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INVESTIGATIONS USING DATA IN ALABAMA FROM ERTS-A

Contract NAS5-21876
GSFC Proposal No. 271

Sixth Bi-Monthly Progress Report

Covering Period

August 7, 1973 - October 6, 1973

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Acting Principal Investigator
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GSFC ID UN604

Submitted to

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National Aeronautics and Space Administration
Greenbelt, Maryland

by

Bureau of Engineering Research
The University of Alabama
University, Alabama

SIXTH BI-MONTHLY REPORT

August 7, 1973 - October 6, 1973

Report of the Geological Survey of Alabama
for the project entitled

INVESTIGATION USING DATA IN ALABAMA FROM EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS-A)

Compiled by

James A. Drahovzal
Principal Investigator for the
Geological Survey of Alabama

October 7, 1973

I

INVESTIGATIONS USING DATA IN ALABAMA

FROM ERTS-A

Contract NAS5-21876

Sixth Bi-Monthly Progress Report
Covering Period August 7, 1973-October 6, 1973

The following items are those listed on page 3 of the contract document as the minimum contents of the bi-monthly progress reports.

a) Title of investigation with ERTS-A proposal number: "Investigations Using Data in Alabama from ERTS-A," Proposal No. 271.

b) GSFC identification number of the principal investigator: Dr. Harold R. Henry (UN604), Acting Principal Investigator, Dr. George P. Whittle.

c) A statement and explanation of any problems that are impeding the progress of the investigation: These are discussed in the contributions of each of the investigators.

d) A discussion of the accomplishments during the reporting period and those planned for the next reporting period: These are discussed in the contributions of each of the investigators.

e) A discussion of significant results: These are discussed in the contributions of each of the investigators.

f) Published articles and in-house reports: There have been no published articles or papers during this reporting period.

g) Recommendation concerning practical changes in operations: Improve quality of visual imagery and decrease time lag for receipt of data.

h) A list by date of any changes in standing order forms: None.

i) ERTS Image Descriptor Forms: Those completed have been sent to ERTS User Services, Code 563, NASA GSFC, Greenbelt, Maryland 20771.

j) A listing by date of any Data Request Forms for retrospective data: August 15 - 20 + 18 = 38, August 31 - 12, September 4 - 20, September 7 - 16, September 14 - 14, October 1 - 40, October 4 - 19.

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INVESTIGATIONS USING DATA IN ALABAMA

FROM ERTS-A

Contract NAS5-21876

Sixth Bi-Monthly Progress Report
Covering Period August 7, 1973–October 6, 1973

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APPENDIX I

LAND USE, MINERAL EXPLORATION, GEOLOGY

With contributions as follows:

Appendix I-A by R. Q. Shotts
Appendix I-B by Darry Ferguson
Appendix I-C by Lee Miller
Appendix I-D by Joseph Robinson

Appendix I-A

Sixth Bi-Monthly Progress Report

By Reynold Q. Shotts
Period August 7, 1973-October 6, 1973

I. The Alabama legislature has met and adjourned its regular biennial session without considering a general land use law. Indeed, none of the proposals before the Congress, most of which appear to involve the idea of "guidelines" for the enactment of State laws, have yet been enacted. Any state, not heretofore having a land use law and the experience gained from its operation, may, therefore, be just as well off to wait for Federal legislation.

The Alabama ERTS project should provide much information of value when the legislature does consider a land use law after Federal legislation has been enacted. Among the things that this project should be able to provide are some of the following:

1. The historical survey as to immediate past patterns of land use in broad categories and for comparison with present patterns, with indicated changes or trends in changes.

2. The principal land use prevailing in each County or physiographic province in the State.

3. Comparisons as to time - and cost - effectiveness of various methods of obtaining land use information from ground surveys and mapping up to low-altitude aerial, to high-altitude aerial and to satellite surveys.

4. Provide cost-effectiveness data for various systems of monitoring air and water pollution and possibly mineral land restoration and forestry health.

5. Provide specific land use studies and comparisons for limited areas as models. These will come largely through graduate theses.

6. Provide a small pool of trained personnel to think in terms of remotely sensed data, land uses and environmental problems that may be used to provide data and know-how for implementing land use control or regulatory systesm.

II. The mineral resource and geology phase of the ERTS investigation, together with ground truth found on geologic maps, in reports and in the files of the Geological Survey of Alabama and other State agencies and of many private companies, will prove invaluable in the implementation of any future state land use regulations.

The average citizen thinks of land use laws in terms of their direct effect upon him and his land, seldom recognizing that indirect effects may be as important, or even more important, than direct ones. If he is opposed to land use regulations he usually fears that he will not be allowed to do with his land what he wants to do, whether it is to build a subdivision, mine a valuable limestone deposit or use it in some other profitable way. If he is for land use laws, it is often because he thinks of them as protecting him, or his land, from the subdivision developer, the miner, the dam builder, etc. In the case of minerals and other land-derived materials, land use laws that do not recognize and provide for these materials will choke our economy and standard of living more effectively than too close a control of credit or of prices or of almost any economic factor. The final report of the President's Commission on materials policy, "Material Needs and the Environment Today and Tomorrow" (June, 1973, GPA Stock No. 5203-00005, $2.75 postpaid), recommends that "---Congress adopt a national land use policy and supporting statues which will:

- promote comprehensive planning for public and private lands;

- provide a means for evaluating land uses and institutions or practices and establishing criteria which take account of economic and national security needs and environmental, esthetic and social values;

- recognize the responsibility of the states and local units of government to develop programs for non-Federal lands and assist states in the formulation, coordination and implementation of land use planning policies;

- assist the states to improve regional and local planning processes; and

- require coordination within the Federal Government and with the States, of Federal and federally assisted programs which significantly affect land uses."

The report discusses the urban land use conflicts whereby many needed mineral deposits may be lost to urban development and recommends that "States use a quarrying and mining zoning classification to reserve essential mineral lands until deposits have been worked out." The conflicts are sharpest over sand, gravel, stone, shale and other widely used building material ingredients but they do exist for coal and other minerals.

In the discussion of surface mining, the Committee concludes that "surface mining is important to the nation" and that "the objective of Federal and State laws and regulations should be the control of surface mining to minimize environmental degradation and provide for prompt reclamation of the land so it can be used for other purposes, rather than prohibition of surface mining." Multiple, successive use planning for surface mined land is stressed.

An amazing statement made in the report is that "about 50 percent of the coal and 90 percent of all other minerals produced in the United States, except petroleum and natural gas, are extracted by surface mining methods."

In the planning for zoning of active mineral source areas there is usually enough ground truth available but in long range planning of provisions for possible mineral occurrences, the lineaments, circular features and other structures revealed in remotely sensed data should assist greatly, especially for regional planning.

Any data that may be developed on the ERTS project with regard to monitoring acid mine drainage or mined land disturbance could be advantageous in formulating land use regulations.

During the past two months great progress has been made in organizing and classifying available remotely sensed data so that potential users can find what they need.

Appendix I-B

Sixth Bi-Monthly Progress Report

Applications of ERTS-I Photography
to the Minerals Field
By Darry Ferguson
Period August 7, 1973-October 6, 1973

Objectives

It is generally accepted that ERTS-I imagery has failed to create any new "discoveries" or "finds" in Mineral Exploration. However, many regional geologic features such as domes, linaments, and fault planes have been identified which have created much speculation insofar as minerals historically associated with these occurrences are concerned. It is the objective of this investigator to find and prove uses of ERTS-I data which are practical; that is, uses which can be applied to replace some other function at a lower cost and give precise, nonspeculative results. The following paragraphs will outline the areas studied and give a brief description of the conclusions.

Mineral Exploration

The phase of study was conducted on "known-scan" basis, concentrating on coal and petroleum. Existing mineral occurrences were located and attempts were made to locate any "feature" on ERTS-I imagery correspon-ding to the occurrences.

Utilizing known oil fields in the State, no distinctive features could be identified on ERTS. However, domes have been located on ERTS-I photographs, leading to speculation of petroleum discoveries. It is my opinion that any occurence identified on ERTS-I images must be field-checked to confirm an anomaly. At this point one should consider the the practical application of "finding" or "locating" a dome. Initially, the user should consider the question, "Has this anomaly been discovered?". If it has, then ERTS-I imagery has been of no value. However, if it is in fact "unknown," can the user successfully "sell" this prospect to industry? Therefore, this anomaly means nothing until someone actually makes use of its existence, either to confirm or disprove the existence of a mineral.

The same was found while making correlations in the Warrior Coal Basin on ERTS-I imagery. The data surveyed failed to display any recognizable feature that could be used to identify coal outcrops or underground coal seams. The imagery generally lacks the quality to use pigment differentiation in these analyses. Once again, several geological occurrences could be noted. The Warrior syncline and the Sequatchie anticline could both be noted on bands four and five. However, it should be noted that these occurrences could more readily be identified on 65,000' U-2 infrared photography.

It is the conclusion of this author that the use of ERTS-I Remote Sensed Data has little meaning in the field of mineral exploration. The imagery lacks sufficient quality to make any identifications on a pigment or coloration basis, and since most mineral deposits are not characterized by any noticeable surface anomalies, the identification of minerals from ERTS-I imagery becomes highly speculative.

Monitoring Stripmine Reclamation with ERTS-I Photographs

The objective of a second course of study is to determine the feasibility of surveying and monitoring stripmine reclamation with ERTS-I imagery. Initial appraisals indicate that "remote sensing" could be a very useful tool in monitoring stripmine reclamation. A course of study has been outlined and mostly completed for the first phase of investigation.

Three strip mines were selected for in-depth study; each mine displaying a varied amount of reclamation. The first phase of study, covering one stripped area, consists of three parts, each being an integral link to prove or disprove the usefulness of ERTS-I in stripmine reclamation. Upon completion of the studies of all three mines, a final conclusion will be reached.

The course of study for Phase I is as follows:

1) Identify the stripped areas on ERTS-I photographs, topo maps, U-2 infrared photographs and geologic maps.
2) Make field data gathering trips to make pictures, observe erosion, weathering, plant growth and take samples in order to present the reader an accurate picture of surface conditions.
3) Correlate material from the field data to that of U-2 infrared photography.
4) Correlate field data and U-2 infrared photography to ERTS-I images.
5) Analyze all data and integrate cost analysis with respect to project objectives.
6) Make tentative conclusions (final conclusions will be made after all phases of study have been finished).

The study of Phase I is nearly finished and should soon be ready for reporting.

Appendix I-C

Sixth Bi-Monthly Progress Report

By Lee Miller
Period August 7, 1973-October 6, 1973

CATALOGUING AND FILING OF ERTS IMAGERY

Purpose

Prior to late September a comprehensive filing system had not been developed. There were several reasons for this during the summer. All research assistants were working to meet deadlines for either theses or individual projects connected with ERTS. The development or maintenance of a filing system was not a high priority. In addition, the volume of ERTS data on hand at that point did not warrant such a system.

Currently a large number of ERTS images are on hand, data is recorded regularly, and the distribution of the data products to the co-investigators has become complex. Approximately 2,737 images are filed and divided among several co-investigators, some of which are located in other cities. To serve the needs of some co-investigators, selected ERTS imagery must be duplicated at the George C. Marshall Space Flight Center. This additional imagery (the duplications) must be accounted for as well. The filing systems that have been devised deals effectively with the situation by accounting for the location of each data product.

In an effort to make the filing system "user oriented" each image is given a quality rating. This quality rating is used to expedite the location of good quality imagery for any area of interest. Many of the images received have large percentages of cloud cover and/or poor quality. Reference to the quality rating is just a simple way to avoid examining images that do not suit the user's or the investigator's needs.

Description of System

All information about the imagery is posted on large poster-size charts. The organization of a typical section of the chart is shown in Figure 1. An explanation of each of the headings is included with the charts for those using the system for the first time.

Filing

All 9.5 inch prints and 9.5 inch positive transparencies are classified by date and then scenes. They are kept in an upright (hanging) file. The 70 mm positive transparencies are mounted in aluminum frames suitable for viewing in a lantern slide projector. These mounted images are kept in filing cabinets. The 70 mm negatives are filed in envelopes that are marked and kept in a filing cabinet for easy access.

CATALOGUING OF UNDERFLIGHT IMAGES

Purpose

Recent developments have dictated the need for cataloguing the underflight data on hand. Inquiries from interested users have become quite numerous. The information needed to answer these inquiries (areas covered, scale, type of imagery, date of coverage, etc.) was located in a number of flight reports, photographic logs, and maps. Only a person familiar with the data on hand could locate the information that was needed.

To expedite the location of suitable data for investigators and users, a booklet was prepared that put the information on hand into a standard form. Now any person on the ERTS project can find the imagery that is needed for him or some user. A copy of this booklet is included.

J	70 mm -	
	70 mm +	
	9.5 + tran.	
	9.5 + print	
	Qual.	
	No.	
	Band	
	Image	
	Date	
K	70 mm -	
	70 mm +	
	9.5 + tran.	
	9.5 + print	
	Qual.	
	No.	
	Band	
	Image	
	Date	
L	70 mm -	
	70 mm +	
	9.5 + tran.	
	9.5 + print	
	Qual.	
	No.	
	Band	
	Image	
	Date	
M	70 mm -	
	70 mm +	
	9.5 + tran.	
	9.5 + Print	
	Qual.	
	No.	
	Band	
	Image	
	Date	

Figure I - Example of Filing Chart for ERTS Data

FILING OF ERTS IMAGERY

ORBIT- The coverage consist of scenes from four adjacent orbits. These have been lettered J, K, L, and M going from east to west. The location of the ground track of these orbits relative to Alabama is shown in the accompanying map. (The coastal part of Orbit I is included at times.)

DATE- The day for which the ERTS image was taken.

SCENE- The University of Alabama has fifteen ERTS scenes on a standing order. The scenes are numbered for each orbit starting with the most northerly scene. The approximate location of these scenes is shown on the accompanying map. The location varies somewhat from date to date due to a slight shift in the orbit and some variation in the location of the individual scenes along the orbital path.

BAND- Whenever a scene is imaged there are four separate images produced. Each image represents the reflectance of the scene in a specific region of the electromagnetic spectrum.

Band	Color	Wavelength(microns)
4	green	0.5-0.6
5	red	0.6-0.7
6	near-infrared	0.7-0.8
7	near-infrared	0.8-1.1

NUMBER- Each image has a number prominently stamped on its left border. This serves as an easy and convienient way to locate images in the file.

QUALITY- This is a quick way the ascertain the quality of individual images without having to go through the files and use a light table or projector. The first digit represents the approximate cloud cover. A zero means there is less than 5% cloud cover, while a nine means there is 85%-95% cloud cover. The second letter gives a quick evaluation of the contrast, the gray scale graduation, and the detail in the image. "G" means good, "F" means fair, and "P" means poor.

FILING OF ERTS IMAGERY (CONTINUED)

The next four columns represent the four types of data products that are recieved regularly. Each space or box in these columns represents a single image. The location of the image is noted in each box by an identifier. The locations where the images may be stored or the co-investigators using individual images are abbreviated with the following identifiers.

UA - ERTS room at the University of Alabama. Room 342 MIB.

GS - Remote Sensing section of the Geological Survey of Alabama

EB - Everett Brett, Dauphin Island Sea Lab; Dauphin Island, Alabama.

DF - Derry Furgeson- Research Assistant

JR - Joe Robinson- Research Assistant

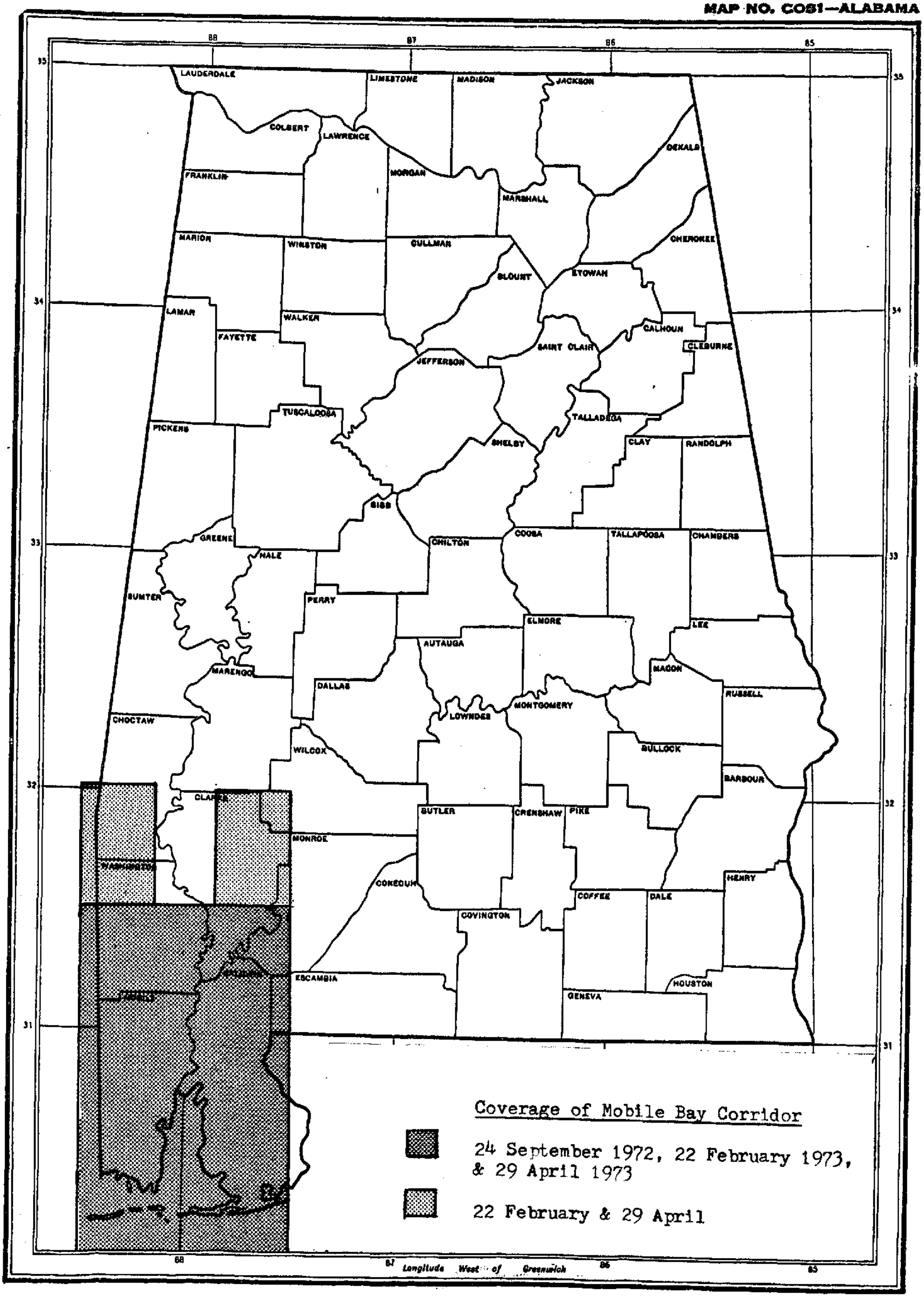
LM - Lee Miller- Research Assistant

UNDERFLIGHT AIRPHOTO COVERAGE OF ALABAMA

IN SUPPORT OF THE ERTS-A PROJECT

AT THE UNIVERSITY OF ALABAMA

MAP NO. COS1—ALABAMA



Date: 24 September 1972

Altitude: 65,000 feet (mean sea level)

Aircraft: U-2

IMAGING SYSTEMS

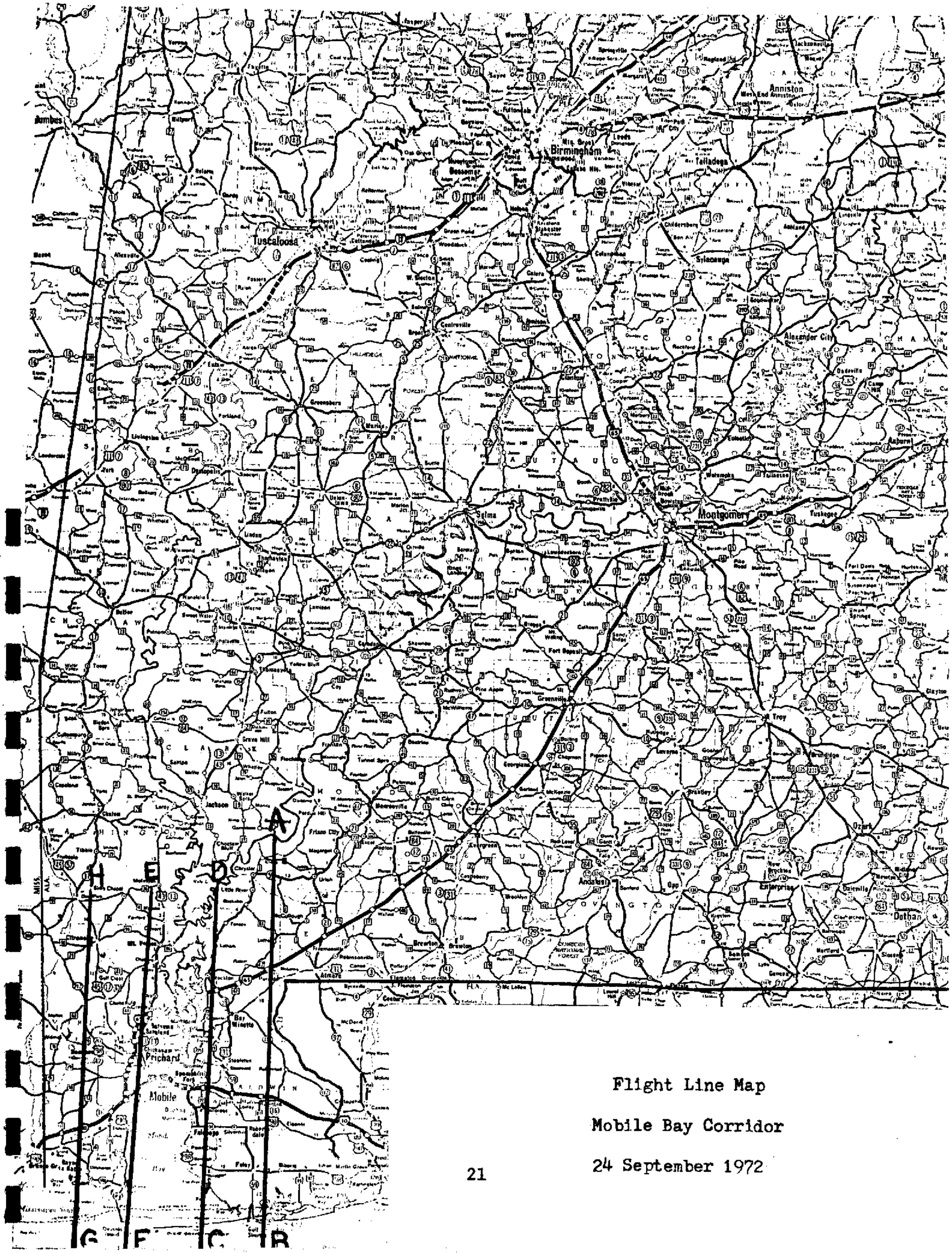
Sensor	Film	Spectral Band	Scale	Overlap
Vinten	2443, (Color) Aerochrome Infrared	510-900 nm	70 mm	50-60
RC-10	2443, (Color) Aerochrome Infrared	510-900 nm	1:131,000	50-60

Date: 24 September 1973

FLIGHT LINE DATA

Vinten Check Points	Frame Numbers	Cloud Cover/ Remarks
A-B	0001-0015	10% scattered cumulus frames 6-8; 50% broken cumulus frames 9-13
C-D	0016-0029	50-60% broken cumulus frames 18-24; 10% scattered cumulus frames 25 & 26
E-F	0030-0043	Scattered to broken cumulus
G-H	0044-0056	20% scattered cumulus frames 44 & 45; 50-70% broken cumulus frames 47-56

RC-10		
A-B	4562-4574	10% scattered cumulus frames 4265-68; 50-60% broken cumulus frames 4269-72
C-D	4575-4586	50-60% broken cumulus frames 4576-82; 10% scattered cumulus frames 4583-85
E-F	4587-4598	Scattered to broken cumulus
G-H	4611-4626	30-50% broken cumulus



Flight Line Map

Mobile Bay Corridor

24 September 1972

Date: 22 February 1973

Altitude: 65,000 feet (mean sea level)

Aircraft: U-2

IMAGING SYSTEMS

Sensor	Film	Spectral Band	Scale	Overlap
Vinten	Plus X 2402 (B&W)	475-575 nm	70mm	60
Vinten	Plus X * 2402 (B&W)	580-680 nm	70mm	60
Vinten	Infrared Aerographic, 2424 (B&W)	690-760 nm	70mm	60
RC-10	Aerochrome Infrared, 2443 (color)	510-900 nm	1:129,000	60

* different spectral band from sensor number one since a different filter is used.

