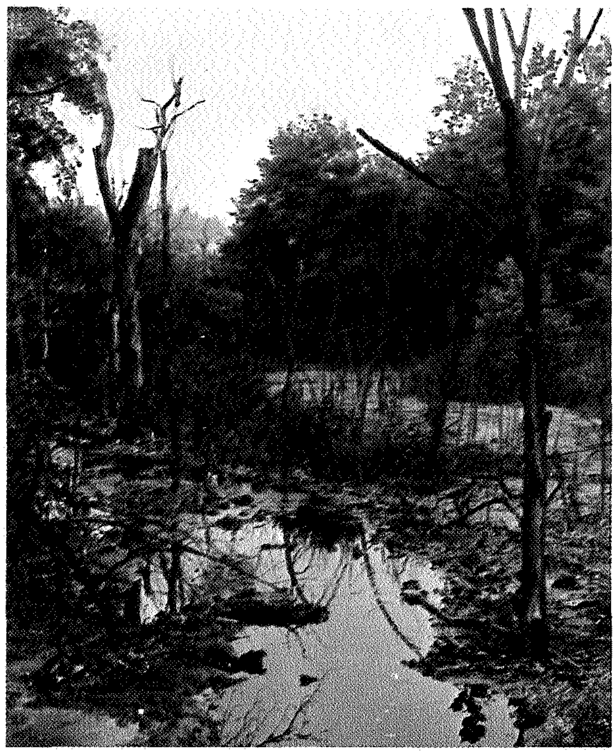


Figure 7. Sediment eroded from spoil banks may fill stream channels, kill vegetation, and cause flooding.

Figure 8. Northern part of the Ohio Power Company mine in Southeastern Muskingun County taken on September 7, 1973 by NASA C-130 aircraft.

Examination of several water quality parameters in lakes, reservoirs, and streams throughout the region indicates a wide range in concentration, both in space and time. Furthermore, the quality cannot be readily predicted from one area to another or, for that matter, from one impoundment to the next in the same mine. Consequently, a detailed regional analysis of water quality characteristics cannot be adequately accomplished without a monumental budget.

ERTS-1 DATA PROCESSING

Local, state, and federal agencies must have repetitive coverage of mining areas and the capability for rapidly evaluating each situation. They must also be able to quickly determine areas of mining reclamation and progress or viability of replanted vegetation, at least on an annual basis. At present, this cannot be done economically by ground teams and aerial photographs rapidly become outdated.

In response to the urgent need for a faster and more economical means of generating strip mine and reclamation maps, this study is evaluating the suitability of using ERTS computer compatible tape (CCT) for automatic mapping. The procedure uses computer target spectral recognition techniques as a basis for classification. To implement these

Figure 9. Southern part of Ohio Power Company strip mine in southeastern Muskingum County taken on September 7, 1973, by NASA C-130 aircraft.

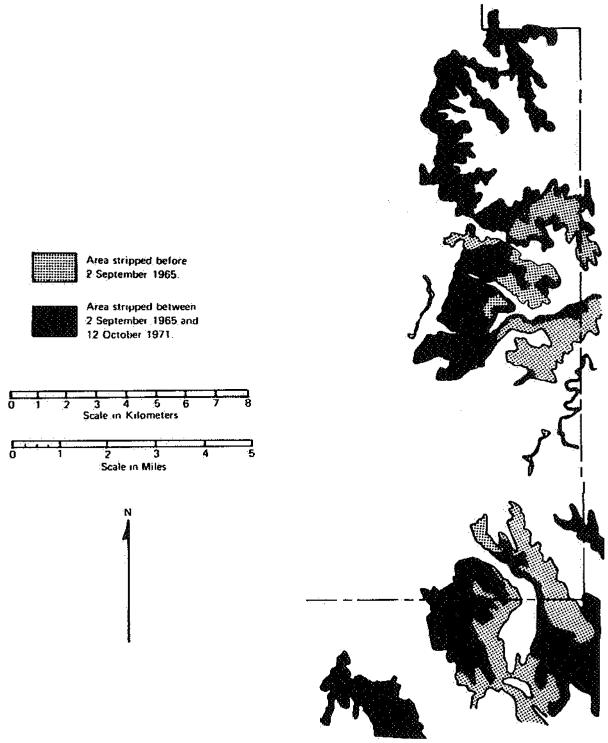


Figure 10. Map of strip mined area in southeastern Muskingum County.

Figure 11. Air view of the Ohio Power Company mining operation with Big Muskie dwarfing nearby cars. This machine is used to strip overburden above the coal seam.

techniques, a computer with a number of samples of ERTS measurements (training sets) for each target category of interest is provided. Once the numerical descriptions, which define the spectral characteristics of each target category, are determined, the operator executes the canonical analysis canonical coefficients. In a decision processing phase, the coefficients are used by the computer to form a linear combination of the ERTS measurements to produce a canonical variable whose amplitude is associated with the probability of an ERTS measurement being from the target that is sought. **A** set of canonical coefficients are derived for each target category of interest. In decision processing, the probability of an ERTS measurement arising from each of the different target categories of interest is computed for each ERTS spatial resolution element, and a decision based on these computations is reached. **If** all probabilities are below a threshold level specified by the operator, the computer is permitted to decide that the target viewed is unknown (an unclassified category).

Before producing decision data on a large amount of ERTS data, a number of tests are applied to evaluate the computer's capability of performing the desired target classification. The tests include generating scatter diagrams, generating classification accuracy tables, and

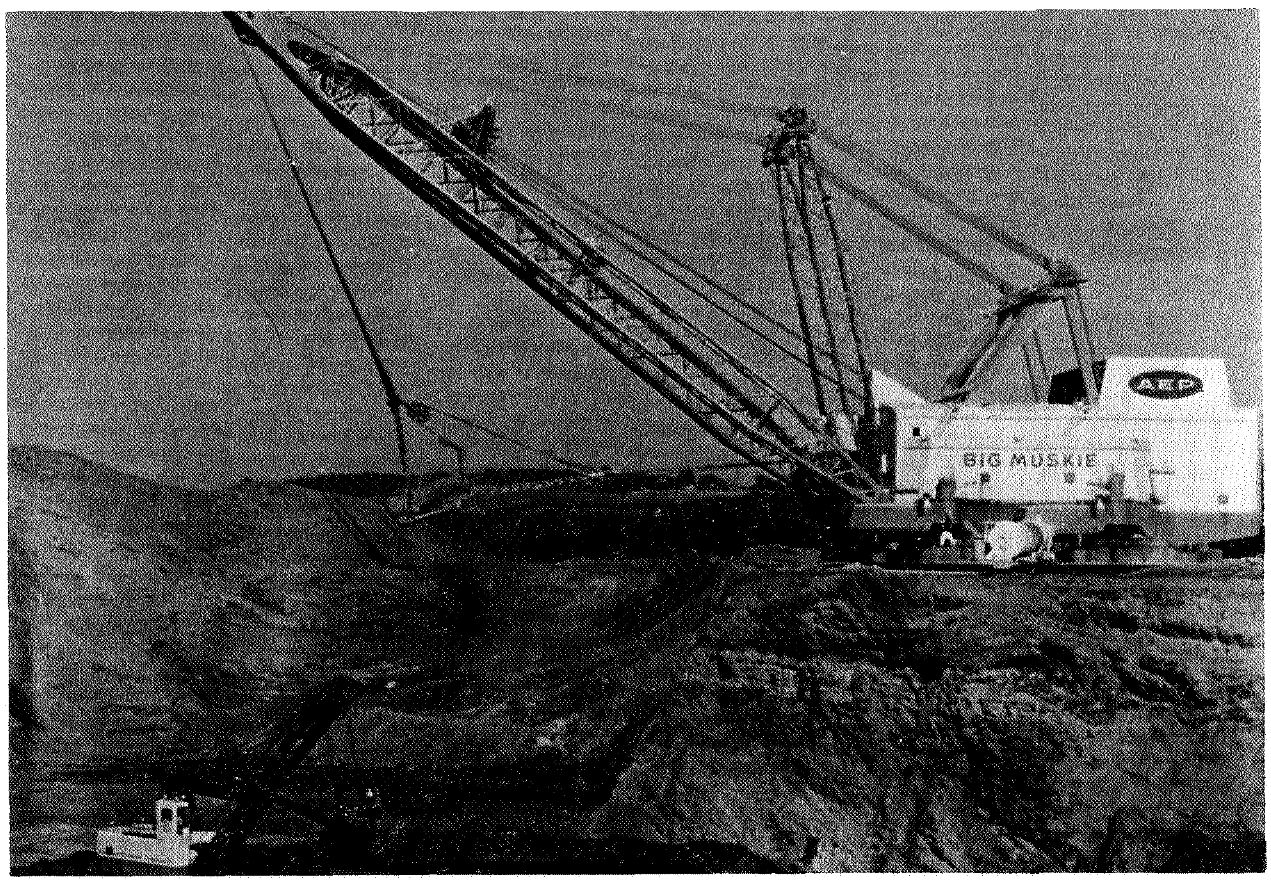
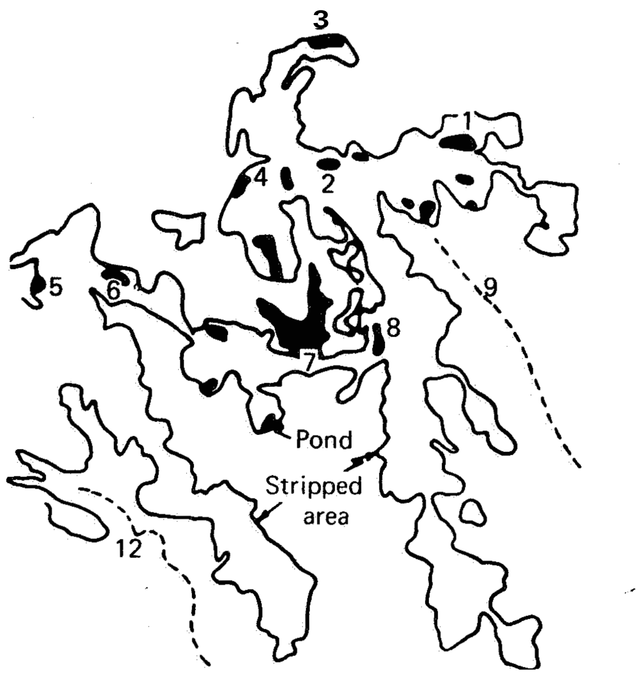


Figure 12. This giant earth-moving machine, Big Muskie, utilizes a dragline bucket that has a capacity of 220 cubic yards. **A** normal size machine in the foreground is used to strip and load the coal.

Figure 13. Area reclaimed under terms of the 1972 legislation. Stripped area graded to its original contour prier to planting.

Figure 14. Stripped area recently reclaimed by the Ohio Power Company.



Site
1. Pond, nonexistent
2. Pond, pH-9.7, conductance-750
3. Lake, nonexistent
4. Lake, nonexistent
5. Lake, nonexistent
6. Pond, pH-9.3, conductance-580
7. Lake, pH-8.9, conductance-600
8. Pond, pH-3.1, conductance-1900
9. Stream, pH-8.2, conductance-775
12. Stream, pH-8.5, conductance-700

Base from May 9, 1972 air photograph
Field check on August 9, 1973

Figure 15. Water quality and reclamation data for the northeastern part of the Ohio Power Company mine between May 9, 1972, and August **9,** 1973.

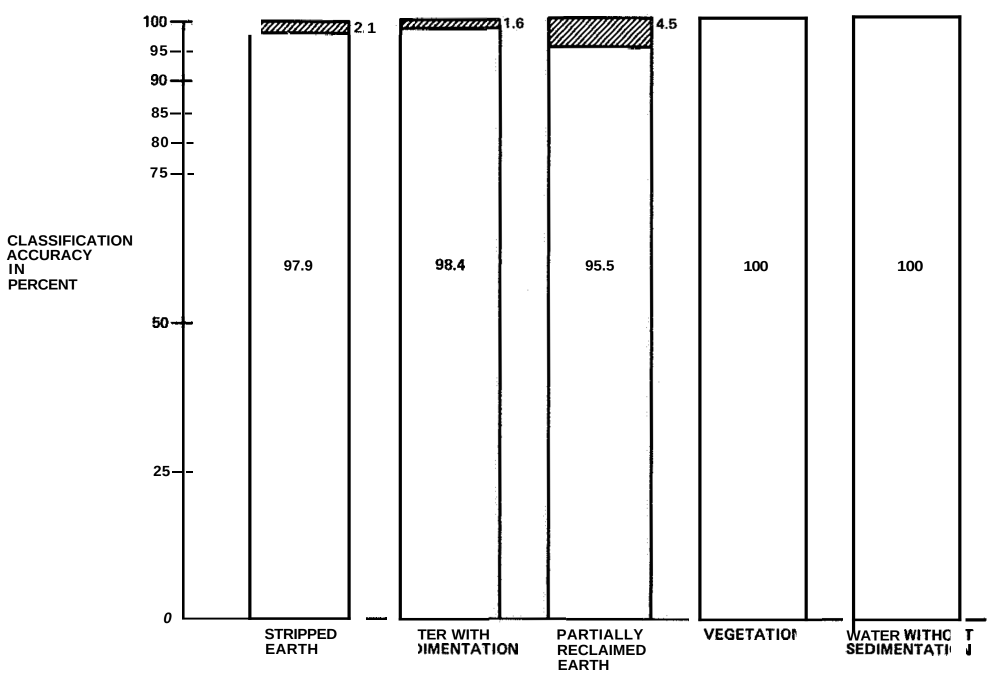


Figure **16.** Classification accuracy data for five categories using the August 21,1972, ERTS-1 CCT.

viewing the results of processed data on a TV monitor. In the test site, the classification accuracy was greater than 95 percent (Figure 16 and Table 1).

Table 1
Classification Accuracies for Five Categories
Using the August 21, 1972, ERTS-1 CCT

Classification Table October 12, 1973 10:11:59
Rejection Level = 0.100000
Percent

Training Set	0	1	2	3	4	5
				Percent Classified as Group		
1	0.000	97.872	0.000	2.128	0.000	0.000
2	0.000	1.587	98.413	0.000	0.000	0.000
3	0.000	4.545	0.000	95.455	0.000	0.000
4	0.000	0.000	0.000	0.000	100.000	0.000
5	0.000	0.000	0.000	0.000	0.000	100.000

Program Run Time = 00:00:21

Designation	Target
1	Stripped earth
2	Water with sedimentation
3	Partially reclaimed earth
4	Vegetation
5	Water without sedimentation

DECISION DATA PRODUCTS

Decision products developed for this investigation, using the August 21, 1972, ERTS-1 CCTs, include a printout table showing the area covered by each target category, decision imagery, and decision-map overlays. The target classifications include stripped earth and major areas of erosion, partially reclaimed earth and minor areas of erosion, vegetation, deep (or clear) water, shallow (or turbid) water, and unclassified areas. Decision imagery can be used to view the entire scene being examined, but it is geometrically-uncorrected. Although decision imagery is an intermediate product, it does demonstrate the high speed decision-making ability of the computer. Decision-map overlays are geometrically-corrected and will directly overlay a Universal Transverse Mercator (UTM) map coordinate system at any scale selected by the operator. The canonical coefficients defining each of the five categories was applied to process that portion of the CCTs covering the Ohio Power Company's surface mining operation. The first step in the decision processing resulted in a new or processed CCT, which contained a code for each spatial element designating it as one of the categories. From this processing Table 2 was generated, showing the area coverage of each category in terms of percent of total area processed, square kilometers, and acres.

Table 2
Area of Each of Five Categories in the
Study Area Based on the August 21, 1972,
ERTS-1 CCT

ERTS Processor October 15, 1973 09:01:32

ERTS Scene 10 - 1029-15361
Date of Scene - August 21, 1972
Center of Scene - N39-25/W081-00
Sun Coordinates - EL53°
AZ130°
Spacecraft Heading - 191°
Tape Number - 1
Starting Scan Line = 450
Ending Scan Line = 950

Category	Percent of Total	Acres	KM^2
Unclassified	4.47	20293.15	82.12
Stripped Earth	0.74	. 3343.62	13.53
Dirty Water	0.80	3610.80	14.61
Reclaimed Earth	· 3.95	17928.80	72.55
Vegetation	89.66	406771.91	1646.13
Clean Water	0.38	1704.79	6.90
Totals	100.00	453653.07.	1835.84

Program Run Time = 00:23:23

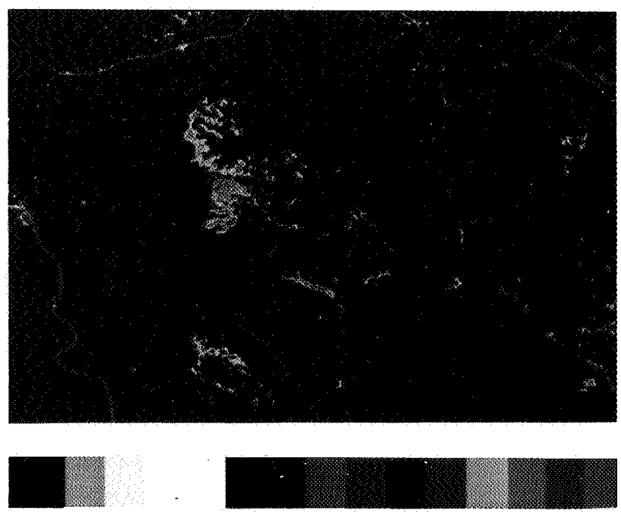
Notable on the list of categories shown are the two water and two disturbed-earth categories, Water without sediment includes deep or clear water such as that characteristic of shallow rivers and strip-mine-associated lakes. The two disturbed earth categories, stripped earth and partial reclamation, need little explanation except for some definition of partial reclamation. Partially reclaimed land may represent areas where reclamation, either natural or manmade, is proceeding very slowly, and usually less than 40 percent of the area is covered with vegetation. It may also represent recently mined areas where there has been a significant amount of spoil-bank grading, as well as planted sites where the vegetation may cover up to 100 percent of the area. Table **2** also shows that stripped earth makes up 0.74 percent of the total area processed or 13 square kilometers (3,344 acres). It can readily be seen that this type of data product could be especially valuable when a quantitative measure is needed for new stripping, to determine progress of reclamation, and to measure changes brought about by surface mining.

The tape produced for decision processing was also used to generate 70-millimeter imagery wherein each image shows only a specified category at a scale of 1:1,000,000. This imagery is geometrically (spatially) identical to the data on the decision CCT and on the CCT provided by **NASA** from which it was produced. Since the tape is from bulk processing, some geometrical errors exist and are carried over into the decision imagery. *Also,* the CCT data provided from the **NASA** bulk processing is not corrected for earth rotation; consequently, the decision imagery will not directly overlay a UTM map-coordinate system.

A method of recording all computer classifications onto a single image, each represented by a different color, was also evaluated. To accomplish this, three images representing the three primary colors (red, green, and blue) and containing all target classes in shades of gray are produced. Using an additive color process, a composite image in which each target class is assigned a distinctive color is created. An example of this process, showing a large portion (about 1750 square kilometers or 700 square miles) of Muskingum County and the Ohio Power Company's operations in that area, is shown in Figure 17.

To produce data that will directly relate to a map, a method for correcting the decision CCT for earth rotation and other geometric errors was developed. **A** second CCT, with these geometric corrections applied in a format suitable for driving a Gerber plotter, was recorded. This tape, when played back on the computer, causes a geometrically-corrected map of each target category to be drawn on a film at a scale specified to the computer by the investigator.

Classified Imagery from ERTS CCT
ERTS Scene 1029-15361
(21 August 1972)



Classifications:

Red	Stripped Earth and Major Sources of Erosion	Lt. Blue -	Shallow Water or Water with Sedimentation
Yellow	Partially Reclaimed Earth and Minor Sources of Erosion	Blue -	Deep Water or Water without Sedimentation
Green	Vegetation	Black -	Unclassified

Figure 17. Decision imagery representing a large part of the study area based on the August 21, 1972, ERTS-1 CCT.

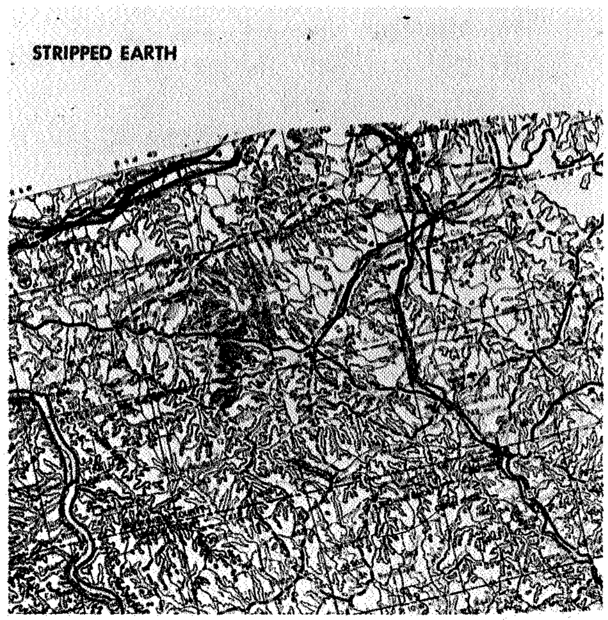


Figure 18. Overlay of computer-generated stripped earth category on a 1:250,000 scale base map.

Figure 19. Overlay of computer generated stripped earth and partial reclamation categories on a 1:250,000 scale base map.

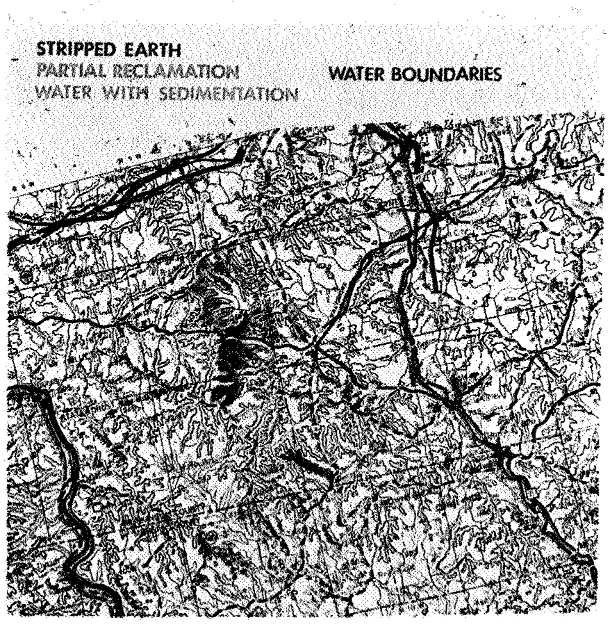


Figure 20. Overlay of computer-generated stripped earth, partial reclamation, water boundaries, and shallow or turbid water categories on a 1:250,000 scale base map.

Figure 21. Overlay of computer-generated stripped earth, partial reclamation, water boundaries, shallow or turbid water, and deep or clear water categories on a 1:250,000 scale base map.

The pen drawings were used to produce color-coded overlays for an Army Map Service (AMS) series map of the same scale. Figures 18 through 21 are photographs of computer-produced transparent maps from the Gerber plotter that overlay a 1:250,000 scale AMS map. The overlay technique was found to be particularly useful for updating base maps, and more importantly, for detecting and identifying changes; that is, change detection between the base maps and ERTS-1 data.

At this time, analyses of the accuracy of classifications have been confined largely to analyses of classification tables generated from data from the training areas. To be truly objective in analyzing accuracy, the final output products must also be evaluated with other areas not used in the computer training process. This was accomplished by comparing classification results with available maps, ground-survey data, and aerial photographs. Figures 8 and 9 are aerial photographs of the Ohio Power Company's strip mine operation, acquired by the NASA C-130 aircraft on September 7, 1973. By comparing Figures 8 and 9 and 18 through 21, it is evident that the target categories are classified correctly in nearly all cases. Especially noticeable is the accuracy with which small lakes, a product of the mining operation, were classified. A direct comparison between aerial photography (1973) and the stripped earth decision image plot (1972) of a part of the mine is shown in Figure 22. This illustration shows not only that there is close agreement between the two techniques, but also that there have been some significant changes in mining areas between August 21, 1972 and September 7, 1973. Thus far, this investigation has demonstrated the feasibility of using ERTS-1 CCTs for mapping and monitoring strip mining. The technique is rapid, accurate, and very inexpensive when compared to standard methods using aerial photographs and ground teams.

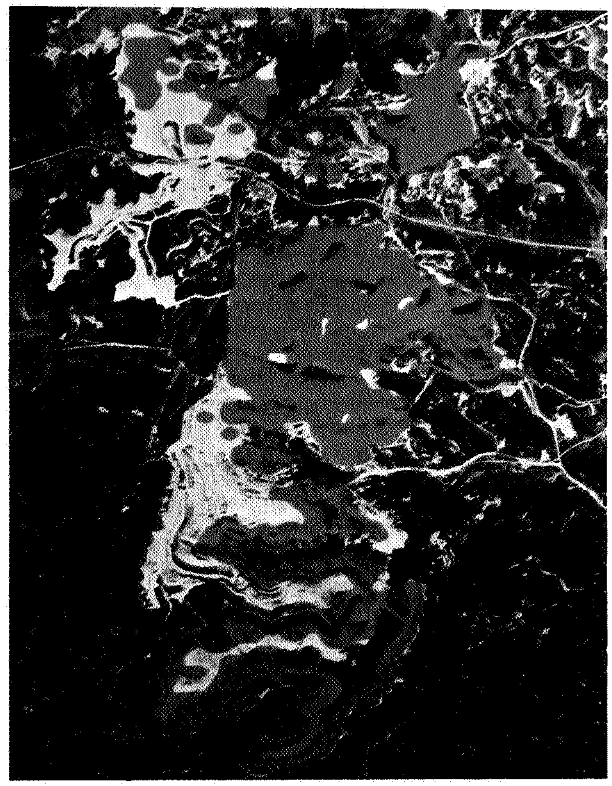


Figure 22. Overlay of stripped earth category (August 21, 1972) on aerial photographs of the southern part of the Ohio Power Company mine taken on September 7, 1973, by NASA C-130 aircraft.

COST COMPARISONS

Aerospace technology provides a ready and efficient means of monitoring strip mine operations that are so essential to the economy of Ohio and to the nation. At the same time it provides a technical base for decisions regarding environmental safeguards. Some months ago, the State of Ohio let a contract to map the eastern third of the state using aerial photography. The aerial photographic maps are to be used to develop, among other things, strip mine and reclamation maps. By using conventional techniques it will require many months or perhaps more than a year to adequately compile the information. Furthermore, the strip mine and reclamation maps will be outdated by the time they are available. The contract cost is approximately $240,000. By using ERTS data and computer processing, however, maps showing the same themes could be generated in a matter of days. From the results of this experiment, it is estimated that a comparable mapping project, including field work, computer processing, and report preparation would cost only one-tenth as much.

UTILITY OF ERTS FOR MONITORING THE BREEDING HABIT OF MIGRATORY WATERFOWL

Edgar W. Work, Jr.
Environmental Research Insitute of Michigan
*Ann **Arbor,** Michigan*

David S. Gilmer
A. T. Klett
Northern Prairie Wildlife Research Center
Jamestown, North Dakota

INTRODUCTION

The Bureau of Sport Fisheries and Wildlife (BSF&W) of the U. S. Department of the Interior is the government agency responsible for the coordinated management of migratory waterfowl in accordance with treaties with Canada, Mexico, and Japan. Figures 1 through 4 illustrate several of the waterfowl species and situations with which this paper is concerned.

Figure 1. A pair of canvasback (*Aythya valisineria*) ducks.

Approaches to the management of waterfowl populations are twofold: habitat management and preservation and population management, including the establishment and administration of hunting regulations. Management of habitat implies preservation through acquisition and lease arrangements, regulation of land use, and manipulation or treatment of certain features to enhance habitat quality. In this context, remote sensing offers a tool for monitoring changes in land. use habitat quality and for evaluating land areas for acquisition. On the other hand, management of populations by the administration of hunting regulations is a more direct approach, has a rapid impact, and occurs on an annual basis. In order to be effective, it requires a rapid assimilation of stochastic data.

Annual waterfowl hunting regulations are established to allow for a reasonable level of harvest by hunters while ensuring the survival of an adequate number of birds to sustain a viable breeding population the following year. In order to establish annual hunting regulations, the

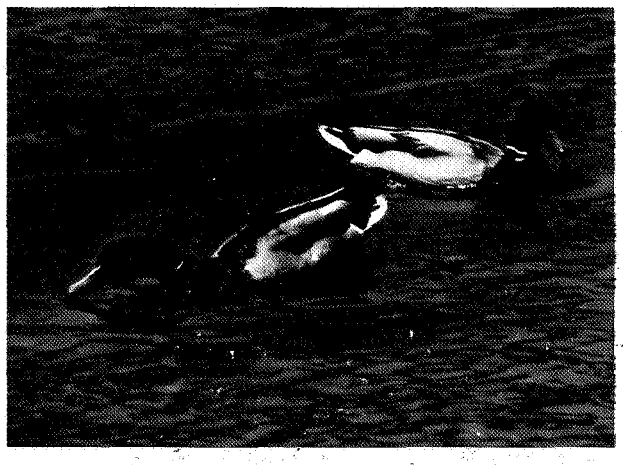


Figure 2. Two mallard drakes.

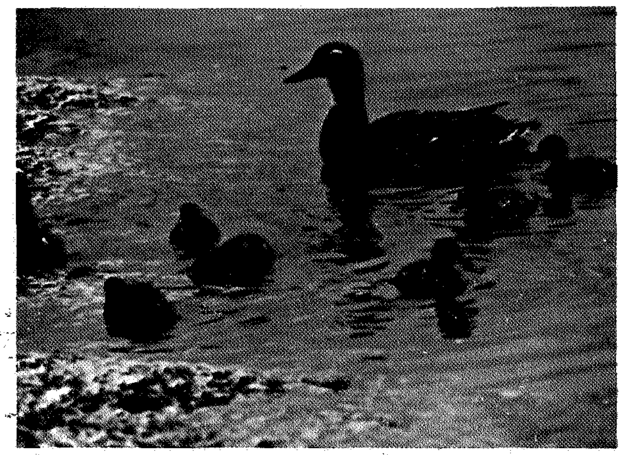


Figure 3. A mallard hen and her brood.

magnitude of the fall flight of birds must be predicted. Figure 5 indicates the stochastic data and sequence and timing of events utilized for this prediction. Note that aside from input data to this model, which are based on a direct count of individual ducks and broods, numbers and changes in numbers of ponds are considered. In particular, Crissey (1969) has emphasized that there is a significant correlation between the abundance of prairie water bodies and the subsequent size of the 'North American duck population. Note too that adjustments, based upon an ecological assessment of wetland abundance and quality and trends associated with long- and short-term land use, may be possible prior to regulation formulation.

Evaluations of aircraft remote sensing techniques for gathering waterfowl habitat information have been conducted (Burge and Brown, 1970; Nelson et al., 1971; Work and Thomson, in press). To date, the Bureau's ERTS investigation has been concerned with identifying and mapping prairie ponds and lakes (Work et al., 1973).