Date: 22 February 1973

FLIGHT LINE DATA

Vinten

Check Points	Frame Numbers	Cloud Cover/Remarks
A-B	0164-0183	Thin scattered cirrus north half of flight line. Thin cirro-stratus south half of flight line
C-D	0184-0196	Thin cirro-stratus south half of flight line.
E-F	0197-0209	Thin cirro-cumulus north end going to thin cirro stratus at south end of flight line
G-H	0210-0230	Thin cirro-stratus at south end going to moderate cirro-cumulus at north end of flight line

RC-10

A-B	8865-8881	Same as above
C-D	8882-8892	
E-F	8893-8903	
G-H	8904-8921	

Date: 29 April 1973

Altitude: 60,000 feet (mean sea level)

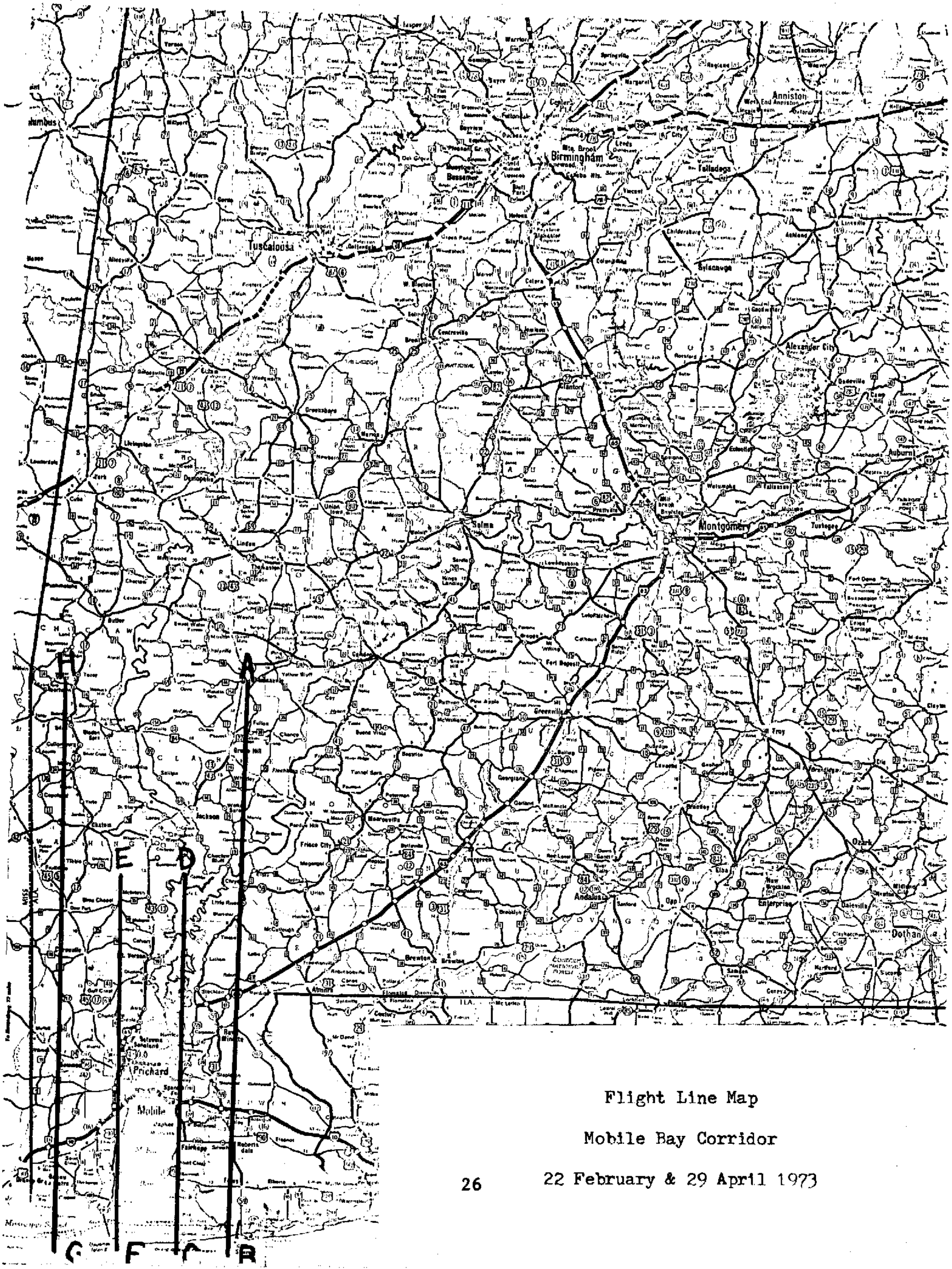
Aircraft: RB-57

IMAGING SYSTEMS

Sensor	Film	Spectral Band	Scale	Overlap
Hass/5R1	2402 (B&W)		70mm	10
Hass/5R2	2402 (B&W)		70mm	10
Hass/5R3	2424 (B&W)		70mm	10
Hass/5R5	2443 (Color)		70mm	10
Hass/5R6	SO356 (Color)		70mm	10
Zeiss/5L	2443 (Color)		1:60,000	18
RC8/4L	SO397 (Color) blue tint		1:122,000	60-70
RC8/4R	2443 (Color) red tint		1:122,000	60-70

Date: 29 April 1973

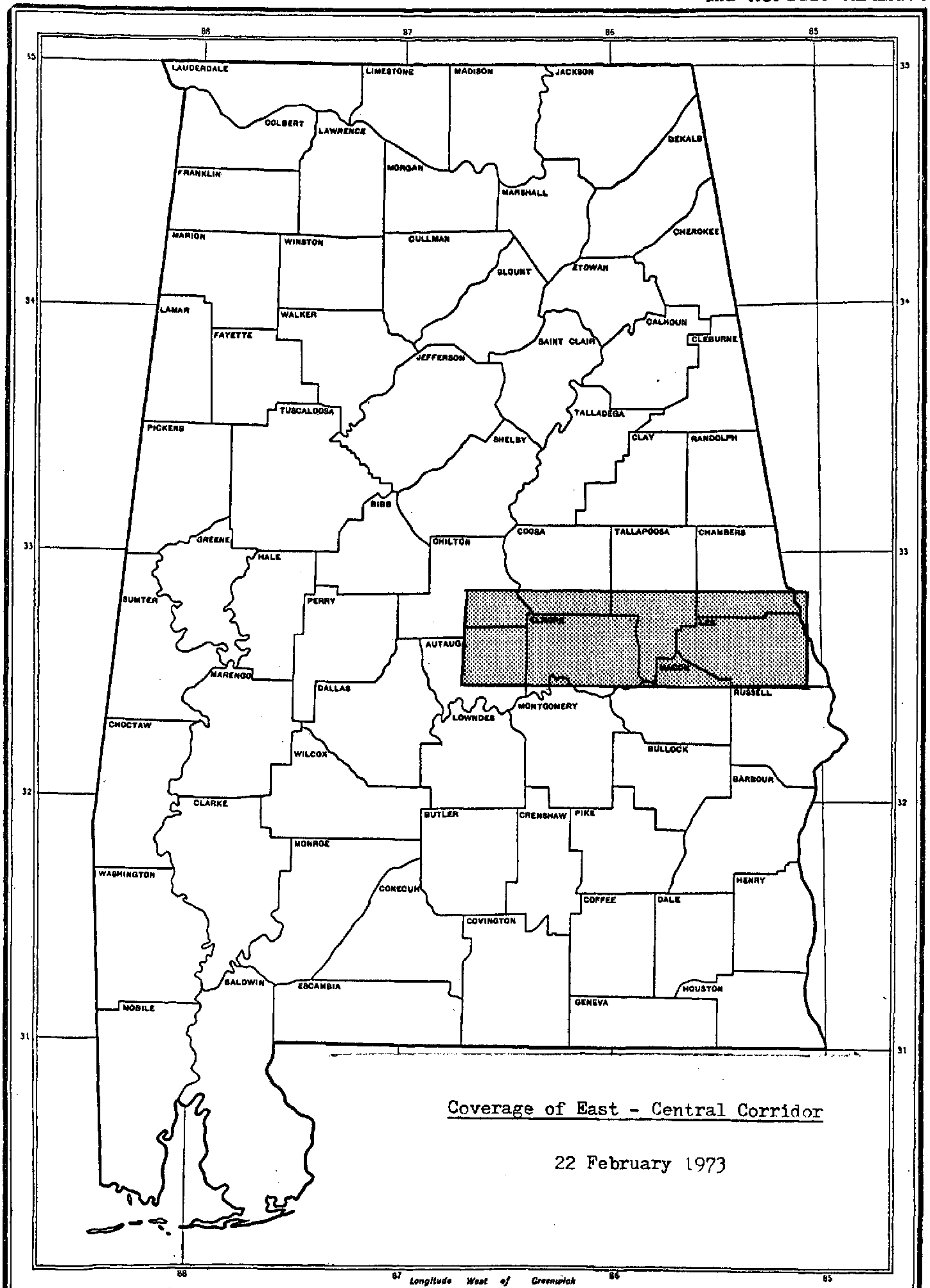
Flight line data is unavaillible for this coverage. All imagery is at the Dauphin Island Sea Lab with Dr. William Schroeder. All request for data should be referred to him.



Flight Line Map

Mobile Bay Corridor

22 February & 29 April 1973



Coverage of East - Central Corridor

22 February 1973

Date: 22 February 1973

Altitude: 65,000 feet (mean sea level)

Aircraft: U-2

IMAGING SYSTEMS

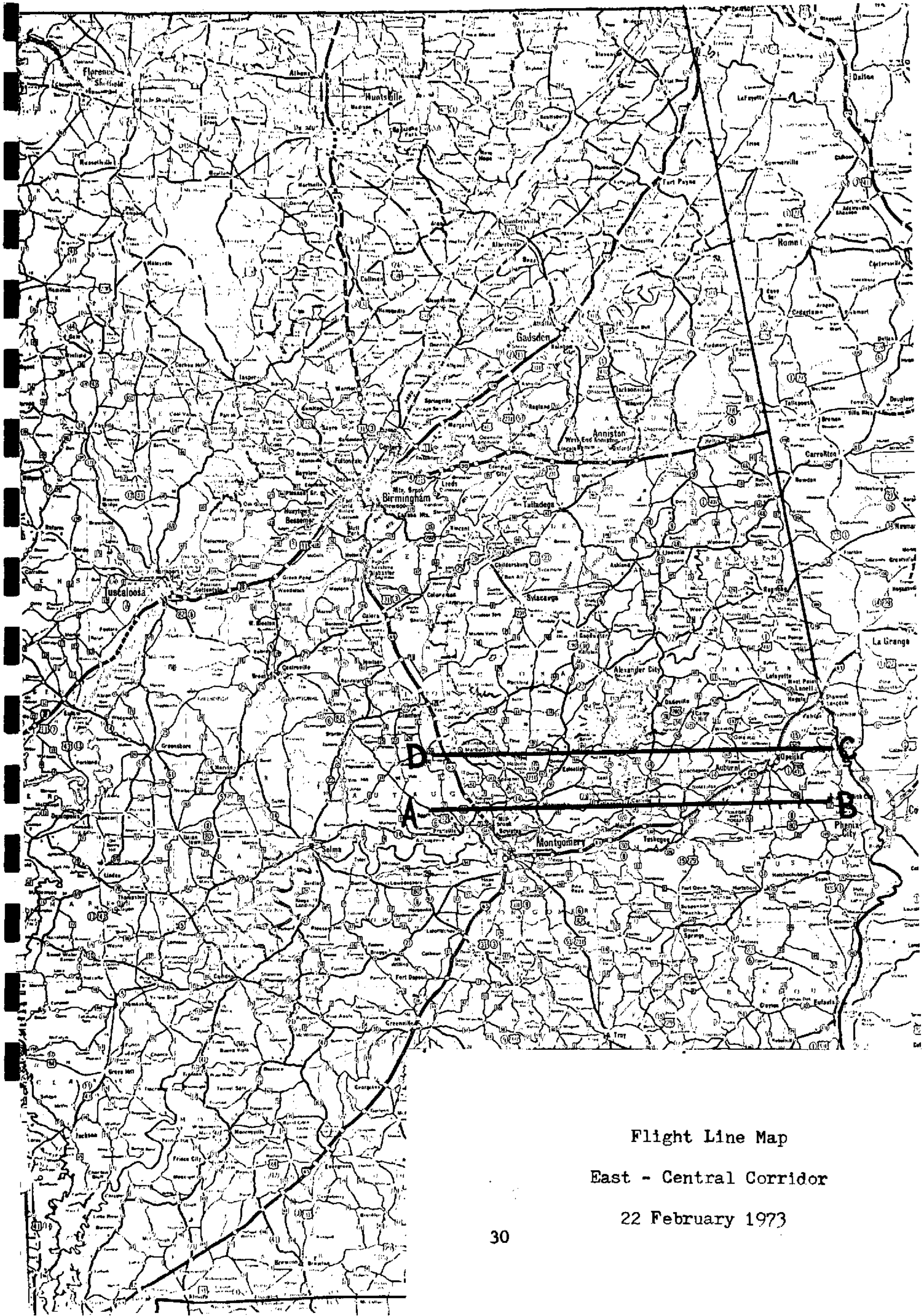
Sensor	Film	Spectral Band	Scale	Overlap
Vinten	Plus X 2402 (B&W)	475-575 nm	70mm	60
Vinten	Plus X * 2402 (B&W)	580-680 nm	70mm	60
Vinten	Infrared Aerographic, 2424 (B&W)	690-760 nm	70mm	60
RC-10	Aerochrome Infrared, 2443 (color)	510-900 nm	1:129,000	60

* different spectral band from sensor number one since a different filter is used.

Date: 22 February 1973

FLIGHT LINE DATA

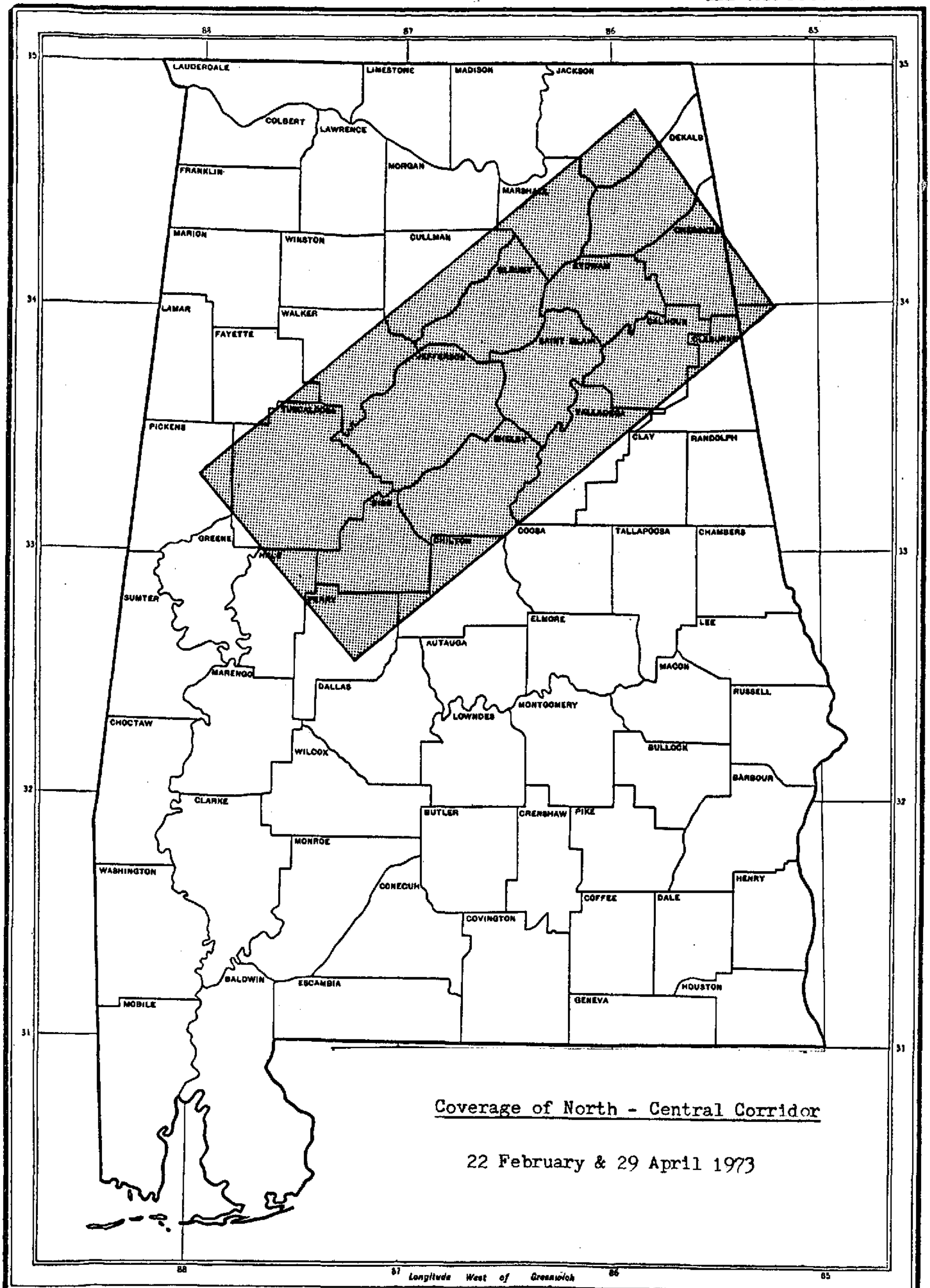
Vinten Check Points	Frame Numbers	Cloud Cover/Remarks
A-B	0134-0148	Thin cirrus west half of flight line
C-D	0149-0163	Thin cirrus west half of flight line
RC-10		
A-B	8839-8851	Same as above
C-D	8852-8864	



Flight Line Map

East - Central Corridor

22 February 1973



Coverage of North - Central Corridor

22 February & 29 April 1973

Date: 22 February 1973

Altitude: 65,000 feet (mean sea level)

Aircraft: U-2

IMAGING SYSTEMS

Sensor	Film	Spectral Band	Scale	Overlap
Vinten	Plus X 2402 (B&W)	475-575 nm	70mm	60
Vinten	Plus X * 2402 (B&W)	580-680 nm	70mm	60
Vinten	Infrared Aerographic, 2424 (B&W)	690-760 nm	70mm	60
RC-10	Aerochrome Infrared, 2443 (color)	510-900 nm	1:129,000	60

* different spectral band from sensor number one since a different filter is used.

Date: 22 February 1973

FLIGHT LINE DATA

Vinten

Check Points	Frame Numbers	Cloud Cover/Remarks
A-B	0001-0022	Clear
C-D	0023-0045	Clear - thin cirrus last two frames
E-F	0046-0067	Thin cirrus first three frames, thin cirrus over B'ham
G-H	0068-0089	Thin cirrus B'ham area and west
I-J	0090-0111	Thin cirrus west half of flight line
K-L	0112-0133	" " " " " " "

RC-10

A-B	8727-8744	Same as above
C-D	8745-8763	
E-F	8764-8781	
G-H	8782-8800	
I-J	8801-8819	
K-L	8820-8838	

Date: 29 April 1973

Altitude: 60,000 feet (mean sea level)

Aircraft: RB-57

IMAGING SYSTEMS

Sensor	Film	Spectral Band	Scale	Overlap
Hass/5R1	2402 (B&W)		70mm	10
Hass/5R2	2402 (B&W)		70mm	10
Hass/5R3	2424 (B&W)		70mm	10
Hass/5R5	2443 (Color)		70mm	10
Hass/5R6	SO356 (Color)		70mm	10
Zeiss/5L	2443 (Color)		1:60,000	18
RC8/4L	SO397 (Color) blue tint		1:122,000	60-70
RC8/4R	2443 (Color) red tint		1:122,000	60-70

Date: 29 April 1973

FLIGHT LINE DATA

Hass/5R1, Hass/5R2, & Hass/5R3

Check Points	Frame Numbers	Cloud Cover/Remarks
A-B	219-230	Shadow over approximately 15% of each image of 5R3
C-D	207-218	
E-F	194-206	
G-H	182-193	
I-J	169-181	
K-L	159-168	

Hass/5R5

A-B	231-242	Frames 235-242 slightly scratched
C-D	219-130	
E-F	206-218	
G-H	194-205	
I-J	181-193	
K-L	170-180	Frame 179 partially obstructed

Hass/5R6

A-B	230-241	
C-D	218-229	
E-F	205-217	
G-H	193-204	
I-J	180-192	
K-L	169-179	

Date: 29 April 1973

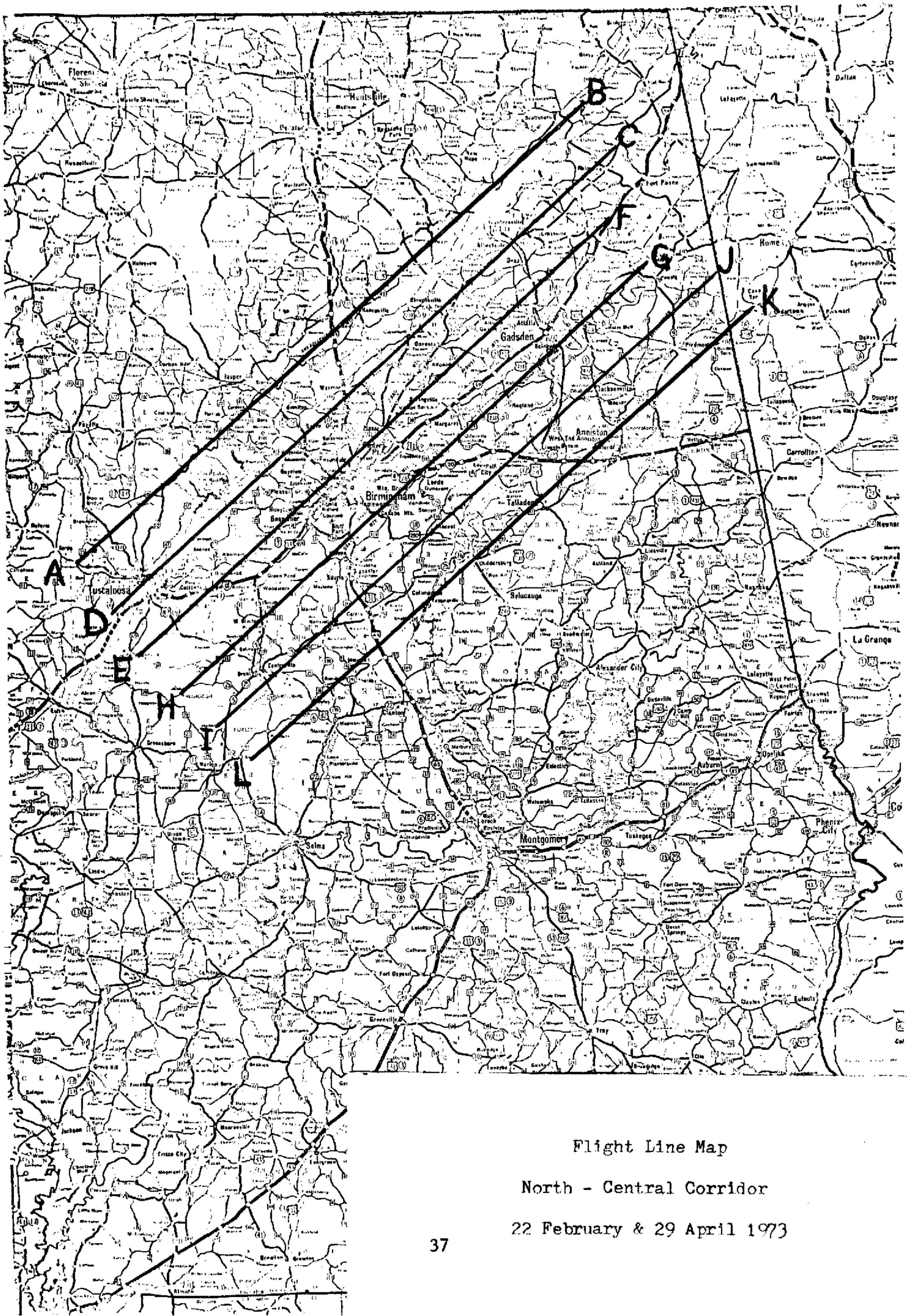
FLIGHT LINE DATA

Zeiss/5L

Check Points	Frame Numbers	Cloud Cover/Remarks
A-B		
C-D		
E-F	0318-0340	
G-H	0297-0317	
I-J	0274-0296	
K-L	0250-0273	

RC8/4L & RC8/4R

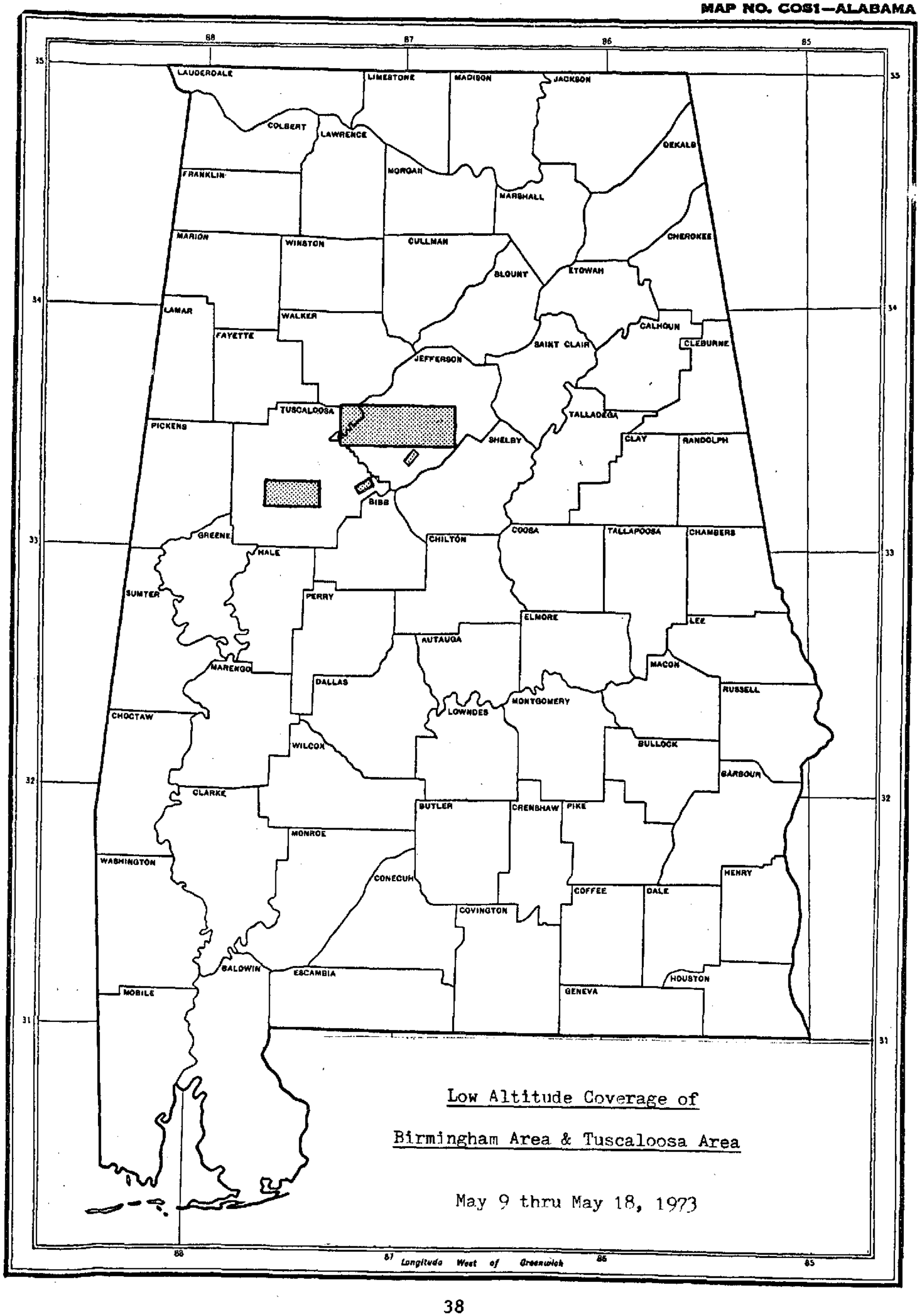
A-B	0168-0189	
C-D	0146-0167	
E-F	0123-0145	
G-H	0101-0122	
I-J	0079-0100	
K-L	0059-0078	



Flight Line Map

North - Central Corridor

22 February & 29 April 1973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87
86
85
35
34
33
32
31
LAUDERDALE
LIMESTONE
MADISON
JACKSON
COLBERT
LAWRENCE
DEKALB
FRANKLIN
MORGAN
MARSHALL
MARION
WINSTON
CULLMAN
CHEROKEE
BLOUNT
ETOWAH
LAMAR
WALKER
CALHOUN
FAYETTE
SAINT CLAIR
CLEBURNE
JEFFERSON
TUSCALOOSA
TALLADEGA
PICKENS
SHELBY
CLAY
RANDOLPH
BIBB
GREENE
CHILTON
COOSA
TALLAPOOSA
CHAMBERS
HALE
SUMTER
PERRY
ELMORE
LEE
AUTAUGA
MARENGO
MACON
DALLAS
RUSSELL
MONTGOMERY
CHOCTAW
LOWNDES
BULLOCK
WILCOX
BARBOUR
CLARKE
BUTLER
CRENSHAW
PIKE
MONROE
WASHINGTON
CONECUH
HENRY
COFFEE
DALE
COVINGTON
BALDWIN
ESCAMBIA
HOUSTON
MOBILE
GENEVA
Low Altitude Coverage of
Birmingham Area & Tuscaloosa Area
May 9 thru May 18, 1973
Longitude West of Greenwich

Date: May 9 - May 18, 1973

Altitude: 12,500 feet (mean sea level)

Aircraft: Cessna

IMAGING SYSTEMS

Sensor	Film	Spectral Band	Scale	Overlap
I^2S	2424 (B&W)	400-480 nm	1:25,4000 (1:10,000 on I^2S viewer)	50
"	"	480-590 nm	"	"
"	"	590-700 nm	"	"
"	"	730-900 nm	"	"

LAND-USE FROM ERTS

Land use for a considerable portion of the state has already been compiled (Figure 2). Our goal is to complete the entire state in the near future. When completed, the dominant land use (urban, agricultural, forest, water, barren or nonforested wetland) per square kilometer will be stored in a computer for rapid retrieval and easy manipulation.

Currently, selected spring images are being enlarged to 1:250,000 scale prints. The images selected were band five and band seven for scenes with superior quality and minimum cloud cover. These enlarged images will be used for land use compilation.

Advantages of this method include excellent spatial resolution contrast at the larger scale, no distortion caused by enlarging the image by projection, and relatively modest cost.

Option being considered is the use of 1:250,000 scale color composites. Although three such composites are on hand they are not suitable for deriving land-use. The scenes of interest were imagery during the fall and winter, and attempts to derive land use from this imagery met with considerable difficulty since the lack of foliage in diceduous forests made interpretation difficult. Arrangements have been made to produce 1:250,000 scale color composites of spring imagery so that this method can be investigated.

UPDATING OF HISTORICAL LAND USE

Prior to the reception of ERTS imagery the historical land use of the state was compiled based on USDA Agricultural Stabilization and Conservation Service air photo mosaics. During this work all military reservations were

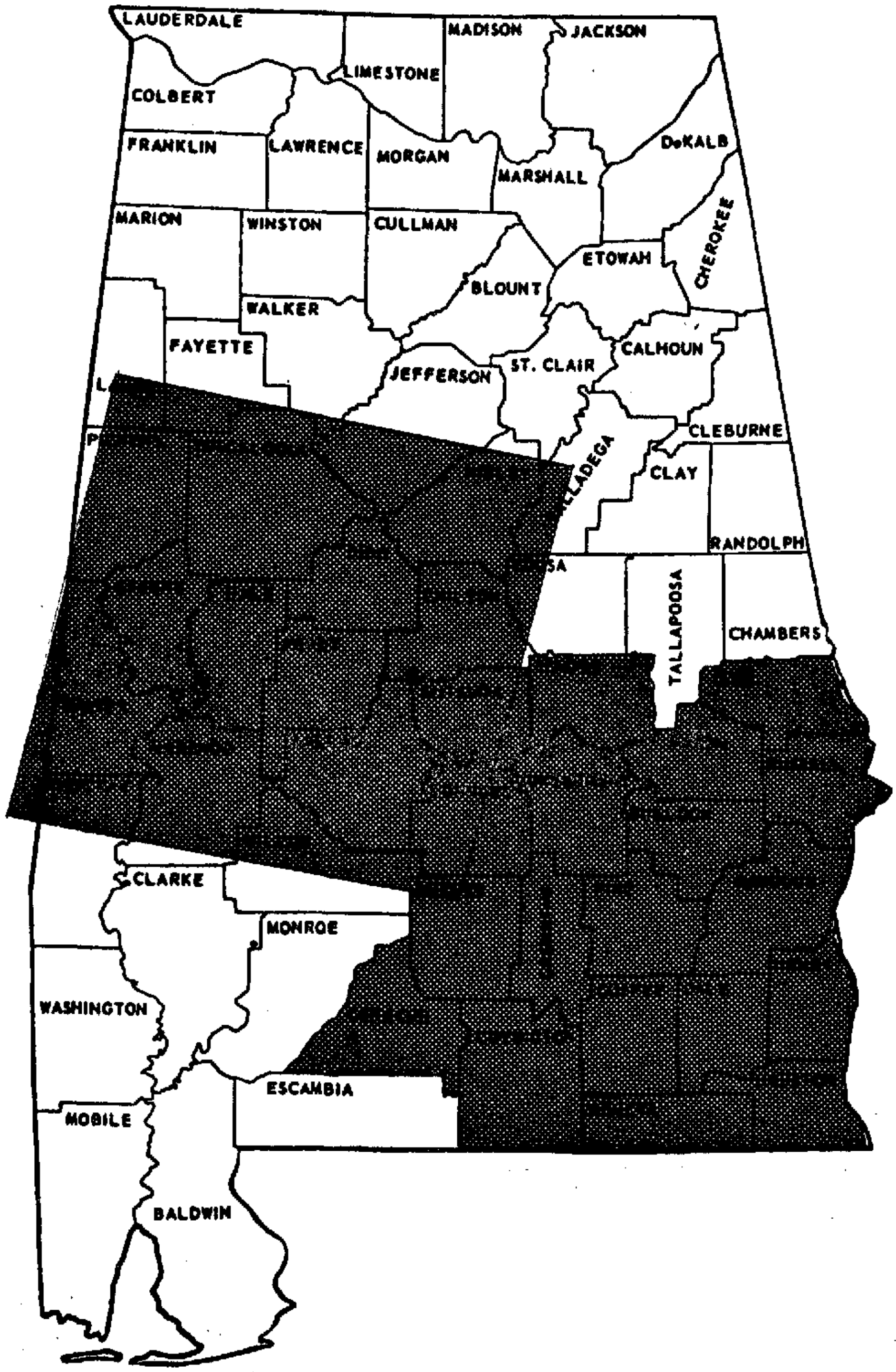


Figure 2 - Portions of Alabama for Which Land Use from ERTS Data Has Been Compiled

not included in the coding of land use since air photos were not available for such areas.

There has been a request from the Alabama Development Office that these areas be coded for land use. In one of the primary uses of this data, they are working to produce a composite map of land use for the entire state. The exclusion of the military reservations from the compilation had caused difficulty.

At this point the updating of the historical data base is almost complete and ready for being read into the computer.

THESIS RESEARCH

Considerable time has been spent on research for my thesis. My research involves correlating the output of the unsupervised clustering of ERTS data with the area's actual characteristics. Most of my time has been spent gathering ground-truth information on by study areas. This has included preparing a map of all agricultural fields in the area and ~~their~~ then searching the tax record for their owners. The condition of each field during the ERTS coverage in question will be found by reference to the USDA Agricultural Stabilization and Conservation Service records or by contacting the owner or the person to which the land was leased at the time.

Preliminary boundary maps for the study areas have been prepared from projecting U-2 and RB-57 high altitude photography up to the maximum scale and tracing the boundaries. A supplementary method is used in areas where low altitude coverage is available. The study area is broken down into subsections and a very detailed and accurate boundary map is drawn for each subsection using a color additive viewer. These boundary maps will be used for reference when analyzing the output of the unsupervised clustering program.

Completion of the thesis is expected within the next two months.

Appendix I-D

Sixth Bi-Monthly Progress Report

Comparison of ERTS-I and U-2 Photographs

By Joseph Robinson

Period August 7, 1973-October 6, 1973

Just how reliable are land use figures obtained from ERTS photographs? A study is presently being undertaken to compare ERTS photograp' of a certain area with photographs taken from U-2 airplanes of the same area. The area under study encompasses Lee County, northwest Russell County and northeast Macon County. This location was chosen for two reasons. 1) Dominant land use figures from a study of ERTS photo graphs for this location were already on store in the computer and 2) U-2 photographs and ERTS photographs of good quality and low cloud coverage, taken at the same time of the year, were available for this area. Areas for which similar studies in progress are shown in Figure 1.

The scale on the ERTS photographs was 1:1,000,000 and the scale on the U-2 photographs was approximately 1:136,000. In later investigations we hope to compare ERTS photographs (Scale 1:250,000) to see just how much difference there is in land use figures.

Since this study was begun only a week prior to this report, results are not available. Hopefully some significant results will be obtained by the time the next bi-monthly report is published.

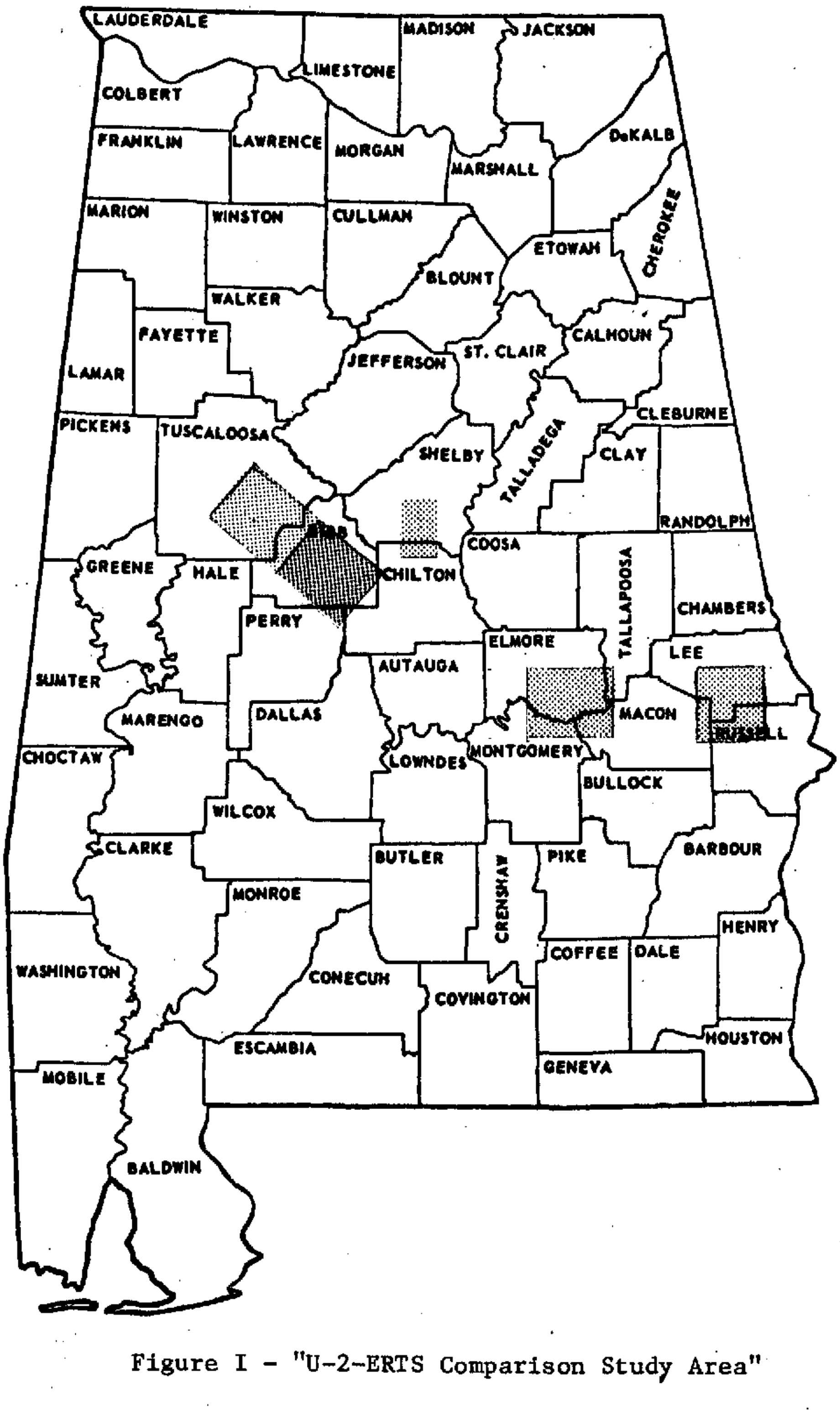


Figure I - "U-2-ERTS Comparison Study Area"

APPENDIX II

NEW ORGANIZATIONAL PROCEDURES IN THE ERTS PROJECT LIBRARY

Appendix II-A by Linda A. Robinson

Appendix II-A

Sixth Bi-Monthly Progress Report

By Linda A. Robinson
Period August 7, 1973-October 6, 1973

Due to the difficulty involved in locating a specific item among the materials associated with the ERTS project, it was deemed advantageous to devise some method of better organizing these materials. As a Library Science major, I have been employed to plan and develop this organizational procedure.

The goal of the present plan is to arrange and catalog the materials in such a way that any specific item will be quickly and easily accessible to any person who has a need for the item. Among the material to be catalogued are maps, photographs, reports, books, government documents, and pamphlets.

The photographs are the priority item in this process as they are the items most frequently used. Present plans are to develop a small card catalog for all materials, with a separate section for each type of material. The cards should contain all information considered important for the user. For example, the ERTS photo card will give date, percentage of cloud cover, orbital designation, scale, band, side number and quality, all of which combined should tell the user the location and the number of the photograph that he needs. Similar cards will be developed for all the other material.

Since this organizational project has been in progress for only one week, little except the basic planning has been accomplished. Cataloging of the ERTS photos has begun, cataloging materials are being purchased, and specific plans are being made for all the other materials.

APPENDIX III

ENVIRONMENTAL, HYDROLOGY, WATER RESOURCES

Appendix III-A by C. Lamar Larrimore

Appendix III-A

Sixth Bi-Monthly Report by C. Lamar Larrimore
August 7, 1973-October 6, 1973

PROGRESS REPORT CONCERNING ENVIRONMENTAL FACTORS

With the recent installation of the fourth data collection platform, our monitoring network is almost complete, lacking only the placement of the final DCP (within the next two weeks). This network of DCPs will allow surveillance of the overall water quality in this sector of the Warrior River near Tuscaloosa, as well as monitoring of smaller segments and individual locations along the river.

Since most of the DCP network has now been "debugged" including elimination of most problems with pH and dissolved oxygen, we are in a position to begin to evaluate the utility of the DCP concept in managing environmental quality.

Our first effort as far as using this collected data has been directed toward obtaining for each DCP a graph showing each of the measured parameters versus time. The points plotted on the graphs represent average values during an overpass of the satellite versus the average time of the overpass. This provides a quick means of scanning the voluminous data to detect changes or developing trends in a particular parameter. Examples of this output are shown in Figures 1, 2, and 3, where dissolved oxygen, temperature, and pH values at one of the platforms are plotted against time. Other averaging intervals to be used in these plots include daily, weekly, and monthly averages.

This data is to be used as input to a model already developed for water quality prediction as well as to a water quality management model incorporating the prediction model. Output from the type of management

DCP NO. 6060

DISSULVED OXYGEN (PPM)
(ORBIT AVERAGES)

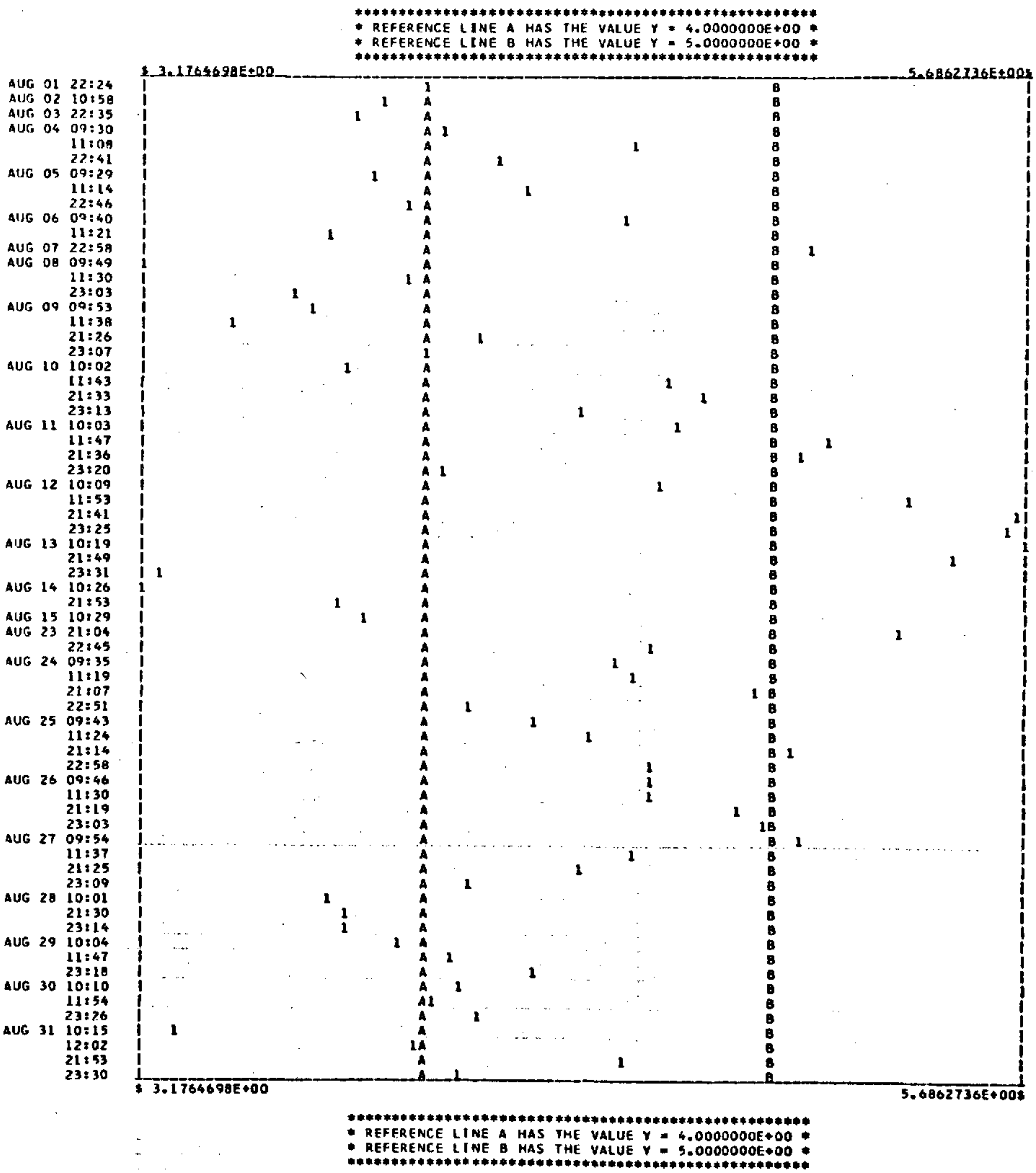
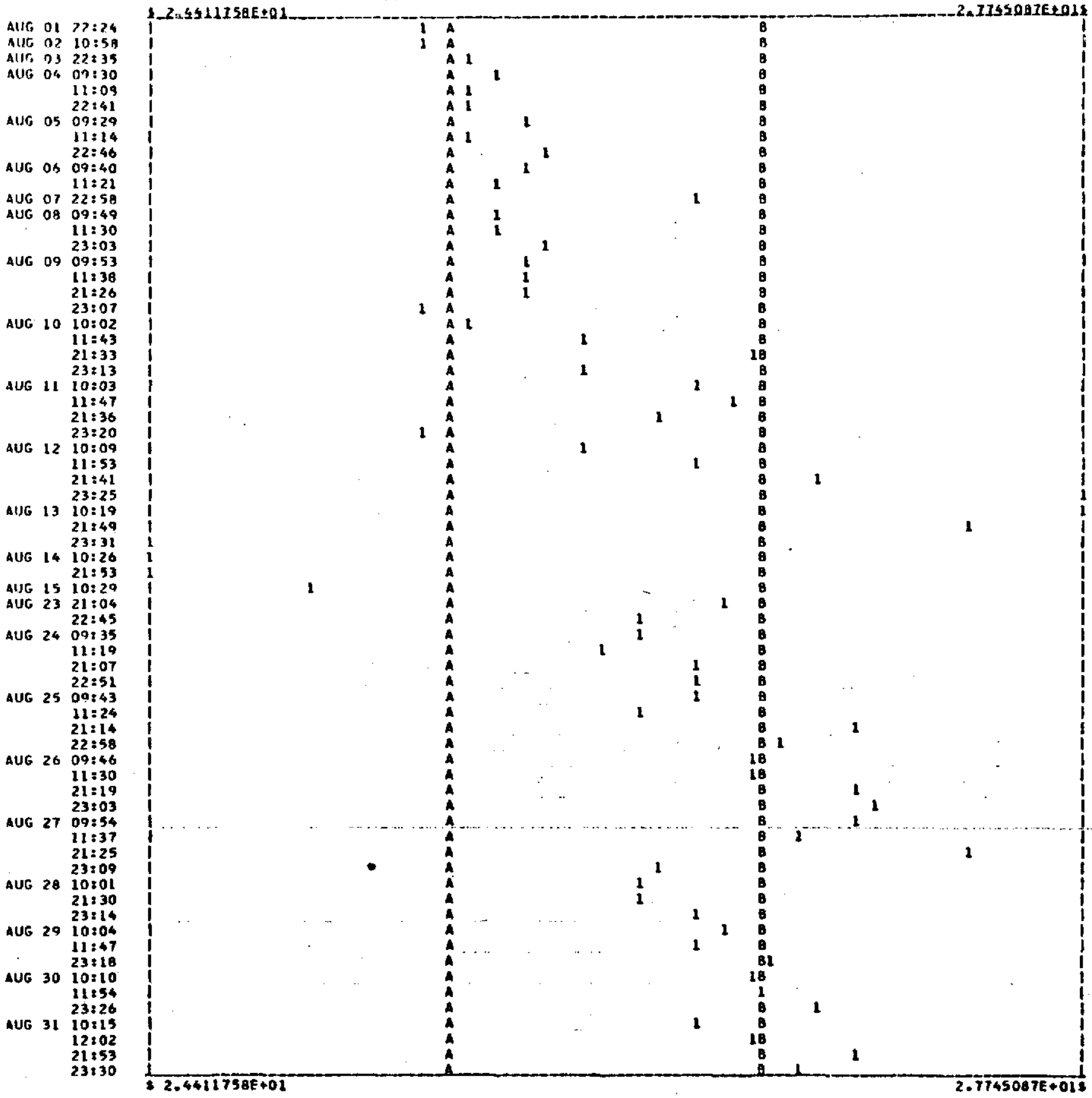


Figure 1

DCP NO. 6060

TEMPERATURE (C)
(ORBIT AVERAGES)

```
*******************************************************
* REFERENCE LINE A HAS THE VALUE Y = 2.5522858E+01 *
* REFERENCE LINE B HAS THE VALUE Y = 2.6633972E+01 *
*******************************************************
```



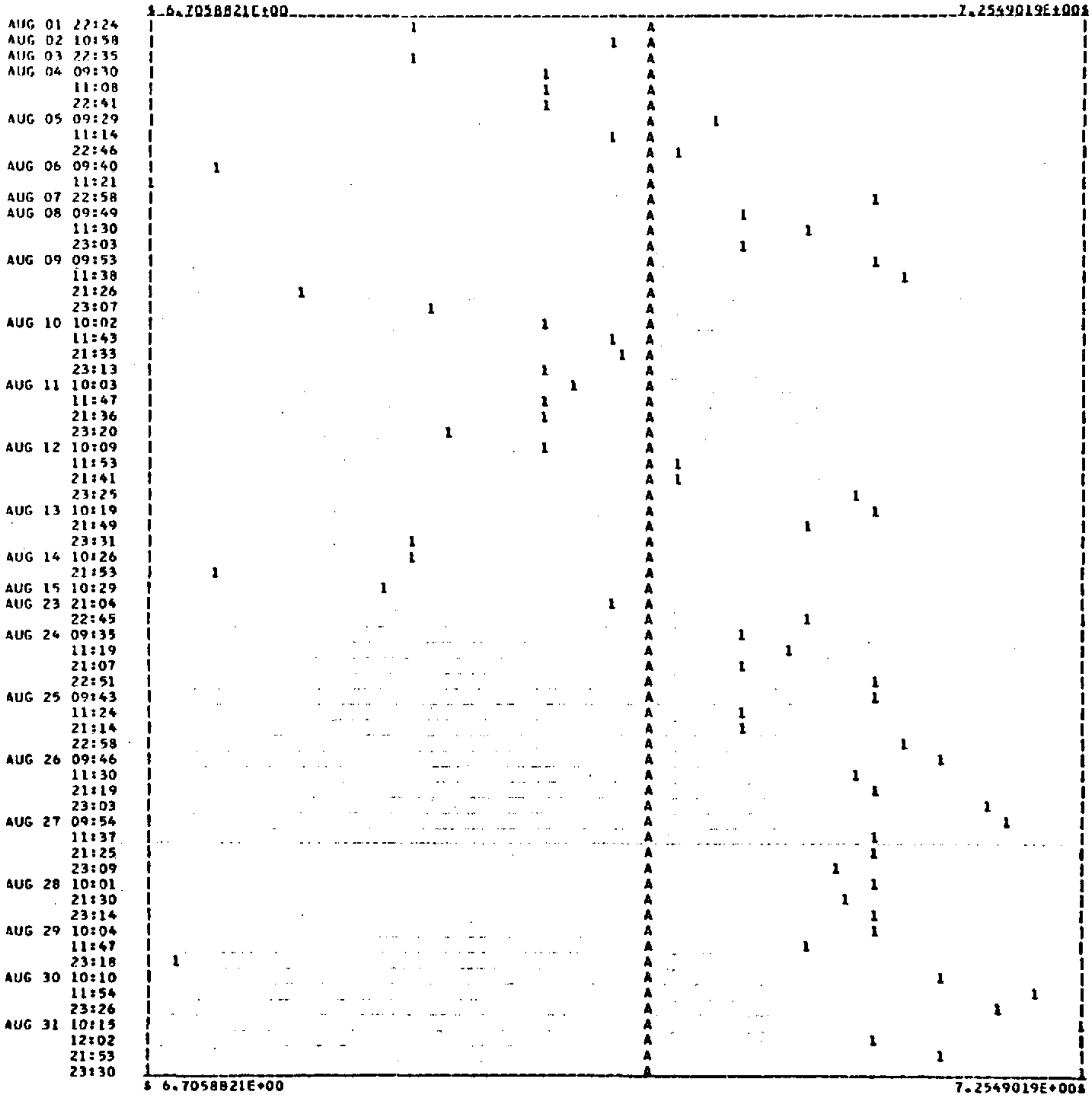

```
*******************************************************
* REFERENCE LINE A HAS THE VALUE Y = 2.5522858E+01 *
* REFERENCE LINE B HAS THE VALUE Y = 2.6633972E+01 *
*******************************************************
```


Figure 2

DCP NO. 6060

PH
(ORBIT AVERAGES)

```
*****************************************************
* REFFRENCE LINE A HAS THE VALUE Y = 7.0000000E+00 *
*****************************************************
```




```
*****************************************************
* REFERENCE LINE A HAS THE VALUE Y = 7.0000000E+00 *
*****************************************************
```

Figure 3

model now envisioned will be decisions regarding the optimum quantity and time for discharge of wastes by industries so as not to violate water quality standards.

In addition to the four water quality parameters monitored by the DCPs, we are also collecting flow data, which will be used as an additional input to the water quality prediction and management models.

We are now conducting servicing operations for the DCPs essentially on our own, since our boat is now fully equipped for all servicing and sampling procedures and we also have a battery charger (borrowed from Marshall Space Flight Center) installed here at the University.

APPENDIX IV

DATA PROCESSING AND DATA MANAGEMENT

Appendix IV-A by E. T. Miller
and Sam Schillaci

Sixth Bi-Monthly Progress Report

By E. T. Miller and Sam Schillaci
Period August 7, 1973-October 6, 1973

In the past bi-monthly period, the data processing section has focused its efforts on two fields of study: 1) the continuing development and modification of programs concerning the land use data, and 2) the collection and analysis of the water quality data from the Data Collection Platforms (DCP).

One of the programs completed was the optimum site location map. This program stems from the thesis written by Paul Wilms concerning the use of ERTS photographs to predict an optimum site for the placing of industry in the State of Alabama. A test area in the lower southeastern corner of Alabama was chosen in his study and the calculations were made by hand. The same area was considered in the program's development.

The algorithm for finding the optimum site location operates using a 10 kilometer square basic area, or "macro cell," instead of a one kilometer square area. Seven factors are taken into consideration in order to give the square a "desirability rating." Four of the factors are determined by the dominant land use for each macro cell; the number of urban, agriculture, forest, and water cells. These were given a weight in the equation of 0.2, 0.15, 0.2, and 0.05 respectively. Three other factors were added to the base file for each section, which were growth potential, availability of roads, and availability of railroads. These were given a weight of 0.2, 0.15, and 0.05. The resulting equation is:

weight for macro cell = (0.2)(#URBAN) + (0.15)(#AGRI) + (0.2)(#FOREST) + (0.05)(#WATER) + (0.2)GP + (0.15)ROADS + (0.05)RAILS.