BREEDING POPULATION AND PRODUCTION SURVEYS

From Figure 5, it becomes apparent that estimating the fall flight of waterfowl is critically dependent upon appraisals of the magnitude of the breeding population and annual production of young. Of these two factors, changes in production influence the size of the fall flight more than do changes in breeding population (Crissey, 1957). Current waterfowl breeding ground surveys evolved from an experimental survey first conducted in 1947. Crissey (1957), Stewart et al. (1958), and more recently Henny et al. (1972), and Pospahala et al. (in preparation) discuss the operational aspects of the breeding ground surveys.

Average continental distribution of breeding and wintering ducks is illustrated in Figure 6. The wintering range is widespread, extending beyond the North American continent into parts of Central and South America. Most of the primary duck breeding habitat in North America is located in the southern portions of the prairie provinces and Northwestern Canada, the Dakotas, and parts of Alaska. Habitat conditions in these areas greatly influence the annual continental waterfowl population.

Figure 4. Waterfowl on a prairie wetland during migration.

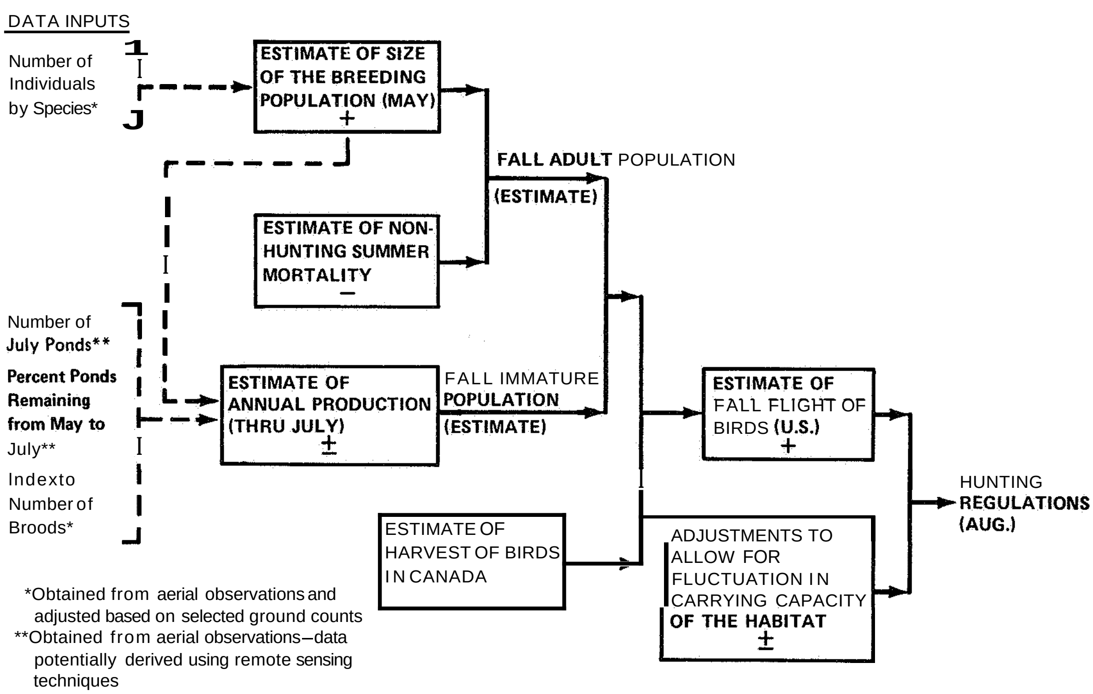


Figure 5. Determining hunting regulations based on the estimated magnitude of the fall flight of migratory waterfowl.

Estimates of waterfowl breeding population and production are obtained using a dual sampling approach. The first sample consists of a series of transects that are flown by light aircraft in May

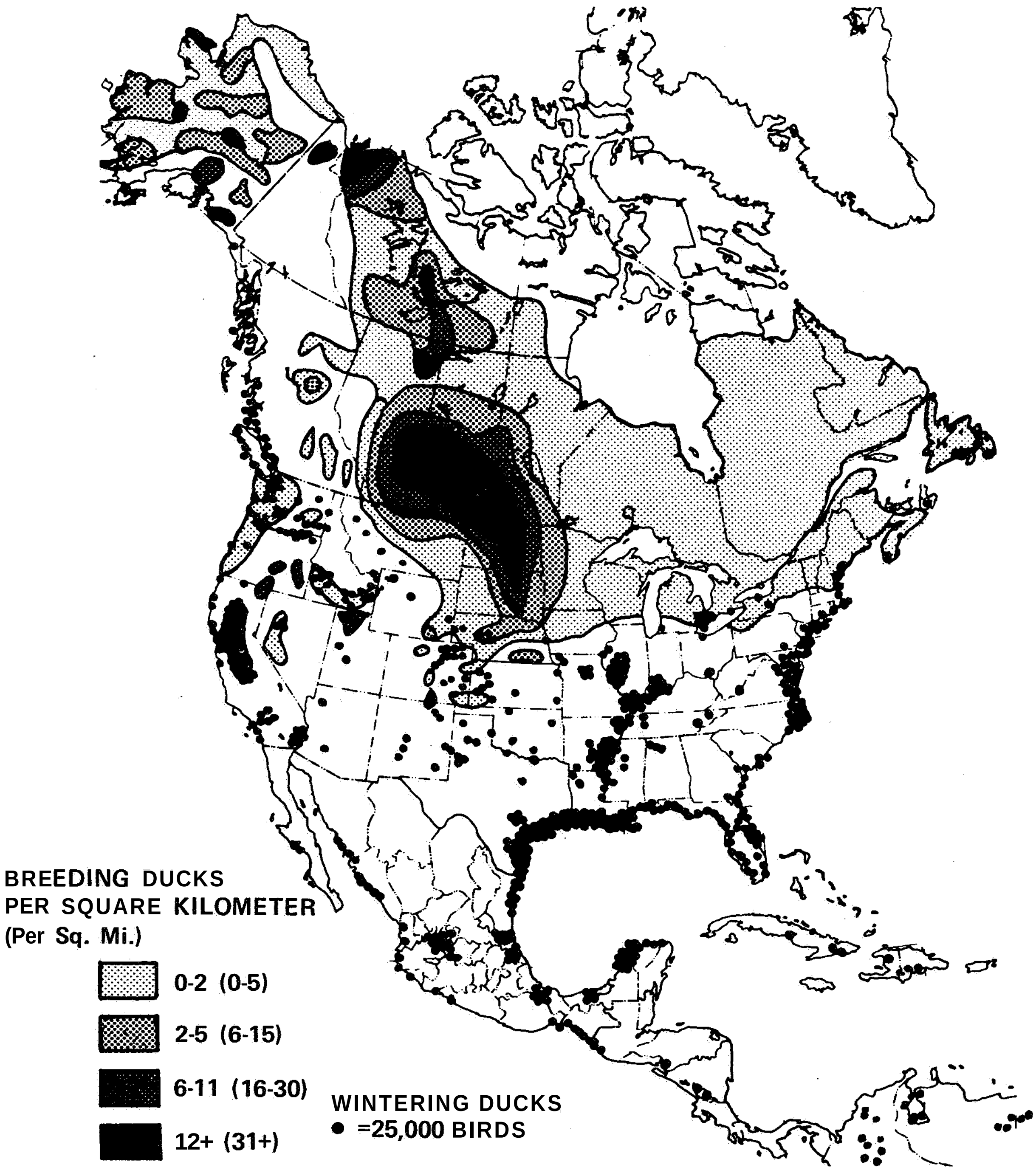


Figure 6. Average distribution of North American breeding and wintering ducks.

and July of each year. Sampling transects and strata are illustrated in Figure 7, Strata were delineated on the basis of expected waterfowl population density, habitat type, and expected variability of the estimates. Over **2.2** million square kilometers of the breeding range are sampled during each survey. Approximately 53,000 transect kilometers are flown at an altitude of 30 to 45 meters. The survey crew normally consists of a pilot and an observer. Together they count and, when possible, identify ducks by species over a 400-meter wide strip in May and a 200-meter wide strip in July. Ponds are counted over a 200-meter wide strip in both May and July (Henny et al., 1972, and Pospahala et al., in preparation). Each crew member records his count on a tape recorder and later the same day transcribes this information onto summary sheets.

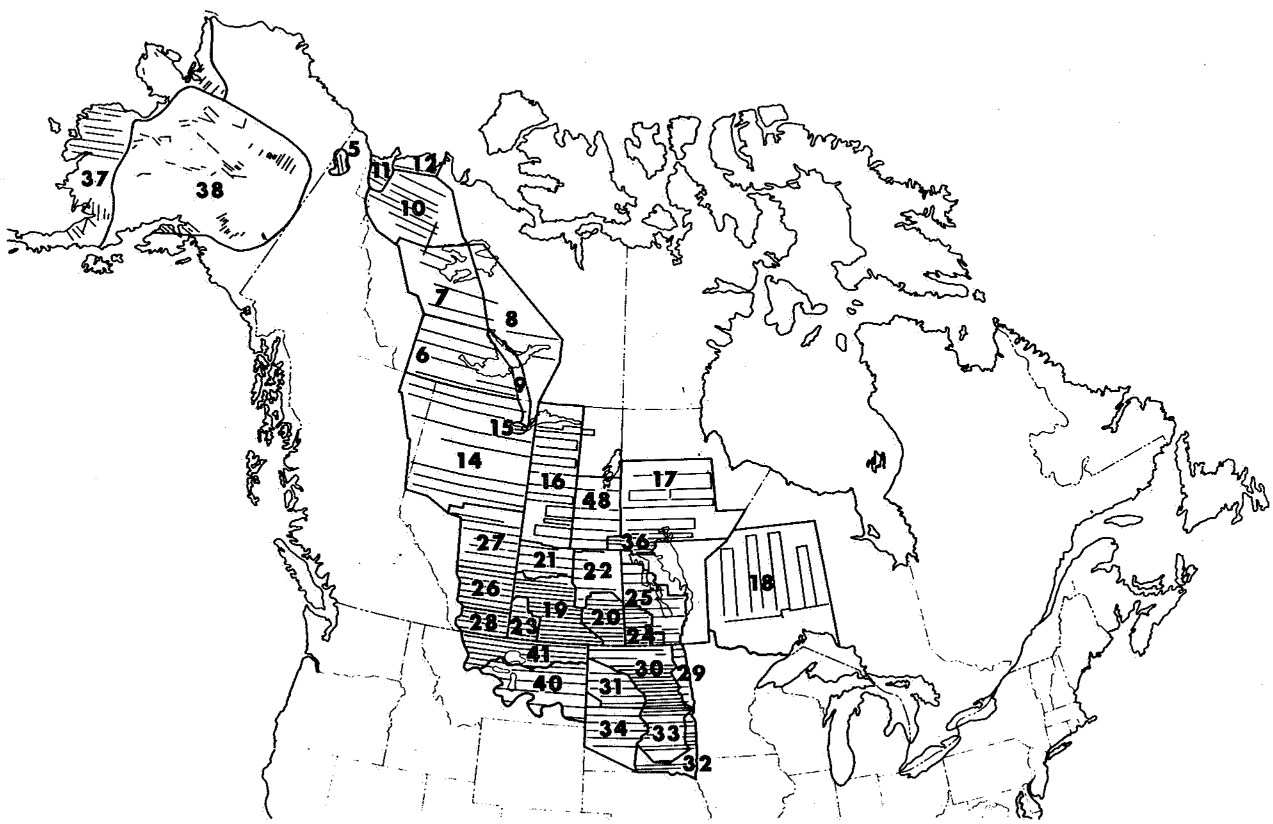


Figure 7. Transects and strata for aerial waterfowl breeding population and production surveys.

The second sample consists of certain air/ground transects that serve to adjust for biases encountered in the first sample (aerial survey). Specifically, these biases are a result of the inability of the aerial crew to see and count all birds present on the ground, to identify all birds with equal ability, and to identify and classify all wetlands. The results of the aerial survey plus appropriate corrections are converted to estimates of birds or broods per square mile and these numbers are then expanded according to the number of square miles in the sampling unit. The survey as carried out in May yields an estimate of the size of the breeding population. This population component must be reduced by a certain amount to account for normal summer mortality (predation, disease, and accidents) when estimating the fall flight (Geis et al., 1969).

PRODUCTION MODELS

In estimating the portion of the fall flight that is made up of the current year's production, additional analysis is required; Geis et al. (1969) described a mathematical model (shown below) for estimating mallard production. The mallard was chosen because: (a) It is the most abundant and widespread waterfowl species in North America and is nearly always killed in greater numbers than any other species (Anderson and Henny, 1972); (b) a large amount of ecological data is available for the species; and (c) populations of several other dabbling duck species are affected by many of the same factors as the mallard.

Example of a Model for Predicting
Annual Production of Young Mallards*

$$\hat{Y} = 7.926 + 1.468X_1 - 0.624X_2 - 0.028X_3 + 0.016X_4$$

where

$\hat{Y}$ = Predicted number of mallard young (millions)
X_1 = July ponds (millions)
X_2 = continental mallard breeding population (millions)
X_3 = percent of ponds remaining from May to July
X_4 = index to number of broods (thousands) unadjusted

The Geis et al. prediction model was developed from a multiple regression analysis based upon 13 years of data. Data from both the May and July surveys are utilized in this model. Referring to the sample prediction model, the quantities X_1 and X_3 potentially may be obtained using remote sensing techniques and automatic processing. X_2 can only be obtained from visual observations made during the May survey, while X_4 is derived from visual observations made in July. More recent analyses have indicated that it may be possible to redesign the model and eliminate use of the brood index (X_4) (D. R. Anderson, 1973). If this is possible, greater emphasis will be placed on the July pond count and this could be effectively accomplished using remote sensing techniques. Application of these techniques will improve the accuracy of pond counts, and other factors such as pond area and perimeter could be incorporated into a model, which might further improve production estimates. The July survey usually lasts until late in the month; however, the results of this survey must be available in early August for use in establishing hunting regulations. Automatic processing of remote sensing data is appropriate for ensuring rapid availability of survey information.

SURFACE WATER SURVEYS USING ERTS DATA

The current ERTS-1 Program conducted by the Bureau of Sport Fisheries and Wildlife in cooperation with the Environmental Research Institute of Michigan is concerned with mapping

*Geis, A. D., R. K. Martinson, and D. R. Anderson (1969).

surface water in May and July. Figure 8 illustrates a typical surface water condition found in the prairie pothole region of the Northern United States and Canada. The work in this type of situation has involved the adaptation to satellite data of techniques previously developed for use with aircraft scanner data. Because the launch date for the ERTS-1 satellite was delayed until mid-1972, it was necessary to defer the bulk of this investigation until a May and July sequence of data was available from the 1973 season. However, to test the feasibility of pond mapping by means of satellite data, July 1972 ERTS tapes were processed upon receipt (Work et al., 1973). **A** 1973 May and July sequence of data is presently being processed. This processing and the subsequent evaluation will complete the next phase of the study.

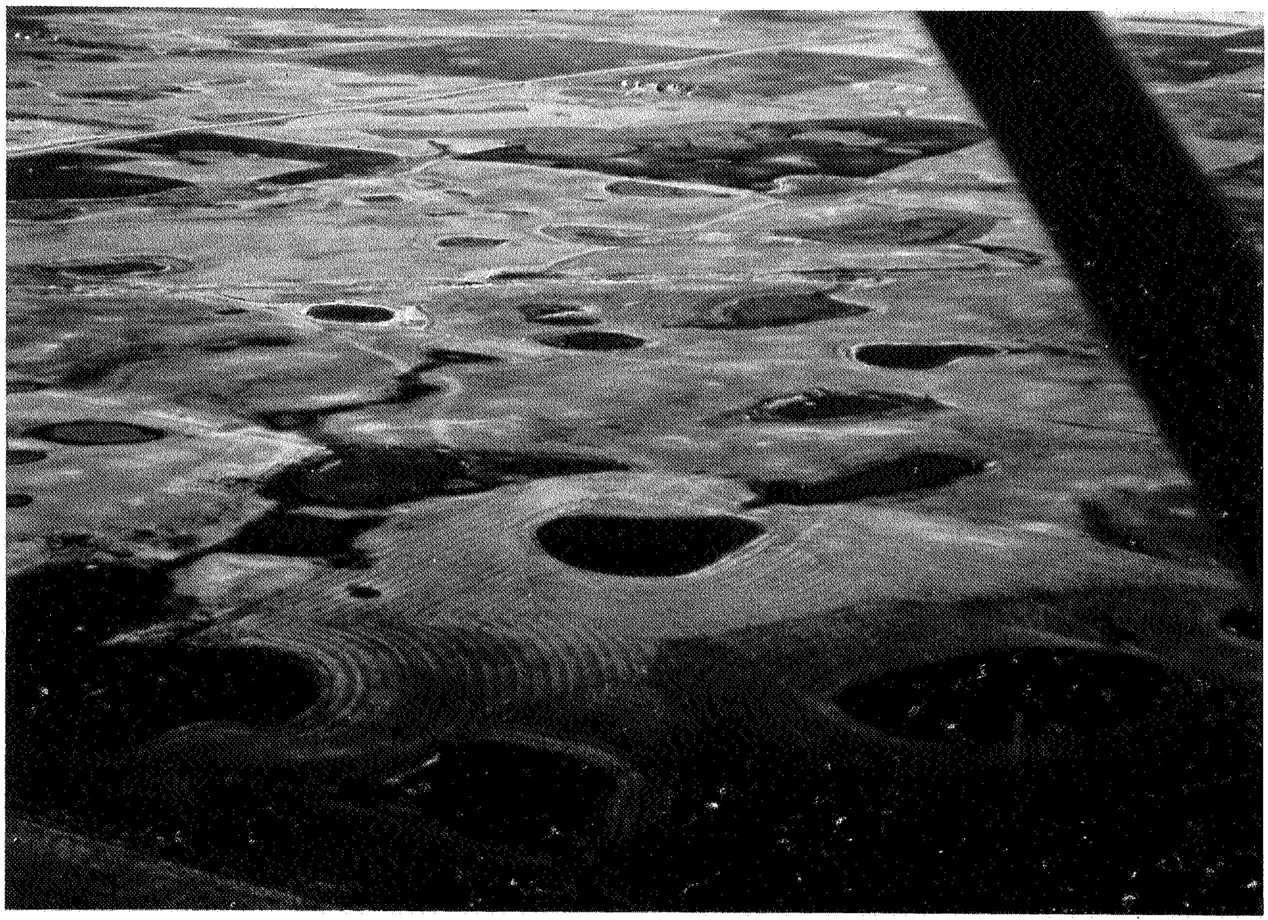


Figure **8.** Prairie wetlands such as these constitute a prime continental waterfowl breeding habitat.

A portion of the July 1972 surface water recognition map representing about 3 percent of an ERTS frame is shown in Figure 9. The area shown is located in central North Dakota and includes a portion of the Missouri Coteau region. The Coteau is a stagnation moraine area featuring many small ponds and lakes and a nonintegrated drainage system, which contains some of the best waterfowl breeding habitat in North America. The data presented in Figure 9 have been assembled from several computer output strips, each having the standard 132-column format. When generated with a general purpose computer, this type of information display is both time-consuming to assemble and unwieldly to handle if the scene is larger than a small fraction of an ERTS frame. For our purposes, the data has generally greater value if it is presented in terms of statistical tables. Figure 10 illustrates statistical tabulations for ponds and lakes for the ERTS scene illustrated in Figure 9. The upper table itemizes all ponds recognized in a portion of the scene and delineates the location of each pond based on a coordinate system using scan line and point numbers. The latitude and longitude of each water body is also listed. It is also possible to list (not illustrated) each pond's perimeter and a factor related to the complexity of its shape. **A** size frequency distribution of ponds in the entire scene is presented in the lower tabulation (Figure 10). With these types of listings, it is possible to obtain separate tabulations by strata.

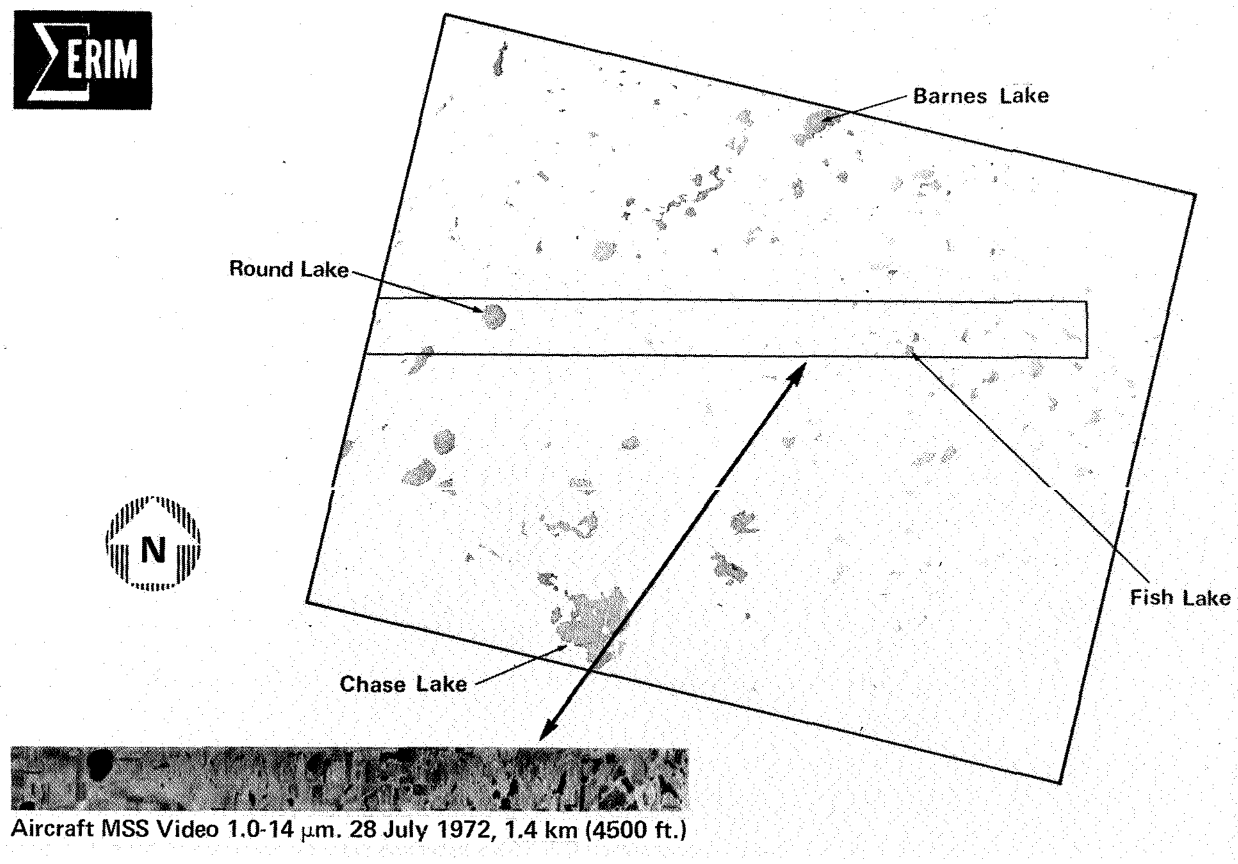


Figure 9. Digital water recognition map of approximately three percent of an ERTS frame.

SPATIAL RESOLUTION OF THE DATA

Figure 11 compares water recognition maps of ponds and several smaller lakes generated from both satellite and aircraft data. Using the aircraft data as a basis of comparison, it is apparent that the satellite data renders a reasonable facsimile of ponds in the size class of Big, Clark, and Fish Lakes. However, many of the smaller ponds are not recognized and other ponds and lakes are not accurately represented in areal extent. Because each ERTS pixel (picture element) is 79 by 57 meters or about 0.45 hectares (1.1 acres), water bodies in the less than

9,000-square-meter (0.9-hectare) range are recognized only conditionally. This resolution anomaly is partly a result of the sensor's line scanning and pixel sampling geometry and the random occurrence of surface water with respect to the sampled pixel.

31JUL72 C N47-17/WC99-27 N N47-17/WC99-25 1008-16594- SUN EL53 AZ134 193-C111-C-1-N-D-C-3-AS1 H ERIM (ERTS DATA)

SCENE NORTH DAKOTA LINES 1141 THRU 1540 POINTS 1 THRU 61C

SCENE AREA= 424 SQ. MI.
= 1099 SQ. KM.

PIXEL LENGTH= 75 METERS PIXEL WIDTH= 57 METERS

MODE= NORMAL
POINTS COUNTED IF VOLTAGE LIES BETWEEN .00 AND 9.10 VOLTS

TABULATION OF RECOGNIZED WATER BODIES

SCAN LINE	POINT	LAT	LONG	AREA (ACRES)	AREA (HECTARES)
1141	414	472 3Sh	99.197W	7.868	3.184
1141	451	47.233N	99.165W	1.115	.451
1141	463	412 334	99.160W	1.115	.451
1142	F4	47.279N	99.437W	5.618	2.274
1142	42c	41.234N	99.17CW	3.355	1.358
1144	41k	47.2 3th	99.194W	4.491	1.813
1144	412	47.228N	99.147W	1.115	.451
1145	329	47.241%	99.259W	37.114	15.02C
1145	4:t	47.233N	99.181W	2.240	.9C7
1146	55	47.279N	99.458W	1.115	.451
1141	359	47.2414	99.239W	3.356	1.358
1147	398	47.231%	99.2C9W	1.115	.451
1148	52	47.274N	99.433W	7.877	3 188
1148	45c	47.229N	99.172W	5.605	2.268
1149	341	47.243N	99.252W	46.075	18.647
115C	154	47.265N	99.388W	1.115	.451
115C	333	47.243N	99.258W	2.241	.907
115C	393	47.24CN	99.243W	5.608	2.210
1150	479	47.225N	99.152W	2.240	.9C6
1151	26C	47.251N	99.311W	1.115	.451
1151	351	47.234N	99.216W	1.115	.451
1152	52	47.276N	99.463W	1.115	.451
1154	11	47.28CN	99.453W	2.246	.909
1154	2 IC	47.248N	99.3C5W	14.504	5.91C
1154	435	47.227N	99.185W	4.470	1.809
1156	225	47.252N	99.338W	4.485	1.815
1156	3t5	47.234N	99.237W	3.367	1.363
1156	3EB	47.231N	99.221W	1.115	.451
1156	41C	47.229N	99.2C3W	2.241	.9C7
1157	3eC	47.235N	99.24CW	2.241	.907
1157	234	47.213N	99.114W	1.115	.451

31JUL72 C N47-17/WC99-27 N N47-17/WC99-25 1008-16594- SUN EL53 AZ134 193-C111-C-1-N-C-C-3-AS1 H ERIM (ERTS DATA)

SCENE NORTH DAKOTA LINES 1141 THRU 1540 POINTS 1 THRU 61

DISTRIBUTION OF LAKES IN THE SCENE BY AREA

AREA (ACRES)	ARC1 (HECTARES)	FRECUENCY
.25 TC .5C	.1C TC .2c	
.5C TC 1.CC	.2c TC .4C	
1.00 TO 2.CO	.4C TC .81	159
2.CC TC 3.CC	.81 TC 1.21	86
3.CC TO 4.CC	1.21 TC 1.62	4b
4.CC TO 6.CC	1.62 TC 2.43	4b
6.00 TO 8.CO	2.43 TC 3.24	36
8.CC TC 1C.CC	3.24 TC 4.C5	18
1C.CO TC 15.CC	4.C5 TC 6.07	31
15.CC TO 2C.CC	6.C7 TC 8.C9	18
2C.CO TC 25.CC	8.C9 TC 1C.12	12
25.CC TC 3C.CC	1C.12 TC 12.14	7
3C.CO TC 4C.CC	12.14 TC 16.19	16
4C.CC TC 5C.CC	16.19 TC 20.23	
5C.CO TO 75.CC	2C.23 TC 3C.35	
75.CC TC 1CC.CC	3C.35 TC 4C.47	
1CC.CO TC 15C.CC	4C.47 TC 6C.7C	--
15C.CC TO 2CC.CC	6C.7C TC 8C.94	4
OVER 2CC.CC	OVER 8C.94	9

Figure 10. Example of digital computer printout of pond and lake statistics for the vicinity of Woodworth, North Dakota, using ERTS-1 data collected at 1659 GMT on July 31,1972.

Figure 12 shows an example of boundary effect in the delineation of pond margins. The dashes represent pixels having low reflectance values that are not low enough to be classified as water. Some of these boundary elements may be attributed to marsh vegetation and/or mud flat margins; both of these exhibit low reflectance characteristics. These boundary elements probably also contain some water. This causes the acreage of ponds to be underestimated because, in the present binary selection, pixels are being classified as either totally water or not water.

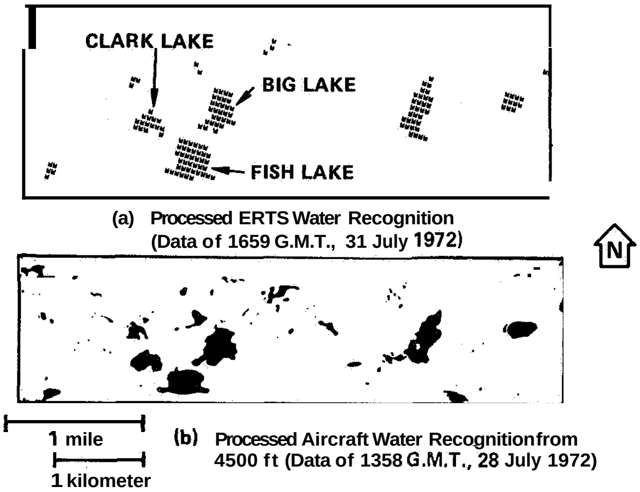


Figure 11. Comparison of details in ERTS-1 and aircraft recognition maps of ponds and lakes near Woodworth, North Dakota.

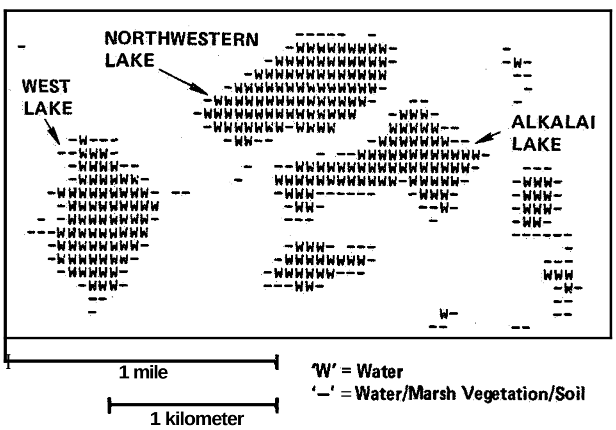
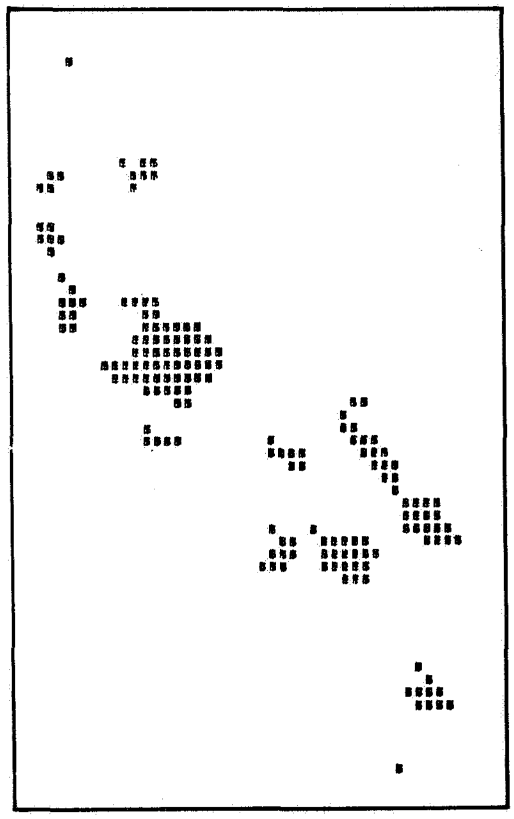


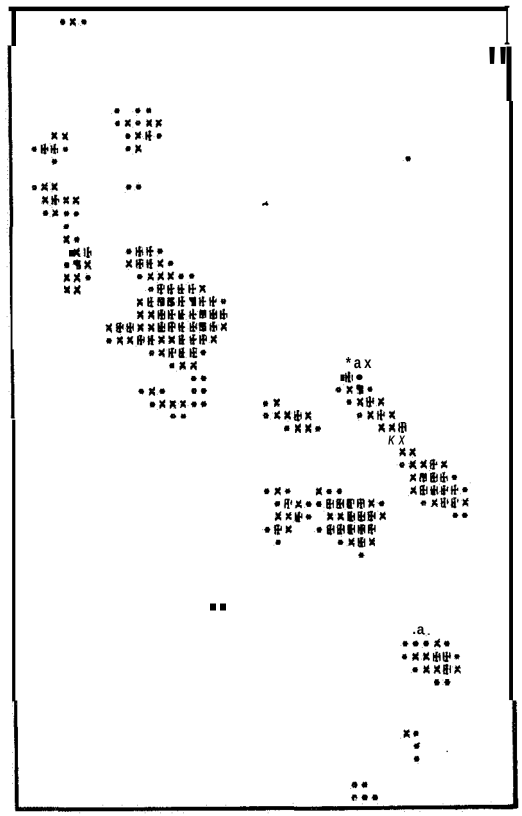
Figure 12. Example of boundary effect associated with recognition map of lakes near Woodworth, North Dakota, using ERTS-1 data collected at 1659 GMT on July 31, 1972.

Improvements in resolution would increase the accuracy of the analysis. In the primary waterfowl breeding range, a majority of the ponds are less than 4,000 square meters (1 acre) in size. Techniques exist that can detect or predict the existence of smaller ponds and improve the size estimates of larger ones. One technique has been proposed by Malila and Nalepka (1973), in which it is possible to estimate the proportion of materials contained in each pixel by taking advantage of the multispectral data-gathering capabilities of ERTS. This permits a more accurate determination of the area covered by each material. The technique has been termed "proportion estimation" and is basically a method for performing fractional-pixel recognition as contrasted to whole-pixel recognition. Figure 13 illustrates the application of the Malila-Nalepka technique to the delineation of lakes in a Michigan test area. Both whole-pixel recognition and proportion estimation recognition are shown. In the case of proportion estimation, the density of the recognition symbol is proportional to the amount of surface water in that pixel. For comparison of results, an aerial photo was used to determine the actual number of lakes and their cumulative area. The comparison indicates that proportion estimation has provided more accurate results than those available using the conventional whole pixel recognition. However, this improvement requires more complex processing and greater training time for the computer.

The joint use of satellite and aircraft data in a properly designed multistage sampling plan could improve the precision of pond number and area estimates. This approach can be used independently or in addition to the proportion estimation method. Multistage sampling would take advantage of the detailed information provided by aircraft sensors in conjunction with the synoptic and more economically obtained satellite data.



Map of Water Bodies Using Whole Pixel Recognition



Map of Water Bodies Using Fractional Pixel Recognition (Proportion Estimation)

	Whole Pixel Recognition	Fractional Pixel Recognition (Proportion Estimation)	Photo Interpretation
Number of Water Bodies Detected	13	18	19
Total Water Area (meters^2)	879,120	1,006,739	1,041,958

Figure **13.** Comparison of processing techniques for ERTS MSS data for Michigan lakes test area.

CONCLUSIONS

Waterfowl breeding-ground surveys conducted twice each year by the BSF&W extend over a vast region of the United States and Canada. Data from these surveys are used to estimate waterfowl production by means of a mathematical model. Counts of May and July ponds are some of the variables used in this model. Annual production estimates are used to predict fall flights of ducks. This information is then used for establishing waterfowl hunting regulations. Our work to date indicates that satellite remote sensing techniques hold considerable promise for the accurate and rapid assessment of waterfowl breeding habitat, especially changes in pond numbers and distribution. Development of an operational system utilizing satellite sensors as a primary source of data appears to be a realistic goal for the future.

REFERENCES

Anderson, D. R., and C. J. Henny, 1972, *Population Ecology of the Mallard: I. A Review of Previous Studies and the Distribution and Migration from Breeding Areas,* U. S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Resource Publication 105.

Anderson, D. R., private communication. October 29 and December 10, 1973. Migratory Bird and Habitat Research Laboratory, Bureau of Sport Fisheries and Wildlife, Laurel, Maryland.

Burge, W. G., and W. L. Brown, 1970, *A Study of Waterfowl Habitat in North Dakota Using Remote Sensing Techniques,* Willow Run Labs., Institute of Science and Technology, The University of Michigan, Ann Arbor, Technical Report No. 2771-7-F.

Crissey, W. F., 1957, "Forecasting Waterfowl Harvest by Flyways," Transcript of the North American Wildlife Conference, 22:256-268.

Crissey, W. F., 1969, *Prairie Potholes from a Continental Viewpoint,* Saskatoon Wetlands Seminar.,Canadian Wildlife Service Report Series, 6:161:171.

Geis, A. D., R. K. Martinson, and D. R. Anderson, 1969, "Establishing Hunting Regulations and Allowable Harvest of Mallards in the United States," *Journal of Wildlife Management,* 33(4) pp. 848-859.

Henny, C. J., D. R. Anderson, and R. S. Pospahala, 1972, *Aerial Surveys of Waterfowl Production in North America, **1955-1971**.* U. S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Special Scientific Report No. 160.

Malila, W. A., and R. J. Nalepka, 1973, "Advanced Processing and Information Extraction Techniques Applied to ERTS-1 MSS Data," (Proceedings of the Third ERTS Symposium, Washington, D. C., 1973).

Nelson, H. K., A. T. Klett, and W. G. Burge, 1970, "Monitoring Migratory Bird Habitat by Remote Sensing Methods," Transcript of the North American Wildlife and National Resources Conference No. 35, pp. 73-84.

Pospahala, R. S., A. R. Brazda, R. C. Hanson, G. H. Jensen, K. D. Norman, G. Pospichal, M. M. Smith, and J. F. Voelzer, (in preparation), *Aerial Surveys of Waterfowl Breeding Populations in North America, **1955-1973**,* U. S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Special Scientific Report.

Stewart, R. E., A. D. Geis, and C. E. Evans, 1958, "Distribution of Populations and Hunting Kill of the Canvasback," *Journal of Wildlife Management,* 22(4), pp. 333-370.

Work, E. A. Jr., D. S. Gilmer, and A. T. Klett, 1973, "Preliminary Evaluation of ERTS-1 for Determining Numbers and Distribution of Prairie Ponds and Lakes," (Proceedings of the

Symposium on Significant Results Obtained from ERTS-1, New Carrollton, Maryland, 1973. Volume I, Section A, pp. 801-808).

Work, E. A. Jr., and F. J. Thomson, (in press), *A Study of Waterfowl Habitat in North Dakota Using Remote Sensing Techniques: Phase II.* Environmental Research Institute of Michigan, Ann Arbor, Report No. 101000-12-F.

AGRICULTURE, FORESTRY, RANGE RESOURCES

Robert **B. MacDonald**
NASA, Johnson Space Center
Houston, Texas

Historically, man has improved his lot through the discovery and utilization of earth's resources. In this century, there is an increasing awareness that these resources are limited in extent and must be more efficiently'managed in the future. The recent food and energy shortages provide further evidence of this. To achieve efficient management, numerous government and private groups in the United States expend considerable effort and dollars to conduct extensive crop, forest, and range inventories, and to map soils. **As** international trade of agricultural products increase, as is currently happening, it becomes more essential to have timely information on how much is being produced, where it is being produced, and how production is changing with time on a global basis.

To put the many results of the ERTS investigations in agriculture, range, and forestry into perspective, they should be viewed in light of the important application objectives. In agriculture, the recognized objective of all nations is the production of adequate quantities of food and fiber to feed and supply the people of the nation and to permit favorable international trade arrangements. In this country, more food is being exported than ever. The agri-business industry continues to be one of the largest in the country. Probably the most important information to the various elements of agriculture are current and accurate crop production measurements. Such information is expensive to acquire and generally takes longer to collect than is desirable.

A key application of ERTS then promises to be the production inventorying of major agricultural crop types. Up to the present time, agricultural inventories such as those performed in the United States by the Statistical Reporting Service of the U. *S*. Department of Agriculture require considerable effort on the part of the on-the-ground enumerators and have presented a formidable data compilation task. Now satellite remote-sensing systems such as ERTS-1, which image 25,000 square kilometers (10,000 square miles) per frame in a fraction of a second in four different frequency bands and provide repetitive global coverage every 18 days, can do much to complement conventional inventorying systems at the national level and also provide a means for conducting global inventories of major crop types in a timely manner. The repetitive coverage at the same time of day, the relatively uniform solar illumination over the large area covered by one ERTS frame, and the lack of obliquity angle effects due to the narrow view angle of the ERTS sensors are several of the important factors which tend to simplify the task of analyzing ERTS data relative to experience with aircraft data. In agriculture, forestry, and range, the necessary elements to perform global inventories are fast being brought together—the satellite, the sensors, the computers, the mathematics, and the phenomenological understanding.

There is a definite need for the type of information that the Statistical Reporting Service provides on a national basis for major crop types on a global basis. Certainly ERTS provides a means to do this. Crop acreage, an important factor in production, can be obtained for major crops over very large areas. Investigators at the Laboratory for Applications of Remote Sensing at Purdue, the Center for Remote Sensing Research at the University of California at Berkeley, the Earth Observations Division of NASA/Houston, the Space Technology Labs at the University of Kansas, and others have clearly demonstrated the capability to identify major crops and measure their acreage over relatively large areas.

For example, Dr. Baumgardner at the Laboratory for Applications of Remote Sensing at Purdue University identified wheat over Greeley County, Kansas, with a 97-percent accuracy, using one pass of ERTS data from June 19, 1973 (Table 1). He estimated the total wheat acreage to be 750 square kilometers (189,000 acres). According to the Statistical Reporting Service, the official estimate for Greeley County was 700 square kilometers (180,000 acres) plus or minus 5 percent, indicating good agreement between the two estimates. Dr. Draeger, at the Center for Remote Sensing in California, demonstrated a capability to utilize ERTS data to measure crop acreage with accuracies approaching 90 percent. Mr. Erb, of the Earth Observations Division of NASA/Houston, in cooperation with the U. S. Department of Agriculture, identified crop types over **six** different parts of the United States (Figure 1). With single-pass data, he obtained accuracies in the 75- to 85-percent range. Using multipass data he was able to identify corn in Nebraska and wheat in Montana to better than 90 percent. Figures 2 and **3** show some of the results of Mr. Erb's work. Table 2 summarizes the results of this one-pass and two-pass data. Note that the identification of corn, popcorn, and sunflowers with temporal data is between 95 and 99 percent. Figure 4 illustrates the rather dramatic improvement that can be achieved by using multitemporal data to identify small grains, wheat in particular. The accuracies of identifying wheat increase correspondingly with additional data sets over time, and the confusion with barley decreased with this increased information.

Table 1
Classification Results – Greeley County, Kansas
ERTS-1 Data, 19 June 1973

Class	Percent Correct Recognition of Tested Fields*
Pasture	96.1
Wheat	97.0
Fallow	97.9

*From underflight photos and limited ground information

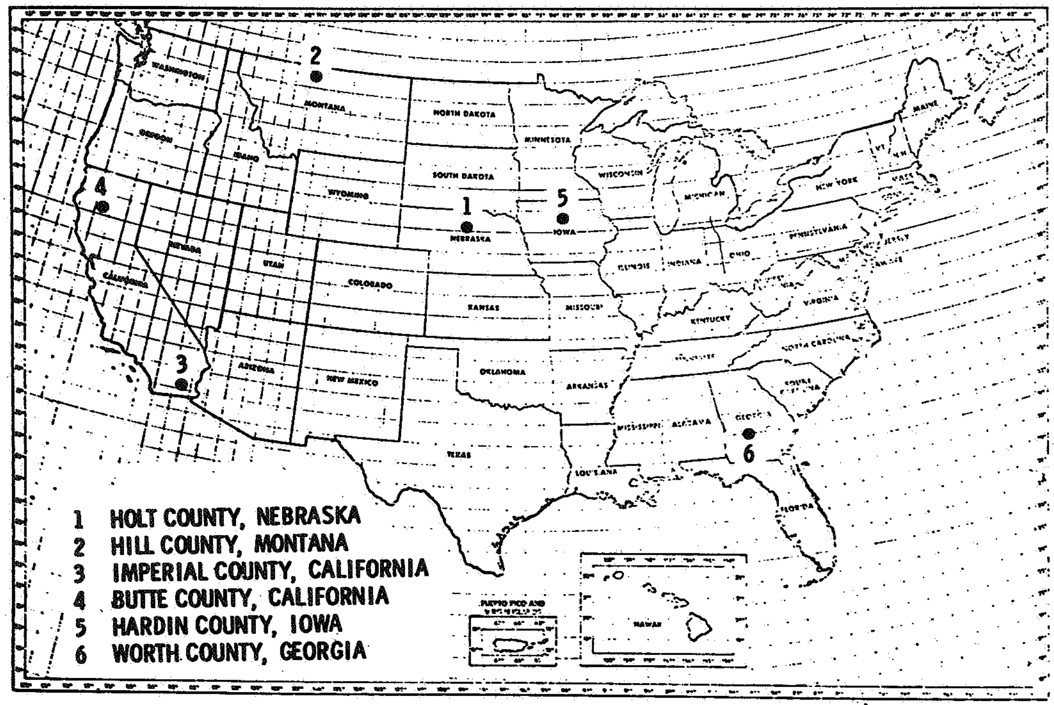


Figure 1. ERTS-1 ASCS test counties.

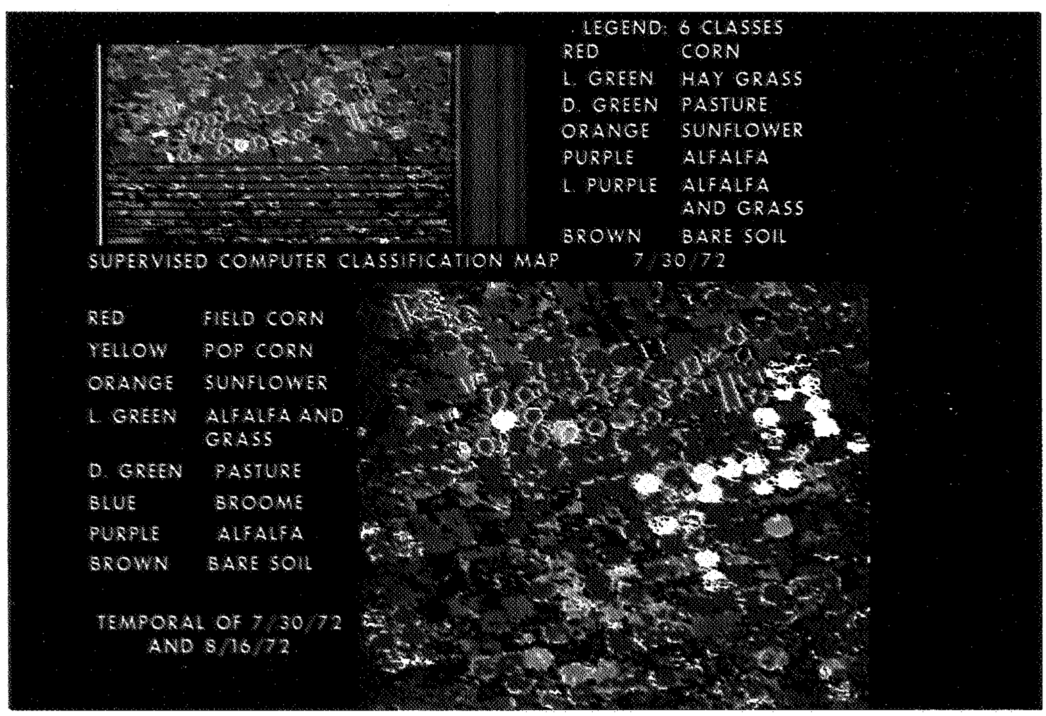


Figure 2. computer classification display of Holt County, **Nebraska, test area using single-pass and two-pass data. Note that corn, popcorn, and sunflowers were separable on the two-pass data. Classification accuracies are** shown **at bottom of Table 2.**

Table 2
Agriculture–Results
Identification (Classification)

Feature	Method	Percent Performance
• Small Grains, Grain Stubble	Image Interpretation (Single Data Set)	33-59
• Sod		91
• Summer Fallow		88
• Small Grains	Supervised ADP (Single Data Set)	96
• Sod		90
• Summer Fallow		87
• Wheat, Barley		65-88
• Truck Farming Crops		78
• Corn Fields	Supervised ADP (Single Data Set)	73 of 76 Fields
• Corn, Popcorn, Sunflowers	Supervised ADP (Registered Set of Two Passes)	95-99

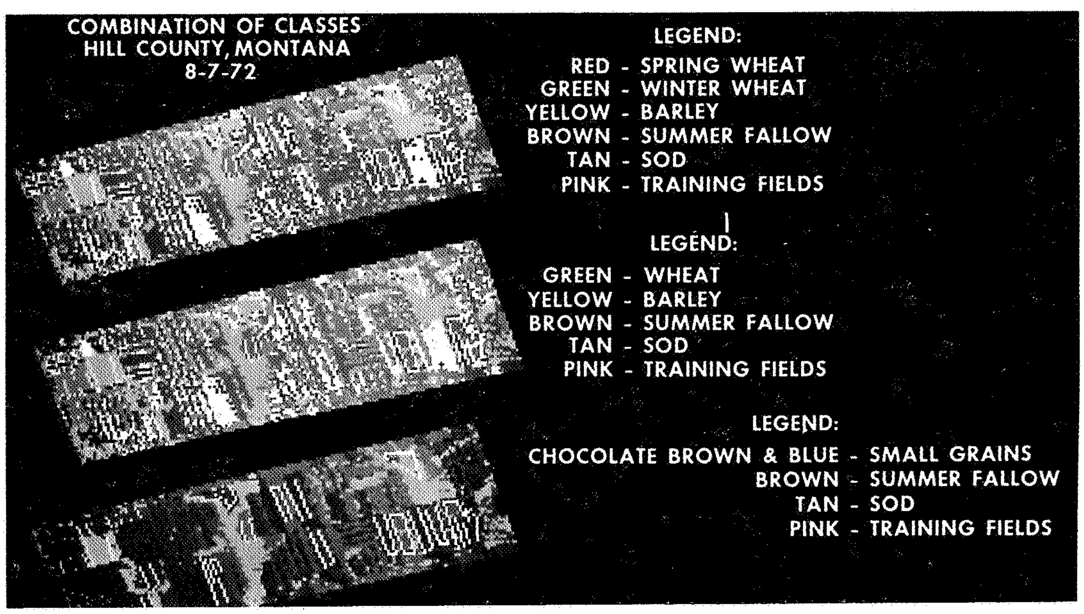


Figure 3. Computer classification display of test area in Hill County, Montana. Classification accuracies are shown in center portion of Table 2.

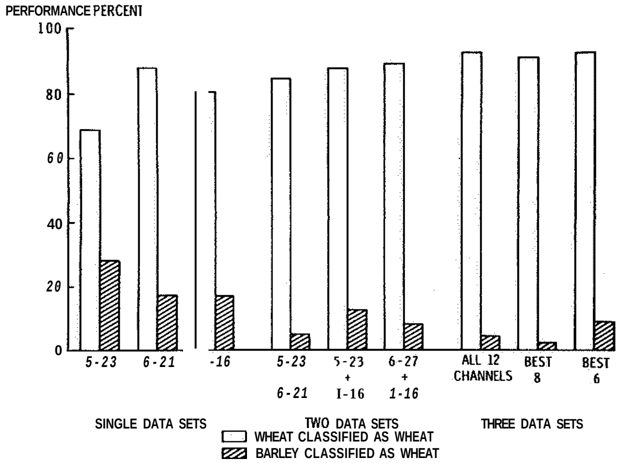


Figure **4.** A comparison of classification results from single and multipass data.

Figure 5 is a mosaic of southwest Kansas. Dr. Morain, University of Kansas, identified wheat acreage over a ten-county area in southwest Kansas to an accuracy of 99 percent in the area shown here. Professor Yassoglou of the Athens faculty in Greece achieved identification accuracies on the order of 90 percent over Grecian wheat fields of 200,000 to 400,000 square meters (50 to 100 acres). However, investigators did experience poorer performance when they attempted to identify and measure crop acreages in fields smaller than 80,000 square meters (20 acres).

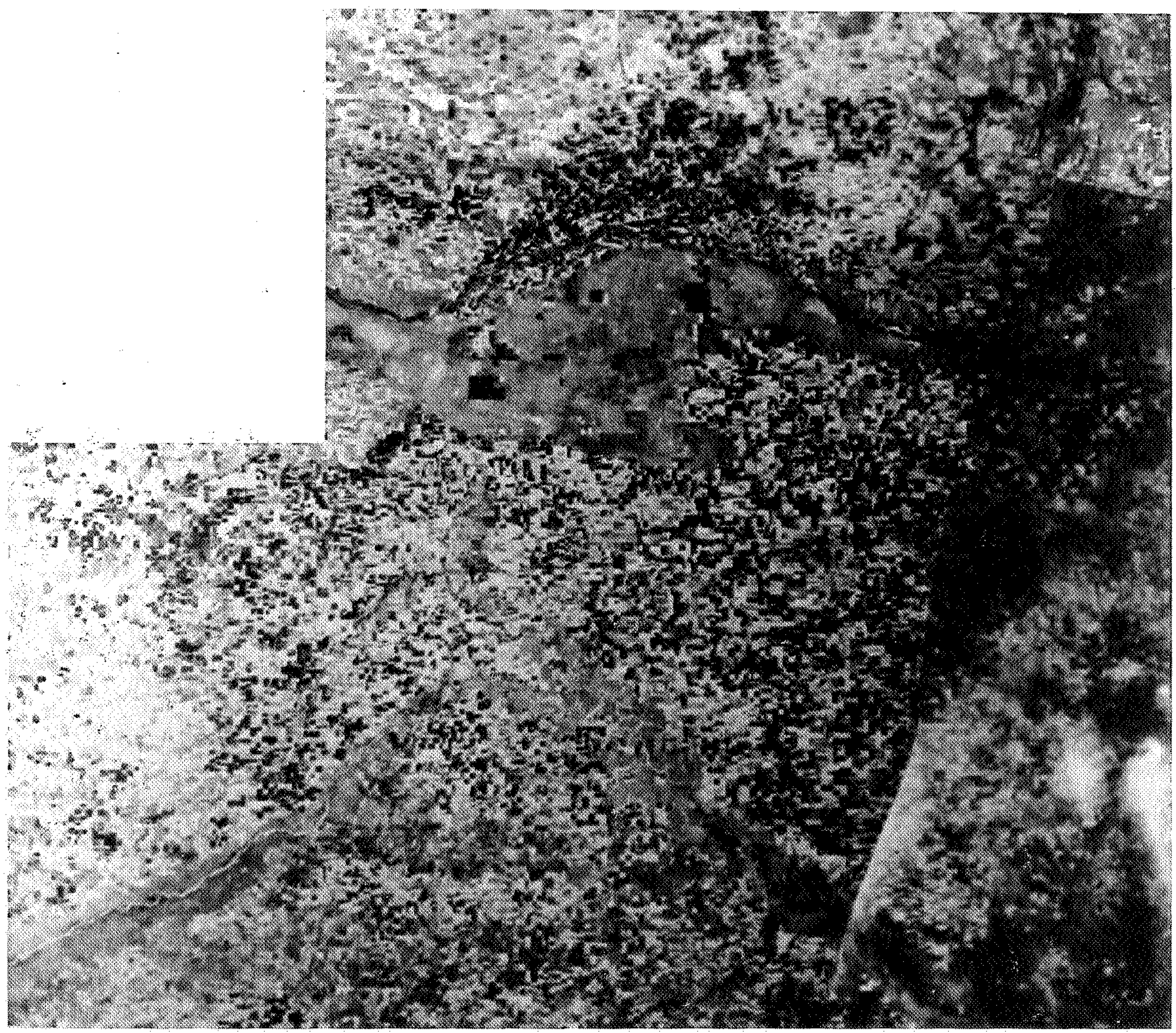


Figure **5.** ERTS mosaic of southwest Kansas wheat survey area.

Considering the yield factor, the two largest variables affecting wheat yield are total available moisture and temperature. Dr. Morain used a model for estimating wheat yield based on moisture and temperature and was able to estimate production in March that was within one-half percent of the official Statistical Reporting Service August Report for that ten-county area.

The imaginative use of data acquired by meteorological satellites, together with crop acreage information such as has been provided by ERTS, promises a means of estimating crop production over large areas in a cost effective and timely manner. Some precursory work has been done to examine the kind of data loads involved in this type of estimating, using sound statistical sampling strategies together with new technology. These studies have shown the data loads to be manageable.

In the area of range applications, the efficient utilization of rangeland for the production of beef is directly related to range management decisions, which in turn are based on knowledge of rangeland conditions at the specific time in question. Currently, only gross information based on climatology reports and limited observations are available to determine range conditions. The beef industry of the Great Plains produces 40 percent of the nation’s beef, a $23 billion operation, which is extremely vulnerable to adverse seasonal or climatic conditions. The beef output of this area is contingent on the decisions made by the farm and ranch owners of the region. Again, timely information on regional range-forage conditions is required to support sound management decisions. An important indicator of rangeland forage conditions is the biomass content. It has been found that the multitemporal data acquired by ERTS is able to provide a measure of this important indicator. Investigators from the Bureau of Land Management, the University of Nebraska, and the Remote Sensing Center at Texas A&M have shown that good estimates of biomass content can be achieved by utilizing ERTS data.

Dr. Rouse, of Texas A&M, working in collaboration with other investigators in the corridor shown in Figure 6, found that radiance measurements in the visible red and reflective infrared bands were correlated at the 93-percent level with above-ground green biomass and vegetative moisture content. (See following band-to-band ratio analysis developed for the measurement of biomass in terms of the Transformed Vegetative Index in the Great Plains Corridor). Approximately 680,000 square kilometers (170 million acres) of U. S. Western rangeland are managed by the Bureau of Land Management, of which one range manager is responsible for approximately 2,800 square kilometers (700,000 acres). Mr. Bentley, of the Bureau of Land Management, established a procedure to visually analyze color-enhanced ERTS imagery and to map broad vegetative communities and broad classes of annual forage production in the arid Southwest. Figure 7 shows the type of data that he was working with. Here again, it is extremely important in all of these approaches to have the temporal measurements taken during the critical times of the range growth cycle.

ERTS is providing a means of acquiring information critical to efficient management of rangelands that previously has been too costly to acquire, and hence has been unavailable. It was reported that in order to be useful in an operational fashion, ERTS data must be in the hands of the range manager within a week to ten days, rather than the six to eight weeks it now takes. There should be no problem in alleviating this problem once the need is established.

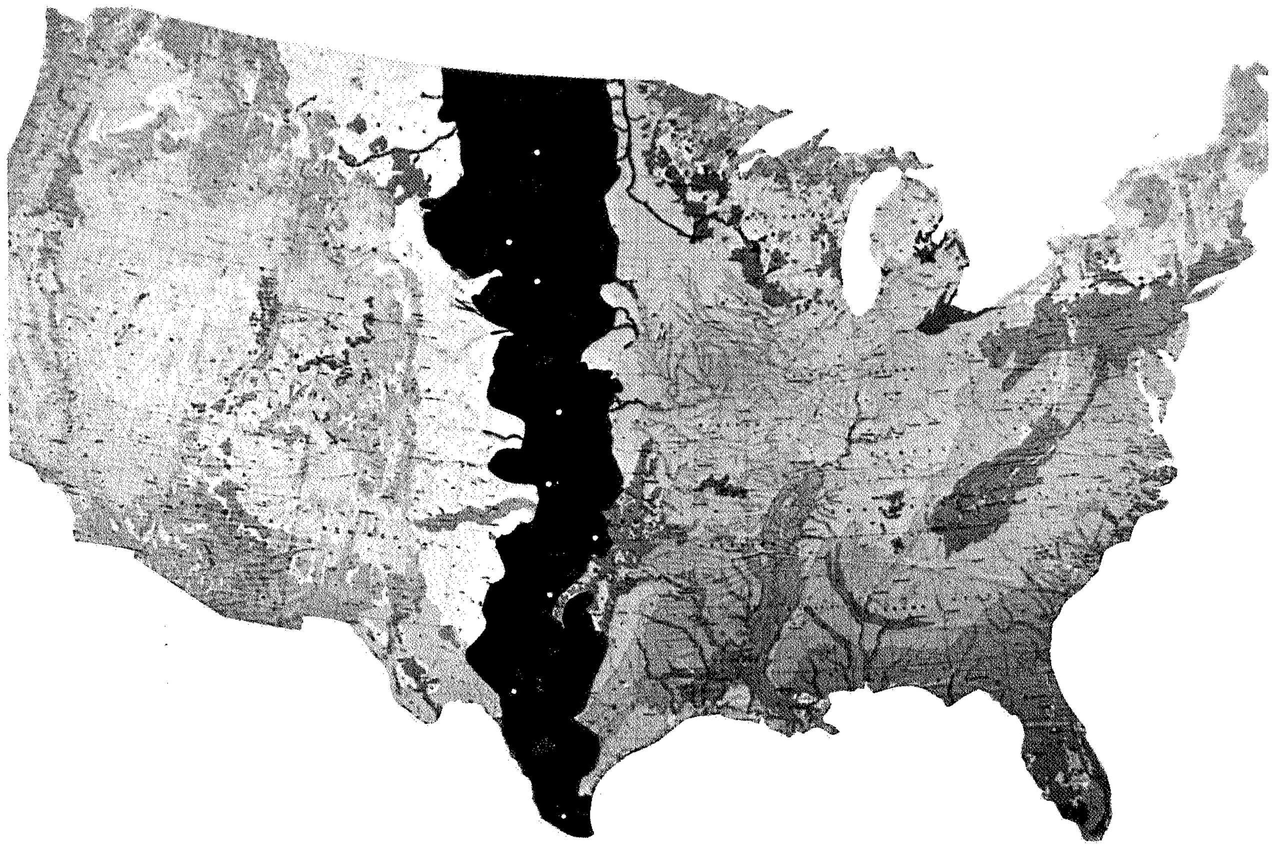


Figure 6. Great Plains Corridor and test site network.