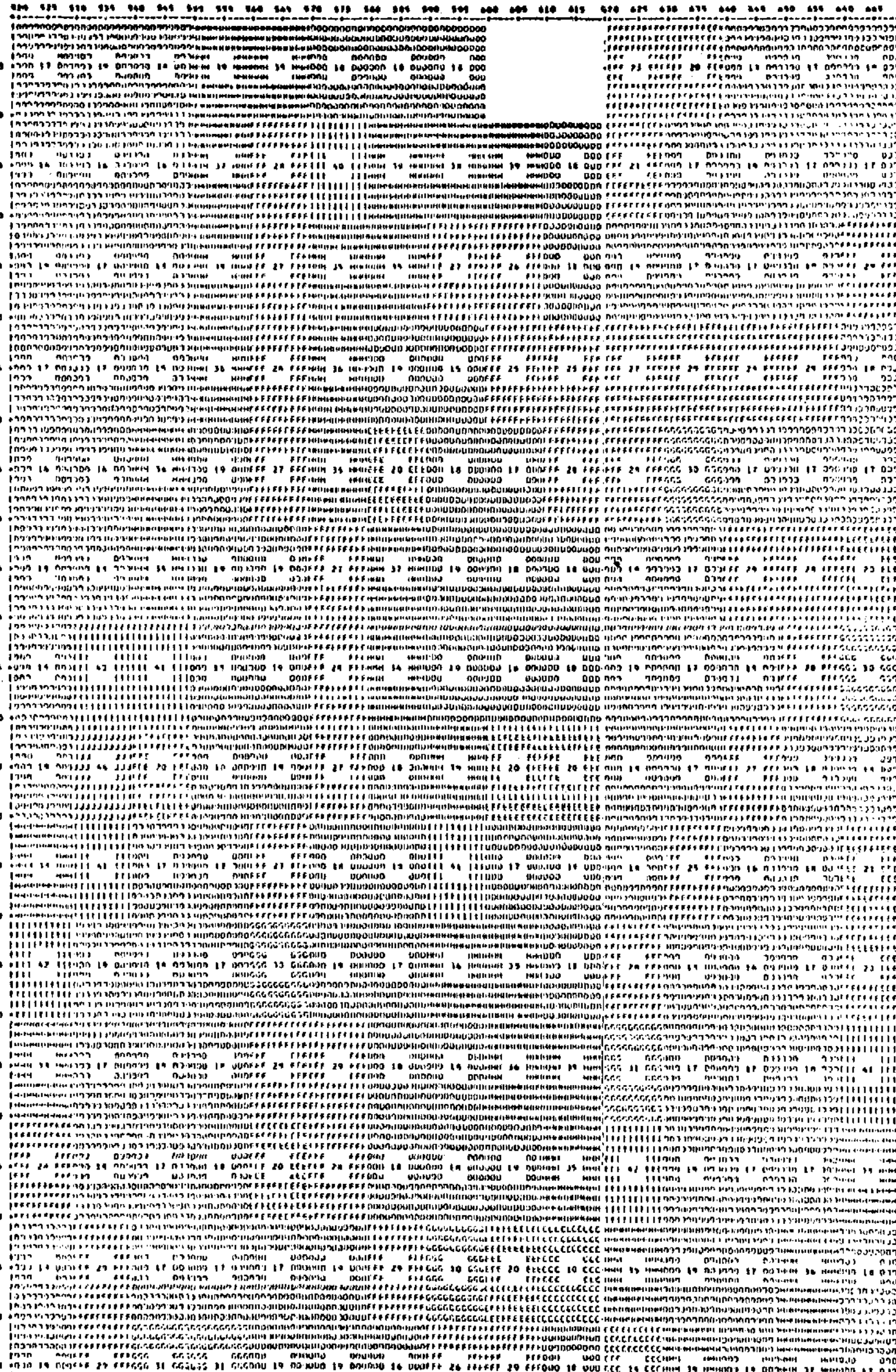
The resulting number was mapped to a letter of the alphabet so that trends could be seen on the map, i.e. 0 - 5 mapped to "A", 6 - 10 to "B", 11 - 15 to "C", etc. The central area of each macro cell was left blank to permit the highlighting of the actual numeric weight which is printed in the cell's center. The resulting map is included in this report.

The other work involved in conjunction with the land use data was changes and modifications with existing programs. The program ERTSSUM, which provides statistics on land use for each county was noted to have some errors and these were corrected. The program which produces a change map, CHGMAP, was modified to give a listing of the number and direction of changes between the two accumulations of land use data for an area. This will be used in the future to check the correlation of land use obtained from ERTS photos and data from U-2 photos.

Another project to be undertaken is the classification of the land included with military reservations which were not originally coded on the historic data. In the beginning all these cells were coded as zero.

Data has been continually added to the DCP disk file, by transferring the data from cards sent from NASA. Also the early data, which was received only in computer print-out form, was keypunched and added to the file.

Two listing programs were written, one to list the actual data in the file and another to list the data with averages printed for each pass of the satellite. A graphing routine has been developed and at the time of this report, some rough graphs have been produced showing monthly trends of dissolved oxygen and temperature. The final project will be



[illegible]
OPTIMUM SITE LOCATION MAP FROM HISTORIC DATA: SCALE 0:60

to design a routine to graph the data by either month, day, or pass of the satellite and to show the difference of levels between day and night sightings.

The data transmitted to the satellite is also to be recorded at the ground station for the two DCP's in Mobile Bay. This data is in the form of a convolutionally encoded bit string which must be decoded prior to analysis. A program was developed to decode the bit string transmitted. Tests on a typical encoded bit string indicate that an average of approximately 10 seconds will be required to decode each bit string. With two bouys transmitting continuously at three minute intervals, each day's data stream would include 960 bit strings to be decoded, requiring 2 2/3 hours of computer time for the decoding process. At prevailing rates on the project, the cost would be approximately $900.00 per day. This figure contains no estimate of time for subsequent analysis of the data decoded. Therefore, under the budgetary constraints of the project, it was determined that decoding the data by a software decoder would be prohibitive. Methods are presently being explored which would permit recording the data after it is decoded by a hardware decoder to eliminate this expense.

APPENDIX V

ECONOMIC CONSIDERATION AND USER LIAISON

Appendix V-A by J. F. Vallery and Larry Davis

APPENDIX V-A

October 6, 1973

MEMORANDUM

To: Experimenters with Remote Sensing Technology

From: Ted Vallery, Project Economic Consultant

Larry Davis and I, working jointly with several experimenters in ERTS and EROS projects, have reviewed the problems and prospects of evaluating the social and economic impacts in several remote sensing applications. We used a combination of guidelines and questionnaires furnished by the Department of Interior, NASA, EarthSat, and our own ideas. Our initial object was to develop a comprehensive questionnaire format which could meet requirements for both National and Alabama evaluations. This memo is to summarize our observations to date and to review the questionnaire substitute approach which we discussed at several meetings.

In general, we found a uniqueness among efforts of the several investigators which greatly reduced the effectiveness of any single questionnaire. Short and simple formats aimed at check-offs and one-line descriptive statements failed to generate the observations sought. The greatest problems, however, can be greatly reduced with a modified approach directed toward a narrative description of findings and including other professional insights.

The first pitfall was in describing an "application" of a particular set of data to a specific problem. Most investigators are working from a particular research design with a conceptualization of their problem which is generally not optimal and sometimes not workable for the secondary economic evaluation. We believe that a restatement of the problem (or redescription of the application) directed toward the estimates of data cost, quality evaluations, and proposals for future systems requirements will be quicker, simpler and more effective than force-fitting the evaluation to the experimental mold most relevant for your emphasis. We noted that investigators tend to review the utility of data only in terms of the central thrust of their experiment thereby omitting many incidental observations of high potential value for the proposed comprehensive evaluation. In general, the solution is to identify the several data manipulations utilized in your work and summarize the actual and projected usefulness of the data, both as is and as it could be assuming equipment modifications, extended time-series coverage, etc.

The second pitfall, as in the problem described above, also stemmed from legitimate but misleading emphasis placed on the need for documenting findings from the research design. But in addition, the economic concept of "benefit" emerged as a major stumbling block. Most experimenters limited their comments and observation to the "benefit" provided by the experimental product envisioned in the research design. In effect, the benefits perceived were limited to known and proven uses such as land use maps. In such cases, the upshot of the evaluation is to compare cost under alternative methods of producing a product, imputing potential cost savings as the only benefit. These cost-effective analyses, while of great value, clearly speak to only a limited scope of the potential utility of remote sensing data. The solution calls for bold and visionary assessments of potential future uses and application drawing upon the full range of your professional expertise as opposed to your findings from the specific application. Since no one knows future utility, your speculative expert judgment is the best possible source for identifying "benefits" other than cost reductions.

These two limitations are perhaps fully offset by a positive result stemming from our interviews. Individual experimenters, especially after some discussion of terminology and probe of the intent of the questionnaires, demonstrated a firm grasp of conceptual problems underlying the cost-benefit approach. Outside of the context of the structured questionnaire, relevant comments and observations were made relative to the information sought. It therefore appears that the short narrative report on cost-benefit aspects of the several experiments can furnish both clearer and more detailed observations than a standardized questionnaire format.

We have therefore recommended a broad scope descriptive narrative as a first-draft presentation of your cost-benefit findings. We believe that insights and speculative assessments stemming from your experimentation will be at least as valuable as experimental results. The various questionnaires will be of primary value in suggesting appropriate content for the narrative. Cost-effective examples should be incorporated where appropriate to the fullest extent possible. The narrative allows and hopefully encourages a discussion of the implications of your cost estimates, considering such factors as the quality of estimates used, comparability of new versus conventional findings, and other factors beyond the scope of a numerical example. The general objective should be to provide an evaluation of future potential and to recommend appropriate system modifications, using the cost insights for appropriate support.

There are several other observations which we also offer as a possible aid in structuring the economic section of your report.

Cost effective evaluations contain a pitfall which often calls for subjective and descriptive modification. Ideally, a daily log would be used to record the exact cost of producing a product in terms of man hours and equipment utilized. Such cost, however, would compare efforts required using conventional methodology and standard equipment with costs incurred using the newly developed techniques and equipment. To the extent that producing a product experimentally required greater effort in developing and checking the methodology, cost figures as obtained from actual records of your experiment will be too high and hypothetical estimate of replication cost would be more appropriate.

Most experimenters used several data sources and/or generated more than one result in the context of a systems evaluation. It will probably be helpful to break up your research design and isolate the elements which directly contribute to insights and evaluation. A review of your observation on the utility of each data source for each specific task, emphasizing relative utility in comparison with other data sources or techniques will be most valuable. Insights or findings relative to the methodology as opposed to data might also be appropriate, such as a description of the unique aspects of using several data sources or processes.

Both actual and potential results from the application of one or more items of project data supplied, stated in terms of a final "product," should be evaluated relative to the "product" which can be generated with existing data sources. If the product replaces or serves as a partial substitute for an alternative, existing source of information, the benefit can be used as a cost effectiveness example. If new information is provided (inclusive of greater frequency, broader scope, and other innovative forms), the potential benefits are speculative as opposed to definitive and call for a description of potential users and uses. Note, however, that identifying whether your experiment produced an old product in a new way or created a new product often is a matter of how you call it. Simply recognizing that most applications have aspects of both, for example, the land use map which is not really the same as a land use map produced under older techniques, gives rise to:

A critical evaluation of the results as a substitute, balancing the discussion in terms of strengths and limitations, and

A probing evaluation of potential new and different uses.

Both should be described, and a sharp distinction should be made between the two descriptions. What is obvious to you and your discipline may not be as readily apparent to evaluators of the system.

When you have completed your draft, at your request we will review your report for technical accuracy in the use of cost-benefit terminology, make suggestions as to relevance in economic context, etc. We can also provide limited technical support on format, etc. relative to the economic problems.

We also plan a final step in the evaluation if the quantity and quality of the speculative insights are sufficient to justify the procedure. Our plan is to compile the projected future uses and perceived "benefits" and circulate them for comment, critique, extensive corrections, etc. by the several investigators. Hopefully, this process can elicit a composite opinion on feasibility and developmental potential of the remote sensing system. Results forthcoming will be made available to each investigator for incorporation of relevant portions in their individual reports.

JFV/mr

THE UNIVERSITY OF ALABAMA
GRADUATE SCHOOL OF BUSINESS

CENTER FOR BUSINESS AND ECONOMIC RESEARCH

POST OFFICE BOX KK
UNIVERSITY, ALABAMA 35486

October 6, 1973

MEMORANDUM

To: Dr. George Whittle, Acting Director
ERTS Project

From: Ted Vallery and Larry Davis, Project Economists

Subject: Bi-monthly progress report (Aug. 7 - Oct.)

Extending the efforts noted in our last bi-monthly report, we have continued with the development of the methodology and refinements in reporting social and economic impacts of ERTS data. Our major thrusts have been to emphasize:

(1) Inclusion of cost-effectiveness and cost-benefit evaluations of the several aspects of each individual investigator's experiments in a more meaningful format, and

(2) Individual's reporting all conceivable benefits suggested by their scientific investigation even though such insights were not documented within the scope of their investigation.

Toward these ends, we have conducted extensive group and individual discussion toward a general understanding of benefit/cost analysis and other methodological approaches for all investigators. We have recommended that cost data of the type requested by questionnaires be incorporated in individual reports, but these should be supplemented by more comprehensive narrative discussions of findings and observations. In particular, speculative perceptions of future benefits should be described in terms of social and economic impact. These recommendations, which were initially presented orally, have also been summarized in a memorandum to individual investigators.

In a more comprehensive interim report, our conceptual approach for evaluating ERTS information flows is outlined in detail. Although the inputs required to make such a system operational are not yet available, the system approach outlined serves as a framework for cost-effective and cost-benefit inputs sought. Two sections of this report then outline the conceptual methodology and more precise specifications for cost analyses and the processing of speculation as to future system benefits. The sections parallel the less technical request for the narrative evaluation outlined above. Finally, the concluding section provides specific examples of some benefits informally reported in our discussions but not yet incorporated in bi-monthly project reports. Hopefully, these will serve as a more definitive example of the type of information sought. Thus, we are continuing to interface the users and investigators and act as a clearinghouse for all relevant information.

JFV/mr

APPENDIX VI

MARINE SCIENCE STUDIES

Appendix VI-A by C. E. Brett and
W. W. Schroeder

Appendix VI-A

Sixth Bi-Monthly Progress Report

By C. Everett Brett and W. W. Schroeder

August 7, 1973, October 6, 1973

MARINE STUDIES IN MOBILE BAY AREA

DCP System

A large part of the ERTS-1 effort since the last report has involved installing the ERTS-1 laboratory at the Dauphin Island Sea Lab and preparing the two DCP buoys for deployment in Mobile Bay.

Partitions have been installed in Marine Science Hall setting off a separate 15 x 20 room designated as the ERTS laboratory. The 8-channel stripchart recorder and the DCP receiver have been placed in this lab along with the necessary battery chargers. All units of equipment have been checked out and are operable. The DCP receiver was a problem for some time because of the difficulty in getting the decoder functioning so that magnetic records of the DCP signals would be compatable with computer facilities available at the University of Alabama.

Adapting the DCP units used elsewhere in Alabam from freshwater to seawater has been the major problem that was anticipated. The two buoys programmed for Mobile Bay are prototypes designed and built at Marshal Space Flight Center. The staff and faculty at the University of Alabama, Dauphin Island have contributed a major part of their time assisting NASA Marshal in adapting and installing these units. One electrical technician has been nearly full-time on this project.

One of the Sea Labs 100' radar towers has been converted to a receiving station for the two DCP buoys. To date, signal reception has been good from the buoys as they are tested on dry land. The buoys are scheduled to be deployed late in October. Arrangements have been made with the U. S. Corps of Engineers to deploy and anchor the two buoys using one of the buoy tenders out of Mobile. A 36' vessel belonging to the University has been modified as an all-weather tender for the buoys after deployment.

One of the features built into the ground truth real-time receiver system at the lab is a warning system that will indicate when the buoys are malfunctioning or are being tampered with. The warning system will sound an alarm at the lab and in the main office.

Initial deployment of the buoys will be at sites considered to be environmentally sensitive in Mobile Bay. Buoy 1 will be placed at the proposed drilling site for the Mobil Oil Corporation wildcat well. This is the first well ever proposed for drilling the Bay. The site is located in the middle of Mobile Inlet half-way between the ship channel and Dauphin Island. We not only will receive data pertaining to environmental conditions at the well site but will be able to study the interchange between the Bay and the Gulf. In addition the Buoy will be located close by allowing us to easily evaluate its performance during early stages of usage.

ERTS Data

Since the last report no new ERTS imagery has been received by the Marine Science Program. It is anticipated that by the time DCP's are installed the imagery inventory will be updated allowing us to develop a comprehensive program of interpretation. Regular field excursions have already been scheduled in anticipation of the DCP installation and receipt of additional imagery.

APPENDIX VII

MARSHALL SPACE FLIGHT CENTER CONTRIBUTIONS

Appendix VII-A by Charles T. N. Paludan

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

REPLY TO
ATTN OF: S&E-EA-DIR

October 4, 1973

Dr. George P. Whittle
Civil and Mineral Engineering Department
University of Alabama
P. O. Box 1466
University, Alabama 35486

Dear George:

For the sixth bi-monthly ERTS-1 progress report, the following are events since August 6, 1973:

DCP DATA BUOYS

This period has been occupied in transporting the two Mobile Bay buoys and ground receiving station to Dauphin Island and assembling them. Considerable work was required to fit the buoy mechanical equipment together due to the lack of suitable facilities and equipment at the MESC for this size project. At present both buoys are completely assembled and have been operationally checked. The buoys are transmitting as planned. The ground station has been a source of problems in that the convolutional decoder was inoperative at first. The decoder was removed and brought back to MSFC and checked out. After reinstallation it seemed to work fine, however due to an oversight, one parameter was not wired into the cable from the decoder to the strip chart recorder. This has been corrected and the decoder and cable will be returned to Dauphin Island next week and reinstalled.

We have received the last instrument package for the fresh water buoy and it is being assembled this week (Oct. 1, 1973). The salt water (Mobile Bay) buoys are planned to be deployed within two weeks and the fresh water buoy sometime next week.

PINE BARK BEETLE

Michael S. Golden, of Alabama A&M University, has had his NASA grant extended, and he continues to investigate the detection of pine bark beetle infestations by color infrared imagery. He has conducted further ground truth surveys in Northeast Alabama (Marshall, Blount, and Etowah Counties), and is using data from the JSC Mission 236 RB-57F flight of April 29, 1973. For this purpose, the film held by the University of Alabama was borrowed and duplicated in the MSFC Photographic Division.

EQUIPMENT AND DATA

Six rolls of multispectral photographic data (positive duplicate) of the Birmingham and Tuscaloosa sites were sent to the University of Alabama on August 3, 1973. To aid in analysis, a Model 6000 color Additive viewer manufactured by International Imaging Systems, Inc. was lent to the University by Marshall Space Flight Center on August 29, 1973. The data sent had the following description:

Format: I^2S, four 89-mm square frames on 9-inch film
Dates: February 22, May 9, 10, and 18, 1973
Scale: Approximately 1:24,000
Filters: (1) Kodak 47B, (2) Kodak 57A, (3) Kodak 25, (4) Kodak 88A, and (5) an infrared rejection filter for bands 1, 2, and 3.
Film: Kodak 2424, black and white infrared.
Roll Numbers: 20-1, 20-2, 20-3, 20-4, 20-5, and 20-6

Sincerely,

Ted Paludan

Charles T. N. Paludan
Deputy Director
Environmental Applications Office

APPENDIX VIII

GEOLOGICAL SURVEY OF ALABAMA CONTRIBUTIONS

With Contributions as Follows:

Appendix VIII-A by James A. Drahovzal,
Charles C. Wielchowsky and
Jacques L. G. Emplaincourt

Appendix VIII-B by Donald B. Moore

Appendix VIII-C by Jacques L. G. Emplaincourt
George F. Moravec and
Philip E. LaMoreaux

Appendix VIII-D by Jacques L. G. Emplaincourt
and Charles C. Wielchowsky

Appendix VIII-E by William M. Warren and
Charles C. Wielchowsky

Appendix VIII-A

Appendix 1

Table of contents of the manuscript report

REMOTE SENSING OF EARTH RESOURCES IN ALABAMA: A NEW ENVIRONMENTAL PERSPECTIVE

By

James A. Drahovzal
Charles C. Wielchowsky
and
Jacques L. G. Emplaincourt

This report describes the activities of the Geological Survey of Alabama from August 6, 1973, through October 6, 1973.

DATA

Our data situation is now somewhat improved. We have received most of the data ordered from the EROS Data Center and Plunkett Blueprint, a commercial photography firm in Atlanta. Much of this data has been reproduced at a scale of 1:250,000. We have found that Plunkett is capable of reproducing ERTS imagery at the 1:250,000 scale from 70 mm negatives. The product is comparable and in some ways superior to similar products produced by the EROS Data Center. The Plunkett products are on a lower grade photographic paper, but much closer to a true 1:250,000 scale than the EROS products. Turn around time with Plunkett is about 10 days as opposed to 2 to 3 months with EDC. The cost is $10.00 for Plunkett products as opposed to $9.00 through EDC. The Survey photography laboratory is now manned and we are able to do some limited work.

We have yet received no word on the retrospective order to NASA which grew out of our special report, Quality of NASA-Provided ERTS-1 Imagery.

USER-ORIENTED WORK

User interest in the state is moderately high, but little has been done to educate many of the interested workers in the use of remotely sensed data. In response to this apparent need, the members of the Remote Sensing Section of the Geological Survey of Alabama have completed a manuscript entitled Remote Sensing of Earth Resources in Alabama: A New Environmental Perspective. The report emphasises the ERTS satellite and the application of ERTS satellite data to earth resources problems in Alabama. The manuscript is now being edited and the Survey plans to publish it within the next six months. The report defines remote sensing and its role in earth resources studies, discusses sensors and platforms, and treats applications of remote sensing techniques to geology, geography, forestry, agriculture, and oceanography. It also discusses current state and federal remote sensing programs important to Alabama and reviews the data currently available for the state (Appendix 1 shows the contents of the report). Support for this report is supplied both through this project and a project of the EROS Program (EROS 14-08-001-13377, User Acceptance and Implementation of ERTS-A Data in Alabama).

Through the EROS project, the Survey recently released a product that should be of interest to reviewers of this report. In cooperation with the EROS Experiments and Evaluation Office at Mississippi Test Facility, the Survey published a band 5 ERTS mosaic of Alabama for the general public. Many of the local news papers printed the photograph and it has been well received by the general public and potential users. Numerous examples of the potential benefit of this kind of dissemination of ERTS data could be cited, but one stands out. A lineman with Alabama Power Company saw the image of the state in the Birmingham News. The Selma Chalk, because of land-use differences, is strikingly displayed on the image. The lineman identified the outcrop area of the Selma as the areas where the company experienced the most trouble with power lines in terms of breaks and failures of various types. Power company geologists together with engineers are now looking into this possible correlation. Had the lineman seen a picture of a geologic map, chances are he would not have taken a second look. The glamour of space imagery caught his eye long enough for him to have hit upon a possibly important factor, heretofore overlooked (Appendix 2).

LINEAMENTS

The geophysical studies discussed in the previous bi-monthly report have been completed and have yielded some encouraging results. Although both gravity and magnetic profiles across the Anniston lineament in the Huntsville area were planned, only gravity was run due to magnetic interference. Eighty gravity stations at 0.1 mile intervals along U. S. Highway 72 southwest of Huntsville were read in producing the profile (Appendix 3). In general, the regional trend from a high in Limestone County to the west to a low in central Madison is confirmed by the profile, but several anomalies are present. The profile is quite smooth along the southwest segment, but about midway the largest anomaly along the traverse occurs. This anomaly of 0.4 miligals corresponds precisely with the Anniston lineament as previously mapped on 7½-minute quadrangle bases using ERTS images. The anomaly is thought to represent a fault downthrown to the southwest and rough calculations indicate that the feature is some 5,000 feet beneath the surface. To date, our best estimate as to the depth to the Precambrian basement in Madison County is in the order of 5,000 to 7,000 feet. Therefore, the gravity differences reflected in the profile may represent basement faults. This may be one of the first good pieces of evidence that clearly shows that some of the lineaments are related to basement faulting, a position that we have been suggesting for the past three years. The density differences of the rocks above the basement may not be great enough to markedly affect the instrument, or it is possible that vertical offset does not occur above the basement. Other smaller anomalies characterize the northeast segment and may relate to a swarm of lineaments recognized in the area on ERTS and SLAR imagery. At least five more profiles are planned across the Anniston lineament in other areas.

Geochemical sampling across the lineament is in progress, but the analyses are not yet complete. Several traverses will be made across the lineament in Madison County in the area where the gravity profile was run. The samples will be analyzed for lead, zinc, copper, molybdenum, and cobalt. Hydrologic studies in the area are now in the planning stages and should be carried out in the next several months. Because of the thick regolith, little field geologic work can be attempted in the Huntsville area, but to the southeast, some structural analyses will be attempted.

During the report period, nine days were spent in the field collecting detailed geologic data in the Coosa Deformed Belt of the Alabama Valley and Ridge. The belt is a narrow zone of highly complex, thin, imbricate thrust sheets and klippen. Special emphasis was placed on areas where major lineaments traverse the belt. Some gross relationships are suggested in the geology, particularly where the Anniston lineament crosses the zone. A detailed jointing study was conducted near the Anniston lineament where Coosa Belt structures terminate or change in structural style. The results of this study are now being analyzed.

ERTS-1 ACTIVITIES

By Jacques Emplaincourt

In the past two months, this co-investigator devoted time to five particular items related to ERTS.

1. Administrative duties relating to the Geological Survey of Alabama's part on the ERTS-1 project.
2. Participation in the writing of a GSA publication entitled: Remote Sensing of Earth Resources in Alabama: A New Environmental Perspective (Appendix 1).
3. Co-authored a paper which will be delivered and published in Split, Yugoslavia, for the annual meeting of the Association Internationale des Hydrogeologues (Commission de l Hydrogeologie du karst). Title of the paper: "Potential Applications of Remotely Sensed Data to Sinkhole Development Problems in Shelby County, Alabama, U.S.A."
4. Wrote a paper to be delivered and published at the Reunion Pleniere Internationale de l Association Internationale des Hydrogeologues in Montpellier, France. Title of paper: "The Role of Remote Sensing in Hydrogeologic Research in the State of Alabama, U.S.A." (Appendix 4).
5. Co-authored a paper with Charles C. Wielchowsky which is entirely devoted to ERTS-1. "Detection of Shoreline Changes from ERTS-1 Data" will be delivered and presented for publication at the Southeastern Division Meeting of the Association of American Geographers in Boone, North Carolina, on November 18, 1973. This paper which is included in Appendix 5 discusses changes in the coastal configuration of Mobile Bay and its offshore islands over the past 15 to 20 years.

ERTS-1 ACTIVITIES

By Charles C. Wielchowsky

The following ERTS-related activities were undertaken during the last two months.