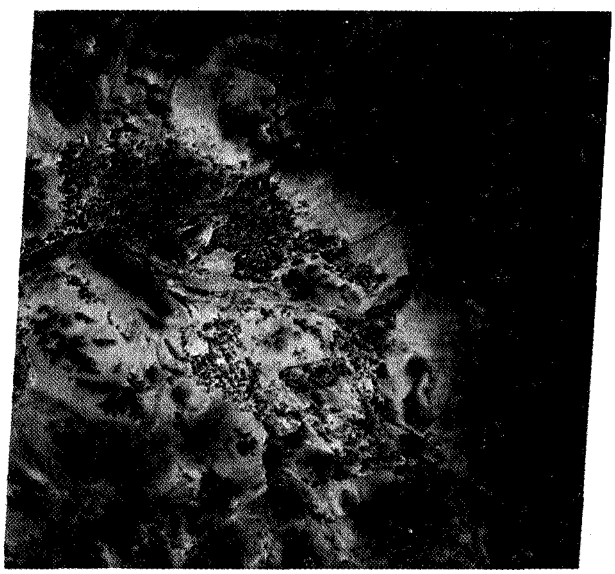


Figure 7. ERTS-1 color composite of arid rangelands surrounding the irrigated croplands in the Phoenix, Arizona, area.

Great Plains Corridor Project
Band-To-Band Ratio Analysis
ERTS-1 **MSS** Data

Vegetation Index (R)	Transformed Vegetation Index (TVI)
$R = \frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$	$TVI = \sqrt{R + 0.5}$

In the management of wildland resources, one of the primary tasks of forest managers is the determination of timber volume. In-place mapping of timber volumes by district over a forest provides critical information to the forest manager. Data from ERTS, remote sensing **aircraft,** ground acquisition, computers, and mathematical models have been combined by University of California investigators to develop an approach that offers a cheaper and faster method of inventorying standing timber volume. In addition, the approach results in decreasing costs per unit surveyed as larger areas are..inventoried. Mr. Nicholas at the Center for Remote Sensing Research at the University of California at Berkeley developed and demonstrated this approach for a ranger district in the Plumas National Forest. The estimate for the true volume of timber was 5 million cubic meters (2.44 billion board feet) with a sampling error of 8.2 percent. Costs per square kilometer for this procedure were $2.70 (1.1 cents per acre) as compared to the cost of approximately $6.20 per square kilometer (25 cents per acre) for an inventory utilizing conventional techniques. The projected costs of an inventory of the entire Plumas National Forest using this method would be approximately $15,000 and take 5 months to complete. In comparison, a conventional inventory of this same forest in 1970 cost $300,000 and took 2 years.

While the procedure based on the use of ERTS data needs to be further tested in different regions and over larger areas, there is every reason to believe it will prove successful. Essentially, in this approach a sampling design was developed that required timber volume estimates to be made from ERTS over the entire area, from photography collected by aircraft over a fraction of the area, and from ground measurements over an extremely small fraction of that sample by the aircraft. The procedure brings together the use of ERTS and conventional acquisition practices to produce timber volume inventory that is more timely, accurate, and cheaper than could be accomplished without ERTS data.

One of man's most precious resources is the soil. In order to conserve and utilize this resource to its fullest capability, soil maps ranging in scales from 1:15,840 to 1:7,000,000 are generated and used for such things as irrigation and drainage planning, forest management, crop yield estimates, farm appraisals, and land use planning, to name a few. Therefore, it is understandable that considerable effort is expended within this country and worldwide to develop current and accurate soils maps with varying degrees of detail. Some 40 years ago, aerial photography provided an increase in our capability to map soils. The capability of ERTS to image a 32,000-square-kilometer (8-million-acre) scene in one frame allows comparisons of soil associations over their entire extent, all at the same instant in time and growth and with all features in proportion, thus providing an increased soil mapping capability. The availability of four spectral bands and repetitive coverage makes subtle differences readily apparent and allows vegetative differences (which are usually a function of varying abilities of the different soil associations to produce vegetation) to be used effectively to help separate soil associations landscapes. Soil association maps which are geographic associations of one or several soils are usually published at scales of 1:500,000 to 1:1,000,000. These maps are very valuable in land use planning and are a very important step toward more detailed soil surveys which require soil profiles and contact sensing.

Investigators have demonstrated that ERTS data provide a valuable means of recognizing soil association boundaries and establishing a base map for listing soils information. Dr. Weston, South Dakota State University, proved ERTS data to be a useful tool for the development of a land value map of South Dakota by using ERTS bands 5 and 7 to help delineate the soil association boundaries. Figure 8 is a color composite that depicts the soil landscapes that make up the soil associations. After delineating major soil areas, more than 4,800 land-sale prices covering a period of 1967 to 1972 were associated with the soils areas and averaged. **A** legend explaining land use, dominant slope, and soil parent materials of each delineated area was developed and an example is given below.

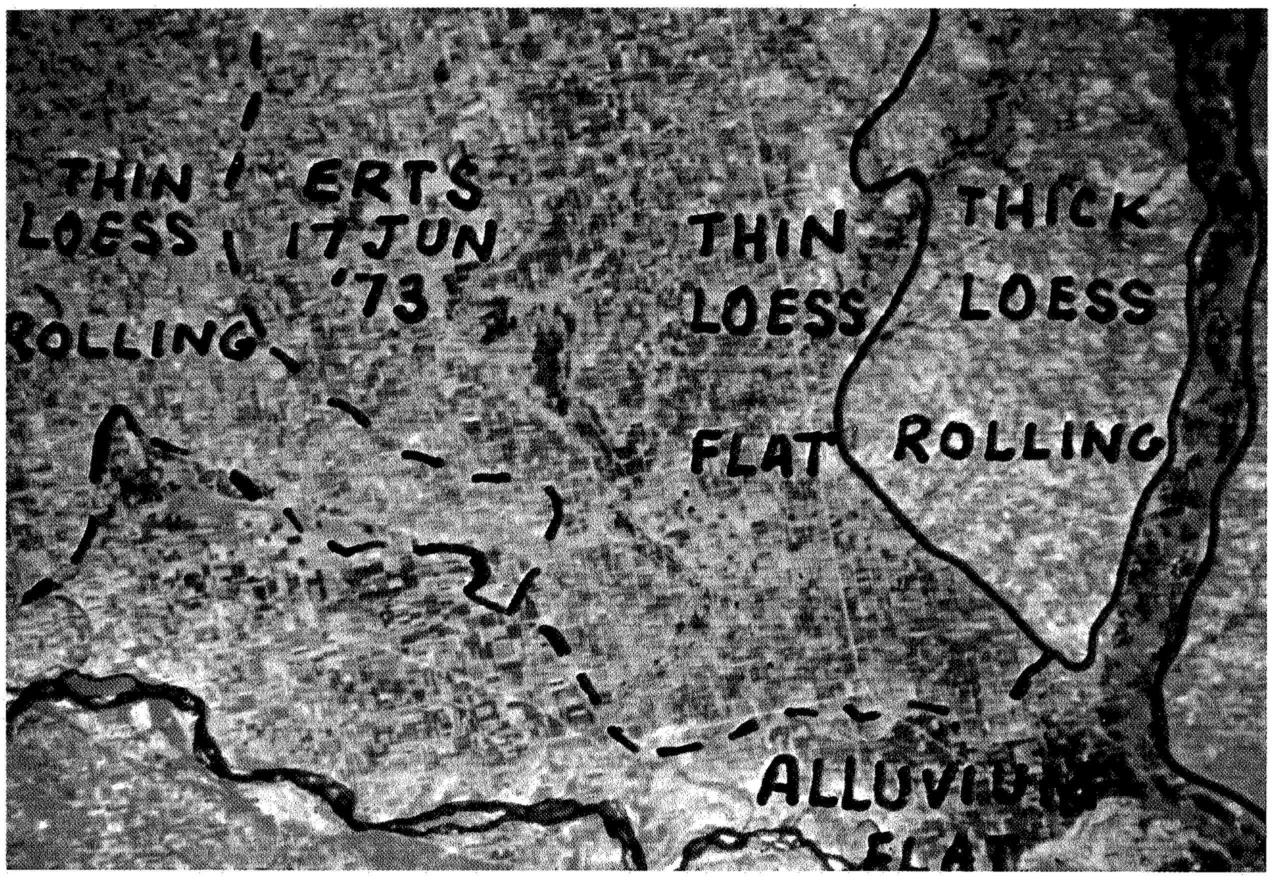


Figure **8.** ERTS-1 color composite on which soil association boundaries have been delineated (southeast South Dakota area).

Example of Legend
(Soil Association Major Areas)

A. Western Rangeland ($15-$20 Average Sale Price Per Acre)

A1 Undulating, Dense Clays from Cretaceous Shale

A2 Undulating, Sandy Loams and Sands from Cretaceous Sedimentary Rocks.

The soil associations were then described as soil association value areas and published on a 1:1,000,000 scale ERTS mosaic of South Dakota using band 7 for the base map (Figure 9). Figure 10 is a line drawing of the soil association value areas of South Dakotawhich is overlaid on the near orthographic ERTS mosaic. The resulting map, when keyed to the legend, describes the current agricultural land use and soils within each of the areas and provides information on which buyers value the land in each of the areas. The map is intended for use by state and county revenue officers to equalize land values in the state; by individual buyers and sellers of land and lending institutions as a reference source; as a reference map by those planning road routes, cable lines, and pipelines; by conservationists in helping to keep current conservation needs inventories; by agronomists needing current information on distribution patterns of crop growth; and by crop yield forecasters to guide sampling strategy.

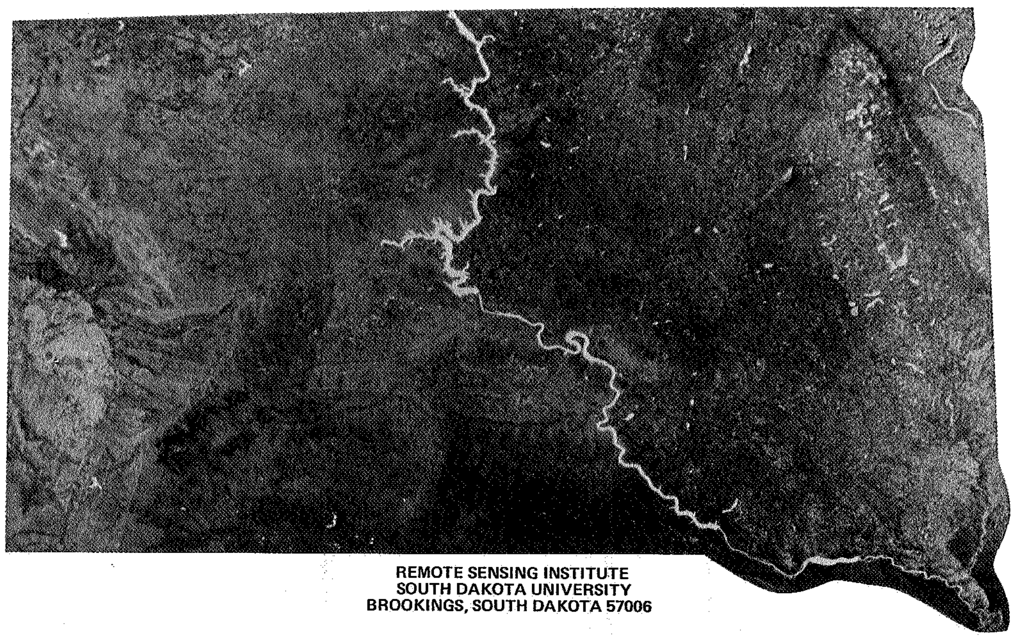


Figure 9. ERTS-1 mosaic *of* South Dakota using **MSS** band 7.

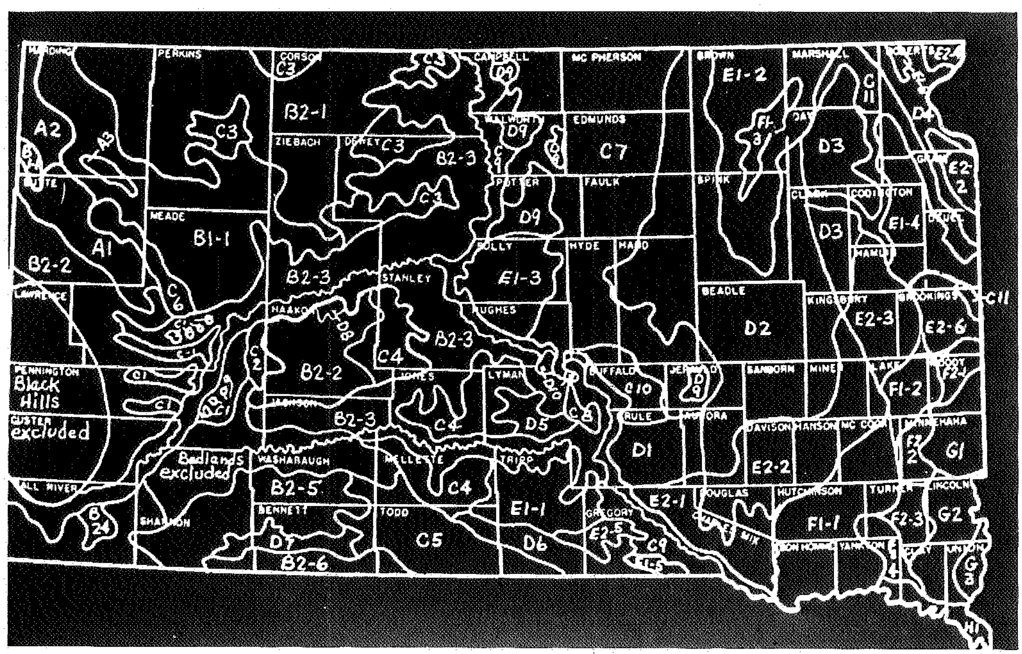


Figure 10. Line drawing overlay of Soil Association Value Areas of South Dakota.

In conclusion, only some of the highlights of the application of ERTS data to agriculture, range, and forestry have been presented here. The surface is just being touched, insofar as the exploitation of ERTS data is concerned in these application areas.

WATER RESOURCES

Vincent V. Salomonson
NASA, Goddard Space Flight Center
Greenbelt, Maryland

Since the launch of ERTS-1, there have been quantitative indications that ERTS data provide very valuable information for water resources. In fact, in the hydrological community, ERTS is called the hydrological satellite. Certainly, it can be seen that the wide-area, synoptic, multispectral view with minimal distortion provides an excellent perspective from which to study and assess the interrelationship and extent of various watershed components. However, the ingredient in the ERTS-1 system that has helped to provide a fundamental advance in the monitoring of water resources is the regular repetitive coverage capability.

In this paper the following major themes will be covered: snow and ice monitoring, surface water monitoring, including monitoring of wetland areas and flood inundated area mapping, and also watershed monitoring for runoff prediction.

There are many instances, such as in the Western United States, where snowmelt and glacial icemelt provide a major portion of the runoff that can be effectively utilized for several purposes, including hydroelectric power generation, irrigation water supply, human consumption, industrial uses, and recreation. Because snow cover and glaciers are often relatively inaccessible by conventional methods of measurement, the satellite provides an obvious tool for this kind of work.

At the last ERTS Symposium, early results showed that snowlines could be observed to within plus or minus 60 meters under good conditions, snow cover area could be observed to within a few percent, and snow cover could be empirically related to runoff. Since that time, results have been obtained that generally support these conclusions, and they come from several areas, including Alaska, Norway, New England, Washington State, California, Arizona, and Wyoming.

Figures 1 and 2 show representative examples that are situated in the southern Sierras – Mono Lake, Yosemite, and the Kings National Forest. Between May 8, 1973, shown in Figure 1, and May 26, 1973, in Figure 2, it is easy to observe the change in the areal extent of the snow cover. Similar observations are available in several areas. The general results show that agreement between the ERTS-1 snow cover estimates and operational aircraft surveys is normally within 5 percent. In addition, the snowline or the edge of the area of significant snow cover can be mapped as precisely from ERTS as from aircraft data.

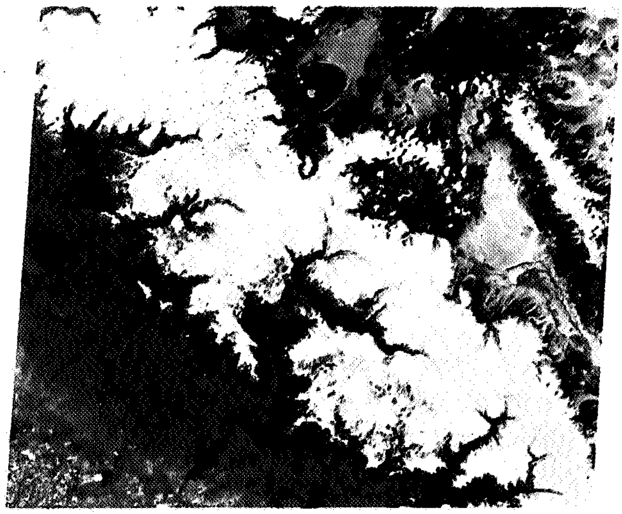


Figure 1. ERTS-1 snow cover observations over the southern Sierras, taken on May 8, 1973. Mono Lake is in the upper center portion of the picture.

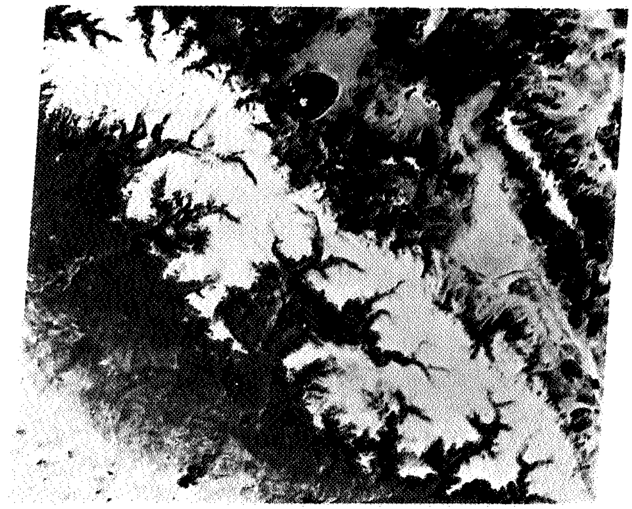


Figure 2. ERTS-1 snow cover observations over the southern Sierras taken on May 26, 1973.

The time and cost benefits for obtaining snow cover information from ERTS-1 are also quite encouraging. A case study was reported on the Feather River Basin in California where the time for assembling and analyzing U-2 data for snow cover information was found to be six times that required for obtaining the same information from ERTS-1 data. In another instance, the cost of acquiring and analyzing snow cover information in several drainage basins in the West, using light aircraft data, was found to be approximately two orders of magnitude larger than that required when using ERTS-1 data. Certainly these overall results show that ERTS-1 data can provide useful and cost-effective information for snow cover monitoring which can then be used for more effective management of reservoir storage and river flow.

ERTS-1 data continue to provide glaciologists with exciting observations as to the location, extent, and character of glaciers and their surface features. With ERTS data it is possible to see the snowlines on the glaciers, which can then be related to the mass balance of the glaciers. An interesting report from Norway showed that the snowline can be observed adequately from ERTS in relation to the mass balance and used as an indication of runoff from these glaciers. There have also been reports in the March Symposium and more recently, which indicate that the character of the medial moraines on the glaciers can be seen; this is used to distinguish surging glaciers from their nonsurging counterparts.

Figure *3* was provided by Dr. Mark Meier from Washington State, and shows the Tweedsmuir Glacier in Canada, which at the present time is surging at rates up to 6 meters per day. It provides a very narrow valley for the Alsec River to flow through. In fact, this canyon is called Turnback Canyon because boats coming up the river have to turn back at a point near the glacier. It is expected that this glacier may create a potentially dangerous situation in this area by blocking off the river and creating a large lake. ERTS provides an opportunity to repetitively monitor this situation.

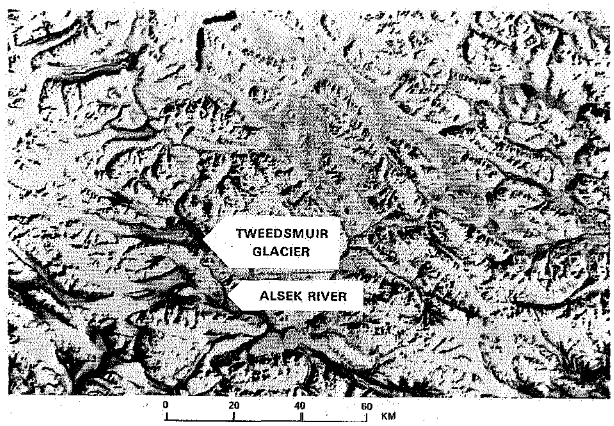


Figure 3. ERTS-1 observation over the Tweedsmuir Glacier in Canada on September 13, 1973.

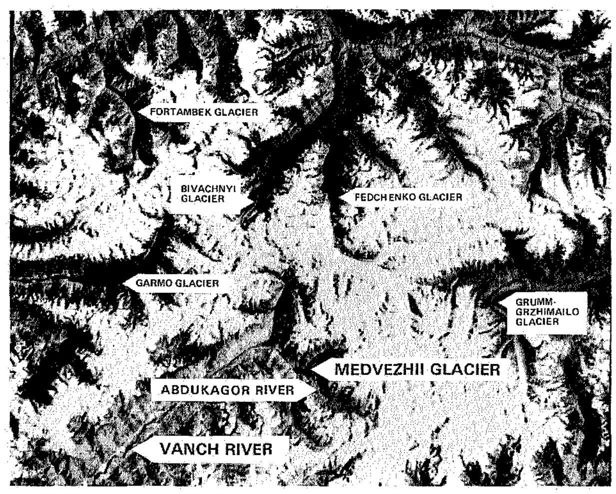


Figure **4.** July 12, 1973, ERTS-1 image of the Pamir Mountains in Tadzhikistan, Soviet Asia. The Medvezhii (Bear) glacier which surged in April 1973 and created a 20 million cubic meter lake is seen. The lake broke through its ice dam on June 20,1973, and caused a flood in the populated Vanch River Valley.

Another situation that developed in April 1973 in the Himalayan region is shown in Figure 4. A glacier called the Bear Glacier had surged and blocked the Abdukagor River. Behind it a lake was created that impounded some 20 million cubic meters (700 million cubic feet). The lake built up until June when it broke and flooded the river valley. This observation (Figure 4) was taken in July; nothing was available before then. In the course of examining this particular ERTS photo, several other surging glaciers that were not suspected before were located. The longest glacier in the Continental U.S.S.R. and one of the most studied was also spotted.

It is quite evident that ERTS data provide useful information to glaciologists. In addition, for those who wish to explore the polar regions, ERTS-1 imagery has provided extensive and numerous changes for the mapping of Antarctica, including particular regions around Ross Ice Shelf, Franklin Island, and various ice tongues. Even though the maps of the Arctic are much more accurate than those in the Antarctic, several changes to be incorporated in the 1974, 1:5,000,000 scale American Geographical Society Arctic Region Map have been facilitated by the presence of ERTS-1 data. ERTS appears to be a very expeditious way for the cartographic community to meet, in a relatively short period, the demands for small-scale mapping by national and international polar scientific projects.

Several ERTS-1 images have been obtained over the Great Lakes where it has become evident that ERTS-1 provides relatively high detail, synoptic views of the ice cover on these lakes. Figure 5, which was taken in March 1973, shows pressure ridges, rotten ice, cracks, and leads. On observations over the Great Lakes using side-lap, ice breakup and changes on lakes in the New England area have been observed. In addition, using the multispectral capability of ERTS to compare the 0.6- to 0.7-micrometer observations with the 0.8- to 1.1-micrometer observations (Figure 6), the area of melting ice can be delineated, as shown in the figure by the darker tones created by the surface melting water.

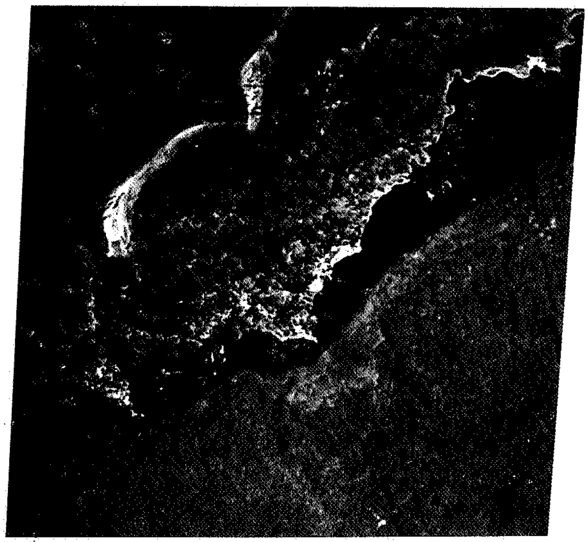


Figure 5. March 8, 1973, 0.6- to 0.7-μm ERTS-1 **MSS** image over Lake Erie showing ice cover.

Figure 6. March 8, 1973, 0.8- to 1.1-μm ERTS-1 **MSS** image over Lake Erie.

In the cases of both snow-cover and lake ice observations, researchers from the National Oceanographic and Atmospheric Administration (NOAA) have shown that a combination of the ERTS-1 data with very high resolution radiometer (VHRR) data from the NOAA satellite, NOAA-2, creates a more effective system-of observation in which the daily visible coverage of the VHRR can supplement the 18-day cycle of ERTS, and the less than 0.1-kilometer spatial resolution observations of ERTS-1 can be used to calibrate the 1-kilometer NOAA-2 observations.

Several projects have been advanced considerably since the March ERTS Symposium in quantifying and demonstrating the ability of ERTS-1 to monitor surface water distribution. In Texas, there are reports dealing with the mapping of thousands of lakes, reservoirs, and other water bodies, and in particular with the response to Public Law 92-367 dealing with the inventorying of dams. The results show that all lakes larger than 40,000 square meters (10 acres) can be identified with 100-percent reliability, and their location spotted to within 300 meters (1,000 feet). Other work in the Great Plains area of Texas shows that the lakes can be monitored, and this is shown in Figure 7.

The largest lake is the Double Lakes Playa, which is 8,000 meters (5 miles) long. The other freckled appearances seen here are the thousands of lakes that exist in this area for which it is impractical to count and monitor the areal extent by any other means.

A preliminary regional wet lake census study and a cost benefit study have been done in this Southern Great Plains area, and it indicates that the benefit cost ratio is as high as 200: 1 when contrasted with using aircraft data as input or when considering the use of ground surveys. It should be emphasized that not only is the ERTS-1 data good for doing these surveys quite rapidly on a one-time basis, but that the surveys can be done many times each year.

Florida is another area where there is difficulty in monitoring the areal extent of surface water by conventional means, yet there have been some very good results from ERTS. Figure 8 shows a view of the southern part of Florida. Three particularly important conservation areas in the Everglades are shown in this figure, the Loxahatchee Wildlife Refuge, Conservation Area Number 1, being one of them. In Figure 9, the areal extent of surface water as seen through ERTS is combined with data collection platform (DCP) data to get depth so that the total volume of water in this region can be estimated, something that is more accurately and easily accomplished using ERTS data.

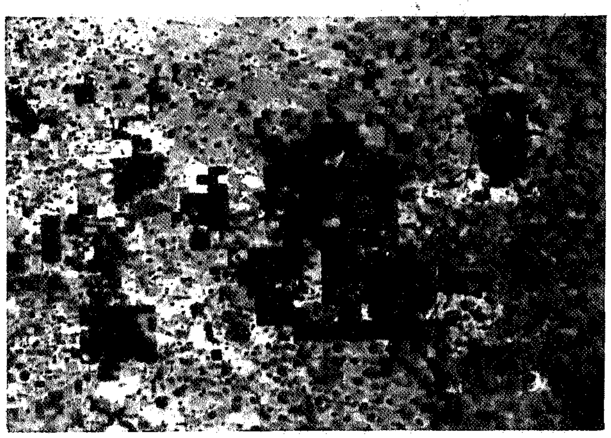


Figure 7. **ERTS-1** color composite view of the Double Lakes Playa region (center) on the Southern High Plains of Texas.

Figure **8. ERTS-1** color composite image of the southern Florida region. Conservation Area Number 1 is in the top right-hand portion of the picture.

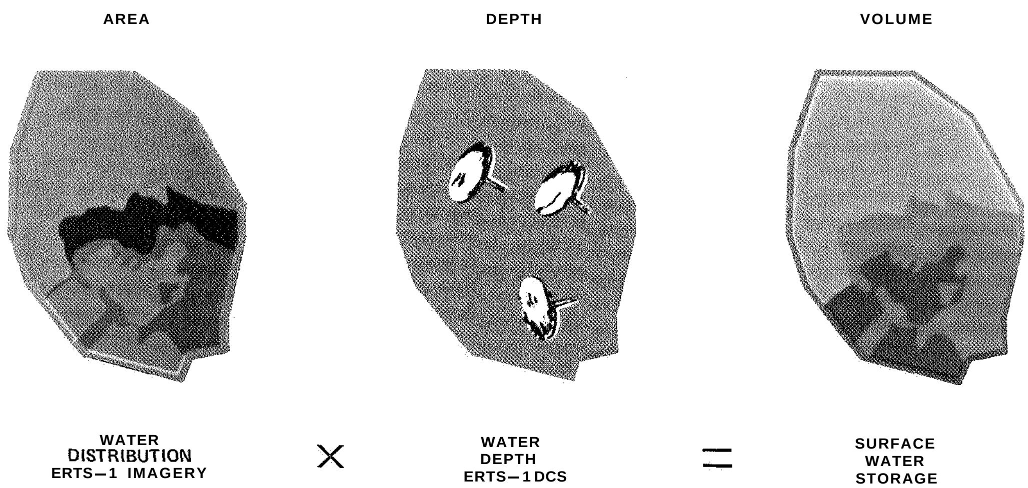


Figure 9. **A** schematic diagram showing how surface water storage in Conservation Area Number 1 may be estimated from **ERTS** data.

Figures 10 and 11 were taken by ERTS on February 14 and March 22, 1973, respectively; here the areal extent of the surface water is generally depicted by blue tones. It can be seen in the 36-day intervening period that the surface water has decreased considerably. Combining that with the DCP data gives an estimate of volume on a repetitive basis. These kinds of data are being made available to state and local agencies as well as federal agencies on a near-real-time basis for use in water management and ecological models.

ERTS-1 has continued to show applicability for regional surveys of flood-related features. Since the March Symposium, ERTS data have been applied to surveying the areal extent of flood-inundated waters during the spring 1973 flood of the Mississippi River. Figure 12

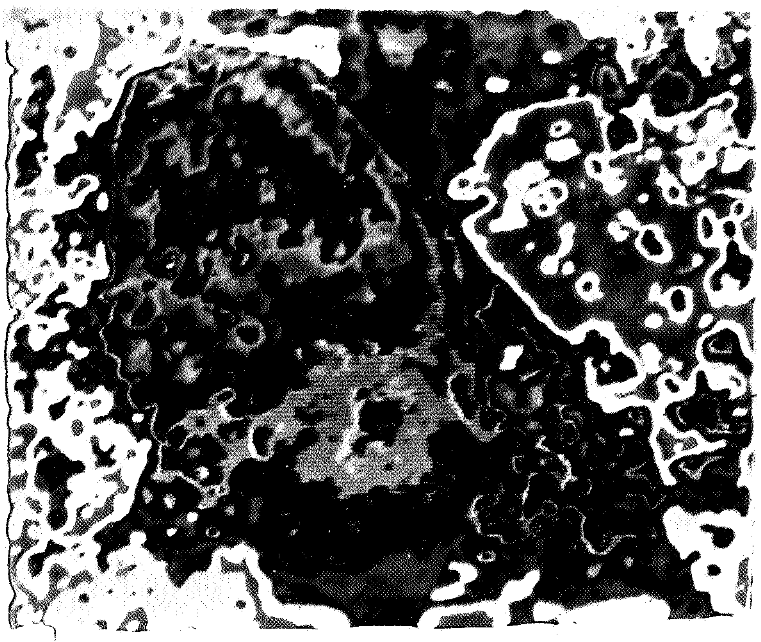


Figure 10. An enhanced density-analyzed result from ERTS-1 MSS imagery over the Loxahatchee Wildlife Refuge (Conservation Area Number 1) acquired February 14, 1973.