1. General administration of ERTS project.
2. Preparation for publication of a band 5 mosaic of the entire state of Alabama (Appendix 2).
3. Writing of a Geological Survey of Alabama publication entitled Remote Sensing of Earth Resources in Alabama: A New Environmental Perspective. This publication is for the present and potential user of remotely-sensed data in Alabama (Appendix 1).
4. Co-authored a paper which will be delivered in Yugoslavia to the Association Internationale des Hydrogeologues. The paper is entitled "Potential Applications of remotely-sensed data to sinkhole development problems in Shelby County, Alabama, U.S.A."
5. Co-authored a paper entitled "Aerial remote sensing of active carbonate terranes in Shelby County, Alabama" to be published in the journal Groundwater (Appendix 6).
6. Co-authored a paper entitled "Detection of Shoreline changes from ERTS-1 data" which will be presented at the Southeastern Division meeting of the Association of American Geographers (Appendix 5).

Appendix VIII-B

ERTS PROJECT - ENERGY RESOURCES RESEARCH DIVISION

Oil and Gas Exploration through the use of ERTS Satellite Imagery

By Donald B. Moore

During the period of August 6 - October 6, 1973, research activities were conducted by the Energy Resources Research Division using ERTS data on Bands 5 and 7 of December 28, 1972. The method undertaken in this research was to identify surface structural impressions revealed by the imagery and correlate these with known subsurface geologic features. This method of investigation proved to be quite satisfactory in that numerous correlations were possible. For example, in central Choctaw County, Alabama, where the Gilbertown Fault System extends east west across the county, a definite distorted zone can be seen on Band 7 of December 28, 1972. The Hatchetigbee Anticline, a northwest southeast trending anticline, lies just south of the distorted zone. The anticline is also very subtly expressed on Band 7. There is also a fault system which bounds the south side of the Hatchetigbee Anticline which can be identified very clearly on the ERTS imagery. This fault system is a northwest-southeast linear trend which is expressed as a narrow disturbed belt. Also on Band 7 a radial anomaly is identifiable in north-central Clarke County. This radial anomaly coincides exactly with a previously discovered subsurface high which was determined on the basis of oil test well data.

The value of being able to detect surface expressions of subsurface structures on ERTS imagery becomes obvious when one considers that if it is possible to identify these features in areas of known subsurface structure then it would also be possible to spot similar features in areas where the subsurface control is not yet available. For example, the Gilbertown Fault System which was observed in central Choctaw County has been the site of the discovery of at least ten oil fields; whereas, the unnamed fault system south of the Hatchetigbee Anticline has been explored very little, and consequently, no oil fields have been found along this fault system.

On Band 5 of the December 28 L-3 orbit many interesting features can be pointed out. One such feature is the fact that the actual well locations for the wells in the Jay-Little Escambia Creek Fields can be detected. The Little Escambia Creek Field is predominently in a vegetated area of low relief, and two to five acres are usually taken up with a typical well location. In preparing a well location the trees and other vegetation are removed, and consequently, these areas show up as small white dots on the imagery that was obtained at a height exceeding 500 miles. Similar dots, which indicate well locations, can be observed in the area of the Citronelle Field. However, since this field was discovered in 1955, these well locations are not nearly as distinct. Northwest and west northwest of the Citronelle Field two distinct radial anomalies can be pointed out. These anomalies probably represent surface expression of a subsurface structural high and would be prime areas for oil and gas exploration.

The main advantage of the ERTS imagery in comparison to conventional low altitude photographs or remote sensing is that it allows a broad perspective with no break in the continuity of the image. In studying photo mosaics different shades of light breakup or distort the tracking of a particular lineation or expression.

The quality of the ERTS imagery has been quite variable, but in some flights such as February 1973 in the L-3 orbit the quality and usefulness of this data are excellent, and in cases such as this, information and ideas of tremendous value can be obtained from close observation of the ERTS imagery. In summary, ERTS imagery can be employed as a valuable supplementary tool to understanding subsurface geology and thus aid in the exploration for oil and gas.

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STATE OF ALABAMA UNCONTROLLED ERTS-1 MOSAIC

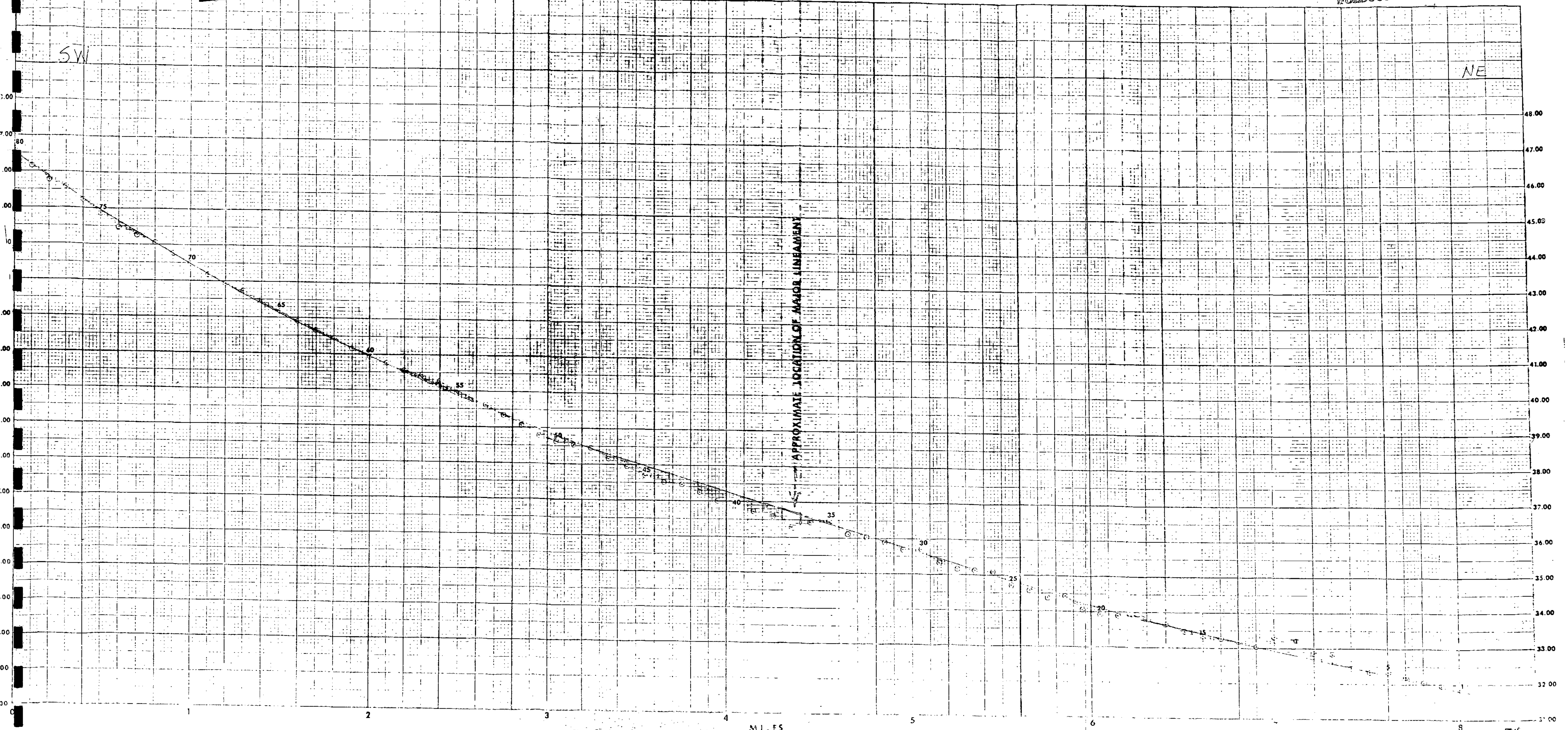
By

Charles C. Wielchowsky

APPENDIX 3

GRAVITY PROFILE ACROSS ANNISTON LINEAMENT

FOLDOUT FRAME 1 FOLDOUT FRAME 2 FOLDOUT FRAME 3



Appendix VIII-C

APPENDIX 4

THE ROLE OF REMOTE SENSING IN HYDROLOGIC RESEARCH IN THE STATE OF ALABAMA, U.S.A.

By

Jacques L. G. Emplaincourt
George F. Moravec
and
Philip E. LaMoreaux

THE ROLE OF REMOTE SENSING IN HYDROGEOLOGIC RESEARCH IN THE STATE OF ALABAMA, U.S.A.[1]

By Jacques L. G. Emplaincourt,
George F. Moravec, and
Philip E. LaMoreaux[2]

Until a few years ago, virtually all photogeologic interpretations were based on relatively low-altitude black and white photographs. Examples of their applications are well documented. In recent years, with the advent of space platforms and the development of new sensor systems, the number and diversity of applications to geologic and hydrologic problems have multiplied many fold.

Remote-sensing research in Alabama dates back to the mid-1950's, but the flurry of recent activities in the State began in 1969 when Apollo 9 studies were initiated. The Apollo 9 study served as a catalyst not only in stimulating related follow-up studies, but also in bringing attention to the whole realm of remote sensing and its importance as a tool for geologic and hydrologic research (Drahovzal, written communication, 1973). With Apollo 9 a momentum was created, and it was maintained when ERTS-1 was successfully launched into orbit in July of 1973. As the volume of data grew, a Remote Sensing Section was established within the Geological Survey of Alabama. Basically, the functions of this section are: to acquire, catalogue, store, and manage remotely sensed data collected within the State of Alabama. Furthermore, the section performs and stimulates remote-sensing research that emphasizes geology and hydrology.

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[1] Approved for publication by the State Geologist.

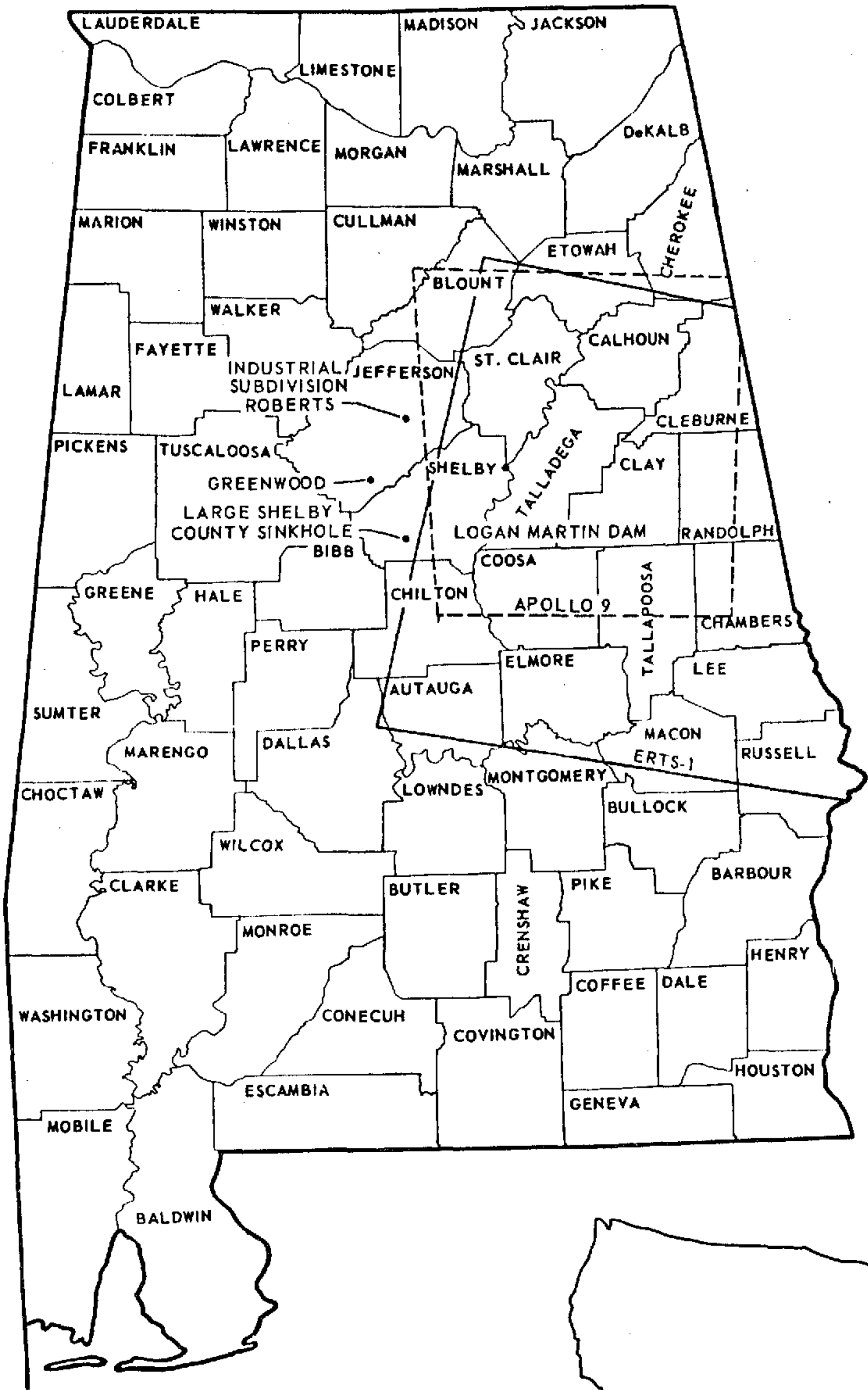
[2] Geological Survey of Alabama, P. O. Drawer O, University, Alabama 35486.

It is the purpose of this paper to discuss the role played by remote sensing in hydrogeologic research conducted by the Geological Survey of Alabama. Emphasis is placed upon specific hydrologic problems that have occurred within the State, and how remote-sensing techniques have aided in discovering, delineating, assessing, and solving these problems.

Remote sensing is the measurement of some property of an object without having the sensor, or measuring device, in direct contact with the object. Thus, information transfer from the object to the sensor must be carried out by use of reflected, emitted, or transmitted fields. In most cases, the field involved consists of electromagnetic radiation, and, thus, remote sensing is simply the observation of variations in this field.

Most of the different sensor types utilized in the following studies represent the state of the arts in the development of remote-sensing techniques. These sensors include: Conventional and multispectral low-altitude photography, high-altitude (18,900 meters) multispectral photography, side-looking airborne radar (SLAR), thermal infrared imagery, and satellite multispectral photographs and imageries. The altitude of the sensors varies between 500 meters and 912 kilometers, depending upon the techniques and methods to be used.

The role of remote sensing in hydrologic research may be best examined by first looking at some of the applications and benefits derived from the use of remote-sensing techniques to specific projects. Geographical location of various study sites relating to these projects are shown in figure 1. Probably the simplest technique of remote sensing, and one that is generally available throughout the world is aerial reconnaissance utilizing black and white (B/W) photography. Such techniques were recently used with



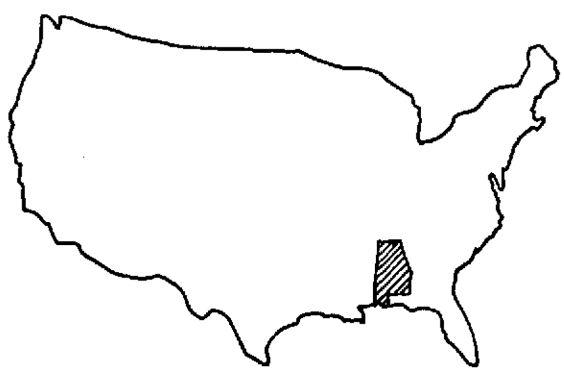


Figure 1. Geographical location of study sites.

significant results in an investigation of collapse and subsidence problems in an industrial area near Birmingham, Alabama.

Collapse and subsidence became a serious hazard in and around the Roberts Industrial Subdivision when sudden collapses and subsidence occurred under warehouses, railroad tracks, an interstate highway, and parking lots. A geologic investigation revealed that the area is located on the northeast flank of an anticline and is underlain by Cambrian and Ordovician limestone and dolomite beds that dip steeply to the northwest. The collapse and subsidence occurred in residual soils 1.5 to 22.5 meters (5 to 75 feet) thick overlying the limestone and dolomite. Approximately 200 have occurred since 1963 in an area of less than one-half square mile.

Black and white photography obtained from various sources and taken at different times revealed the location, distribution, and history of collapse (sinkhole) development of the area. Collapse and subsidence can be correlated to lithology, rainfall, fluctuation of the water table and dewatering from surface mining activity. Aerial photographs clearly show the relationship between collapses under the interstate and railroad to the quarry operation. The collapses form a relatively straight-line pattern, which if extended would intersect the quarry. The sediment plume due to subterranean ground-water discharge in the quarry show that discharging ground water is carrying a heavy sediment load (fig. 2). The relative position of the sediment plume to the collapse pattern indicates that the cavity system within the dolomite is interconnected from the collapses to the points of ground-water discharge in the quarry.

Aerial photographs, in this case, indicate that quarry operations are, at least in part, responsible for collapse and subsidence problems in the area by lowering the water table through dewatering operations.

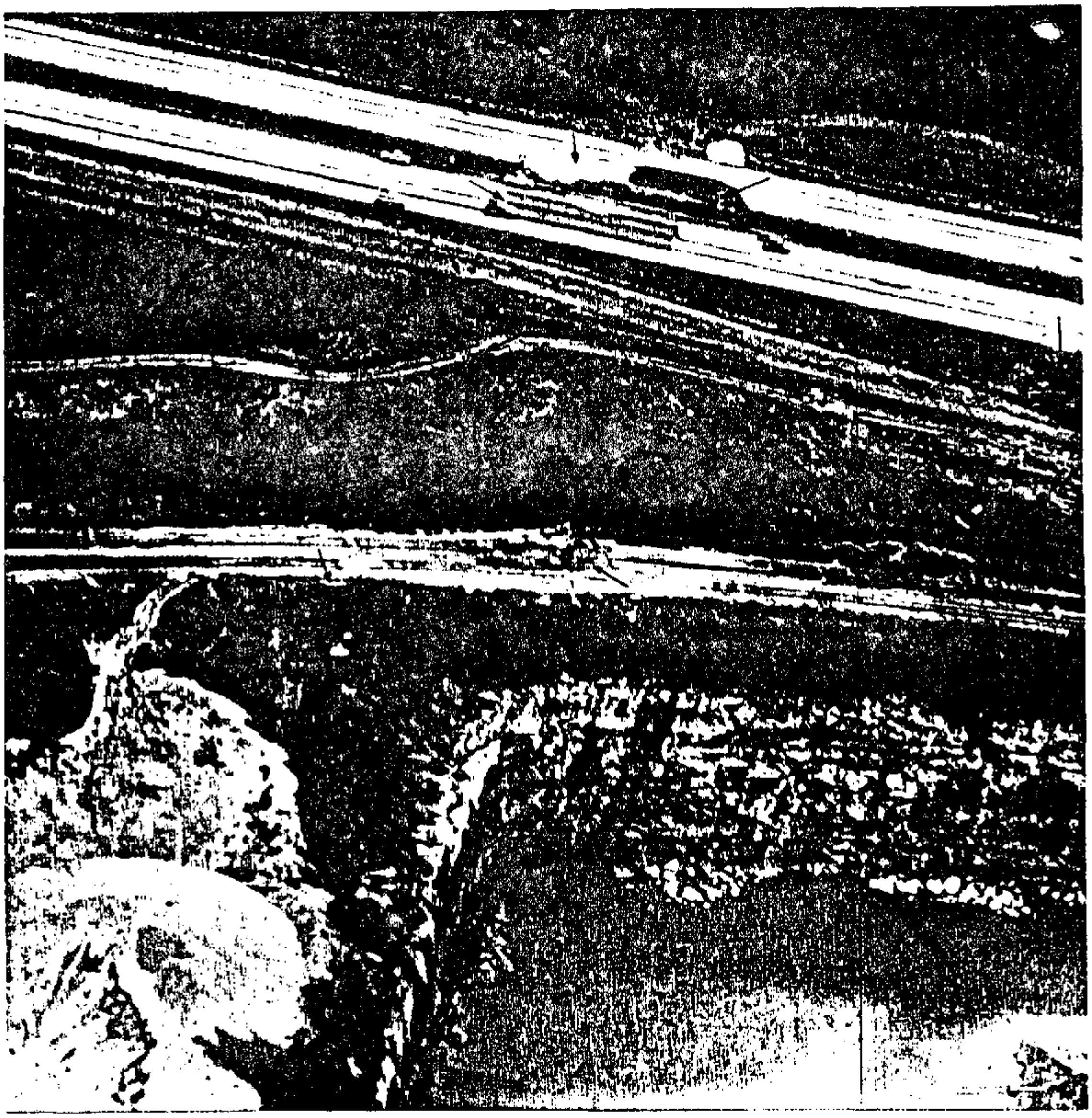


Figure 2. Oblique aerial photograph showing sinkhole-prone area near Roberts Industrial Park. Arrows indicate sinkhole.

On December 2, 1972, Hershel Byrd, a resident of rural southern Shelby County, Alabama, was startled by a house-shaking rumble and the sound of trees breaking. Two days later, hunters in nearby woods found a crater 95 meters (325 feet) long, 90 meters (300 feet) wide, and 35 meters (120 feet) deep. This giant sinkhole collapse (fig. 3) is the largest in an area plagued with sinkhole collapses.

Aerial reconnaissance and photographs revealed that in an approximately 40-square-kilometer area about 1,000 sinkholes, other indications of subsidence, and internal-drainage features have formed. Most of the sinks are in Dry Valley (underlain by limestone) where solution activity and subsurface soil erosion are most pronounced. Deeply weathered Cambrian dolomite beds of the Knox Group underlie the low eroded ridge where the large collapse is located. This collapse occurred in white and orange residual clay, and no bedrock is exposed throughout the bottom or sides. Steep sides are usually found in recent collapses, but not in this case. This is probably due to its large size and unstable walls. Slumping is active on all sides, indicating that the sinkhole will continue to grow until a stable slope angle is reached.

Sinkhole collapses are related to natural phenomena such as heavy rainfall, seasonal fluctuations in the water table altitude, earthquakes, or other changes in the hydrogeologic regime affecting residuum stability. Man-imposed effects such as artificial drainage, dewatering, seismic shocks (blasting), breaks in water or sewage pipes, or even overwatering in irrigated areas may result in a collapse in carbonate terrains.

Shelby County will be the subject of a reconnaissance study that will examine not only existing sinkhole activity, but past and future problems.

To accomplish this end, a great deal of time will be spent in the examination of remotely sensed data. Remote-sensing technology will be applied from the early planning stages throughout the entire project. In order to delineate the areas of interest and to eliminate wasted man hours searching rugged terrain, county-wide photography, such as in figure 3, will pinpoint active areas and their aerial extent (Warren and Wielchowsky, 1973).

In 1972 the Geological Survey of Alabama was engaged by the State Highway Department to investigate potential sinkhole problems for a section of proposed interstate highway located in an area of active sinkhole development near Greenwood, Alabama. The area is in the Birmingham iron ore mining district where extensive underground mining and dewatering has taken place. The proposed highway route crosses the flank of an asymmetrical northeast-plunging anticline and major normal faults.

The area of active sinkhole development is underlain by Mississippian age limestone and chert that project upward through younger shale layers. Residual deposits 0.5 to 15 meters (2 to 50 feet) thick overlie bedrock in most of the area. Shallow water-table conditions existed in the area until underground mining operations commenced in the early 1950's. Due to the lowering of the water table, collapses in residual deposits and subsidence bagan shortly after mine dewatering operations started.

The Greenwood study attempted the following objectives: 1) to define the area where sinkholes have occurred and where future collapses may occur; 2) to determine how the formation of sinkholes relates to the geology and hydrology of the area; 3) to define the history and status of sinkhole development; 4) to relate the effects of highway construction to the potential development of sinkholes.

Figure 3. Recent sinkhole collapse in Shelby County, Alabama. (Photograph courtesy of W. J. Powell and Prescott Research Group.)

Remote sensing was employed in the project because the study area is obscured by dense forest and a thick residual soil.

Specifically, two types of remote-sensing sensors and techniques were utilized: multispectral photography and thermal imagery. A multispectral camera takes several simultaneous photographs of a single area. Each photograph records electromagnetic radiation in a different band of the spectrum by filtering techniques. This allows the interpreter to distinguish very subtle differences between objects on a photograph that a broad-band camera and film might miss.

Thermography, a term that was proposed by Williams (1972) to replace the more cumbersome term, thermal-infrared imagery, is particularly useful in hydrologic studies. Infrared radiation is emitted by all objects as a function of their temperature (assuming that the object's temperature is above absolute zero) and emissivity (Robinove, 1965). The emissivity of an object is a measure of its absorbing and emitting efficiency.

In the Greenwood study, the two systems were utilized to aid in locating areas of water loss in streams, to locate geologic structures, and to evaluate their utility in locating uncollapsed cavities in unconsolidated deposits overlying bedrock. An overflight altitude of 500 meters (1,600 feet) above mean terrain was selected to provide ground resolution of features or objects smaller than 0.5 square meters (5 square feet) in area. A battery of four 70-millimeter cameras was used simultaneously with the following film types: infrared color, color Ektachrome, black and white infrared, and aerocolor. The first two film types defined existing or prior vegetative stress that has resulted from subsidence and interior drainage through unconsolidated sediments at the land surface. This definition aided in locating areas in which conditions are favorable for the formation of cavities in residual clay and in which they are present. Figure 4 illustrates the vegetative stress near sinkholes.

Infrared black and white photography was obtained to better delineate water and land boundaries. Figure 5 shows prominent lineaments formed by the channel of Allen Brook trending along a fault and associated highly inclined strata, a stream discharging into a sinkhole, and water-filled sinkholes.

Daytime thermal imagery flown in March 1972 (fig. 6) indicates faults mapped during the project and points where water loss occurs (arrows on fig. 6). The image appears fuzzy because only thermal infrared radiation is being detected, and not visible light. The light areas on the imagery represent relatively "hot" surfaces whereas the dark areas represent relatively "cool" ones. On the lower image, a special processing technique called "contouring" enhances lineaments or fault traces along the proposed route, thus defining areas of increased solution activity and sinkhole development.

Most geologic and hydrologic features in the area were located prior to the acquisition of photography and thermal mapping. The availability of these tools during early stages of the project would have resulted in less test drilling and field work. This, in turn, would have resulted in an earlier completion date and economic gain. The locating of geologic and hydrologic features that cause or are related to the development of sinkholes indicates the potential value of applying multispectral photography and thermal imagery in the evaluation of proposed highway corridors.