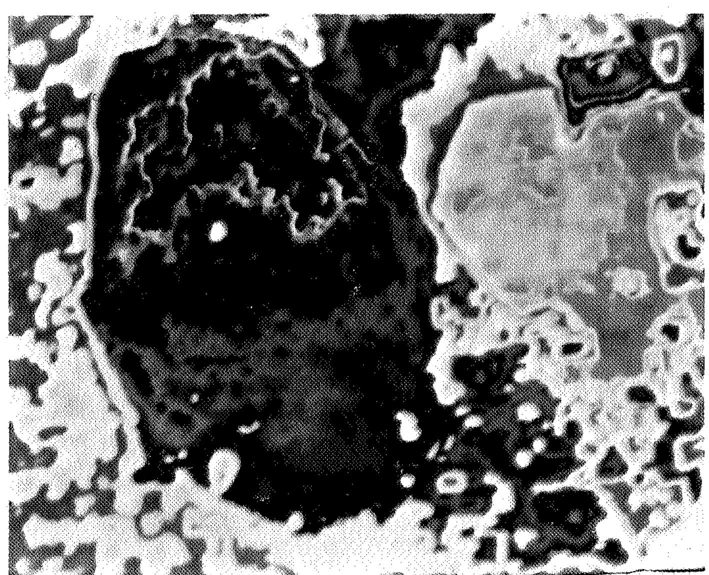


Figure 11. Same area shown in Figure 10 but with imagery acquired 36 days later on March 22, 1973.

shows a temporal color composite stretching from St. Louis some 2,000 kilometers (1,200 river miles) south. What was done here was to combine before-flood images from October 1972 with images from March 31, 1973 and May 5, 1973, and process them in such a way that those areas that were affected by the flooding in the spring 1973 flood are depicted here in red. Similar investigations have supported the results presented in this paper, stating that regional surveys of flood-inundated areas can be done over very large areas such as this much faster than can be done by ordinary surveys. Interest has been expressed in utilizing these data by several Federal agencies and by insurance groups.

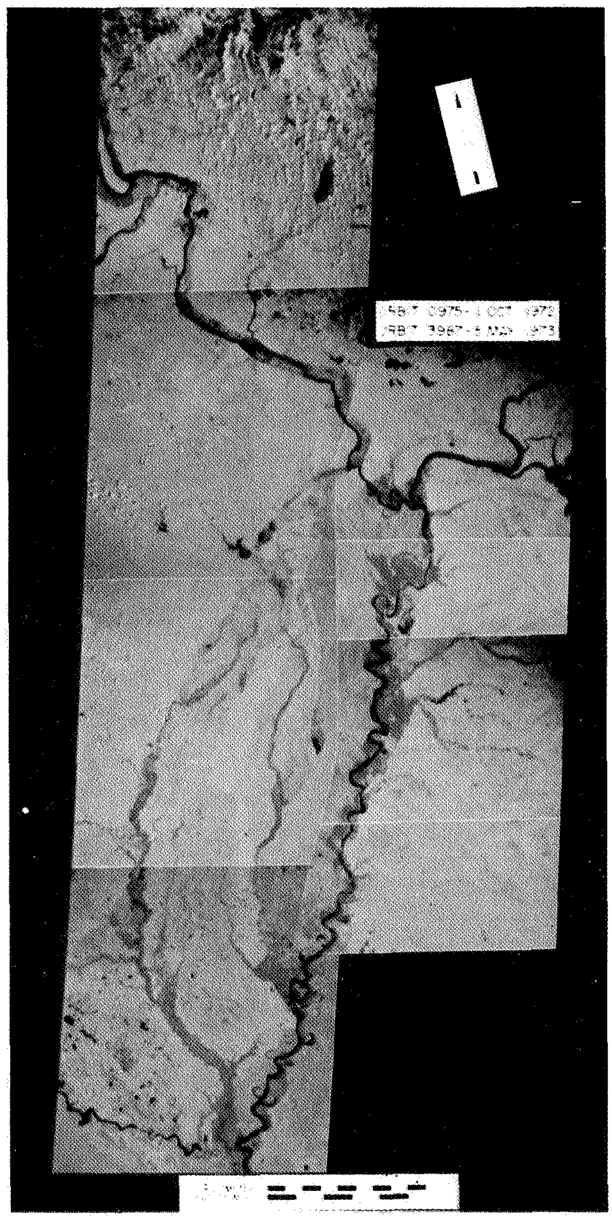
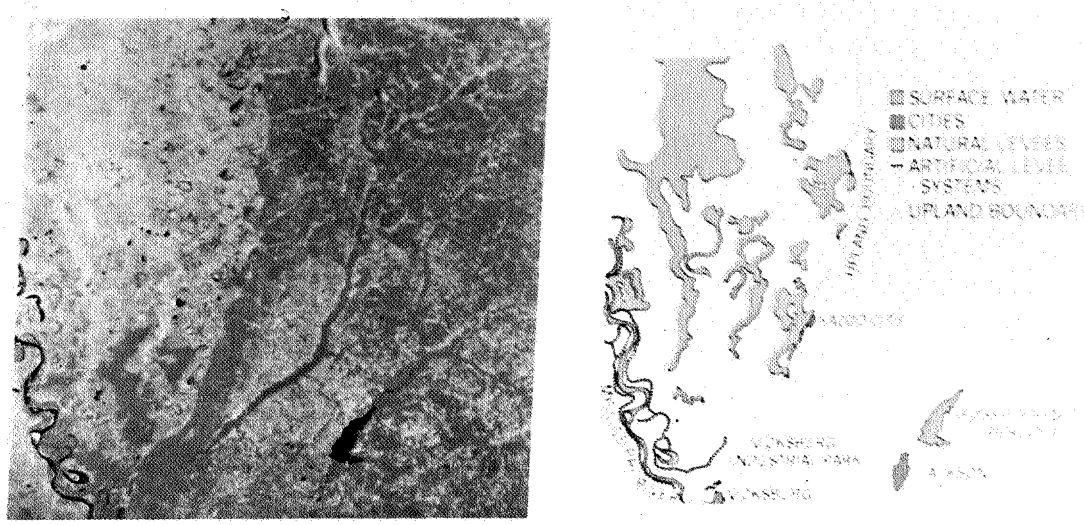


Figure 12. A temporal color composite comparing the Mississippi region from St. Louis to the Arkansas-Mississippi River Junction as imaged by ERTS-1 before flood (October 1972) and after flood (March 31 and May 5, 1973). The red tones along the Mississippi delineated areas subjected to flooding in the spring 1973 period.

In addition to monitoring the flood-inundated area, which has been done on this river as well as many others, there are results which indicate that, as depicted in Figure 13, flood-prone regions can be mapped well before or well after a flood actually occurs. Figure 13 shows the division on the Mississippi between the flood plain and the upland area. The natural levees are depicted here by the light tone. **As** in the case of Georgia, smaller rivers and their flood plains can also be delineated. Similar types of work are going on in Maryland and Virginia, and more than likely, in many other areas.

Results supporting early indications that coastal and inland wetlands can be mapped from ERTS-1 have been achieved. Several wetland vegetation species can also be mapped in useful fashion on scales up to 1:125,000, and some general features can be delineated at even larger scales, particularly when using ERTS-1 digital data. The extent and change of man's activities can also be monitored and delineated.

In Figure 14, four examples are shown where highway construction can be seen as it relates to wetlands, lagooning along the New Jersey coast, and dredging and filling on the Delaware coast. The figure also shows instances where damming has occurred and changes in turbidity can be



SEPTEMBER 13 1972
COLOR COMPOSITE

OVERLAY SHOWING FLOODPLAIN
FEATURES EXTRACTED FROM THE
SEPTEMBER 13, 1972 ERTS-1 IMAGE

Figure 13. Analysis of ERTS-1 imagery showing various flood plain features in the Vicksburg, Mississippi, region.

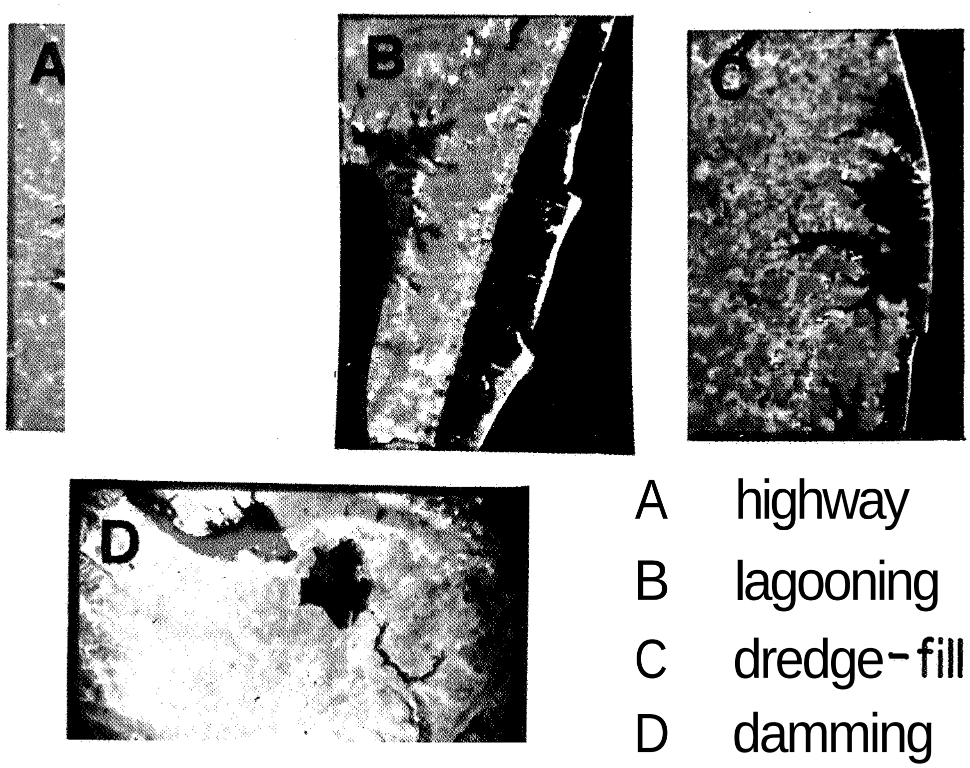


Figure 14. ERTS-1 imagery showing extent and changes occurring in wetlands areas due to the activities of man.

assessed. With this kind of information, better field surveys can be conducted to study these situations more intensively.

Relative variations in water quality are dramatically illustrated in ERTS-1 imagery. Recent 1973 observations as shown in Figure 15 of the Lake Huron-Lake St. Clair area certainly illustrate this rather clearly; plumes along the shore and wide variations in turbidity in Lake St. Clair can be seen. Observations such as these are usually general indications of lake dynamics, pollution dispersion, shoreline and bottom erosion, and overall water quality. At the March Symposium it was reported that ERTS imagery had been used as informational material for a suit by the State of Vermont against the State of New York concerning the pollution of Lake Champlain. Since then that data has been accepted as legal evidence in a court of law.

Figure 15. ERTS-1 imagery over the Lake Superior–Lake St. Clair area showing turbidity patterns on March 27, 1973.

Figure 16 depicts turbidity variations in Lake Superior. The cross indicates the place where a water intake line was placed by an engineer for the city of Cloquet, Minnesota, a job costing $8 million. No imagery was used then, but since that time this image has been used to point out the error that was made; it has been found that the whole operation is unusable.

There are some quantitative indications that ERTS-1 data can be used to estimate sediment load. Updated results from the Tuttle Creek Reservoir in Kansas are seen in Figures 17 and 18 and indicate that, for ranges of sediment load between 0 and 900 parts per million, accuracy is good to plus or minus 30 or 20 parts per million, depending on the band used. For ranges between 0 and 60 parts per million, accuracy increases to plus or minus 5 parts per million. Results like these have also been obtained in other situations in the Virginia-Chesapeake Bay area, the Wisconsin area, and in Alaska.

One of the most interesting areas of study in water resources as far as long-term benefit is concerned is watershed surveys. It involves the repetitive satellite monitoring of watersheds for improved estimates of runoff. Results already described show that snow and ice cover and surface water extent can be mapped from ERTS-1 with useful accuracy and frequency for this purpose. Results described in many other reports at this Symposium indicate that the extent of other themes such as impervious area and vegetation and bare soil could be mapped repetitively and serve as improved inputs to models of widely varying applicability and sophistication.

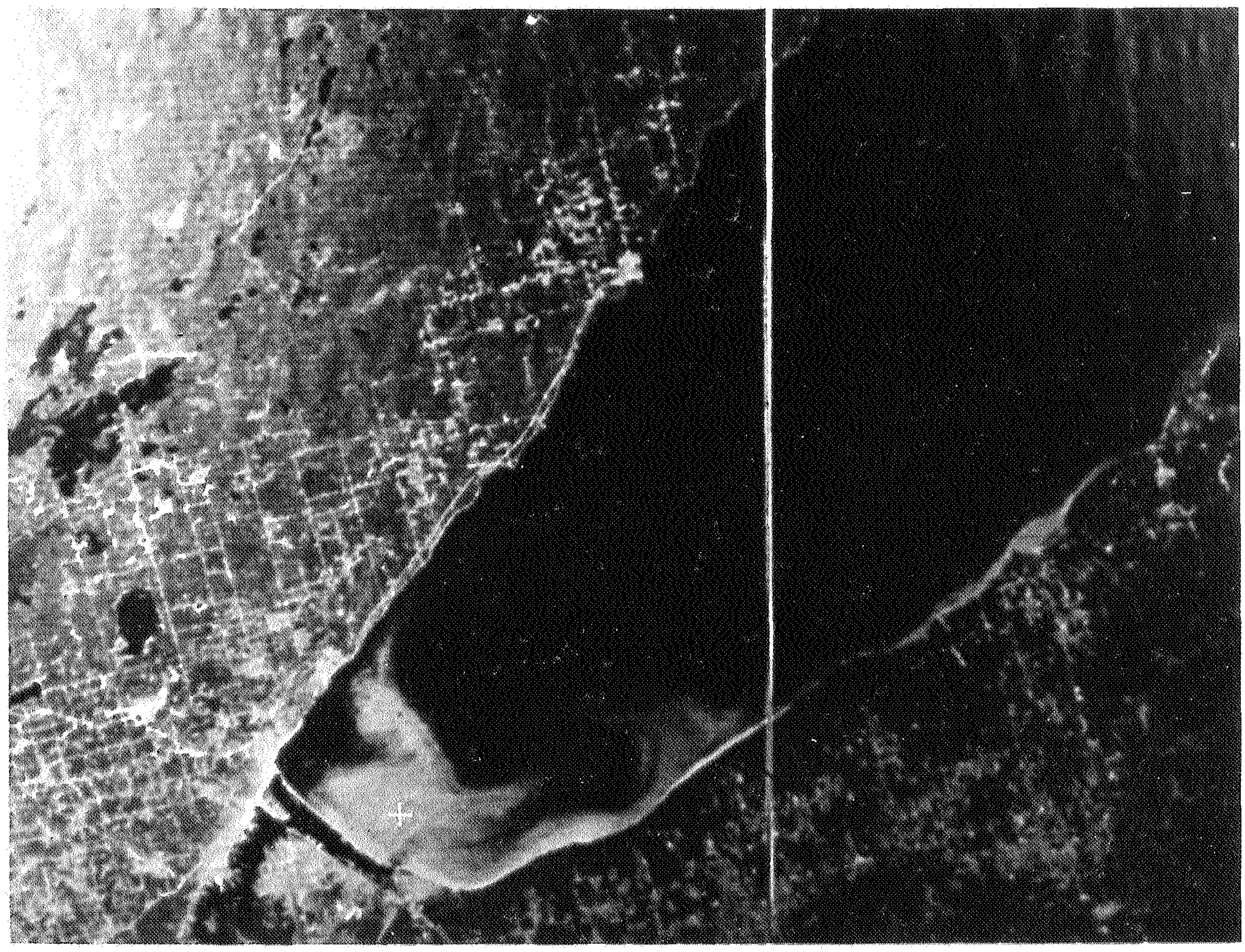


Figure 16. Lake Superior ERTS-1 imagery showing highly turbid water near Duluth, Minnesota. The cross indicates the location of a water intake for the city of Cloquet, Minnesota, that resulted in unsatisfactory water supplies.

In terms of catchment physiography, a study in Kansas indicates that more stream order information is derivable from ERTS-1 data than is normally depicted on 1:250,000 scale standard topographic maps. Furthermore, digital data and computer techniques have been used to delineate watershed features in Colorado, and in particular it was found to be possible to obtain drainage basin area to within two percent of that obtained from other reliable and conventional data sources. Results have also been reported from the Oklahoma area concerning the use of ERTS data for estimating coefficients in runoff equations that are used to design small flood-control structures. These equations are the type that are usually referred to as the "rational" formula equations, where the discharge is a function of the area of the watershed, the intensity of precipitation, and a coefficient, which takes into account the forest cover, slope, and the general character of the watershed.

By using ERTS data and taking the mean of the reflectances over the watershed in band 5 and subtracting the mean reflectances in band 4, the information can be related to the observed

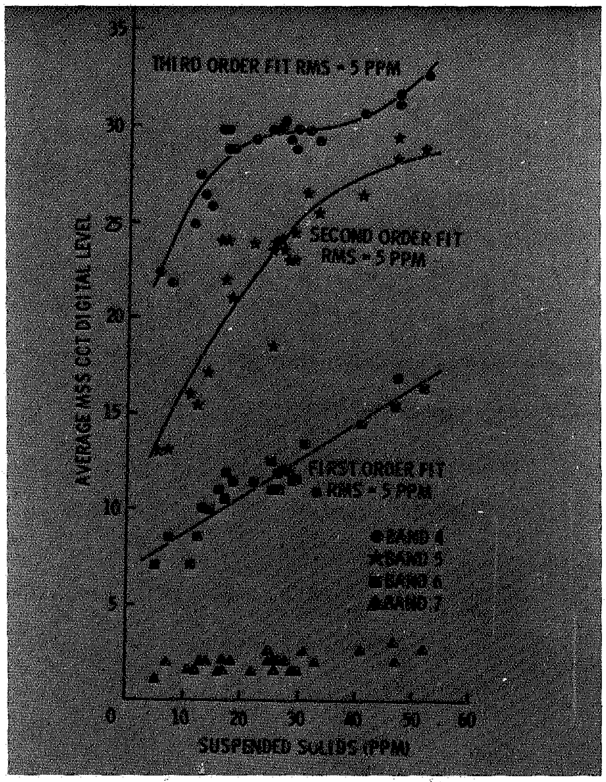


Figure 17. ERTS-1 MSS digital values versus suspended solids for the Tuttle Creek Reservoir in Kansas.

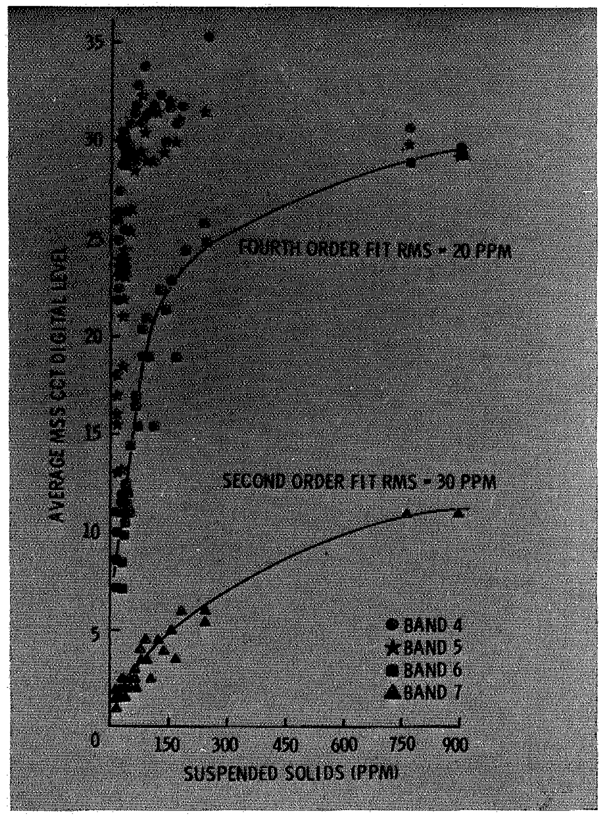


Figure 18. ERTS-1 MSS digital values versus suspended solids for the Tuttle Creek Reservoir in Kansas.

coefficients in the way that is shown in Figure 19. **A** rather smoothly varying, reasonable relationship is found. It is exciting to see this kind of encouraging result coming forth when it is recognized that these kinds of results can be obtained much more objectively than is possible with conventional coefficient derivation methods. Figure 20 illustrates this point. Here measured coefficients are on the ordinate and the design coefficients that are normally applied are on the abscissa. Note that the design coefficients are usually much larger than really necessary. The Soil Conservation Service spends $50 million a year on a national scale in construction costs for small dams. It can be seen by this indication that estimates of these design coefficients can be improved objectively, and that considerable savings can come from improved accuracy estimates of these coefficients in this way alone.

There are several investigators who have utilized the data collection system in water resources monitoring and in all cases they have found that it provides excellent and reliable data to several agencies in various parts of the country in near-real time. In Arizona this year, the runoff was many times that which is normally experienced because of much greater snowfall in the southern Arizona mountains, particularly on the Salt Verde River Watershed. Through the use of the ERTS data collection system, data was provided to the Salt River Project in near-real time, so that it was possible to effectively control and regulate this flow to create a minimum of inconvenience in the Phoenix area. In addition, the data collection system has been employed

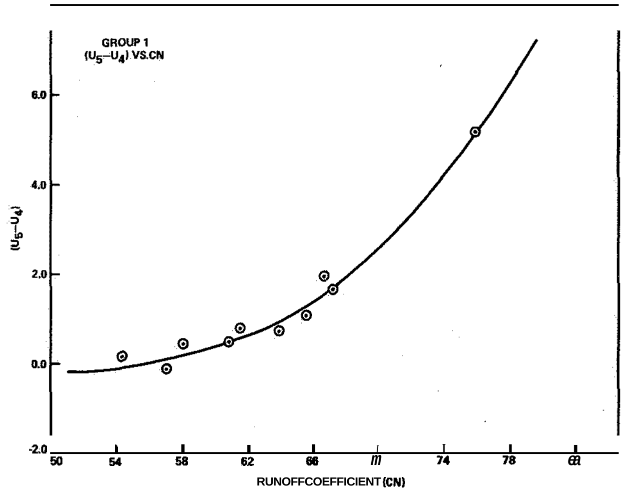


Figure 19. The difference in mean watershed reflectance for the 0.6- to 0.7-pm (μ_5) and the 0.5- to 0.6-pm (μ_4) spectral regions versus measured runoff coefficient.

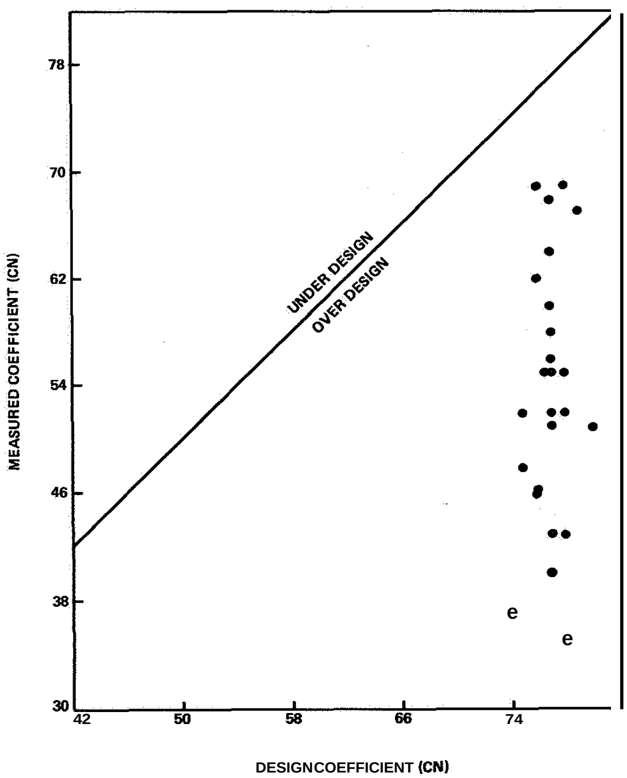


Figure 20. Typical measured coefficients versus design coefficients for small watersheds.

by the *Corps* of Engineers to obtain valuable and unique data in relationship to the spring 1973 floods in New England.

Overall, considerable enthusiasm exists among the users of the data collection system for water resources purposes. They are enthusiastic about the general satellite data collection and relay concept and this enthusiasm is due in no small part to the success of the ERTS-1 system and the delivery of the data in near-real time.

In summary, there are many other results which could not be reported now because of the lack of time. Nevertheless, they were very important and relevant to water resources monitoring and management. As just a small example, there are results to indicate that geological features can be noted from ERTS which relate to ground water. The results that have been mentioned in this summary indicate that ERTS-1 data definitely provide accurate and timely information for snow cover and surface water surveys, including flooding and wetland monitoring. The data can be used successfully in operational situations by water resources management agencies. It is also particularly encouraging to see results which quantitatively indicate that ERTS data can be used effectively in the estimation of coefficients used in empirical runoff prediction models.

Although there is a great deal of work to be done, it is quite clear that much progress has been made in water resources monitoring using ERTS data, even since the March Symposium. Furthermore, it is quite clear that ERTS-1 data supply a body of results that provide definitive evidence as to the utility of ERTS data for better accomplishing the many tasks associated with the monitoring and management of water resources.

LAND USE AND MAPPING

Armond T. Joyce
NASA, Earth Resources Laboratory
Bay St. Louis, Mississippi

The obvious importance of our land resource and the ways in which its use affects our lives points to the need for baseline information showing how the land resource is being used. The ERTS program has given us a tool to achieve this by providing data that can be used to derive information relative to the actual use of the land resource, in a practical and timely manner. ERTS data provide coverage of total land areas, and its repetitive nature enables the detection and monitoring of changes taking place in land use. Generally, the techniques and the procedures used to extract information from ERTS data may be categorized as pertaining to either the interpretations of ERTS imagery or to the use of digital data and computer techniques.

First the use of ERTS imagery will be discussed. The product illustrated in Figure 1 was derived from ERTS imagery with a simple technique employing conventional interpretation, which, in this case, provided a land use map covering the states of Connecticut, Rhode Island, and Massachusetts. In this example, 11 land use categories are shown. Their color codes are shown in the legend in the upper right. For example, residential low-density areas are shown in yellow, rural open land in light green, and woodland in dark green. Other land use categories shown by their respective colors are the commercial-industrial, residential high density, transportation, developed open spaces, rural open land, agriculture, woodland, and marshland. This, then, is a product resulting from a technique that can be used to produce a map rapidly with simple equipment. In this case the interpretation took place over a period of three months, and the investigator's cost figures show that it is very cost-effective. The map was produced for about 40 cents per square kilometer ($1 per square mile). This figure can be compared with the use of aircraft-acquired photography for a similar purpose which may cost up to $6 per square kilometer ($15 per square mile).

Figure *2* shows a color composite image made in false color from ERTS data acquired over the Chesapeake Bay and Washington, D.C. metropolitan area. In Figure **3** is seen the resulting land use classification map. On this map the delineation of land uses is coded by numbers. For example, the number 18 is used to designate the mixed urban areas, such as the metropolitan area of Washington, D. **C.,** located at right center. Code 153 corresponds to airports, illustrated by Andrews Air Force Base, in the lower right, as well as Dulles International in the left-center. This product resulting from an image interpretation technique is another illustration of a way in which simple techniques have been used. It requires only low-cost equipment and skills that are commonly available.

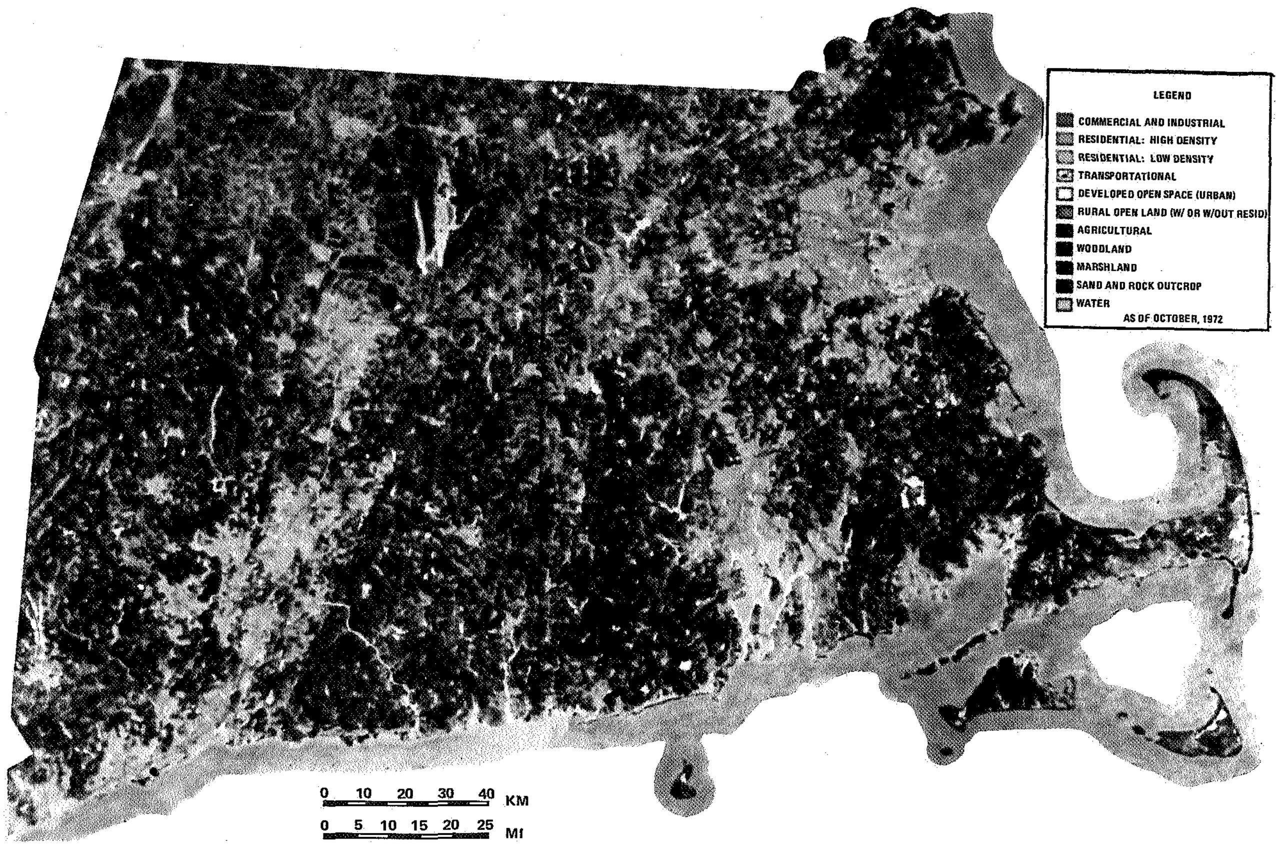


Figure 1. Land **use** map of Connecticut, Rhode Island, and Massachusetts derived from ERTS imagery.