Radar is rather unique among the remote-sensing devices in that it needs no daylight, clear weather, or thermal emission from objects to operate. Most radars simply provide their own illumination by means of a pulse

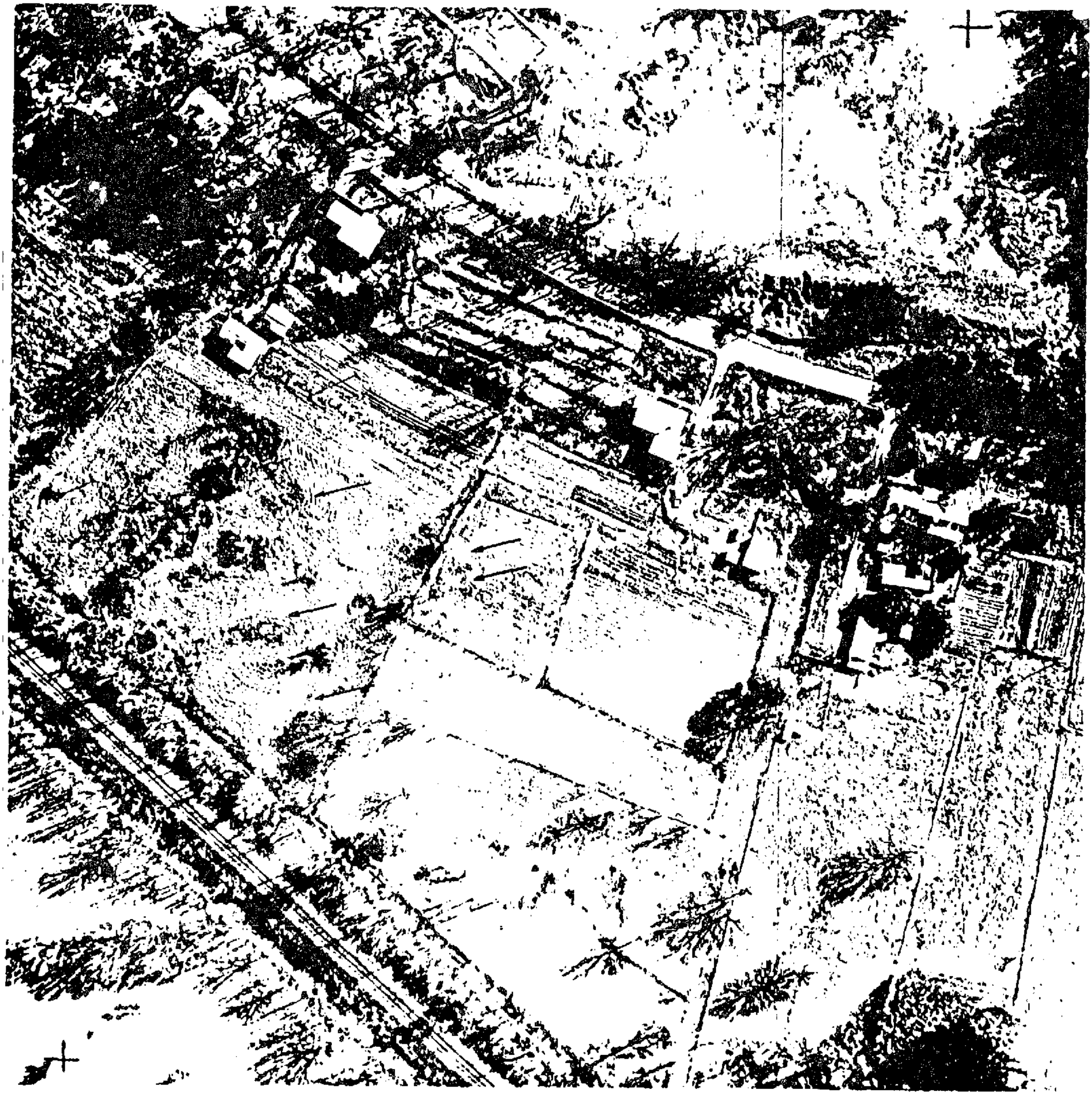


Figure 4. Vegetative stress near sinkholes. (Photograph by Environmental Systems Corporation.)

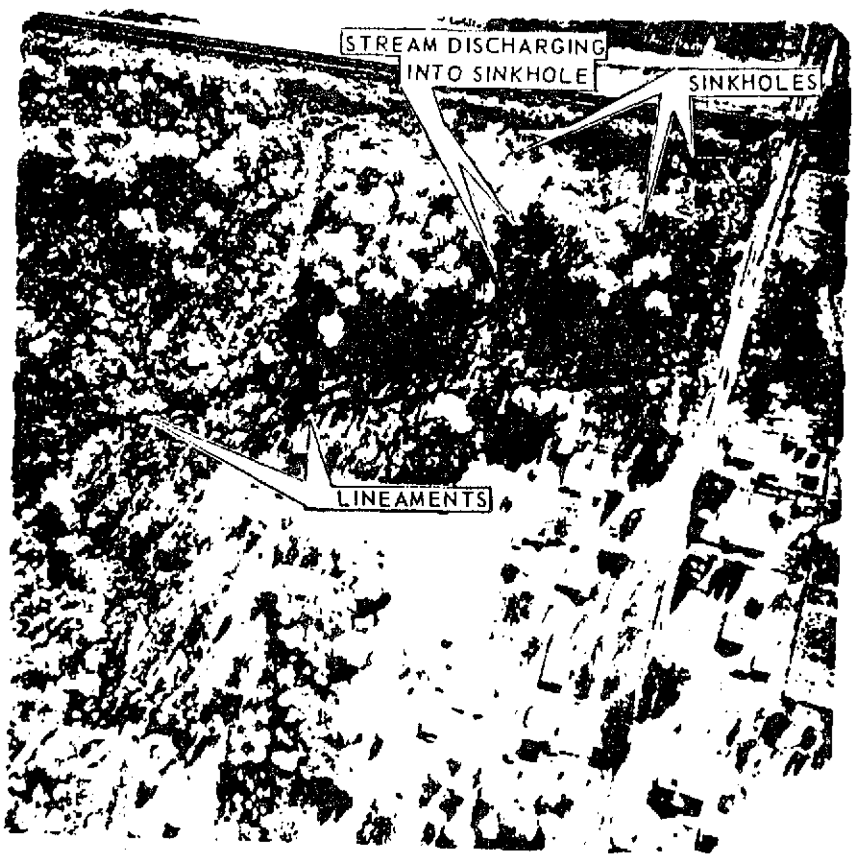
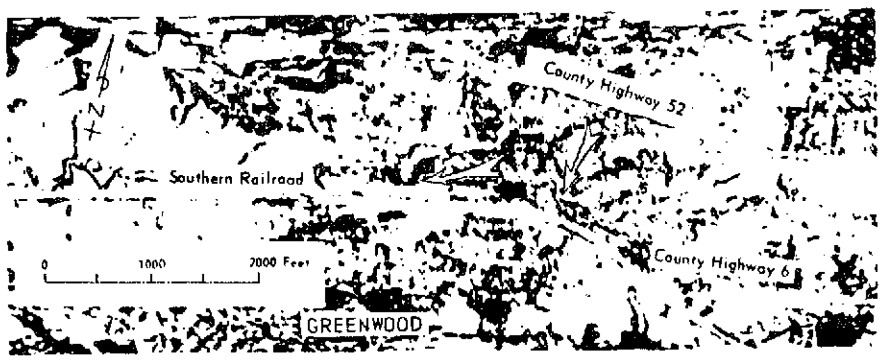
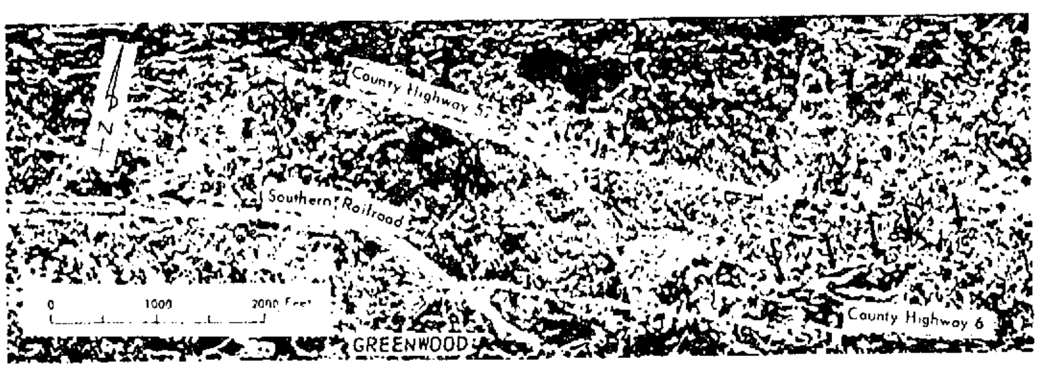


Figure 5.– Black and white infrared showing lineaments, water loss, and sinkholes. (Photograph by Environmental Systems Corporation.)

Figure 6



Thermal infrared imagery showing water loss. (Imagery by Environmental Systems Corporation.)



Thermal infrared imagery showing locations of lineaments indicating faults. (Imagery by Environmental Systems Corporation.)

transmitter which generates radio waves from 0.1 to 100 cm in length. An antenna is used both to send and receive the signal produced by the transmitter. SLAR (side-looking airborne radar) can obtain excellent resolution with a long, narrow antenna that senses to the side of the platform from about 55° to 20° (degrees) from the horizontal.

Logan Martin Dam has had a history of leakage problems. Most of the leakage problems are related to solutionally enlarged joints, fractures, and possible fault planes in rocks forming the foundation. The dam was constructed in an area underlain by Cambrian and Ordovician age dolomite, dolomitic limestone, and chert. The rocks in the vicinity of the dam have been extensively folded, faulted, and fractured. The region exhibits typical "Valley and Ridge-type structure" having parallel fold axes and low angle thrust faults. The geology and structure are obscured by a lack of marker beds and a thick residual mantle; thus, interpretation of geology and structure is very difficult from surface exposures.

In 1969, when Apollo 9 photographs of Alabama were received, a lineament was found to be running parallel to the axis of the dam (see section on Apollo 9 for further details on discovered lineaments). The presence of the Apollo 9 lineament was confirmed and more clearly defined using SLAR imagery (fig. 7). Thus, investigations were conducted to evaluate SLAR imageries in an attempt to delineate geologic features that might provide paths of water leakage between the reservoir and tailrace (Bailey, 1970; Alverson, 1970). Results of the investigations indicated that SLAR is considered to be an excellent tool for regional hydrologic and geologic studies, especially when used in conjunction with other space imagery (such as Apollo 9). New geologic information appearing in the images includes support for

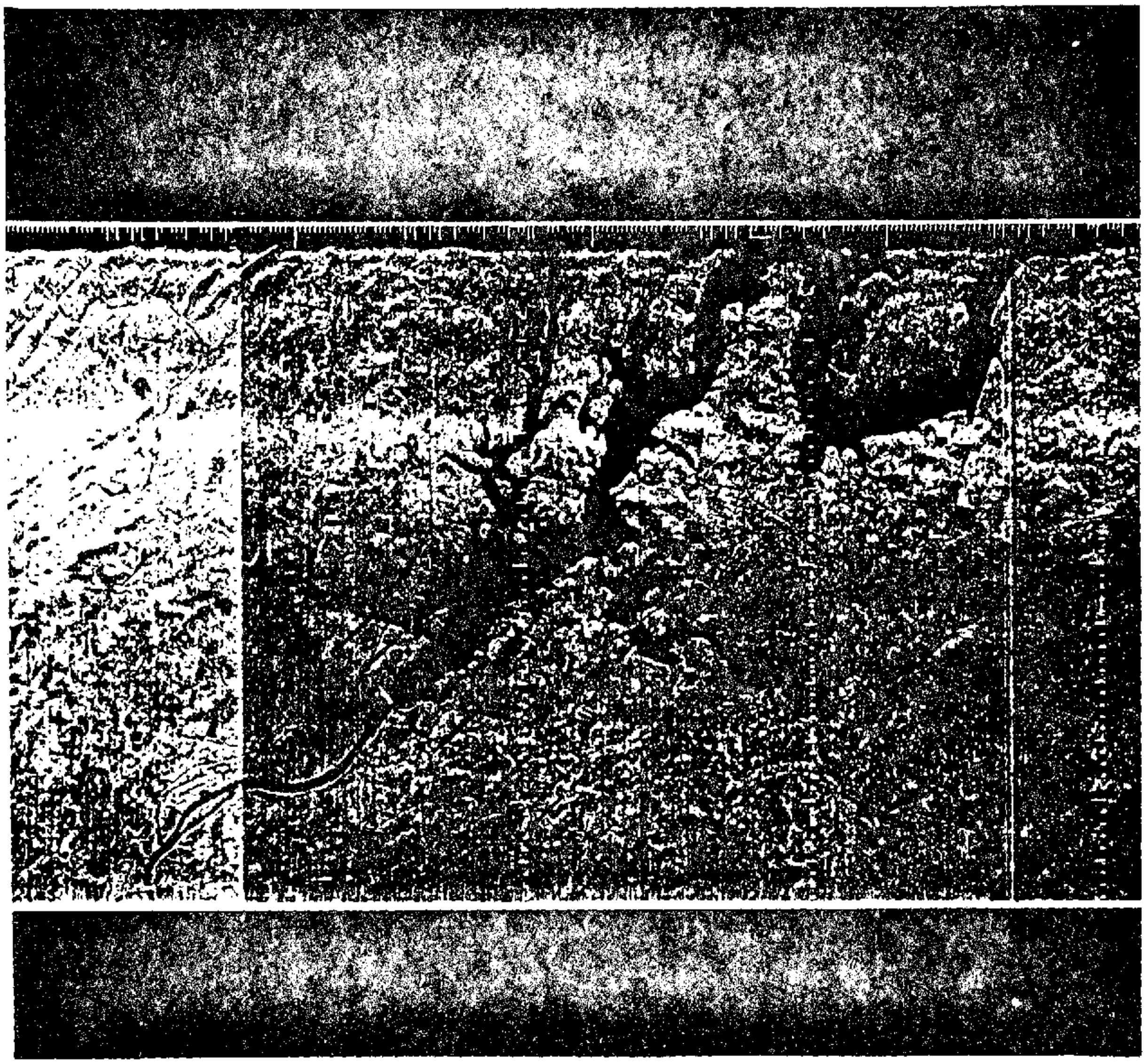


Figure 7. SLAR imagery of Logan Martin Dam. Arrows indicate lineament. (Imagery by Westinghouse Electric Corporation.)

the existence of lineations near the dam. The interpretations made of the radar imagery indicate the following:

1. Topography and cultural patterns are the most prominent elements on SLAR.
2. A northwest-southeast lineation shown on the imagery may have a profound effect on the hydrology along the axis of the dam.
3. SLAR is useful in locating sites for construction of hydroelectric dams and stream generating plants.
4. Extremely helpful in determining structure in remote areas.

In 1969 the Geological Survey of Alabama was asked to join the U. S. Geological Survey in the evaluation of some Apollo 9 multispectral photography of east-central Alabama. The satellite photography was taken as part of the Multispectral Terrain Photography Experiment aimed at testing the feasibility of the present ERTS (Earth Resources Technology Satellite) system to collect significant earth resource information. The photographs made from an altitude of 196 km (106 nautical miles) in space cover a 16,000 square-kilometer (6,400 square-mile) area and each scene is recorded in color infrared, black and white infrared, green and red spectral bands. A study was made of a single scene in Alabama (NASA AS9-26-3790A)(fig. 8).

The most significant geologic features shown by the photographs are the relatively straight, generally long lineaments that were unknown previous to the acquisition of these data. The lineaments are simply tonal variations that may be aligned into lines ranging from about 6 km (4 miles) to at least 260 kilometers (160 miles) in length. These tonal variations

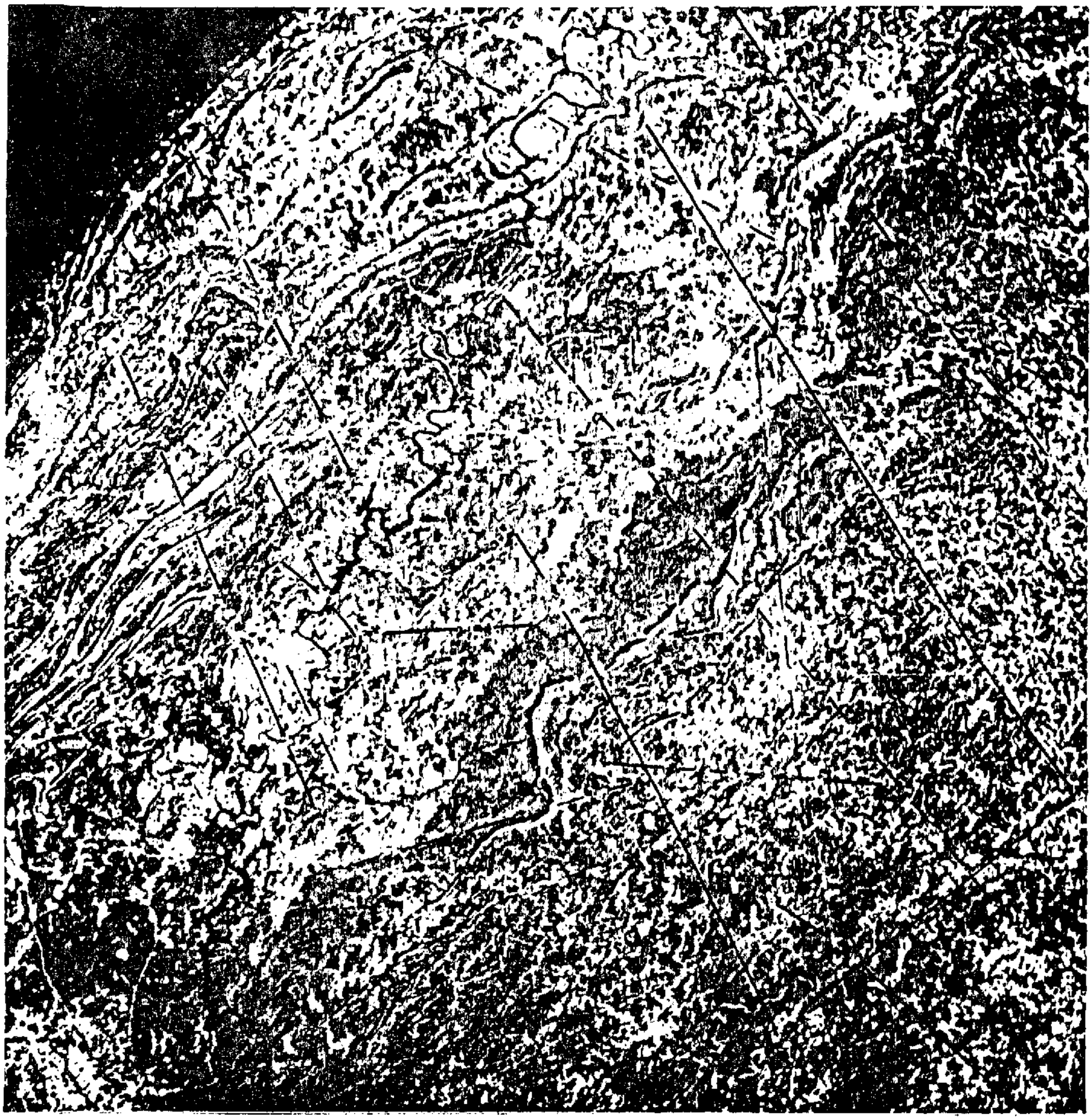


Figure 8. Apollo 9 photograph of east-central Alabama with major lineaments. (Photograph by NASA.)

reflect topographic and vegetative differences which in turn may be related to fracturing in the bedrock. Some of the fractures may extend to the basement and bound major basement blocks. Most of the lineaments are straight, but some are arcuate. Most cross one another with no offset, and some appear to bifurcate. Both north-south and east-west sets are known, but the majority are oriented northwest-southeast at nearly right angles to Appalachian structural strike (fig. 8).

Lineaments observed on the color infrared photograph (fig. 8) can be correlated with the movement and availability of ground and surface waters in the area. Figure 9 illustrates a direct relationship between the location of high yield springs and wells and major lineament traces. The red circles represent wells or springs with flow between 1.3 and 0.5 cubic meters per second; the yellow, flows between 0.5 and 0.05 cubic meters per second; and the black, flows between 0.05 and 0.01 cubic meters per second (Drahovzal and Neathery, 1972). Furthermore, evidence of the movement of water along these lineaments is displayed during periods of low flow along several of the streams in areas where streams flow over the lineaments. Thus, Apollo 9 photographs were found to be useful in the follow-up applications:

1. Determining areas of ground water;
2. Determining areas where large quantities of ground water are available;
3. Determining areas for making low-flow measurements;
4. Determining areas for location of gaging stations;
5. Locating sites of optimum hydrologeologic conditions for the construction of dams and reservoirs;

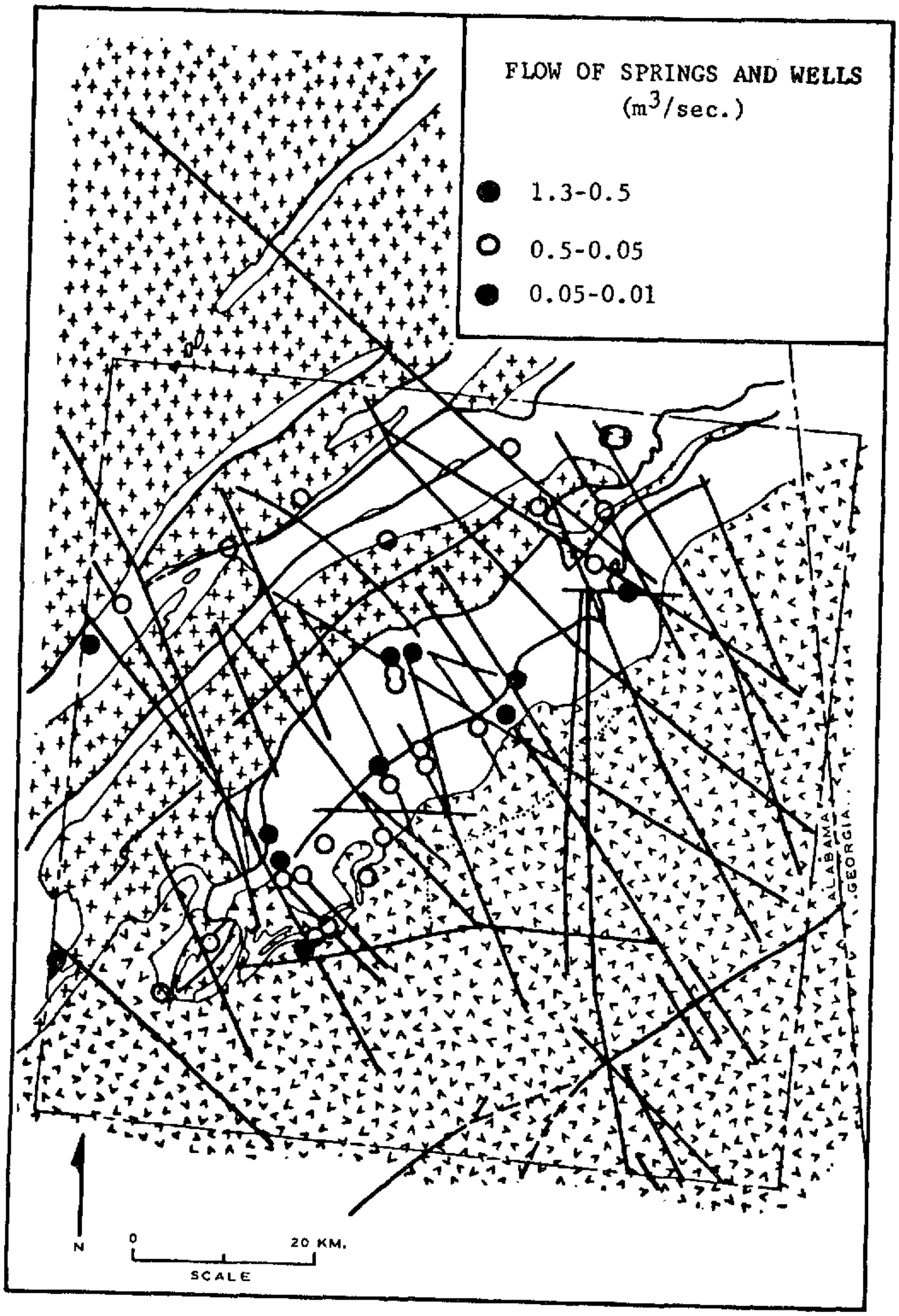


Figure 9. Location of high yield wells and springs associated with Apollo 9 lineaments (after Drahovzal and Neathery, 1972).

6. As an aid in geologic mapping;
7. As an aid in the study of structural geology of an area (Powell, et al, 1970).

Lineament detection and the associated geologic and hydrologic aspects are presently being investigated on a state-wide basis under a project which is probably the most important remote-sensing program ever developed in past history: ERTS-1. The ERTS-1 (Earth Resources Technology Satellite) program is a research and development tool designed by NASA to evaluate the feasibility and practicability of carrying out efficient inventory and management procedures of the earth's resources. The program represents more than nine years of planning and research by resource agencies of the Federal Government in cooperation with NASA, state and local governments and institutions.

ERTS-1 is equipped with two types of remote sensing subsystems: a return beam vidicon (RBV) and a multispectral scanner (MSS). Three RBV cameras are coaligned and therefore view the identical scene but in three different spectral bands, blue-green (0.475μ - 0.575μ), red (0.580μ - 0.680μ), and near infrared (0.690μ - 0.830μ). The MSS subsystem collects electromagnetic energy in 4 regions of the spectrum: green (0.5μ - 0.6μ), red (0.6μ - 0.7μ), and two near infrareds (0.7μ - 0.8μ and 0.8μ -1.1μ).

Many of the areas of research initiated by Apollo 9 studies are presently being followed-up in two ERTS-1 studies. Because ERTS-1 is providing repetitive coverage of the entire state on an 18-day basis, it has been possible to expand the lineament investigations. Lineaments that were undetected on Apollo 9 photography have been discovered on ERTS imagery (fig.

10). The reason for this situation is not due to resolution differences, although good ERTS imagery appears to be somewhat more well-defined, band for band, than the Apollo 9 photography, but it is probably due to differences in meterologic conditions, sun-angle, and atmospheric interference. Other lineaments known from Apollo 9 photography have been confirmed and extended into areas where satellite coverage was not previously available.

ERTS-1 imagery shows great potential for applications to hydrologic studies such as flood mapping. For example the Iowa Geological Survey was able to map flood inundations from an ERTS-1 scene 7 days following flood recession. In that case, the inundated areas had sharply reduced infrared reflectance because of surface water, excessive soil moisture, and stressed plants.

ERTS-1 imagery and correlation with flood-prone area maps are presently being investigated in Alabama. Areas around the Tombigbee, Alabama, and Mobile Rivers were imaged by ERTS-1 under flood conditions. Flood patterns on the imagery corresponded very closely to the related maps; and thus providing an excellent tool for monitoring floods.

In Alabama, remote-sensing technology is being used to solve many of our most pressing problems. Data acquired through remote-sensing techniques are not only applied to geology and hydrology, but to other disciplines such as oceanography, geography, forestry, and agriculture. However, caution must also be applied when working with remote sensing: it is not an end in itself, but merely a beginning point, a technique that can supplement other tools for hydrogeologists and geoscientists to better understand the physical environment.