The area shown in Figure 4 is a small portion of the same Washington, D. C., area shown in Figures 2 and **3** (upper portion slightly to the right of center). The maps shows areas delineated by black lines within which change in the use of land has occurred during the course of two years. Such change in land use was detected by comparing ERTS imagery with a land use map that was two years old at the time of comparison. Changes that took place are indicated by a number code shown in the lower right. For example, appearing quite frequently on this map is the number 80, its significance being that the use of land previously designated as unimproved open space has changed to a use for commercial and service purposes. Areas on the map that are delineated and designated with the number 64 indicate areas of land that were agricultural but have changed to single-family residential areas. Other types of change are illustrated by the two-digit number in a manner such that the first digit indicates the previous use and the second digit indicates the current use. Such change detection is made possible by the repetitive coverage of ERTS.

Figure 5 shows a land use classification resulting from a computer-implemented technique, supervised classification, that was used to classify the Mississippi Gulf Coast area. For geographic reference, New Orleans is located in the lower-left. The focus, however was the Mississippi coast for which the three coastal counties – Haneock, Harrison, and Jackson – were delineated. This particular map demonstrates a computer-implemented technique using ERTS digital data to perform **a** generalized land use classification as indicated by the color code. The green color indicates forested areas; red, marsh areas; white, urban centers; yellow, grass areas; and lavender, cultivated agricultural areas. This same area had been mapped previously by a local planning agency.

Considerable effort and $90,000 were spent over a period of one year to complete the

Figure 2. ERTS color composite image of the Washington, D. C., area.

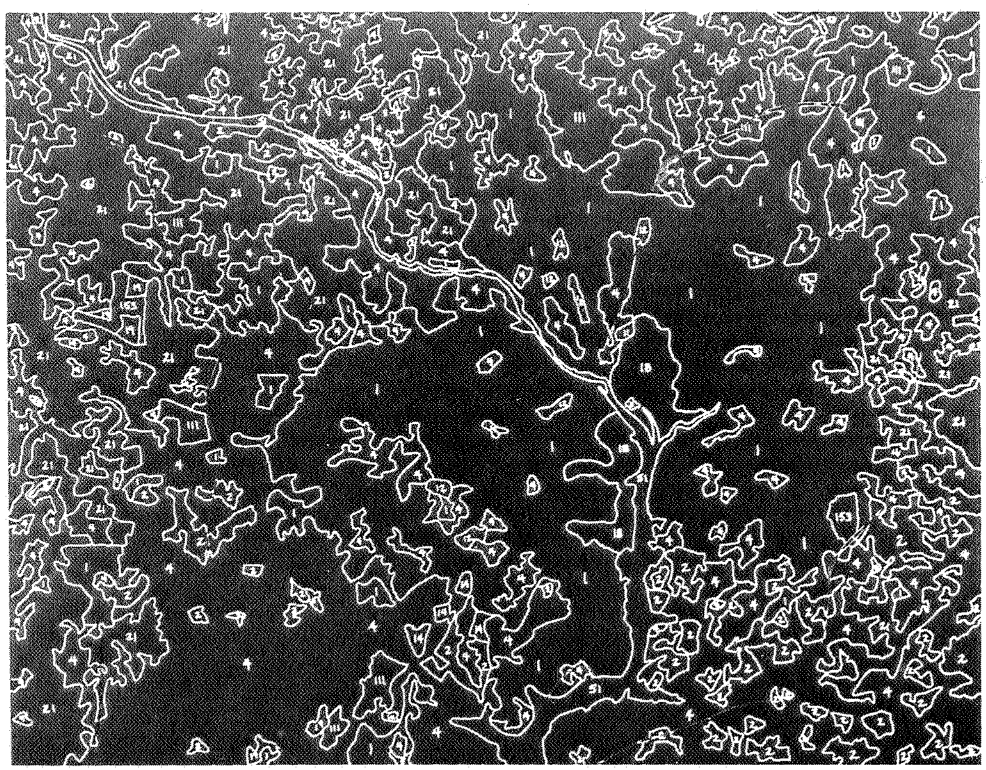
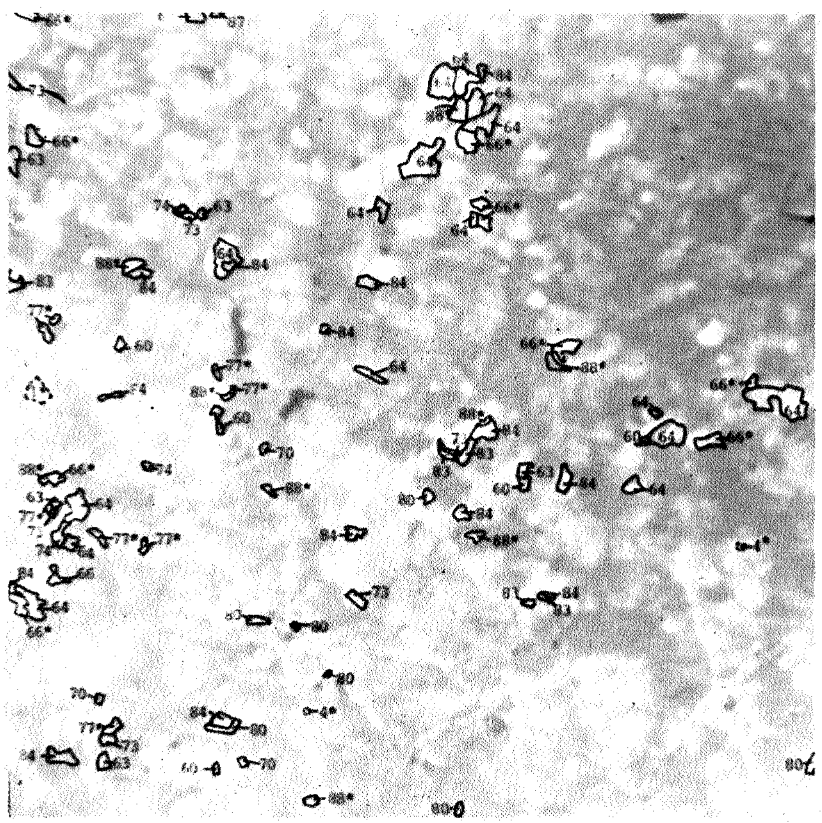


Figure 3. Washington area land use **map derived from ERTS image shown in Figure 2.**

mapping. Several months later, Hurricane Camille hit the Gulf Coast and essentially made this land use map obsolete. The computer-implemented technique used to produce a similar classification, as shown in Figure 5, was carried out in one month at a cost of about $3,000.



CHANGE 1970-72	FROM	TO
COMMERCIAL AND SERVICES	0	0
INDUSTRY	1	1
TRANSPORTATION	2	2
MULTI-FAMILY RESIDENCE	3	3
SINGLE-FAMILY RESIDENCE	4	4
STRIP AND CLUSTER DEVELOPMENT	5	5
AGRICULTURE, WITH RESIDENCED	6	6
IMPROVED OPEN SPACE	7	7
UNIMPROVED OPEN SPACE	8	8
WATER	9	9
LAND USE IN TRANSITION		

Figure 4. Change detection map for a portion of the Washington area.

This classification, however, does not focus on the urban areas. Figures 6 and 7 show that the digital format of the ERTS data has also allowed specialized classifications of urban areas to be made. These two illustrations, with Figure 6 illustrating the supervised technique and Figure 7 the unsupervised (clustering) technique, concentrate on the Houston area. Figure 6 shows a classification of various urban features. Figure 7 shows a similar classification but with somewhat more detail, especially in the residential areas. These products illustrate the progress that has been made possible through the use of ERTS data in a digital format, which is an additional attribute of the ERTS system.

Another approach to urban classification is illustrated by Figures 8 and 9, which show themes produced for the Los Angeles area with an interactive, multispectral information extraction system. Figure 8 shows heavy commercial areas in yellow, and Figure 9 shows heavy industrial areas in pink. These are two types of information that the urban planner can obtain through a man-machine interaction with ERTS data.

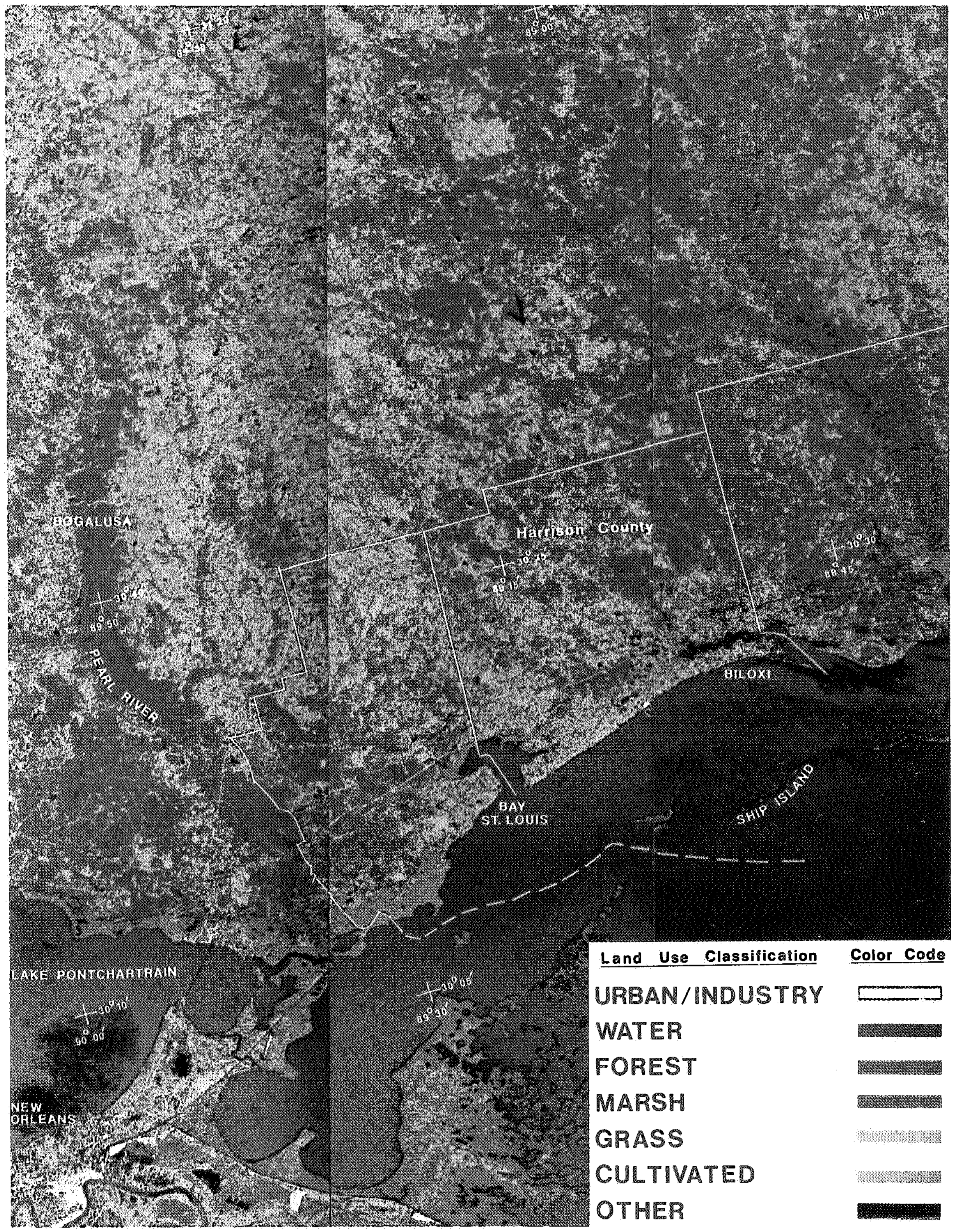


Figure ***5.*** Computer-derived land use classification of **ERTS** data for the Mississippi Gulf Coast.

Figure 6. Urban features analysis of the Houston Metropolitan area. **A** supervised computer classification map made from ERTS data.

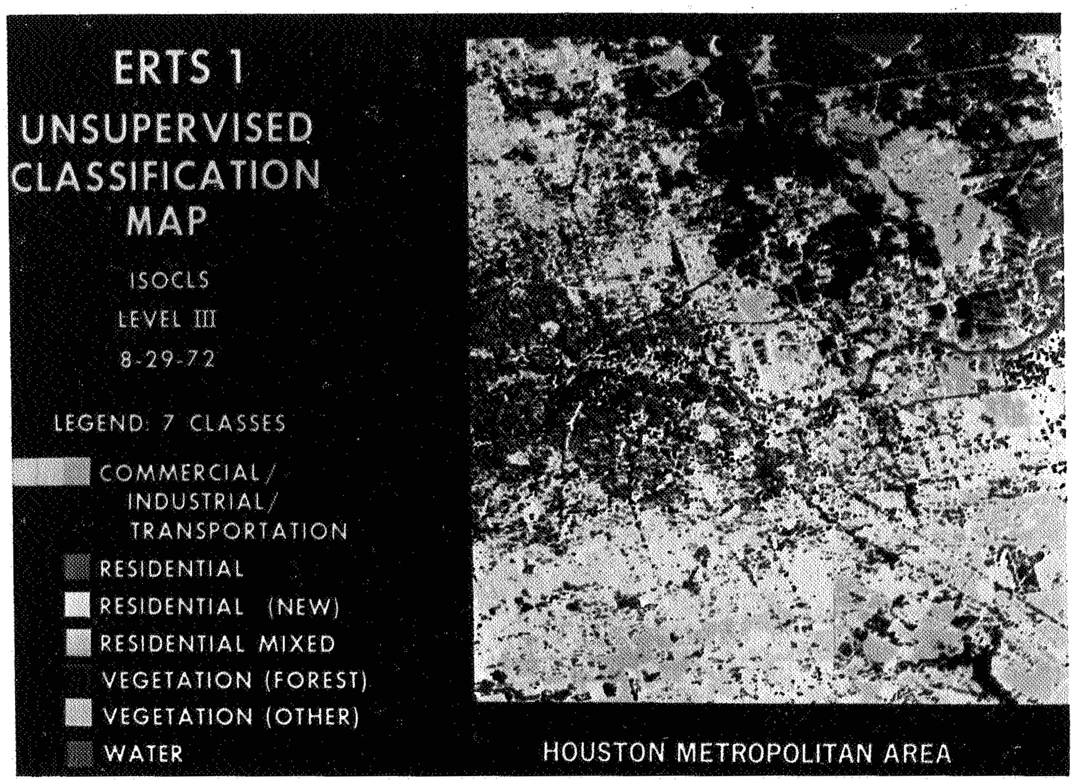


Figure 7. Urban features analysis of the Houston Metropolitan area. An unsupervised computer classification map made from ERTS data using seven classifications.

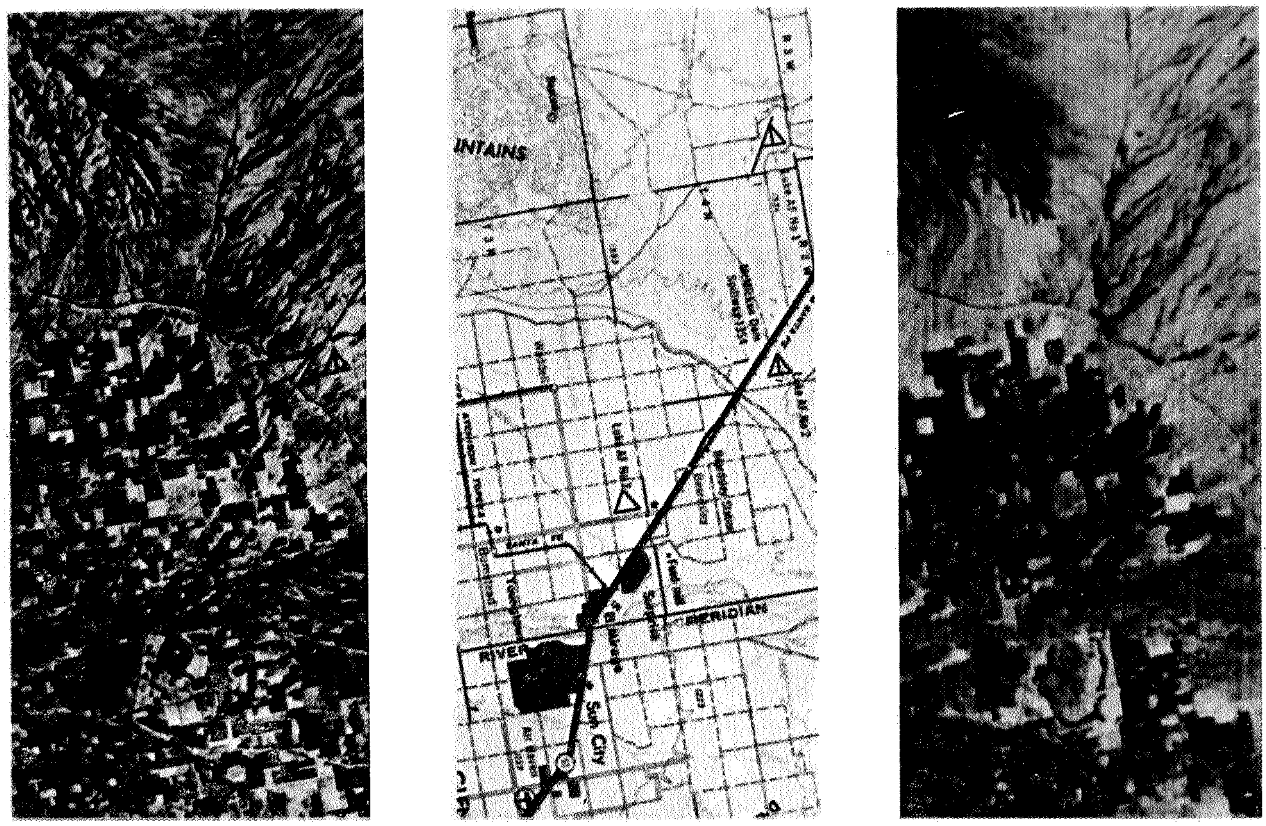
Figure 8. Example of an ERTS product produced with a interactive multispectral information extraction system. Heavy commercial areas are shown in yellow for **Los** Angeles, California.

Figure 10 illustrates a cartographic application of ERTS data. It should be noted that cartographic applications such as this are closely related to the land use classification work in the previous illustrations. Figure 10 shows the results of a cartographic application in the Phoenix, Arizona, area. The left-hand section shows a photomap produced from **U-2,** aircraft-acquired imagery. The center segment shows a line map. And the right segment shows an image map made from ERTS data. In comparing the three segments, it is obvious that there is much more informational context with respect to land use information in the U-2 photomap and the ERTS image map than in the line map. It is also apparent that there is more detail in the U-2 photomap than in the ERTS image map, but cost estimates show that the ERTS image map can be produced for one-tenth the cost of producing the photomap based on U-2 acquired imagery.

In summary, the advancements made in developing techniques for the present use of ERTS data for land use classification should be acknowledged. It has been demonstrated that land use information that has been derived from ERTS-1 data has exceeded the expectations at the time of launch, however, it is also evident that all work is not complete. Significant gains appear imminent through additional effort to capitalize on the repetitive coverage of land areas by ERTS for purposes of change detection and obtaining even better land use classifications. There is the need for better documentation of the procedures used to obtain land use classifications and those used to combine this information with other data, such as that on the physical characteristics of the land resource, that is, soil and socioeconomic data.

Figure 9. Same type product as Figure 8, except that heavy industrial areas (pink) in Los Angeles are extracted.

Land use classification systems such as the system defined by U. S. Geological Survey Circular 671 have been tested to determine what information can be provided with aircraft and what information can be provided with spacecraft, but future work is needed to define how the two sources of remotely-sensed data can better complement one another However, it is obvious at this point that they do in fact complement one another.



AIRCRAFT (U-2) PHOTOMAP 1970

STANDARD LINE MAP 1969

SPACE (ERTS) IMAGE MAP 1972

Figure 10. 1:250,000 scale **maps of** the **Phoenix, Arizona, area.**

In conclusion, it is feasible for the first time to acquire information about the use of land rapidly and economically over large areas. The fact that ERTS data have been shown to be radiometrically constant has allowed this to happen, and has allowed the use of machine processing. These are indispensable capabilities that provide information needed to use our land use resources wisely.

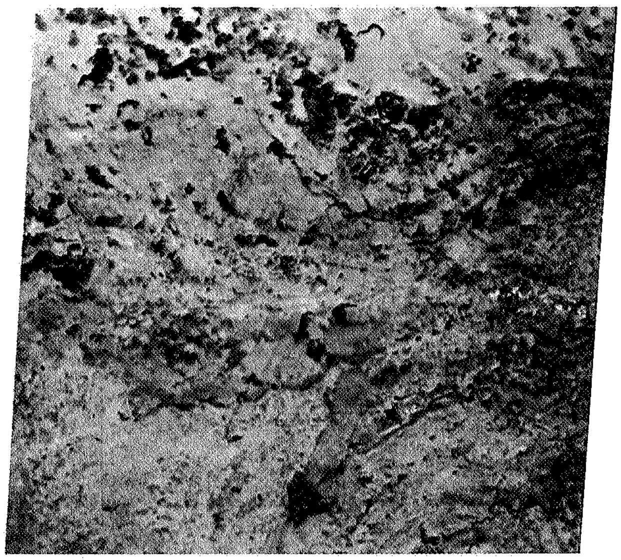
MINERAL RESOURCES, GEOLOGICAL STRUCTURES, AND LANDFORM SURVEYS

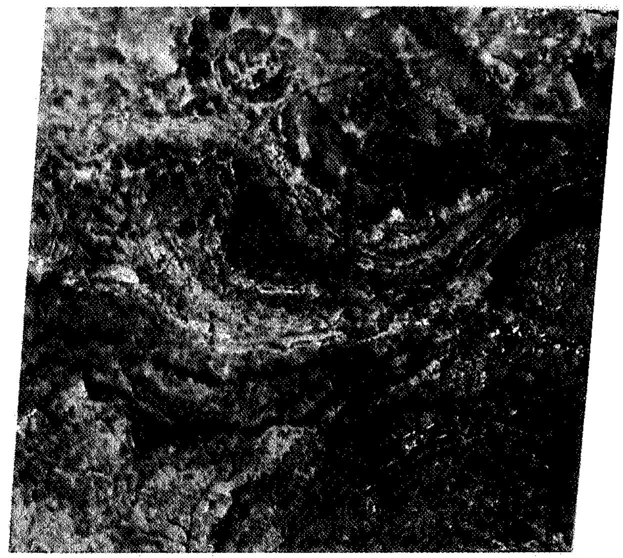
Nicholas M. Short
NASA, Goddard Space Flight Center
Greenbelt, Maryland

The results of the geological investigations reported at the March 1973 ERTS Symposium could have been summarized as interesting. Now, as the December 1973 Symposium closes, the achievements of the past eight months are realized to be not only interesting, but useful. In October 1973, thirty-nine United States investigators reviewed their work before a NASA Geology Discipline panel. Sixteen of these, and an additional ten foreign investigators, have presented papers here. This summary of current significant results draws heavily on the several geology sessions held during this Symposium, and also includes results from the October review. The subjects will be discussed in the following sequence: map making, landforms analysis, structural geology, lithologic identification, mineral exploration, and engineering and environmental geology. (See NASA/GSFC X-650-73-316, "Earth Observations from Space: Outlook for the Geological Sciences," Nicholas M. Short and P. D. Lowman, Jr.)

Some strong opinions have been expressed that geology has only a one-shot opportunity to obtain useful data from ERTS; that is, repetitive coverage is unnecessary and redundant. Figures 1a and 1b should convince the reader that geologists can make effective use of temporal data. The area shown is in the southern part of South Africa and is under study by J. Grootenboer of Spectral Africa (Pty) Ltd. The scene in Figure 1a was obtained during the winter when most of the vegetation, including grasses, was dormant. Despite the fact that the region contains very intensely folded rocks and some intrusions, the major rocks are barely discernible against the background of the brownish coloration imposed by the vegetation. However, the identical region (Figure 1b), when seen in the late spring, reveals a striking amount of new information. The differential distribution of vegetation, in varying degrees of ripening, enhances differences in the rock unit with which the grasses and trees co-associate. This seasonal effect proves to be a great aid in defining and separating units for mapping purposes.

How well can maps be made from ERTS data? Figure 2a shows part of the published geological map of the state of Wyoming at 1:1,000,000 scale. The region depicted stretches from the southern end of the Bighorns through the westward-trending Owl Creek Mountains. The mapped units are stratigraphic, specified by their relative ages and by their characteristic rock types—information that is obtained by field work on the ground and by analysis of the individual rock units. Using the ERTS imagery reproduced in Figure 2b, R. S. Houston of the University of Wyoming produced the map appearing in Figure 2c by straightforward photointerpretation based on recognizing differences in tone and topographic expression. The result is a map that locates distinguishable surface units and marks their contacts; the units are not, however, identified as to their actual ages. Comparison of the maps in Figures 2a and 2c demonstrates an overall strong correspondence between the ground-based and ERTS products. In fact, some of the ERTS-drawn contacts, after field checking, are located better than before. ERTS permits more detail in the mapping of facies and formational subunits (members) in certain parts of the region, particularly in the Casper Arch-Powder River Basin, than previously attained from conventional methods (Figure 2d).





Two views of an area just west of Johannesburg, South Africa.

Figure la. September 1972 scene in which the geologic features in the terrain are masked by the dormant vegetation of the Southern Hemisphere spring.

Figure lb. Same area in December 1972 during the Southern Hemisphere summer; where vegetation has aided in emphasizing differences in rock units.

The Wyoming map is an example of results for an area where mapping has been fairly complete and detailed. There are sections of Africa, by contrast, where mapping is still relatively primitive. Figure 3a is a color composite mosaic of an area in South Africa and South West Africa lacking either good large- or small-scale maps- Interpretation of ERTS imagery has led the investigator, R. **P.** Viljoen of Johannesburg Consolidated Investment Co., to draw the more detailed map shown in Figure 3b. The area shown is noted for copper-nickel mineralization. Now that the regional features are more accurately represented on a map, future exploration for these and other metals should be more effective.

Another function of map making that is likely to benefit from ERTS is map revision or editing. Many of the small-scale maps of the world, even in the United States, often have extensive inaccuracies. The example shown in Figure 4a is a case in point. This region, part of the Hammersley Range in western Australia, consists of large instrusions or batholiths of granitic rocks surrounded by metamorphic rocks. Note particularly the large intrusion labeled A in the ERTS image (Figure 4a). When checked against its counterpart on the 1:2,000,000 tectonic map of Australia (Figure 4b), it can readily be seen that the real structure is almost twice as wide as indicated on the map. This type of error is a great problem to the explorer trying to plan a field program when he discovers the real world has a much different representation.

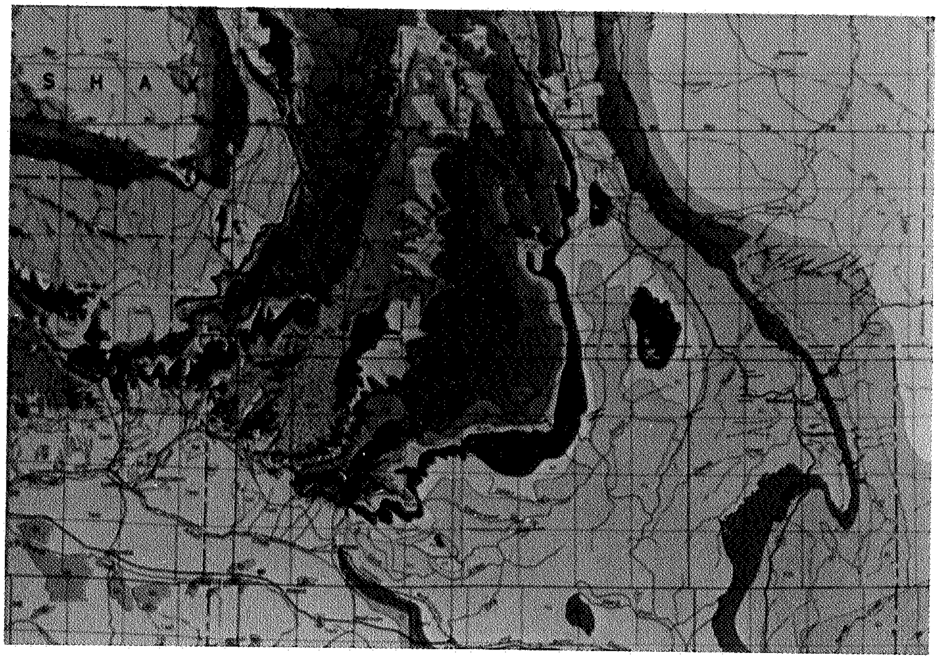


Figure 2a. Portion of the geologic map of Wyoming covering the southern end of the Bighorn Mountains, the north end of the Casper Arch, and small sections of the Powder River (right), Wind River (lower left), and Bighorn (upper left) basins.

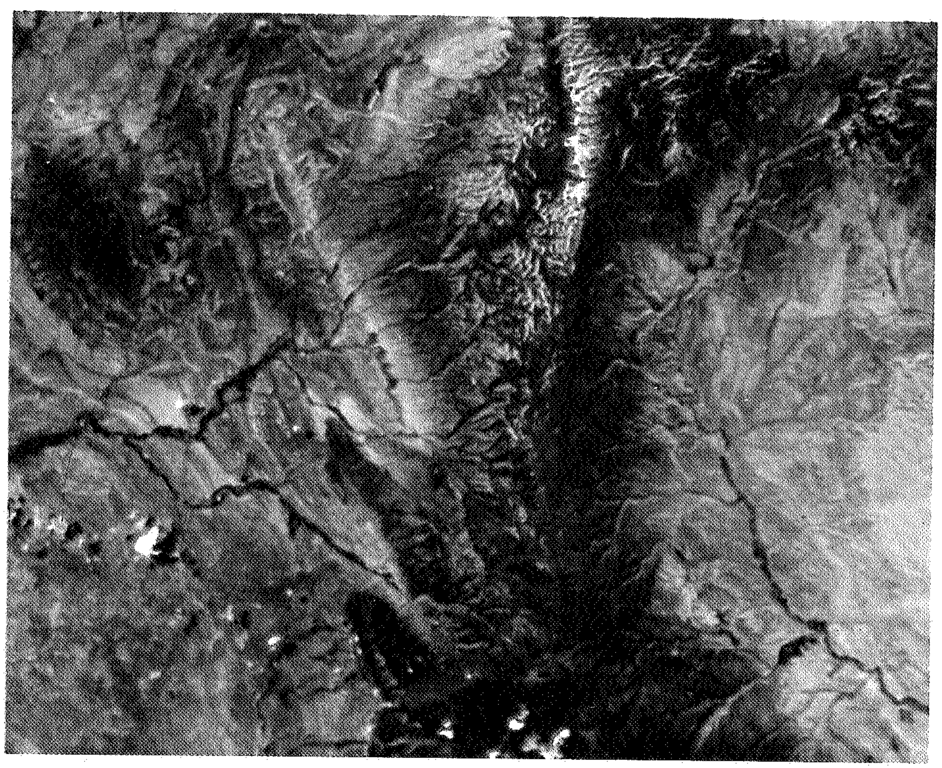


Figure 2b. Same region shown in (a) as it appears in an enlarged part of an **ERTS** frame.