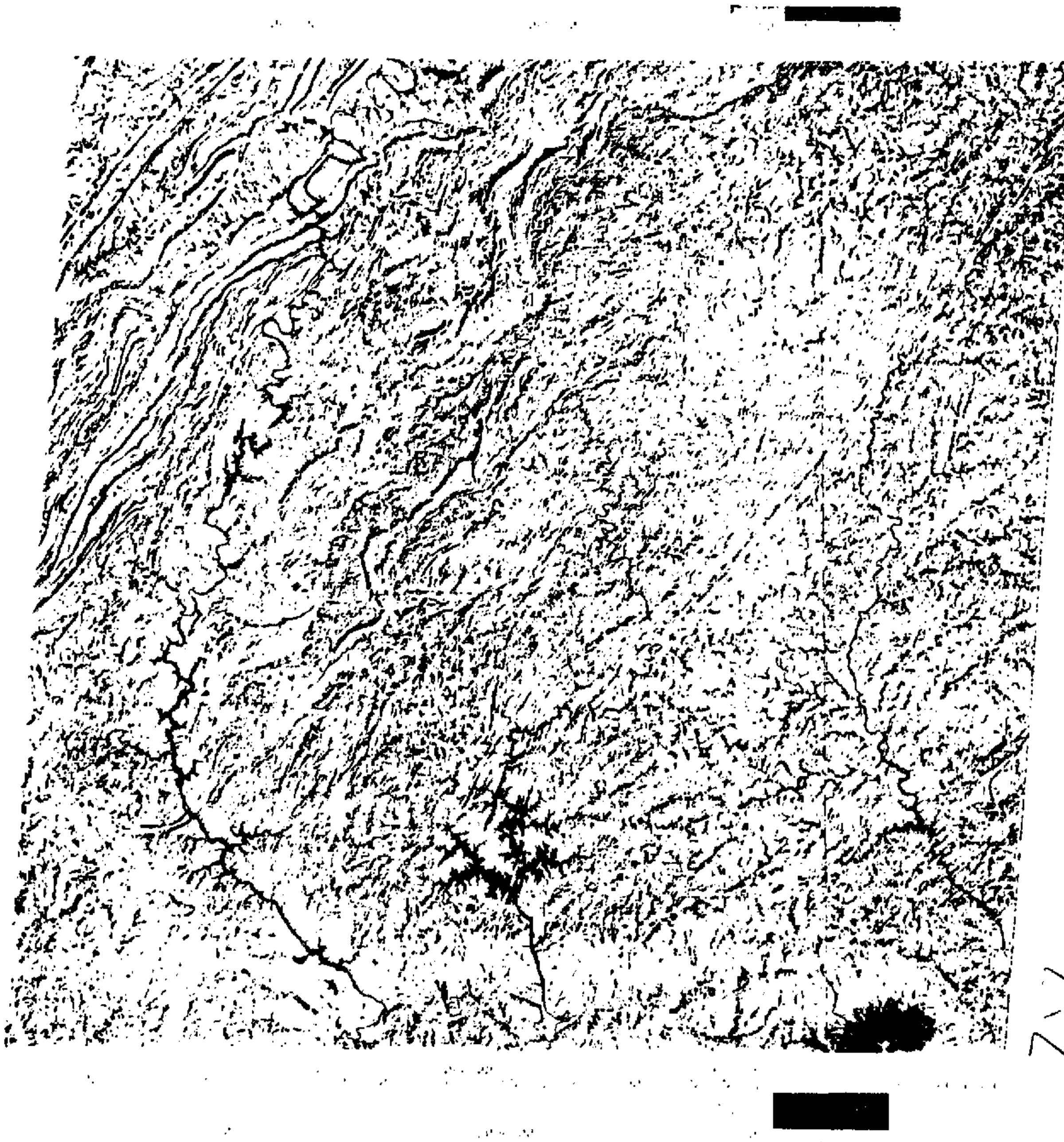


Figure 10. Scene of east-central Alabama imaged by ERTS-1 multispectral scanner on January 14, 1973. This particular image, Band 6, represents near infrared reflected electromagnetic radiation (.7μ - .8 μ). (Image by NASA.)

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Appendix VIII-D

APPENDIX 5

DETECTION OF SHORELINE CHANGES FROM ERTS-1 DATA

By

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and
Charles C. Wielchowsky

DETECTION OF SHORELINE CHANGES FROM ERTS-1 DATA*

Jacques L. G. Emplaincourt
Charles C. Wielchowsky

Geological Survey of Alabama
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Four ERTS-1 band 7 (near-infrared) images collected over Mobile Bay, Alabama, during a period of six months (August 1972 to February 1973) were compared to 1953 and 1957 AMS maps at a scale of 1:250,000. ERTS-1 data indicate that significant changes have taken place in the configuration of the shoreline in the past 15 to 20 years, and that cartographic errors were made during the preparation of the 1:250,000 maps. Sand Island and Pelican Island have been reduced to one narrow strip of land; Dauphin Island has prograded westward as much as 1.6 km (1 mi). The Fort Morgan-Mobile Point spit was originally mapped wider than it actually appears at present. In Portersville Bay, Isle aux Dames and another small island have completely disappeared. Some rather drastic changes have occurred in the upper reaches of the bay. For example, islands are now joined to the mainland, passes and bays have been filled, and promontories have been added.

The changes that did not result from cartographic error can be attributed to: 1) man's activities, and 2) physical processes such as wind, waves, tides, and associated currents. Changes detected on ERTS-1 data were supported by high-altitude color infrared photographs, low-altitude black and white photo mosaics, and large-scale topographic maps. ERTS-1 data cannot yet be used to prepare planimetric maps that meet U. S. National Map Accuracy Standards; however, such data can be extremely valuable in detecting shoreline configuration changes in a dynamic estuarine environment.

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*Approved for publication by the State Geologist.

DETECTION OF SHORELINE CHANGES FROM ERTS-1 DATA

Geographers have always had a desire to reach high observation points in order to obtain a synoptic view of the earth's surface; however, their efforts have, until now, been frustrated by the limitations of available tools. Areal coverage under uniform lighting conditions, for example, has always been restricted because observations have been confined to suborbital views of a few tens of square miles. Furthermore, there have been limitations in the timing of observations. A world-wide view of any geographic phenomena formerly had to be obtained by piecing together a great number of observations made at different times. In many cases the phenomena of interest are changing at such a rate that the big picture is obsolete before it is put together (1). Another restriction has been that heretofore the earth could be seen only through the sensing of visible light with the naked eye or camera. Today, however, with new sensors capable of gathering environmental information in a much wider band of the electromagnetic spectrum, earth scientists are able to observe phenomena in totally different "lights."

With the launching of ERTS-1, NASA's first Earth Resources Technology Satellite and the first satellite dedicated entirely to the study of the earth, geographers have an excellent opportunity to apply their expertise in making and updating maps and in analyzing the physical and cultural dynamics of the environment. To date, however, ERTS data have been regarded by some as "the universal geographic tool" and by others as nothing more than an interesting experiment with little practical geographic value. The authors feel, however, that the true geographic value of ERTS data lies somewhere between these two extremes. Therefore, the purpose of this paper is to demonstrate how ERTS-1 imagery can be used in a limited study of a relatively small but dynamic area. Specifically, ERTS-1 data were used to detect changes in the configuration of the land/water interface (shoreline) that have taken place in the last 15 to 20 years in the Alabama coastal zone (fig. 1). This was done by comparing ERTS-1 images (see fig. 2) to fairly recent (1953 and 1957) AMS 1:250,000 scale maps. Further investigation revealed that the configurational changes noted on the maps resulted from either cartographic error or the addition or subtraction of land area by the continuation of the physical processes that shaped the shoreline, or by an interruption of the dynamic equilibrium that was present. The physical and cultural agents responsible for addition or subtraction of land area over the last 15 to 20 years were also identified on a preliminary basis.

METHODS. The ERTS-1 Multispectral Scanner Subsystem (MSS) images the earth's surface in four different bands of the electromagnetic spectrum (2). These bands are:

Band 4 (0.5μ - 0.6μ) - Green

Band 5 (0.6μ - 0.7μ) - Red

Band 6 (0.6μ - 0.8μ) - Near Infrared

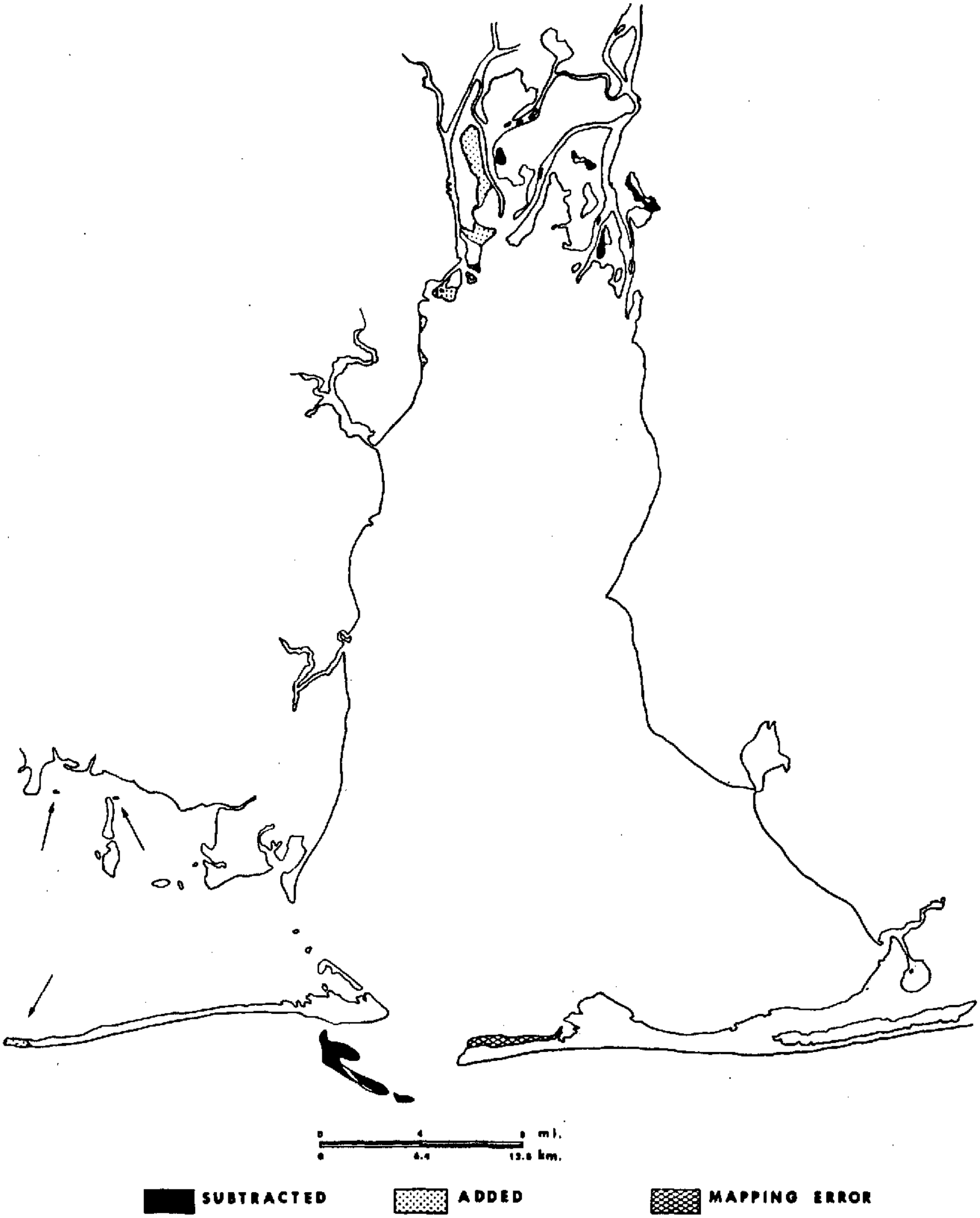
Band 7 (0.8μ - 1.1μ) - Near Infrared

The Return Beam Vidicon (RBV) subsystem, which was turned off early in the mission because of technical problems, images the earth's surface in three separate bands (3). These are:

Band 1 ($.475\mu$ - $.575\mu$) - Blue-Green

Band 2 ($.58\mu$ - $.68\mu$) - Green-Yellow

Band 3 ($.698\mu$ - $.83\mu$) - Red-Near Infrared



CHANGES IN MOBILE BAY

Figure 1

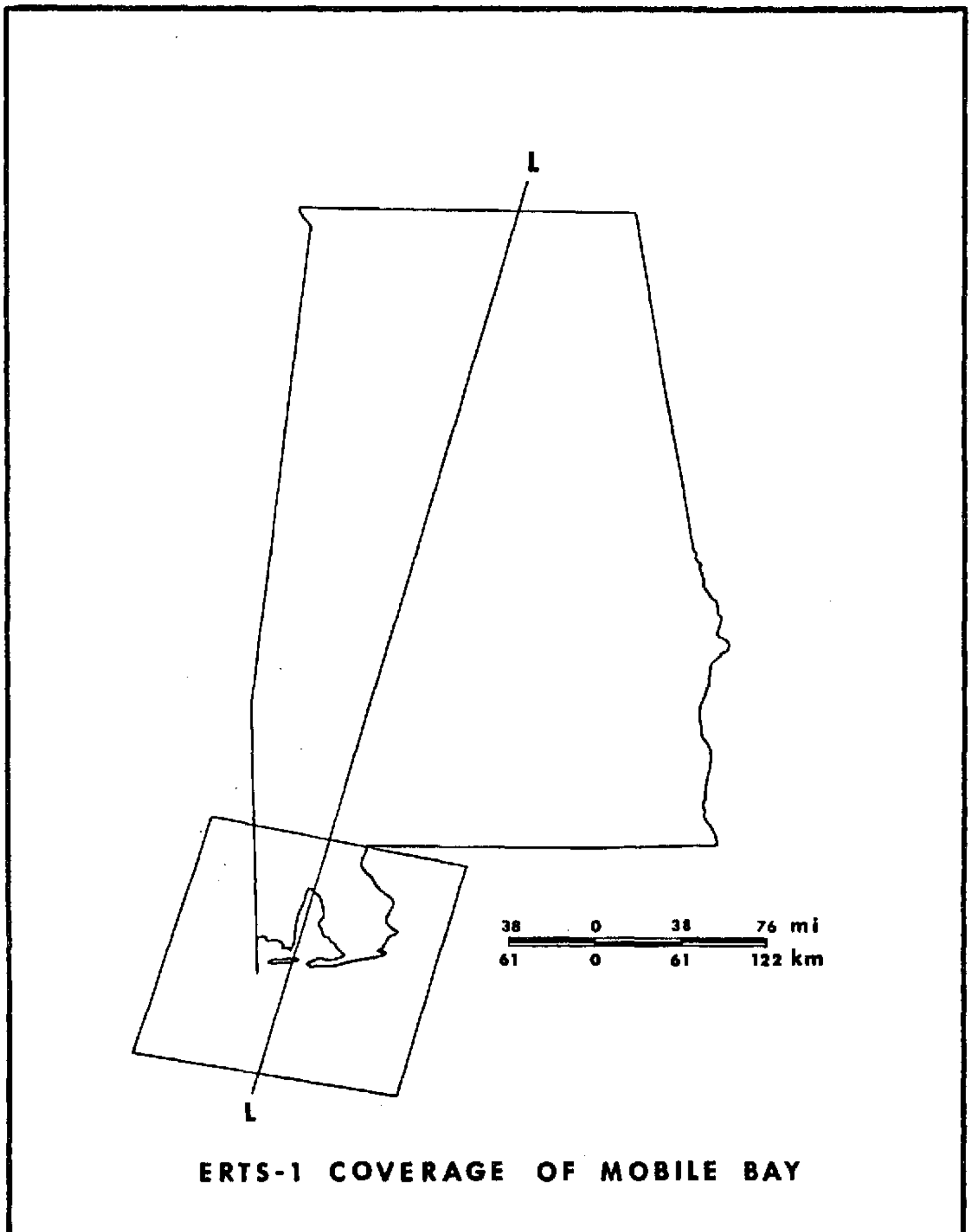


Figure 2

Band 7, the farther of the two near-infrared bands of the MSS, is perhaps the most useful for cartographic applications. It allows penetration of thin clouds, yields excellent land/water delineation, and gives superior natural-feature definition (4). Therefore, transparencies of band 7 MSS images acquired on four different dates over Mobile Bay, Alabama, were enlarged to a scale of 1:250,000 so that they could be compared with AMS maps of the same scale. This scale was selected because: 1) only two AMS 1:250,000 maps are required to cover the entire study area; 2) perceptional image quality is good on MSS bulk data to scales of 1:250,000 (5); 3) 1:250,000 is a scale that is compatible with the magnitude of the major detected changes. In addition, one band 3 RBV image was used to support the findings on the MSS data. Tidal fluctuations were ignored in this study due to the fact that mean tidal range is only about 1 foot (30 cm) at the lower end of the bay and 1.5 feet (45 cm) at the upper end (6). Also, no significant differences were noted in the shoreline configuration when comparing ERTS and U-2 data from the various passes (TABLE 1) though tidal stages were significantly different.

It has been shown that bulk MSS data cannot yet meet U. S. National Map Accuracy Standards, because root mean square (rms) error in position should be less than 75 meters at a scale of 1:250,000, but rms error can be as great as 450 meters for both MSS and RBV data (7). This error is distributed randomly over the image and is due to both internal and external distortions. Also, ground resolution for these data is 250 meters (8), which is greater than the allowable rms location error. Due to these handicaps, it was decided that a totally empirical approach should be taken in locating changes in the Mobile Bay area.

TABLE 1

TIDE CHART FOR SELECTED ERTS-1 FRAMES
AND U-2 FLIGHTS

Date	Tide	Time	ERTS-1 Time	ERTS Frame ID#/ U-2 Flight #	U-2 Time
6 AUG 72	H	9:42 a.m.	10:00 a.m.	1014-15555-3	---
	L	9:32 p.m.		(RBV)	
24 AUG 72	H	1:04 p.m.	10:00 a.m.	1032-15555-7	---
	L	10:12 p.m.		(MSS)	
24 SEP 72	H	12:09 a.m.	---	72-170	9:30 a.m.
	L	9:23 p.m.			
28 DEC 72	H	7:15 p.m.	10:00 a.m.	1158-15564-7	---
	L	7:29 a.m.		(MSS)	
15 JAN 73	H	8:51 p.m.	10:00 a.m.	1176-15562-7	---
	L	8:12 a.m.		(MSS)	
2 FEB 73	H	No high occurred	10:00 a.m.	1194-15564-7	---
	L	10:20 a.m.		(MSS)	
22 FEB 73	H	3:45 p.m.	---	73-023	12:30 p.m.
	L	1:32 a.m.			

NOTE: These data were compiled at the northern end of Mobile Bay. To obtain times for high and low tides at the southern end of the bay at Fort Morgan, 1 hour 40 minutes should be subtracted from the above figures.

The ERTS-1 images were overlain on AMS 1:250,000 scale maps NH 16-5, Pensacola, Florida; Alabama (published 1957, limited revision, 1966), and NH 16-4, Mobile, Alabama; Mississippi; Louisiana (published 1953, limited revision, 1962). Four separate sheets of each map were used to minimize any distortion that might be present due to changes in the dimensions of the paper. It was found that there were no significant differences from one map sheet to another.

Once the areas of change were delineated, a polar planimeter was used to calculate the approximate loss and gain of land area. No volumetric calculations were attempted.

Sources of data used to support the finding made on the ERTS-1 images included: 1) high-altitude color infrared photography taken at a scale of 1:130,000 during two NASA/Ames U-2 flights made on September 24, 1972, and February 22, 1973; 2) low-altitude 1:62,500 USDA photo mosaics collected on December 2, 1970; and, 3) 1:62,500 topographic maps published in 1941 and 1958 and 1:24,000 topographic maps published in 1953 and 1958, some of which were photorevised in 1967.

CHANGES. Some of the offshore islands have undergone major configurational changes (fig. 3). Sand Island and Pelican Island, which were both located near the entrance of Mobile Bay, have been modified into one narrow strip of land that is now called Sand Island (9). In addition, Dauphin Island has prograded westward as much as 1 mile (1.6 km).

When the 1:250,000 AMS maps were compiled, the Fort Morgan-Mobile Point spit (fig. 4) was depicted as being about 1 mile (1.6 km) wide from north to south. ERTS-1 imagery indicates that the spit is only about 0.6 mile wide. This is confirmed by U-2 photography and detailed 1:24,000 maps.

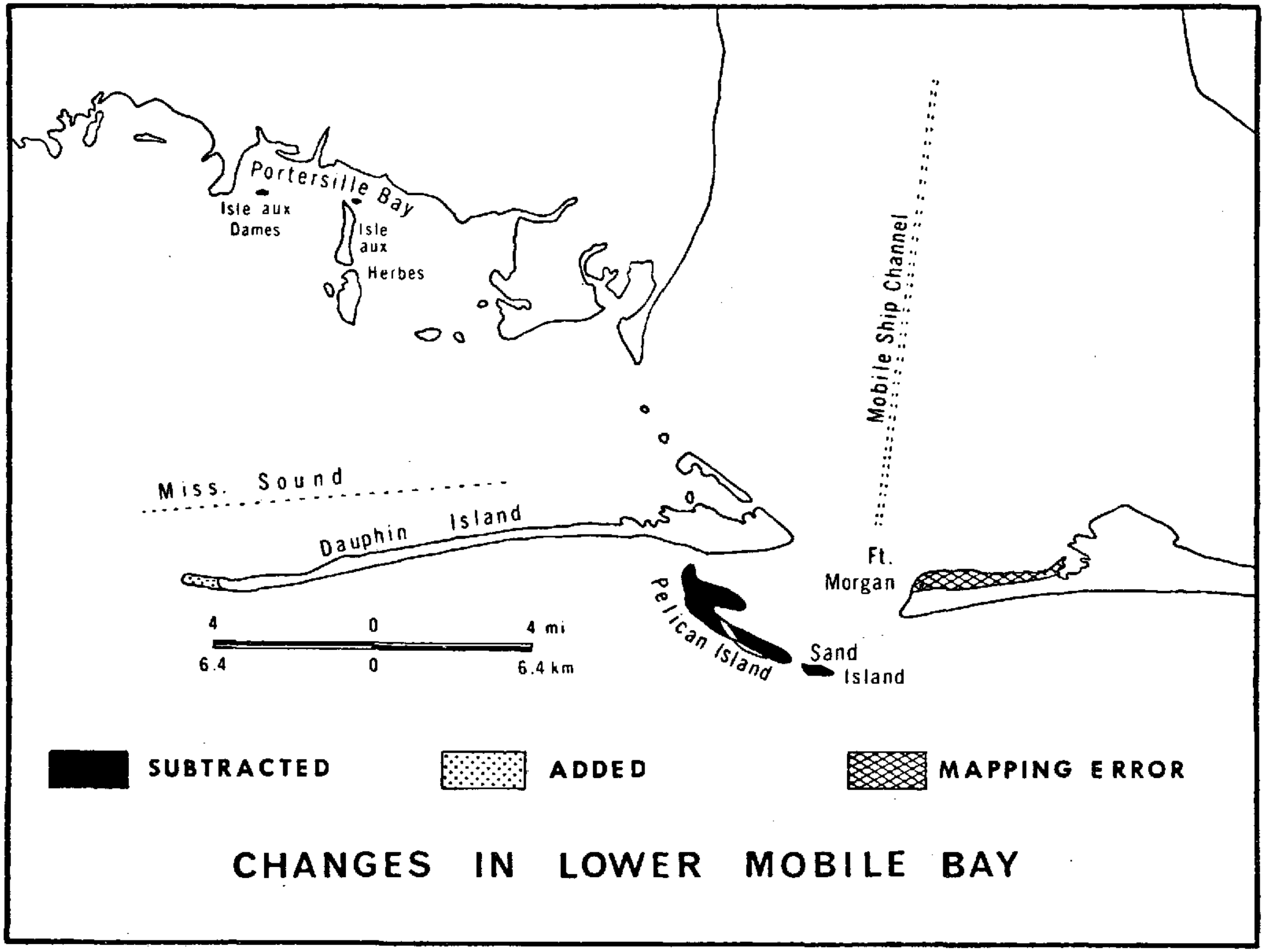

Portersille Bay
Isle aux Dames
Isle aux Herbes
Mobile Ship Channel
Miss. Sound
Dauphin Island
Ft. Morgan
Pelican Island
Sand Island
4 0 4 mi
6.4 0 6.4 km
SUBTRACTED
ADDED
MAPPING ERROR
CHANGES IN LOWER MOBILE BAY

Figure 3

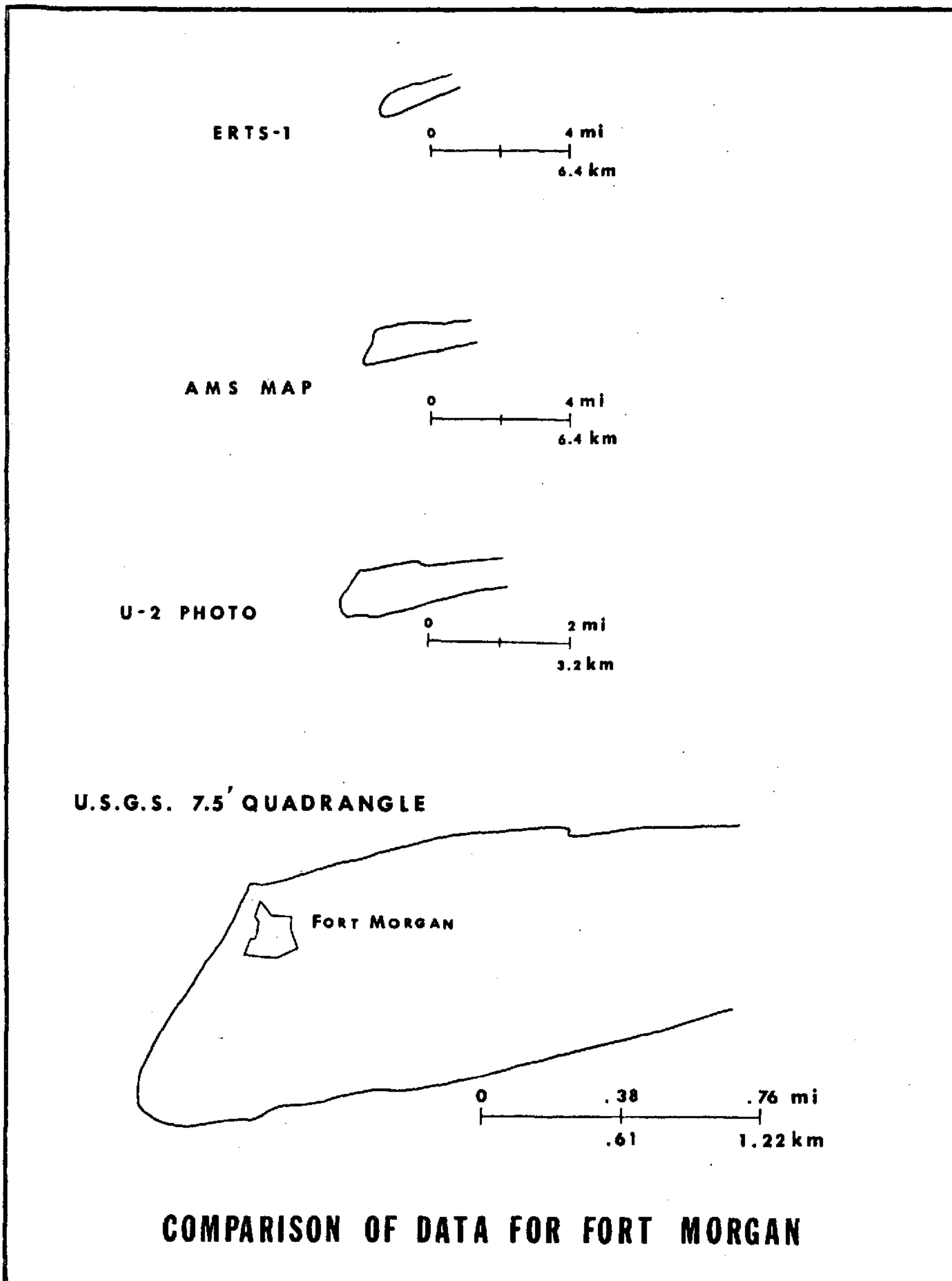

ERTS-1
0
4 mi
6.4 km
AMS MAP
0
4 mi
6.4 km
U-2 PHOTO
0
2 mi
3.2 km
U.S.G.S. 7.5' QUADRANGLE
FORT MORGAN
0
.38
.76 mi
.61
1.22 km
COMPARISON OF DATA FOR FORT MORGAN

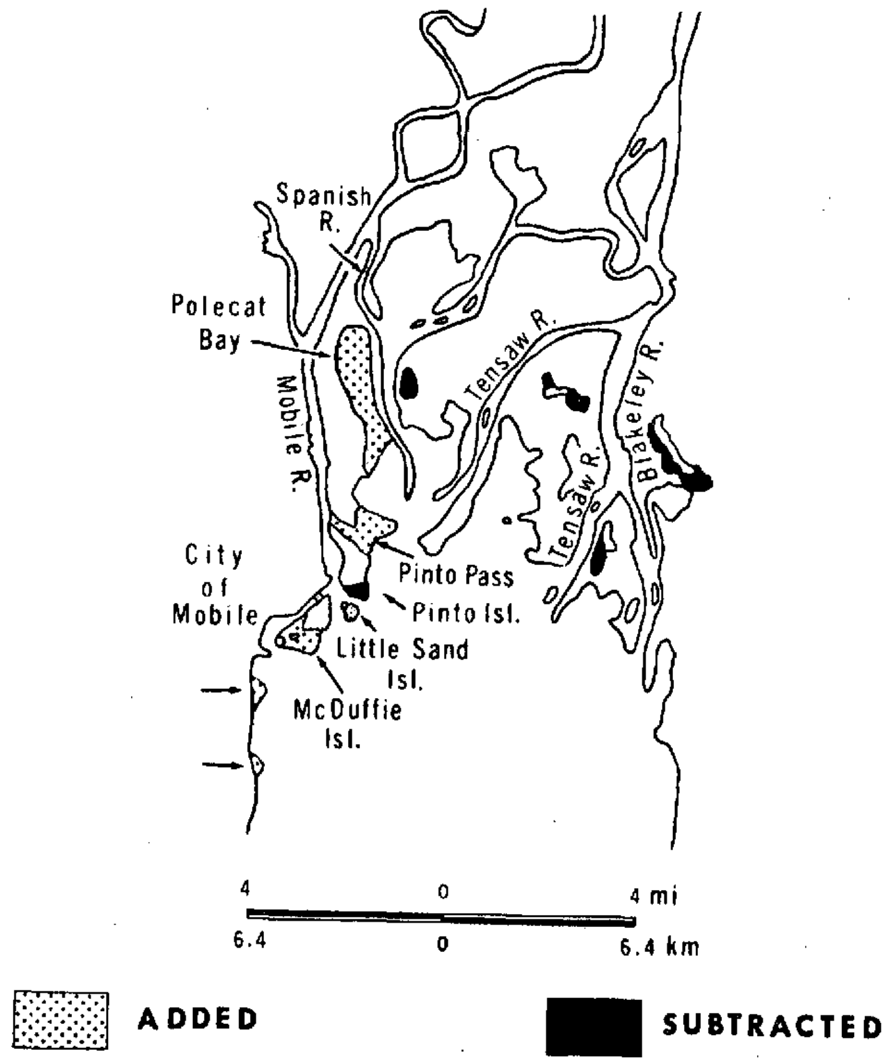
Figure 4

Since shorelines are mapped at mean high water, it appears that a cartographic error was made.