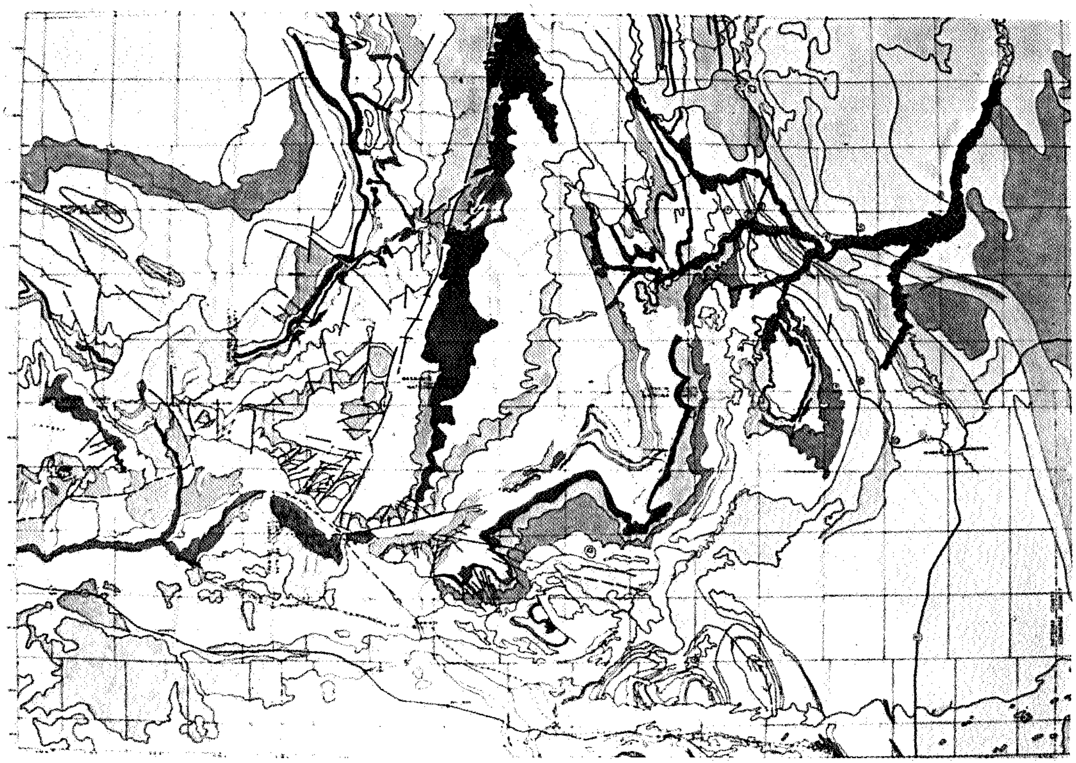


Figure 2c. Rock units map of the region shown in (a) produced entirely from photointerpretation of the ERTS imagery of (b).

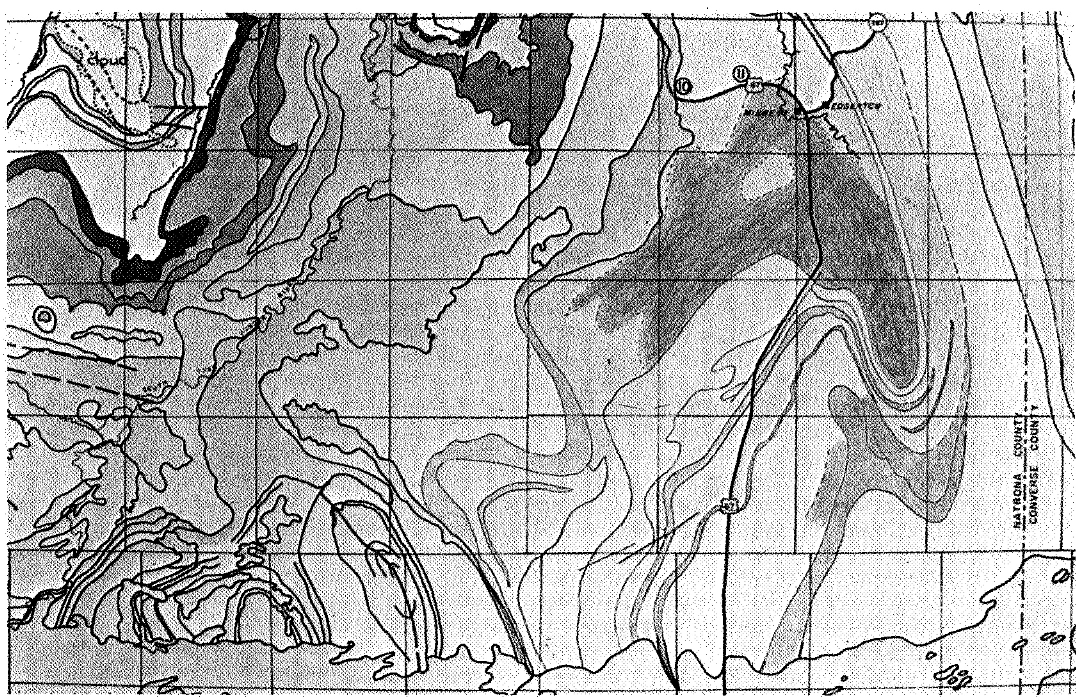


Figure 2d. Larger scale map of a section of the image shown in (b) giving details of rock units in the Casper Arch-Powder River basin area.

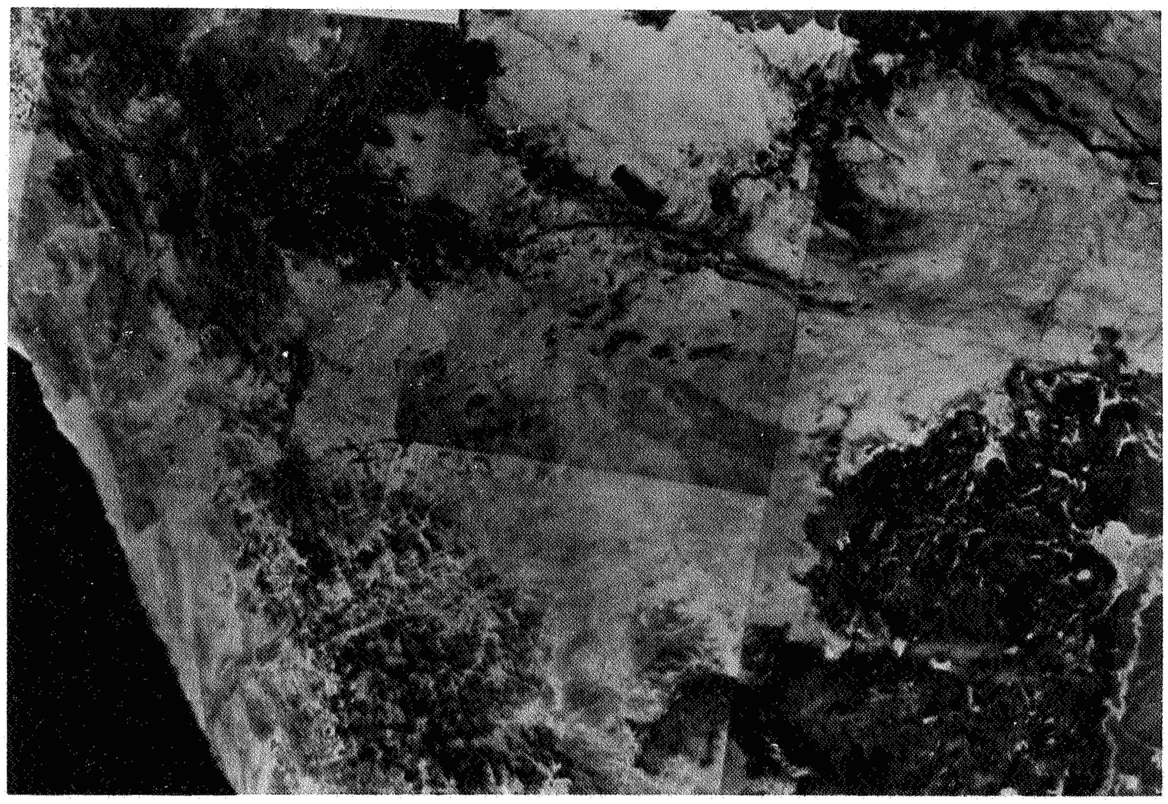


Figure 3a. Color composite mosaic of a region in Africa that includes part of western South Africa (below the Orange River) and a small part of southwest Africa to the north (area shown represents about **483** kilometers east-west).

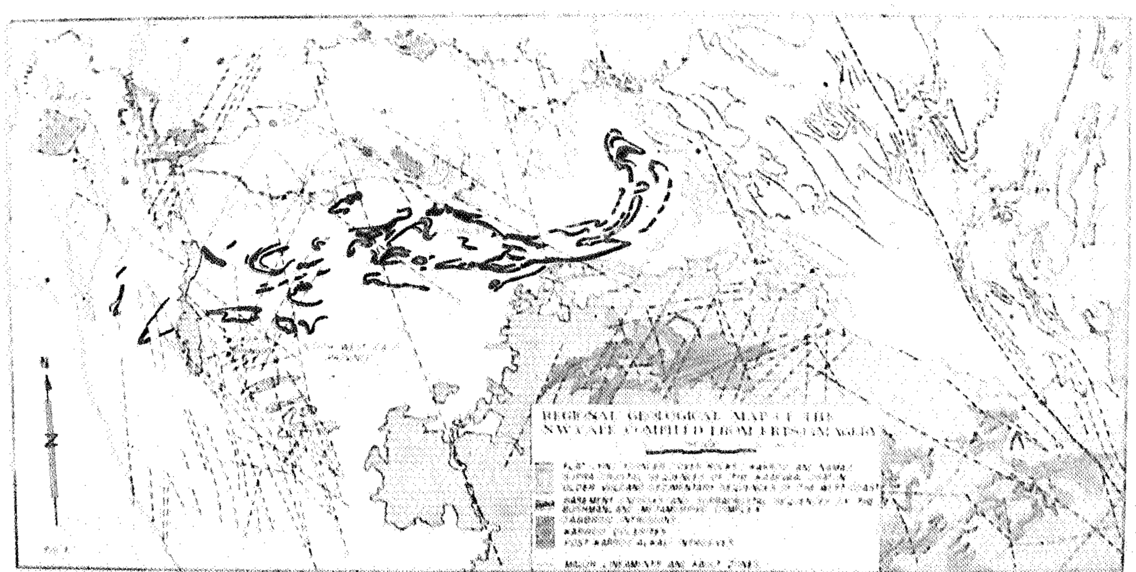


Figure 3b. Geologic map compiled primarily from **ERTS** data for the region shown in (a).

Figure 4a. ERTS red-band image of a region in western Australia just south of the northwest coast near Port Hedlund, showing several large igneous plutons cutting into metamorphic rocks.

Figure 4b. Section of the tectonic map of Australia corresponding to the area shown in (a). (Compare the sizes and shapes of the light-colored intrusives in (a) with their counterparts in (b).)

What does this mean to geologists? The basic tool for carrying out mineral exploration and doing other kinds of practical work has always been the geologic map. Whenever major improvements in the accuracy and completeness of essential maps can be obtained, both the planning of exploration and the eventual field work can be made substantially more efficient. Several investigators have stated that ERTS images are potentially capable of increasing the rapidity of mapping and reducing the corresponding costs by as much as 30 to 50 percent in unexplored regions. Mapping remains effective at ERTS enlargement scales of 1:250,000 or larger.

The subject of landforms surveys and analysis will not be treated here except to point out that most of the reported results were of a scientific nature. They are of interest, of course, in a practical sense as well, as studies of the movements of great sand deposits (by E. D. McKee and **C.** B. Breed of the U. **S.** Geological Survey) or the location of extensive glacial deposits (Houston) have shown.

Turning next to the third category, structural geology, it should be noted, first that the main topic during the March 1973 ERTS Symposium was linears, or lineations. This situation still exists in that many investigations continue to emphasize these features. However, now the investigators have focused their attention on some relevant questions: What is the nature of these linears? How many different types show up in ERTS? How do the linears appear when seen close-up on the ground? How well can they be mapped in ERTS imagery? What do the linears mean in terms of practical implications? Answers to these questions are illustrated by just three examples.

Figure 5a is a sketch outline of the Laramie Range in southeast Wyoming. This large uplift has been practically unmapped insofar as major fractures and other linears are concerned. Figure 5b depicts the results of several days of examination of ERTS imagery by **D.** L. Blackstone of the University of Wyoming. The increase in the number of fractures now recorded has been dramatic. What does this imply in a practical sense? Blackstone has found that the most frequent orientations of these linear features happen to define azimuthal trends that are very close to those of the off-the-uplift anticlinal oil traps in the adjacent basins. This would indicate that the anticlines are being controlled by the distribution of basement fractures, now determined for the first time from the large sample of the basement exposed as the uplift.

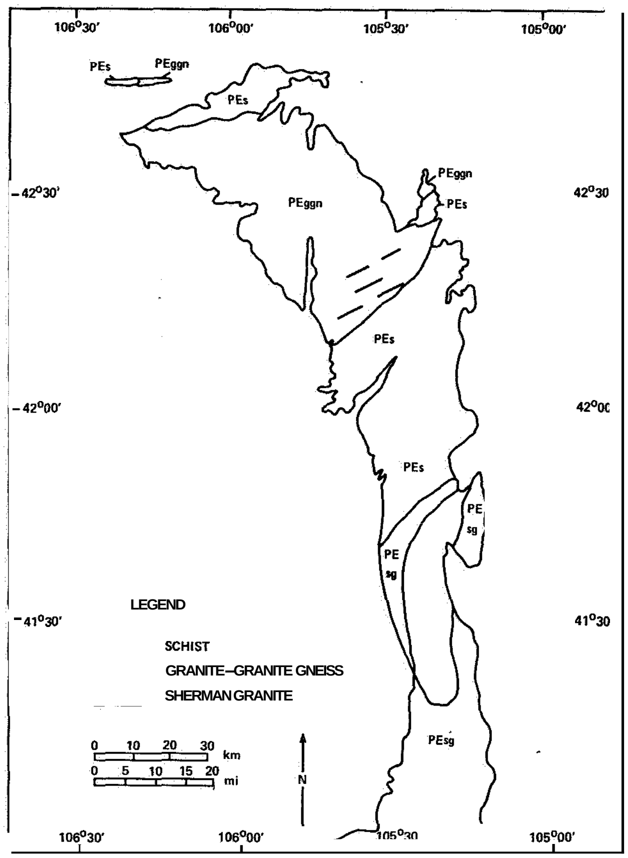


Figure 5a. Outline of the Laramie Range in Wyoming denoting the principal mapped rock units. (Note almost total absence of identified rock lineaments.)

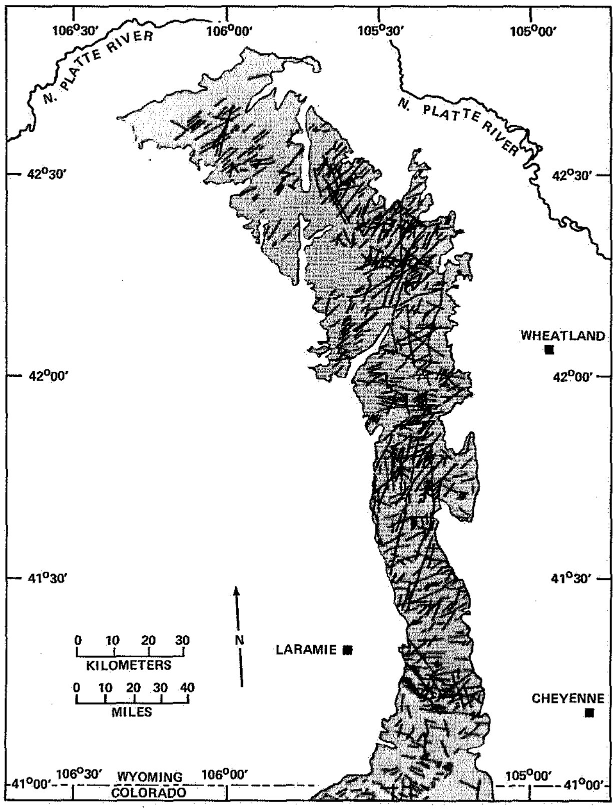


Figure 5b. Map of the major lineaments detected in ERTS imagery covering the Laramie Range.

The next example occurs in north-central Arizona, just south of the Holy of Holies for geologists – the Grand Canyon. It might be assumed that a region such as this would have been thoroughly mapped in terms of fractures. But it obviously has not been mapped as judged by the ERTS-produced map of linear features (Figure 6) made by A. F. H. Goetz of the Jet Propulsion Laboratory. This map contains a much higher density of fractures, including joints, than found on maps made by other methods. This increase, as discussed below, has important implications for ground water prospecting.

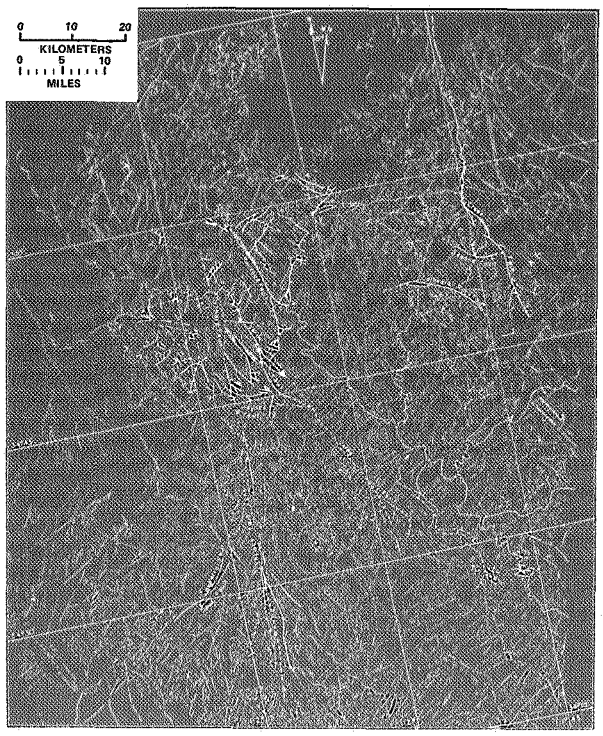


Figure 6.
Fault and lineament map of a region of north-central Arizona south-west of Flagstaff, made from interpretation of ERTS images. Solid lines represent previously known linears (mostly faults); dashed lines are linears found in the ERTS images (includes both faults and joint systems).

It is possible to use computer processing to extract more data about linears than is evident in the imagery. Goetz subjected a scene to a computer-controlled stretching process that serves as a contrast-enhancement, followed by passing the computer product as an image through an optical space filter. This brings out a great deal of new information not readily visible in an ERTS transparency. When applied to an area in northern Arizona, southwest of Flagstaff, the technique discloses numerous close-spaced, criss-crossing linears that correspond to surface traces of joints as well as drainage patterns (Figure 7). In another area south of the Grand Canyon, Goetz noticed a distinctive tonal anomaly which, upon field investigation, proved to be sandstone units within the Kaibab limestone. His map of the units, along with newly discovered linears (Figure 8), suggested that the sandstone units might contain concentrated water in perched zones associated with the fractures cutting the sandstones. Following his recommendations, drillers located usable water at the sites marked as “test holes wet” on Figure 8 – these are the first producing wells in that area. This discovery has real significance to the local ranchers for the watering of cattle.

At the March 1973 Symposium, Y. W. Isachsen of the New York State Geological Survey showed an ERTS mosaic of eastern New York including the great Adirondacks Mountains uplift. The view from space clearly defined the large number of valleys within the Adirondacks that tended to be straight, as though controlled by linears. At that time he displayed an updated fractures map for the region in which new linears were marked by dotted lines. He recognized then, however, that many of the linears were not real in the sense of being structural expressions and wondered how many were spurious artifacts of natural or man-made character. During the present Symposium, Isachsen reported on his work in checking these linear features against recorded map information and actual visits in the field. The breakdown of different types of

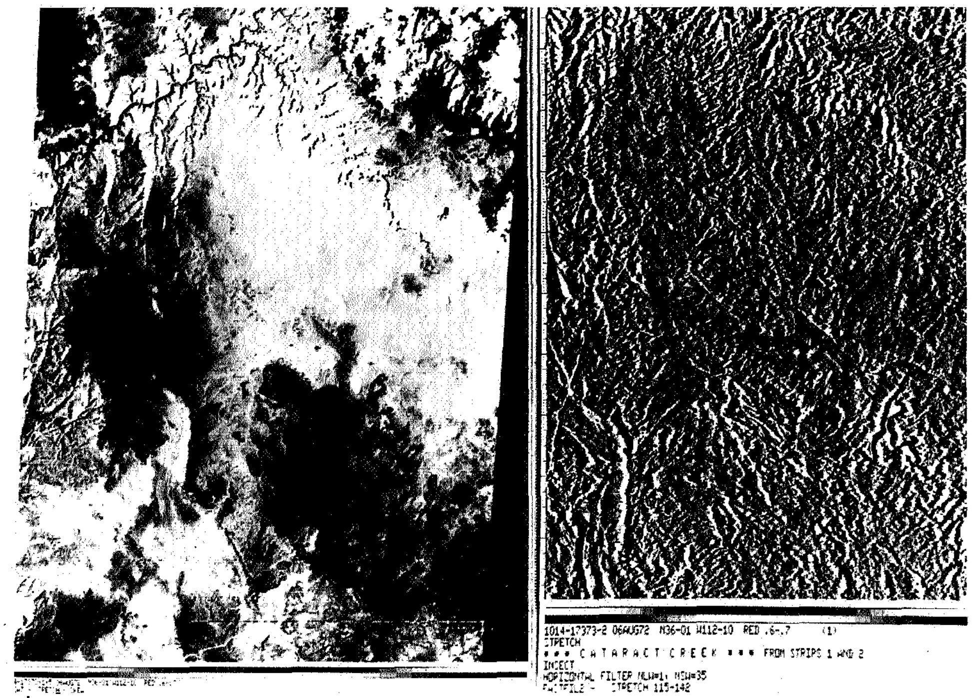


Figure 7. On the left is part of an ERTS image (red-band) of a section of the Coconino Plateau south of the Grand Canyon; this image has been enhanced through computer processing to increase contrast by stretching. The figure on the right shows most of the same area seen to the left after the enhanced image is further processed by optical spatial filtering.

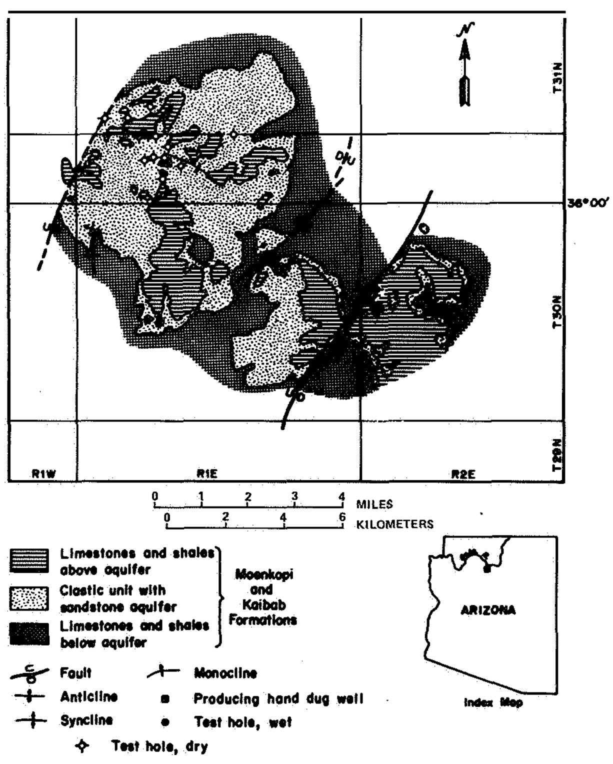


Figure 8.
Sketch map of a small area of the Coconino Plateau showing rock units and linears recognized in a reprocessed ERTS image; units were then identified as to age by subsequent field work.

linears resulting from this analysis is given in Table 1. Many linears have turned out to be stream valley segments, alignments of vegetation, fence line effects, and the like; others remained geological in nature, as subsequently confirmed for some when examined on the ground. This is evidenced by the two examples of subtle linear features having the prominent topographic expression shown in Figures 9a and b.

Table 1
Field Identification of Linears in New York State.

Cultural "linears"	20
Linears parallel to lithological trends	51
Straight segments of stream courses	96
Straight stream valleys	27
Winding streams	7
Elongate lakes or straight shorelines	7
Ridge crests	3
Edge of topographic high or aligned segments of same	5
Alignments of vegetation:	
Dark vegetation strips (may be valleys)	30
Vegetation border	7
Combinations of one or more of the above	57
Unexplained	125
Total	435

In addition to straight lines, ERTS can "see" various kinds of circular features, or closed anomalies as they have been called. Some of these are now known to be related to igneous intrusions, an important observation because these are often associated with ore deposits. Others are related to different phenomena. Figure 10 covers an area in south-central Oregon; Crater Lake is seen near the middle left of the ERTS image. For the very first time, Oregon geologists have noticed something that is strikingly obvious in the ERTS image – in fact, perhaps the most distinctive single structure in the entire state – that appears as an elliptical ring (some 40 by 48 kilometers in dimension) outlined by heavy vegetation. This ring has tentatively been identified as a volcanic feature, presumably a ring dike, along the perimeter of which are cinder cones and flows. This structure, as such, was totally unknown before ERTS.

Figure 11 exemplifies a truly serendipitous discovery made through the aid of ERTS. While searching for frames from another part of the world, a feature in southwest Brazil (about 644 kilometers from Brasilia) was observed, which stood out as a large bull's-eye circumscribed by a second or double ring. The inner ring is about 21 kilometers in diameter while the outer ring exceeds 40 kilometers in diameter. Previously, Bevan French of the U. S. National Science Foundation had received samples from this structure, called the Araguainha Dome by the Brazilians. He identified rocks from the structure as shocked, which confirms it to be an impact crater. What no one knew prior to looking at the ERTS image was that the structure is about twice as wide as reported by geologists after field studies. As such, the Araguainha Dome (actually an astrobleme) ranks now as one of the largest of its kind on earth.

Figure 9a. Large elongate valley in the Adirondacks of New York.

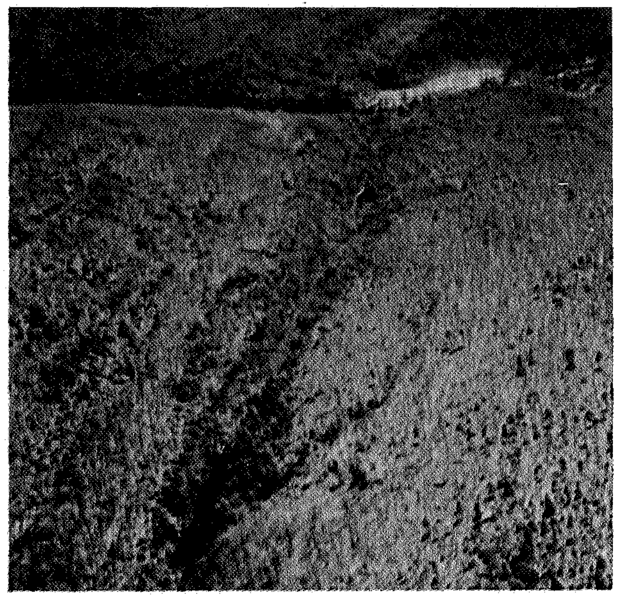


Figure 9b. Small, straight depression in flat uplands of the Catskills of New York. Both topographic features show up as visible linears in ERTS imagery.

In the matter of rock identification, ERTS data has generally proved unreliable. Ordinarily, rock types are identified by determining rock composition from hand specimen and microscope work. ERTS can only provide information about rock color and relative reflectance, both of which are poor criteria, often fallible and misleading, by which to identify and classify rocks. In some instances several obvious rock types, such as basalt and granite, can be recognized in ERTS imagery, mainly from their topographic expression, distinctive tones, and contextual relations. But there are some new tricks to be learned. The most promising technique consists of ratioing pairs of MSS bands and reproducing images or computer printouts from the ratio signals. Different combinations of bands can be chosen but a common ratio is that of band 5 to band 7. An example of the resulting enhancement is shown in Figure 12. **A** red sandstone in central Wyoming, the Triassic Chugwater Formation, is made to stand out in the band ratio-processed ERTS image that covers most of the Wind River Basin. This work, done by R. Vincent of the Environmental Research Institute of Michigan (ERIM) has indicated that iron-rich rock units can be separated from other units by selective ratioing; work by Goetz and by L. C. Rowan of the U. S. Geological Survey yield similar conclusions.

Next, ERTS will be evaluated as a means for finding minerals and petroleum. At the Summary Session of the March 1973 ERTS Symposium, W. Fischer and E. Lathram of the U. S. Geological Survey described their new model for the distribution of metallic ore deposits in the western Cordillera in Canada and Alaska. In earlier concepts, ore deposition was related to the general trends of folded sedimentary belts and associated intrusives which, in turn, were influenced by the distribution of geosynclines. Using Nimbus meteorological satellite imagery, Fischer and Lathram have observed prominent linears that they presume to be major crustal fractures running northeast and northwest. Because many known ore deposits are located close to these linears, Fischer and Lathram conclude that the fractures are the primary control in localizing mineralization. According to Lathram, ERTS images provide better definition of these linears and support the hypothesis. Since March, there has been a new report of porphyry copper deposits in central Alaska northeast of Fairbanks. On an ERTS image (Figure 13), several of the intrusives have been recognized and are seen to lie along or near a regional linear. While there has not yet been an ore deposit found directly through the use of ERTS, this Alaskan example confirms the validity of one approach to exploration, namely, that recognition of controlling linears, and sometimes of the deposits themselves, is possible in the ERTS imagery.

The principle has been stated many times that ore deposits tend to be controlled during emplacement by fractures in the crust. The work by D. H. Knepper et al. of the Colorado School of Mines offers a strong demonstration of this. His group chose to look at an area in central Colorado famed for its large number of metal-producing mines. These are located on the snowcovered winter scene of the area taken by ERTS (Figure 14). Aided by the snow enhancement, these investigators identified numerous linears (Figure 15), many of which are new discoveries. Some of these linears are nearly straight but others are curved or arcuate. Most are assumed to be large fractures; the arcuate ones are probably related to underlying intrusions that have cracked the country rock above. Knepper's group has contoured the relative densities of these fractures. Circles 14.5 kilometers in diameter are drawn (Figure 15) around areas of highest fracture density. Of the ten circles on the ERTS image, five coincide with major mining districts, indicating a strong correlation between extensive fracturing and the localization of minable ore deposits. The remaining five, which do not correspond to known mining districts, should constitute potential targets for exploration.

There is another way in which geologists and prospectors commonly search for signs of ore at the surface. This involves looking for surface alteration products, usually gossan or iron rust (hydrated iron oxide) formed from the breakdown of iron pyrites. It now appears that ERTS can search for telltale signs of iron alteration on a regional basis by means of a special processing technique. The method, developed by Goetz, uses the band ratio images previously described. After enhanced black-and-white images representing several ratios are obtained, they are passed through an optical instrument that produces color composites. Various renditions of these ratio color composites can be produced, depending on the band ratios selected, enhancements chosen, and different color combinations attempted. Rowan has applied this technique to the famous Goldfield mining district of central Nevada. On a standard color composite (Figure 16a), there is no obvious surface alteration anomaly around Goldfield. But after trying several combinations of bands and filters, Goetz and Rowan extracted the result shown in Figure 16b. **As** is customary, the sparse regional vegetation is shown as red, many of the rock types appear in greenish to bluish tones (some improved differentiation of rock types, for example, rhyolites from basalts, was achieved), and iron-rich surface alteration products are rendered in shades of brown to yellow-brown. In the immediate vicinity of the Goldfield deposits, the ratio color composite reveals a distinct circle or halo of brown tones – presumably a now-visible manifestation of gossan or a similar alteration effect. This is likely caused by an aureole of altered sulphides associated with the gold and silver ores. Other parts of this scene show similar signs of hydrothermal alteration; these can be color-coded in an overlay which then provides a map extract of specific locations for exploration.

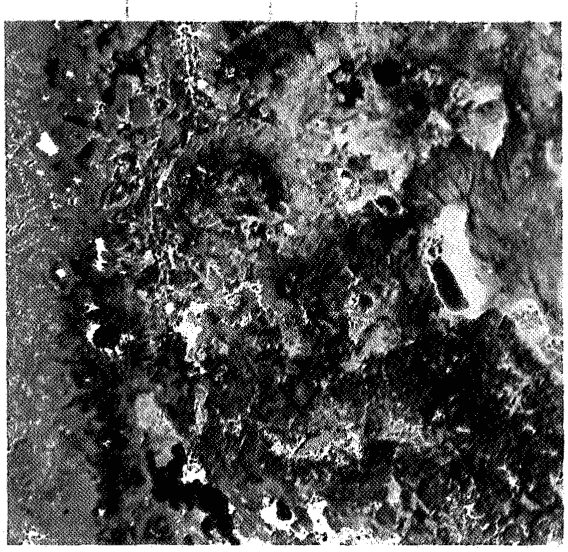


Figure 10. ERTS view of south-central Oregon, with the high Cascades on the left (Crater Lake at left center), Klamath Lake near bottom, Newberry Volcano (center top), and a large elliptical structure below it.

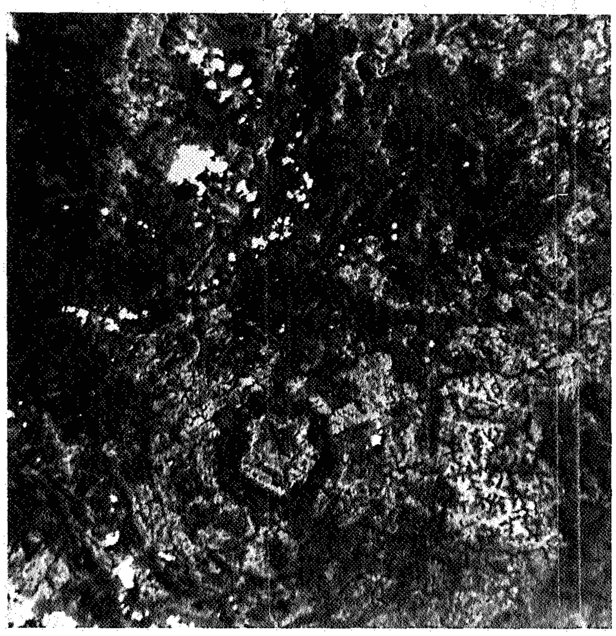


Figure 11. Enlargement of part of an **ERTS** frame showing the double ring structure, known as the Araguainha Dome, southwest of Brasilia in Brazil. This feature, about 40 kilometers in diameter, has now been identified as an impact crater scar.

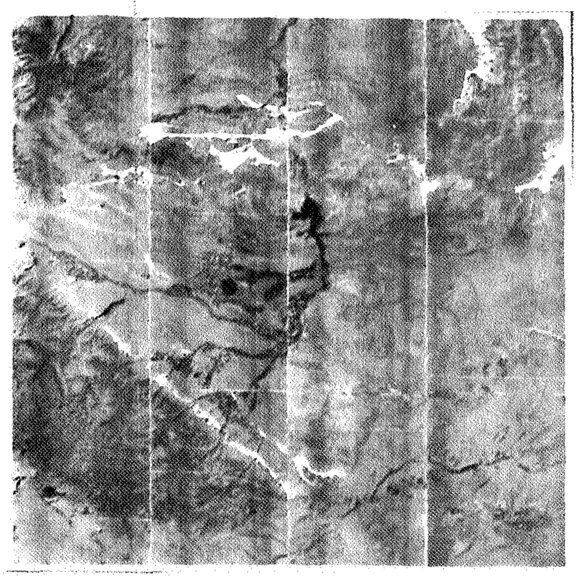


Figure **12.** Computer-enhanced ERTS image of the Wind River Basin and surrounding mountains in central Wyoming. In this rendition, the ratio of **MSS** band 5 to 4 causes the red beds of the Triassic Chugwater Formation to appear in very light, whitish tones.

Figure **13.** A part of a mosaic of red-band ERTS images of central Alaska including Fairbanks. The great DeNali Fault (arc across the middle of the picture) marks the northern boundary of the Alaska Range. In this area several porphyry copper intrusives have recently been discovered with the aid of space imagery.

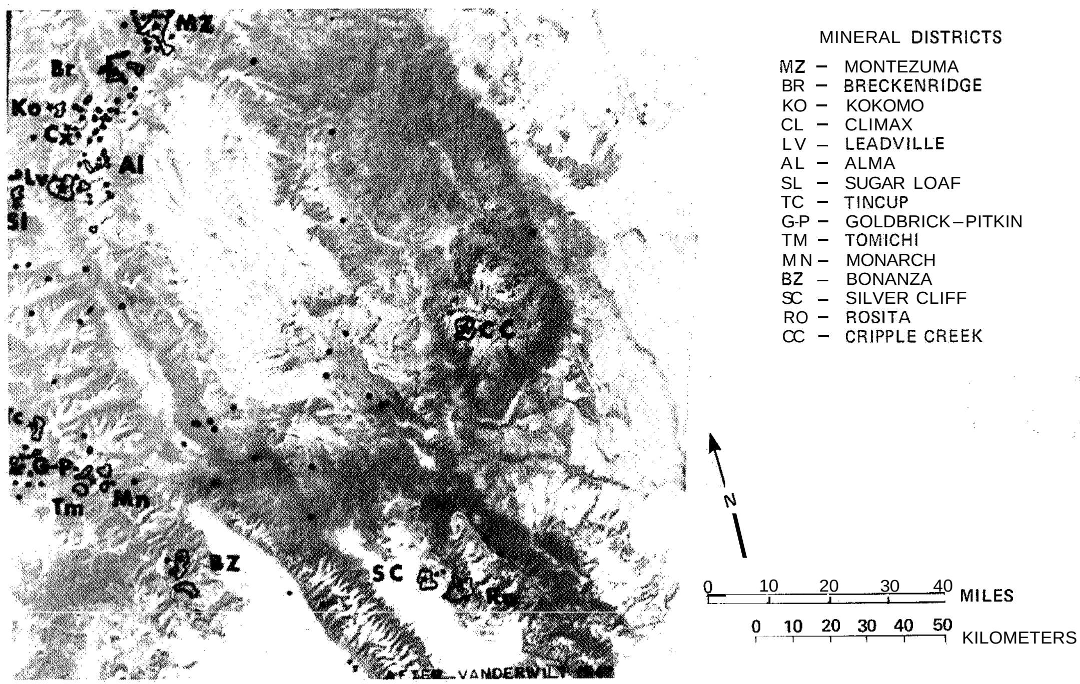


Figure **14.** ERTS frame showing the central Colorado mineralized district in the Colorado Rockies west of Colorado Springs. Major mineral districts are labeled.

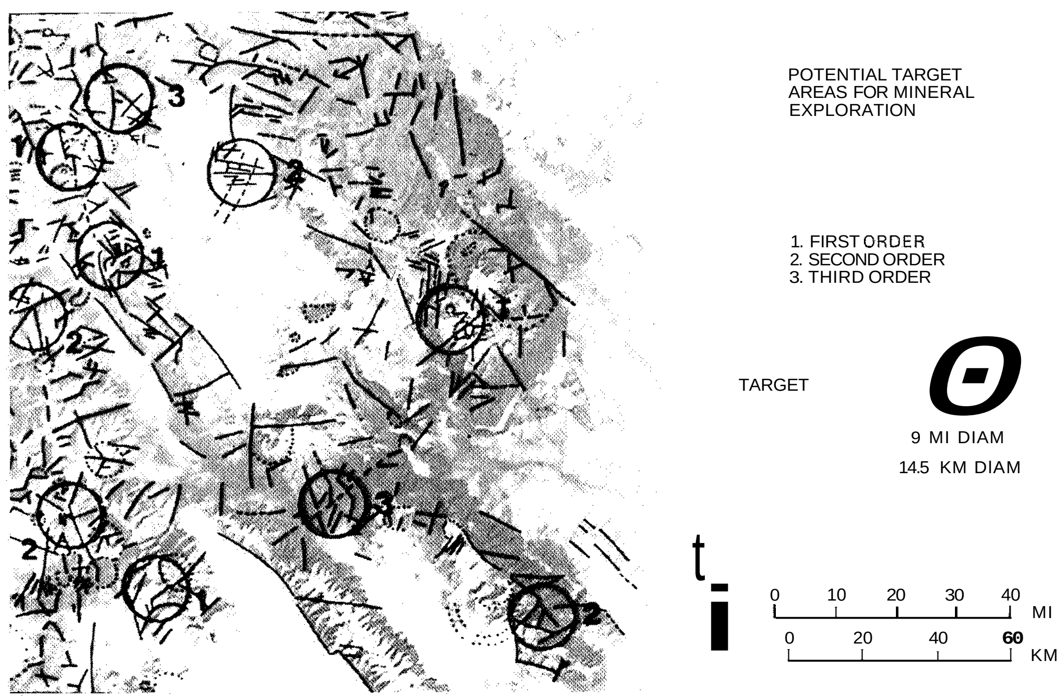


Figure 15. Snow-covered scene in Figure 14. The principal linears recognized in the ERTS imagery have been traced as black lines. Areas of highest densities have been circumscribed. Some of these correspond to well-known mining districts.

Figure 16a.
Modified color composite made from single bands 4, 5, and 7 for an area in central Nevada that includes the Goldfield mining district (arrow).

Figure 16b.
Color composite prepared from three separate band ratios. Crosses mark areas of hydrothermal alteration, mainly hydrated iron oxide (gossan); the Goldfield gold and silver deposits are ringed by a narrow alteration aureole that is almost invisible in the standard color composite.

Perhaps the best way to use ERTS to search for minerals is to couple this surface alteration enhancement technique with the method(s) for linears analysis now available. This provides a powerful two-pronged attack aimed at pinpointing possible new deposits worldwide. However, ERTS alone still cannot substitute for the important conventional methods of geophysical and geochemical field measurements, followed by drilling.

ERTS shows great promise as an exploration tool in the search for hydrocarbons. Summary papers given by J. Everett of Earth Satellite Corporation and **G.** Petzel of the Eason Oil Co. on their exciting studies in the Anadarko Basin of Oklahoma and by J. M. Miller of the University of Alaska, referring to the observation made by Lathram on possible extension of the North Slope-Prudhoe Bay fields in Alaska, indicate the kinds of surface features that afford clues to the presence of petroleum. One additional example supplements this. The area shown in this ERTS image (Figure 17) of western Alaska, southwest of the DeLong Mountains, had been very poorly mapped prior to ERTS. In the middle of the image, numerous contorted patterns can be seen that correspond to intensely folded sedimentary rocks on the ground. This image was used to make the map reproduced in Figure 18. Such a map, with the additional detail now shown, is invaluable to oil prospectors by calling attention to a geologic setting containing structural features known, in general, to favor oil accumulation.

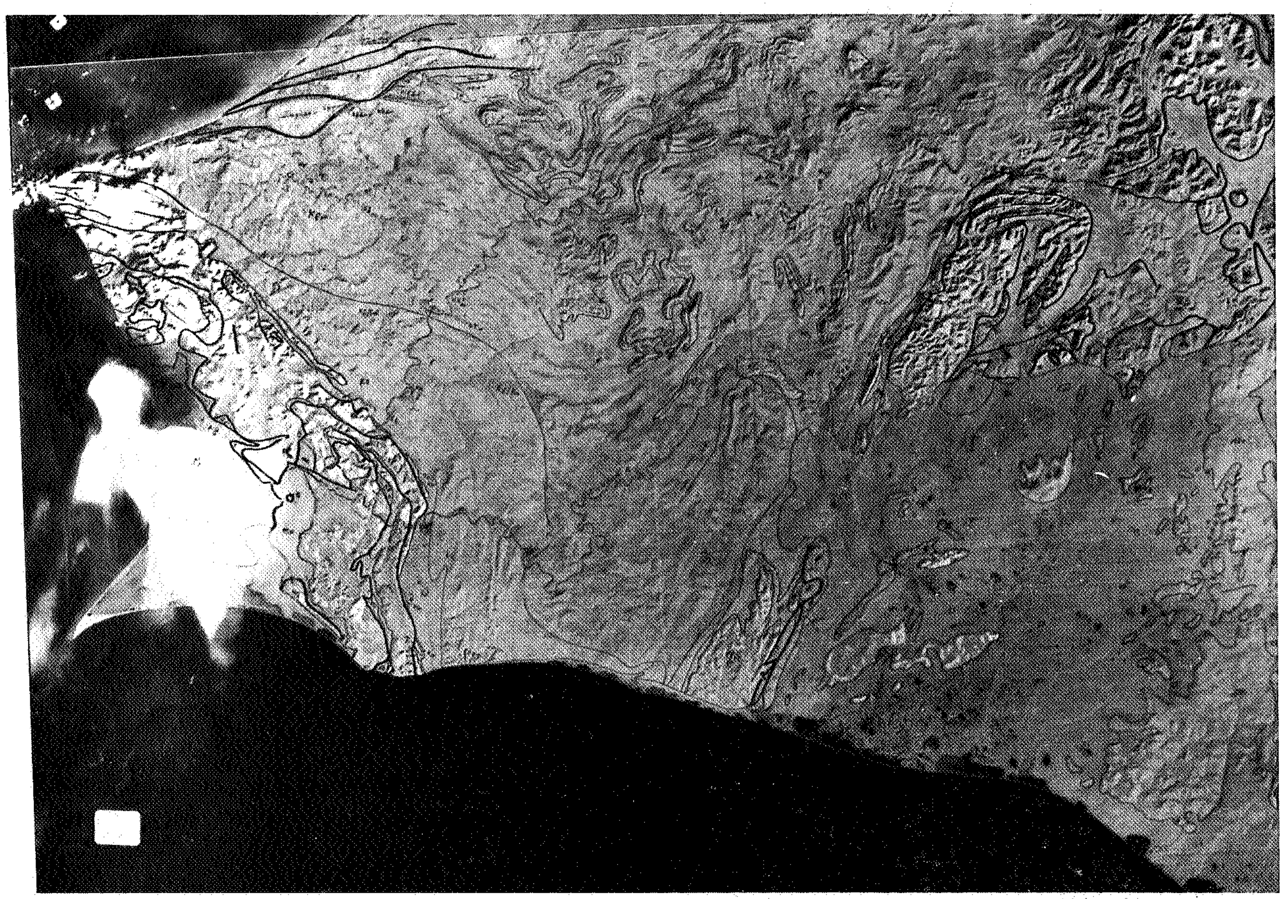


Figure 17. ERTS view of part of western Alaska around Capes Lisburne and Hope. The DeLong Mountains appear at the right. To their left (west) is a region of strongly folded sedimentary rocks, practically unknown prior to interpretation of the ERTS imagery.

Figure **18.** Geologic map of the folded region shown in Figure 17, prepared largely from ERTS imagery.

The following situation shows how recognition of just one new set of linear features can explain some hitherto puzzling aspects of known mineral deposits. Figure 19a shows a newly recognized pair of extensive linears (since then, confirmed as faults) running northwest across the folded Appalachians in Alabama out into the Allegheny Plateau over a distance exceeding 322 kilometers. The loci of known barite (barium sulphate) deposits have been plotted in this figure by J. **A.** Drahovzal of the Alabama Geological Survey. It seems evident that the linears are responsible in part for localizing these deposits. A separate plot of producing water wells also shows a close correlation, and hence, probable control. That these linears represent active zones of movement in the crust is strongly suggested by the co-association of earthquake epicenters and the linears, as seen in Figure 19b.

Two examples will suffice to illustrate the practical use of **ERTS** data in picking out potential geologic hazards as well as correlating previous happenings with new discoveries of geologic features. The first, discussed by Miller at this Symposium, concerns the earthquake-prone region of central Alaska around Fairbanks. Figure 20 shows the nine-frame mosaic of the mountainous areas of this part of Alaska. The Alaskan investigators, L. Gedney and J. van Wormer of the University of Alaska, have not only found previously mapped major fractures, but they have also located some new, large linears (assumed to be fault traces), including a distinctive set of shear fractures that allow the directions of stress to be deduced for the region. They have also plotted the epicenters of larger earthquakes over the last few years. Some of these clearly coincide or fall close to fracture intersections or individual linears defined from the ERTS images. At the least, this new information focuses attention on areas where now-identified linears can account for some of the seismic activity of concern to the inhabitants.

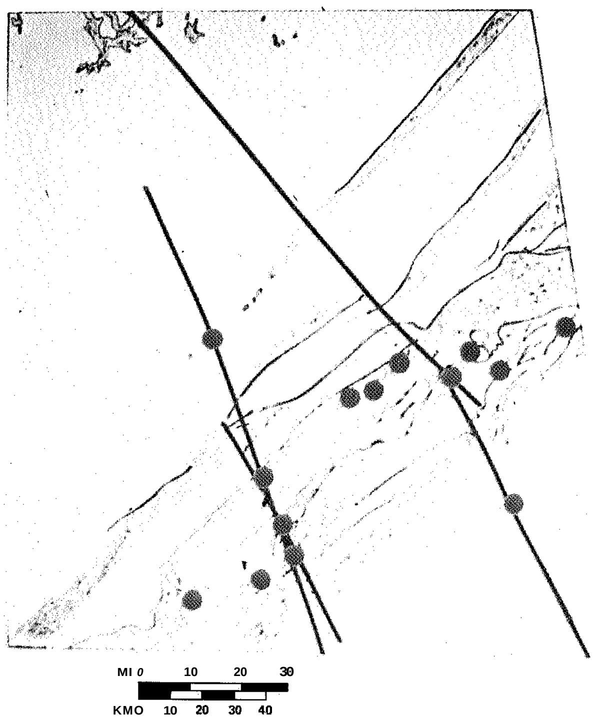


Figure 19a. Plot of two major lineaments crossing the folded Appalachians of northern Alabama (these lineaments were first detected in the ERTS imagery of that area); location of major barite mines and prospects shows a strong correlation with one lineament and some possible control by the second lineament.

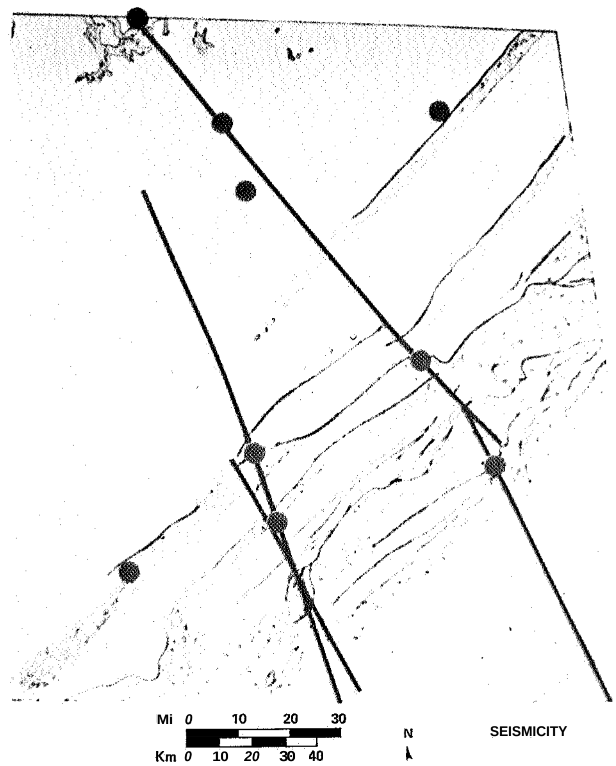


Figure 19b. Correlation of seismic epicenters with the two lineaments found by ERTS.

The other example pertains to a situation in which human lives can be at stake. Figure 21 consists of a very large-scale map of the Kings Station coal mine in southwestern Indiana. Like many mines in the area, this one is prone to occasional rooffalls of considerable danger to the miners. These commonly are tied to local fractures or joints – failure planes that may be factors in any collapse. Mapping inside the mine has spotted many smaller fractures that could influence failure. However, ERTS and aircraft images have brought to light several larger, through-running linears that may be even more serious hazards. C. E. Wier and others of the

Indiana Geological Survey report that present evidence indicates an increased likelihood of failure at intersections of the regional linears (shown as shaded zones in Figure 21), especially where these associate with clusters of smaller fractures. This new information is invaluable in planning better mine safety procedures at this and other mines in coal-producing regions of the Midwest.

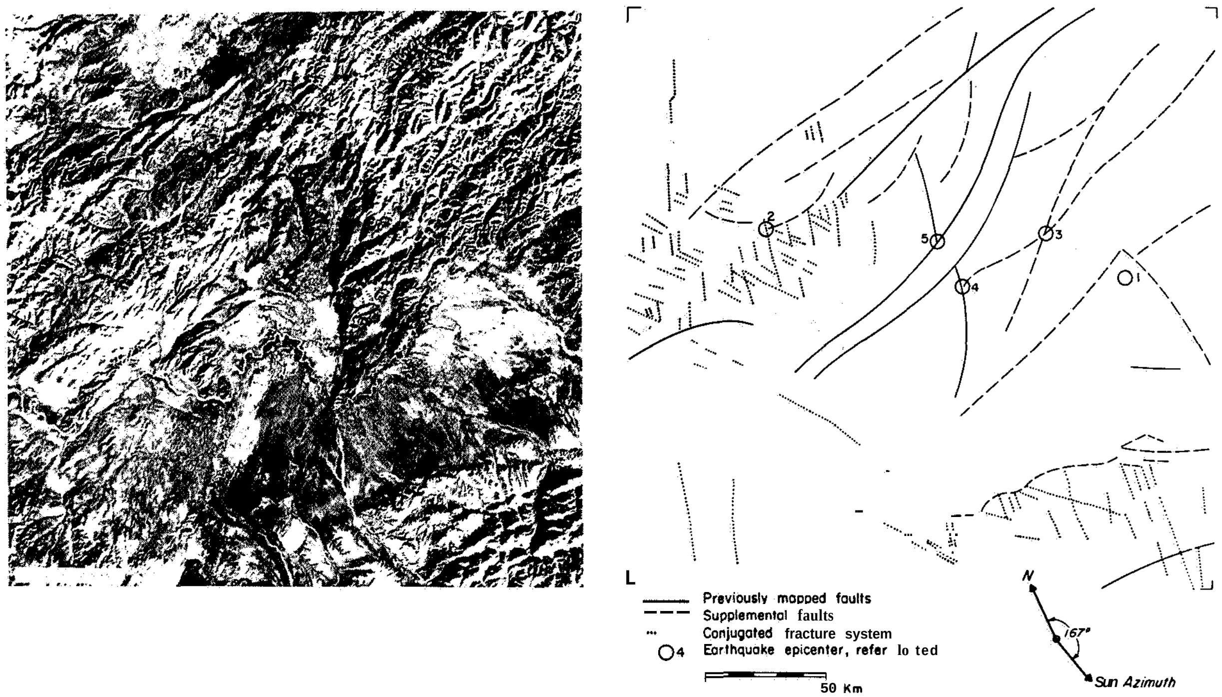


Figure 20. Nine-frame ERTS mosaic (left) of parts of central Alaska north of Anchorage. Both new and previously known faults and fractures visible in this mosaic are plotted on the right. Circles refer to intersections of these linears that also correspond to active earthquake epicenters.

The final topic to be considered is the Missouri State Geological Survey's use of ERTS for a variety of applications (Figure 22). Southeast Missouri is the largest lead-producing area in the United States. The Missouri investigators have found some new regional linears in the lead district which can now be interpreted as possible guiding channels for localizing the ore deposits. Other new linears show up in the south-central part of the state where a second major lead district has been opened up in recent years. Surface features that may relate to the concentration of barite deposits are also evident in the imagery. Imagery of much of the northern half of the state has been particularly helpful in defining the distribution and limits of moraines and other glacial deposits. This new perspective has saved several man-years of effort in planning programs to map the characteristics of these deposits. Of particular interest are the zones of moisture (shown in blue) in the flood plains of rivers in northwest Missouri. Once this

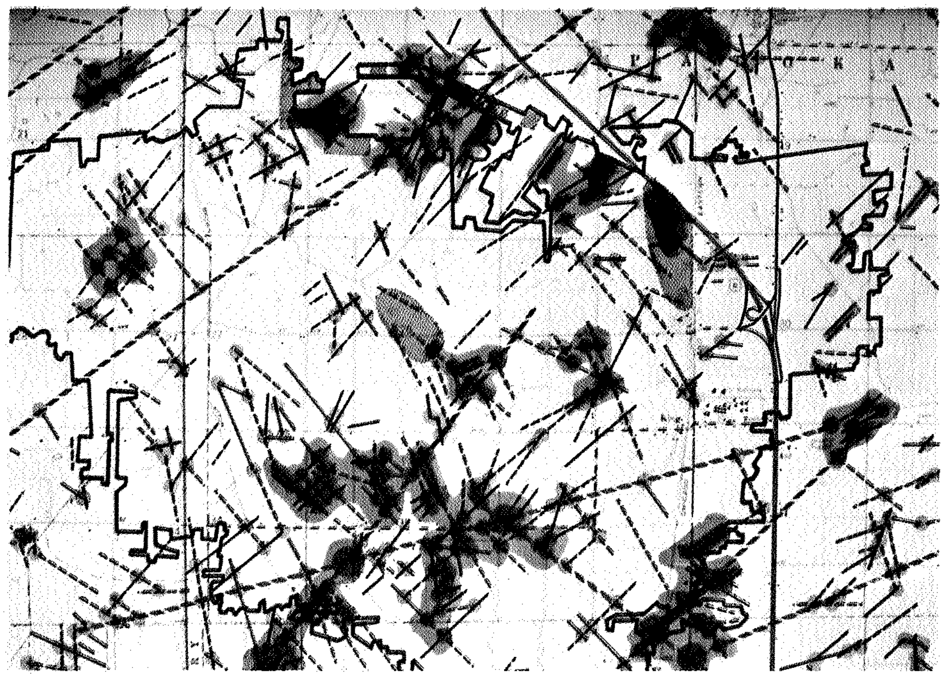


Figure 21. Large-scale map of the Kings Station coal mine in southwestern Indiana. The solid and dashed black lines represent surface- and subsurface-located fractures found during ground mapping. The dashed red lines are regional linears identified first from ERTS imagery. The orange-shaded areas are zones of high likelihood of rooffalls in the mine, as determined by higher densities of fractures **and** association with the large linears, coupled with records of earlier falls or other failures in the mine.

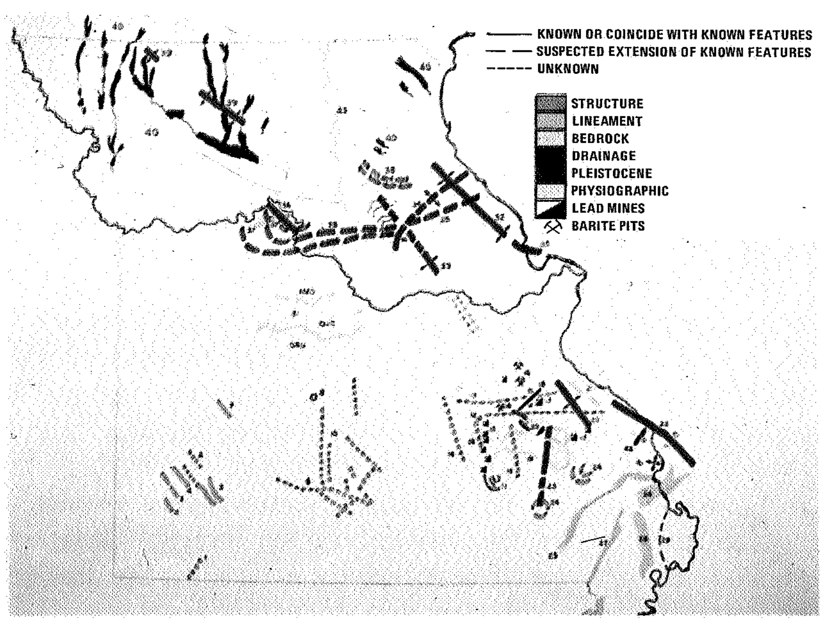


Figure 22. Plot on the outline of the state of Missouri of various geologic and hydrologic features recognized for the first time or confirmed from ERTS imagery.

phenomenon was seen in **ERTS** imagery, the investigators checked its distribution against glacial and subsurface geology maps of the region. They discovered that buried bedrock ridges under the drift served, in effect, to impede the flow of stream water penetrating the underlying stream bed, thus leading to accumulation of moisture in the surrounding flood plains.

In summary, since March 1973 there has been a shift in **ERTS** results in geology from the initial show-and-tell stage to a period in which scientific studies predominated, and now to an emphasis on effective applications having economic benefits and clearcut relevance to national needs. Many years will be spent on geological tasks resulting from **ERTS** alone: reconnaissance mapping in inaccessible regions, map revisions, regional or synoptic analysis of crustal fractures, assessment of dynamic surficial processes, systematic search for mineral wealth, use of sophisticated enhancement techniques, recognition of potential geologic hazards, and many more applications that still need to be defined.

APPENDIX A

CONTENTS OF VOLUMES I AND III

TABLE OF CONTENTS

VOLUME I

TECHNICAL PRESENTATIONS

Paper
No.

AGRICULTURE/FORESTRY/RANGE RESOURCES

MIMERAL RESOURCES, GEOLOGICAL STRUCTURE AND LANDFORM SURVEYS

WATER RESOURCES

MARINE RESOURCES

ENVIRONMENT SURVEYS

INTERPRETATION TECHNIQUES

TABLE OF CONTENTS

VOLUME III

DISCIPLINE SUMMARY REPORTS

☆ U.S. GOVERNMENT PRINTING OFFICE : 1974 0—557-168