In Portersville Bay, west of Mobile Bay (fig. 3), two islands depicted on the AMS maps, Isle aux Dames and a small island located off the northeast coast of Isle aux Herbes, do not appear either on the ERTS imagery or on the recent U-2 photographs.

According to ERTS data, some rather drastic changes have occurred in the upper reaches of Mobile Bay where the Mobile, Tensaw, Appalachee, Spanish, and Blakeley Rivers empty into the bay (fig. 5). McDuffie Island appears to have linked up with the mainland and has been enlarged so that now it extends some distance into the bay. The link with the mainland may represent a cartographic error, because the 1953 1:24,000 quadrangle shows this connection, whereas the 1953 1:250,000 does not. Little Sand Island has also been enlarged. Pinto Pass, located between Blakeley Island and Pinto Island, has been filled as has most of Polecat Bay. Directly south of the City of Mobile, two coastal points have been added. In addition, several areas in the delta have been inundated.

CAUSES OF CHANGES. The configurational changes noted in the shoreline of the Mobile Bay area resulted from both cartographic error and subtraction and addition of land area (TABLE 2). These subtractions and additions were caused by the processes of erosion, sedimentation, and compaction, along with subsequent subsidence in the delta region (10). The following agents were identified as the probable causes of erosion and sedimentation: 1) waves; 2) tides; 3) wind; 4) currents associated with the previous agents; 5) streams; and 6) man. These agents were all instrumental in shaping the shoreline in the Mobile Bay area.



CHANGES IN UPPER MOBILE BAY

Figure 5

TABLE 2

APPROXIMATE AREAL CHANGES

Location	Change (sq mi)	(sq km)
Pelican/Sand Island	-1.87	-4.84
Dauphin Island	+ .31	+ .80
Portersville Bay Area	- .05	- .13
Delta Area	+2.65	+6.86
	- .93	-2.41
	+1.72	+4.45

Pelican and Sand Islands were actually emergent parts of a tidal delta that extends some 5 miles (8 km) seaward from the pass between Dauphin Island and Mobile Point (11). The prevailing southeasterly winds generate waves that in turn produce a westward-flowing longshore current of 1 to 2.5 knots, which increases to 2.5 to 5 knots with the incoming tide. Also, tidal current velocities of as much as 7 knots have been measured in the various passes (12). These currents, along with the direct action of storm waves, probably caused the changes in the configuration of Pelican and Sand Islands.

Dauphin Island is part of a chain of barrier islands that extends about 150 miles along the coast of Florida, Alabama, and Mississippi. It is being extended to the west by accretion of sediment transported by the westward-moving longshore current. May (13) reports that the western end has been extended 4 miles (6.4 km) in the last 100 years. In addition ERTS data appear to indicate a loss of land area on the Gulf side of the island; however, due to the very narrow strip of land involved (probably less than 200 meters in width), this change cannot be supported at this time. Boone (14) points out that significant erosion has taken place on the Gulf side since marsh deposits and tree stumps are exposed in the surf zone. This possible change warrants further investigation.

The two small islands that have disappeared in Portersville Bay were probably removed by the direct action of storm waves and by the slow (.8 knots) westward longshore drift in the Mississippi Sound area. Foxworth and others (15) have reported that this current is strong enough to move sand-size sediment. Tidal currents and stream discharge also affect circulation patterns in the bay area and thus influence sites of erosion and deposition.

The most striking changes noted were in north Mobile Bay and in the delta region. Here man has played a major role in causing the configurational changes detected on ERTS data. The two promontories immediately to the south of the City of Mobile and the southern extension of McDuffie Island are areas that have been filled by man. The southernmost of the two promontories was made so that Brookley Field (presently a commercial airfield) could be extended; the land added to McDuffie Island was placed there for a bulk processing plant (16). Polecat Bay was filled as a result of the dredging of the Mobile River (17). Other filled areas that are probably related to either dredging activity or natural deltaic sedimentation are located at Little Sand Island, Pinto Island, and Pinto Pass. The areas of land subtraction in the delta are probably related to natural sediment compaction with subsequent subsidence (18). It is known that the Mobile River delta is prograding and that the entire bay is being filled at a rate of about 1.7 feet (0.5 m) per century (19); however, no distinctive progradation above water was noted in this study.

CONCLUSIONS. Though ERTS-1 data cannot yet be used to prepare planimetric maps that meet U. S. National Map Accuracy Standards, ERTS-1 imagery can be used for the following:

1. to detect cartographic errors on maps of 1:250,000 or smaller scale;
2. when compared to maps of the same scale, to delineate changes in the configuration of the land/water interface.

ACKNOWLEDGMENTS. This paper is an outgrowth of ERTS-1 research supported by the National Aeronautics and Space Administration and the Department of Interior's Earth Resources Observation Systems (EROS) program.

FOOTNOTES

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Appendix VIII-E

APPENDIX 6

AERIAL REMOTE SENSING OF CARBONATE TERRANES IN SHELBY COUNTY, ALABAMA

By

William M. Warren
and
Charles C. Wielchowsky

AERIAL REMOTE SENSING OF CARBONATE TERRANES
IN SHELBY COUNTY, ALABAMA[a]

By William M. Warren and
Charles C. Wielchowsky[b]

ABSTRACT

Remotely sensed data are being used by the Geological Survey of Alabama in the study of subsidence and collapse problems in several carbonate terranes. Active areas in Shelby County, Alabama, have been delineated by on-the-ground inspection and by use of airborne remote sensors. These active terranes present formidable problems to those who presently live in the area as well as to those who will be involved in the future development of this region; therefore, techniques must be found that can be used to predict subsidence and collapse.

Study of a 70-square-mile test area in the county indicates that aerial infrared photography, thermography, and side-looking airborne radar (SLAR) imagery can be used for 1) locating, inventorying, and monitoring sinkholes, 2) predicting potential collapses, 3) mapping fracture traces, lineaments, regional geologic structure, and alignment of sinkholes, and 4) assisting general project planning. Tremendous time and effort can be saved by using remote-sensing techniques because large areas can be examined in a very short period of time.

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INTRODUCTION

Recent subsidence and collapses of the land surface (sinkholes) in at least three areas underlain by carbonate rocks in Shelby County, Alabama, have dramatically demonstrated the need for a greater understanding of the causative mechanisms involved. Buildings, highways, utility lines, and construction of all types are threatened by collapses that result from the failure of soils or rocks in the subsurface. Repair of the resulting damage in many cases is not feasible due to high cost or lack of sufficient technology. It is far more economical and much safer to apply corrective measures during the planning and development of carbonate terranes rather than to wait until the problem manifests itself at the surface. Subsidence and collapse are not new to Shelby County (Powell and LaMoreaux, 1969), but activity has intensified in recent years. This is evidenced by the numerous requests received by the Geological Survey of Alabama for assistance in combating subsidence and the resulting damage in the county.

An effective means of predicting the occurrence of subsurface conditions that cause subsidence and collapse must be developed. Remote-sensing, geological, hydrological, and geophysical techniques are applicable as primary methods of evaluating near-surface geologic conditions. Determining causes and means of predicting collapses will aid planners, industrialists, and developers, and will protect Alabama citizens from possible injury in the affected areas.

The Geological Survey of Alabama is planning a demonstration project to be carried out in Shelby County. This project will show how remote-sensing technology and environmental geology can be applied to the delineation and prediction of collapses. Emphasis will be placed on the limits and capabilities of predictive techniques.

Previous investigations in Alabama by Newton, Copeland, and Scarbrough (1973) demonstrated the usefulness of thermal infrared imagery or thermography (Williams, 1972), and infrared photography in illustrating signatures related to the development of active subsidence along a proposed interstate highway route in Jefferson County. In addition, photographs obtained during and after a study of subsidence problems in and near Roberts Industrial Subdivision, Birmingham, Alabama (Newton and Hyde, 1971), indicated that infrared photography may be extremely useful in locating areas of potential collapse (J. G. Newton, personal communication). Sonderegger (1970) used panchromatic, color, and infrared photography to locate fracture traces in a limestone terrane in northern Alabama. These fractures apparently control movement of ground water in the area. In Kentucky, remote-sensing techniques were used in engineering-site selection studies in several carbonate terranes (Sowers, 1973). In Florida, Coker, Marshall, and Thomson (1969) used multispectral scanning equipment, several types of photography, and a special-purpose computer to detect stressed vegetation and terrain-surface temperature anomalies that were associated with areas of impending collapse. They concluded that such an approach could potentially detect hydrogeological phenomena as much as 100 feet below the land surface. Matalucci and Abdel-Hady (1969) pointed out the usefulness of infrared surveys in the delineation of highway construction problems in carbonate terranes. In Pennsylvania, Lattman and Parizek (1964) investigated the relationship between solution cavities and photogeologic fracture traces in a carbonate area within the Valley and Ridge physiographic province. Again a relationship was found between ground-water movement and fracture traces. On the basis of the success of these previous studies and our initial investigations, it is felt that Shelby County sinkhole problems should provide an ideal test case for an extensive study of an active carbonate terrane utilizing remote-sensing techniques.

REMOTE SENSING

Remote sensing is the measurement of some property of an object without having the measuring device, or sensor, in direct contact with the object (Parker, 1962). Thus, information transfer from the object to the sensor must be carried out by use of reflected, emitted, or transmitted fields. In most cases, the field involved consists of electromagnetic radiation; thus, remote sensing is simply the observation of variations in this field.

The instruments that collect and record electromagnetic energy are called remote sensors. Scanners, cameras, and radars are probably the three most common operational categories of aerial electromagnetic sensors used by earth scientists.

Multispectral scanners collect electromagnetic radiation simultaneously in several regions of the visible (roughly 0.4 to 0.7 microns in wavelength), near-infrared (about 0.7 to 1.1 microns in wavelength), and thermal infrared (approximately 3 to 1,000 microns in wavelength) spectra. A scanner usually consists of three basic elements: 1) an oscillating mirror that sweeps a path perpendicular to the flight line of the sensor platform, 2) a detector that senses the electromagnetic energy reaching the scanner, and 3) some type of recording device. An example of such an instrument is the four-channel Multispectral Scanner Subsystem (MSS) on board the National Aeronautics and Space Administration's (NASA) first Earth Resources Technology Satellite (ERTS-1). The satellite's scanner imaged the scene of central Alabama shown in figure 1 on January 15, 1973, at about 10 a.m. CST from an altitude of roughly 570 miles.

This particular image records only reflected near-infrared radiation of an area that is about 115 by 115 miles. The Valley and Ridge physiographic province, which consists of faulted and folded rocks of Paleozoic age, shows up well in the northeastern part of the scene. The relatively undisturbed Paleozoic rocks of the Cumberland Plateau can be seen to the west of the Valley and Ridge province. The igneous and metamorphic rocks of the Piedmont are exposed in the southeastern part of the scene. Cretaceous sediments lap onto the Plateau, Valley and Ridge, and Piedmont provinces from the south. Sediments of the Coastal Plain province can be distinguished from the flat-lying rocks of the Cumberland Plateau province by differences in drainage texture and stream-meander characteristics. This imagery, especially the near-infrared band, is an excellent aid in regional structural interpretation. Powell, Copeland, and Drahovzal (1970) found this to be also true of Apollo 9 photography of east Alabama. The Shelby County sinkholes do not show up in figure 1 because the diameter of the largest sink (about 300 feet) approaches the limit of the smallest object that the MSS can detect; however, large-scale lineaments, to which solution activity may be related, do show up well.

Cameras collect and record visible electromagnetic radiation of about 0.4 to 0.7 microns in wavelength on color and black and white film. In addition, reflected infrared radiation from about 0.7 to 1.1 microns in wavelength can be recorded on color and black and white infrared film (Cato, 1972). Cameras can also be arranged, through the use of different film and filter combinations, to record electromagnetic radiation simultaneously in several different spectral bands. For example, figure 2 shows simultaneous photographs that were taken on the morning of February 22, 1973, by a NASA/Ames U-2 aircraft flying at 65,000 feet. The three images record blue-green, red, and near-infrared electromagnetic radiation reflected from an area in Shelby County that is presently subject to active subsidence and collapse. The blue-green band gives good water penetration and is useful in mapping siliceous rocks (Hughes, 1973), the red band shows cultural features well, and the near-infrared band enhances land/water contacts, topography, and differences between various exposed carbonate units (Hughes, 1973). These photographs can be studied separately or can be combined into a composite with color added. Each covers an area of roughly 15 by 16 miles.

The scene in figure 3 was photographed from the same U-2 aircraft with an aerial mapping camera that recorded reflected infrared radiation of 0.51 to 0.9 microns in wavelength. In such a color infrared photograph, reflected green radiation is recorded as blue on the film, reflected red radiation is recorded as green, and reflected near-infrared radiation is recorded as red; hence, the name false color is often used for this film type (Allum, 1973). Since healthy plants reflect highly in the near-infrared region, vegetative vigor is generally indicated by the color red. Vegetation that is under stress will undergo a change in reflectance in the infrared region of the spectrum (e.g., some types of stressed vegetation show up in a bluish hue).

Another sensor type, side-looking airborne radar (SLAR), generates its own electromagnetic energy by use of a pulse transmitter to sense earth objects in the microwave region. The return signal from the ground or target is a function of terrain roughness and complex dielectric constant (Waite, 1973). This sensor is especially valuable as a tool for fracture- and fault-trace mapping since the "look" direction of the radar is a function of flight path. In addition, SLAR not only has excellent cloud penetration ability, but also can operate at night because it provides its own "illumination."

The information derived from the use of these instruments can be valuable in the study of carbonate terranes and the problems associated with subsidence and collapse. Moreover, because large areas can be examined in a very short period of time, remote-sensing technology can be viewed as a time-saving tool. Specific uses and possible applications include: 1) inventorying sinkholes, 2) monitoring sinkhole development, 3) mapping sinkhole alignments, 4) investigating the relationships among sinkhole development, ground-water movement, fracture traces, and lineaments, 5) preparing and up-dating base maps, 6) delineating incipient collapse zones, 7) detecting areas of abnormal surface drainage, 8) mapping regional geologic structure, 9) locating exposures of bedrock, and 10) aiding in general project planning.

LOCATION OF AREA

To demonstrate the usefulness of remotely sensed data in the study of subsidence problems in carbonate terranes, a 70-square-mile area of southern Shelby County, located about 25 miles south of Birmingham, was selected (figs. 1, 3, and 5). Montevallo, in the southwestern corner, and Calera, in the southeastern corner, are the two most populous cities in the area of coverage. The primary economic activities are agriculture and mining; however, the area is becoming increasingly popular for industry and home building due to the accessibility of Birmingham via Interstate Highway 65.

GEOLOGIC SETTING

The area lies within the Valley and Ridge physiographic province and contains rocks and geologic structure characteristic of the province. In Alabama, the Valley and Ridge consists of a series of parallel ridges and valleys underlain by highly folded and faulted sedimentary rocks of Cambrian to Pennsylvanian age.

Six southwest-northeast trending folds and four major faults are the primary influences on the geology, hydrology, and geomorphology of the area. Erosion of the disturbed formations has formed a series of northeast-trending parallel bands of rocks, often dipping at high angles near fault zones. Figure 4 depicts the theoretical alteration of the once flat-lying formations to their present positions typical of the Valley and Ridge province.

The Camp Branch anticline is the major eroded fold plunging toward the northeast, diagonally across figure 3. The rocks that crop out on the flanks of the anticline are mainly limestone and dolomite that dip under clastic rocks to the east and northeast. Faulting associated with folding causes a repetition of carbonate units at the town of Calera and in the western part of the photograph (see fig. 5).

The differences of erosion rates of the various formations are quite apparent in figure 3 and the outcrop trends are easily discerned. Dry Valley, Cahaba Valley, and Opossum Valley, the three major valleys, are all formed on the more soluble limestone and dolomite formations. More resistant dolomites form low ridges that are often highly eroded and deeply weathered. The highest and steepest ridges to the north are underlain by resistant sandstones. The cross section in figure 5 shows the influence of solutional erosion and weathering on topography.

HYDROLOGIC SETTING

The area covered in figure 3 lies in the drainage basin of the Cahaba River and all streams flow south with the exception of Buck Creek, which flows north. Many of the streams, such as tributaries to Dry Creek located between Montevallo and Calera in Dry Valley, lose flow to well-developed solution cavity systems in the carbonate rocks. Dry Creek probably loses most or all of its water to the underlying cavity systems during extended periods of dry weather (see fig. 5).

Ground water in the area occurs in openings in the rocks along faults, fractures, and bedding planes and in the overlying residuum. Many of these openings have become enlarged through acidic and abrasive action of circulating ground water to form rather extensive solution-cavity systems that serve as conduits for the movement of large quantities of ground water. Wells that tap the openings are capable of yielding sufficient quantities of water to supply municipalities and housing subdivisions in the area, as well as industries. Yields of as much as 500 gallons per minute or more have been obtained from water wells tapping carbonate aquifers. Ground water also discharges from at least 10 major springs and several smaller springs in the area. Most springs discharging from the limestones and dolomites are near geologic contacts, faults, or fractures. Spring Creek, east of Montevallo, receives flow from several springs along a fault line. The largest springflow is from Blue Springs, at Siluria, which discharges more than 500 gallons per minute and is used to supply a textile mill and Siluria residents.

SINKHOLES IN THE AREA

Ancient sinkholes (not to be confused with recent collapses) are present in the area covered by the photograph in figure 3. These sinkholes vary in size from about 25 feet to one-half mile in diameter, and probably resulted from collapse of solution cavities in the underlying limestone or dolomite. The fracturing of the carbonate rocks during folding and faulting allowed a greater movement of water underground. Subsequently, the openings were enlarged by the dissolving action of weak carbonic acid (water plus carbon dioxide from soils and vegetation). Over thousands of years, cavity systems grew and connected with one another. The high bearing strengths of the carbonate rocks permitted them to maintain support of the overlying load of rock and soil until eventual failure. This failure was reflected at the land surface as an enclosed depression that, with time, became a relatively stable land form on the topography. These features are usually not active unless their hydrogeologic regimen is grossly changed (e.g., by an increased concentration of surface-water runoff or a nearby major withdrawal of ground water). Ancient sinkholes can be seen in the Cahaba Valley, on Pine Ridge, and east of Longview (see fig. 5).

AN ACTIVE SINKHOLE AREA

On December 2, 1972, Hershel Byrd, a resident of this area, was startled by a house-shaking rumble and the sound of trees breaking. Two days later, hunters in nearby woods found a crater 325 feet long, 300 feet wide and 120 feet deep. This giant sinkhole collapse, visible in the lower right corner of the area outlined in figure 3, is the largest in an area plagued with sinkhole collapses. Figure 6 is a low-altitude color infrared photograph of this sink taken on March 12, 1973.

Based on ground reconnaissance and aerial photographs, it is estimated that about 1,000 collapses or related features have formed in a 16-square-mile area. Other indications of subsidence are present also. Most of the sinks are in Dry Valley (underlain by limestone) where solution activity and subsurface soil erosion are most pronounced. Deeply weathered Cambrian dolomites of the Knox Group underlie the low eroded ridge where the large collapse is located. This collapse occurred in white and orange residual clays and no bedrock is exposed in the bottom or sides. Slumping is active on all sides, indicating that the sinkhole will continue to grow until a stable slope angle is reached (LaMoreaux and Warren, 1973).

Sinkhole collapses are related to natural phenomena such as heavy rainfall, seasonal fluctuations in the water-table altitude, earthquakes, or other changes in the hydrogeologic regimen affecting residuum stability. Man imposed effects such as artificial drainage, dewatering, seismic shocks (blasting), breaks in water or sewage pipes, or even overwatering in irrigated areas may result in a collapse in carbonate terranes.

A distinction can be drawn between ancient sinkholes and most sinkhole collapses in active areas on the basis of the subsurface zone in which each occurs (i.e., they occur either in the carbonate bedrock or in the overlying subsoils). According to Newton, Copeland, and Scarbrough (1973) and Newton and Hyde (1971), formation of sinkholes often results from the collapse of cavities in residual clays that is caused by "spalling," or downward migration of clay through openings in underlying carbonate rocks (fig. 7). The spalling and formation of cavities is caused by (or accelerated by) a lowering of the water table resulting in a loss of bouyant support to clay overlying openings in bedrock; fluctuation of the water table against the base of residual clay; downward movement of surface water through openings in the clay; or an increase in water velocity in cones of depression to points of discharge. Collapses have occurred where spalling and resulting enlargement of cavities have progressed upward until the overlying clay could not support itself, and where sufficient vibration, shock, or loading over cavities caused the clay to be jarred loose or forced down.

Sinkholes caused by the roof-collapse of cavities in bedrock are believed to be extremely rare in this area and normally not hazardous to construction if adequate engineering safeguards are put into effect. However, collapses in the residuum are a problem often caused by conditions created elsewhere. Therefore, their dangers can be reduced only by recognizing active areas of subsidence and then eliminating the cause at its source.

GEOLOGICAL SURVEY OF ALABAMA COUNTY-WIDE STUDY

Previous similar studies in carbonate terranes have concentrated on sinkhole activity and causes in local areas, but these studies have done little to aid planners prior to development of the problems. In areas underlain primarily by carbonate rocks with highly developed structure and solution cavity systems, there is a need for the study of potential sinkhole problems prior to construction and development.

Shelby County will be the subject of an intensive study that will examine not only existing sinkhole activity, but past and future problems. To accomplish this end, a great deal of time will be spent in the examination of remotely sensed data. Remote-sensing technology will be applied from the early planning stages through the entire project. In order to delineate the areas of interest and to eliminate wasted man hours searching in rugged and forested terrane, county-wide photography, such as in figure 3, will pinpoint active zones and their areal extent. The latest topographic map (fig. 5) of this section of Shelby County was prepared in 1910 at a scale of 1:62,500. For a detailed hydrogeologic study, this base map or even the latest transportation map would be inadequate to plot the detail required. However, using the photographs in figures 3, 6, or 8 as a base map, the latest road systems and all other present reference points are easily located. By tracing landmarks and road systems on mylar overlays, field maps can be prepared for more detailed field investigations; thus, valuable field time is saved and accurate, recent coverage of problem areas is made available.

High-altitude photographs taken at regular intervals are an invaluable tool in tracing the history of sinkhole problems. Often inaccurate information, based on personal interviews, can be eliminated by a complete photographic history. Thus, historic remotely sensed data can provide information on subsidence during past, as well as present, active stages.

The distribution of sinkholes offers many clues to the causes of their occurrence in one area as opposed to other nearby areas. Figure 8 is a low-altitude color infrared photograph of a presently active area in Dry Valley southwest of the sinkhole in figure 6. The trend of sinks (B-B') is along the strike of the underlying limestone formation. This indicates that the bed over which these sinks occur is more susceptible to solution and contains more openings for the downward movement of clay than the adjacent rocks. Often, the alignment of sinkholes will be at an angle to strike, as is the case in the area of figure 6. At least five sinkholes are on the line A-A' indicating there is a more permeable feature cutting across the bedding planes, possibly a fracture or fault. A lineament shows up well along the trend of these sinks.

Surface drainage features are an important aspect of the formation of recent sinkholes, because surface water moving through the overburden into bedrock openings aids in the sinkhole formation process. Surface water impoundments, areas of poor drainage or blocked drains (e.g., by road beds), or rerouted channels in an active terrane are suspect for future problems. Black and white infrared photography or thermography taken during the leafless season and after rainfalls will reveal where water (distinctly dark on the imagery) is entering the subsurface through sinkhole collapses. This will save considerable field time in locating and plotting the exact location of surface-water loss, an important aspect in sinkhole studies.

Previous investigations have shown the usefulness of remotely sensed data in detecting changes in the soil moisture content and surface temperature anomalies that are caused by subsurface development of uncollapsed cavities (Coker, Marshall, and Thomson, 1969; Newton, Copeland, and Scarbrough, 1973). Voids in the residual clays that have little or no surface expression can sometimes be detected by specific signatures on photographs that record vegetative vigor or lack of vigor. In open fields, circular vegetative patterns indicate that water may be concentrated on the surface due to subsidence over a subsurface cavity or that water is draining into openings in the ground. The vegetation may show increased vigor due to extra water, or non-growth and drowning due to an excess of water. Vegetative anomalies may also result from evaporation beneath the land surface where cavities in residuum have progressed upward into the root zone. The borders of these circular vegetative patterns sometimes appear as ring-like features (J. G. Newton, personal communication).

Trees may show a lack of vigor as a result of subsurface collapse exposing their root zones to excessive evaporation. Such a collapse could also cause trees to fall and die. Subsurface voids in the residuum beneath or near a tree could cause a weakened condition that would be detected by infrared film. Some correlation has been observed on color infrared photographs between pine tree "kills" by insects and the occurrence of collapses in Shelby County. The death or weakening of trees caused by collapses or the formation of subsurface voids in root zones results in infestation by beetles or other insects because of their affinity for attacking trees in a weakened state (J. G. Newton, personal communication).

CONCLUSIONS

Remotely sensed data show great promise in the study of limestone hydrology and subsidence problems. Correct interpretation and ground verification of the imagery are the keys to its usefulness and time saving potential. However, the obvious should not be overlooked, such as use of the imagery to supplement poor topographic map coverage and for project planning purposes. Remote sensing is not an end in itself, but a beginning point for hydrologists and geologist to better understand the perplexing problems of subsidence in limestone terranes throughout the world.

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