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III

INTERDISCIPLINARY APPLICATIONS AND INTERPRETATIONS OF ERTS DATA WITHIN THE SUSQUEHANNA RIVER BASIN

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Resource Inventory, Land Use and Pollution

THE PENNSYLVANIA STATE UNIVERSITY

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16. Abstract

ERTS-1 data of Pennsylvania have been analyzed and interpretation techniques have been developed. The effectiveness of the data and of interdisciplinary and university-industry related research has been evaluated, and the potential value of these data to local and state agencies for the management of land resources has been demonstrated. Specific objectives have been obtained within the categories of digital processing and pattern recognition, inventory of natural resources and land use, geology and hydrology, and environmental quality.

Geologic interpretations have been made from ERTS-1 imagery and digital data have been processed for detailed mapping, with quantitative analysis and evaluation. Photointerpretive techniques with aircraft photography have been used extensively for verification of digital data classifications. An interdisciplinary team and an interactive display system are both highly recommended.

The major advantages of ERTS-1 data are temporal coverage, large areal coverage, and their multispectral nature. It is recommended that the ground resolution be improved, that a thermal channel be added, and that orbital passes be more frequent. Turn-around time between requests for data and receipt by users should be considerably reduced. A national central data processing network with regional data centers should be considered. Ground truth aerial photography should be from over 5000 m and an MSS unit should be flown on the U2 aircraft.

17. ERTS-1 data evaluation, MSS digital data processing, land use mapping, lineaments, mineral exploration, forest resources, mine refuse, strip mines, gypsy moths, hydrology, geology, canonical analysis, cluster analysis, interdisciplinary research, interactive display, signature transference, environment.	18. Distribution Statement		
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Preface

This report presents a comprehensive review of the efforts of the Office for Remote Sensing of Earth Resources (ORSER) of the Space Science and Engineering Laboratory (SSEL) at The Pennsylvania State University, in analyzing ERTS-1 data over the period 1 June 1972 through 30 April 1975. This has been an interdisciplinary effort involving nine faculty members and numerous graduate students from six departments in three colleges of the University.

The general objectives of this project were to develop interpretation techniques for ERTS-1 data and evaluate the data temporally and spatially, to apply remote sensing techniques in regional resource management, to provide graduate and undergraduate instruction in remote sensing, and to evaluate the effectiveness of interdisciplinary and university-industry related research. The specific objectives were obtained within the categories of digital processing and pattern recognition, inventory of natural resources and land use, geology and hydrology, and environmental quality. The geographic area of interest covered that portion of the Susquehanna River Basin within the borders of the state of Pennsylvania.

Experience on this project has indicated that the primary value of ERTS-1 imagery is in making broad regional interpretations, such as delineation of physiographic and generalized land use features and geologic mapping. Of special value is the visibility of large but subtle features, such as lineaments, which are obscured by the details found in data of higher resolution. Detailed mapping with quantitative analysis and evaluation is best performed using ERTS-1 digital data. Both spectral and spatial resolution within the limits of the ERTS-1 system can be preserved at all stages of the analysis. Areas of 4 ha or larger can be regularly classified, and smaller areas may be identified depending on scene contrast and other factors.

A hybrid approach to the interpretation of MSS data appears to be highly desirable. In the case of ERTS-1 data, this involves extensive use of photointerpretive techniques applied to aircraft underflight photography for purposes of verification and interpretation of the digital data processing results. Due to the large area covered by ERTS-1 data and the nature of the problems to which such data are most suitably applied, an interdisciplinary team is recommended for most interpretations.

The quality of ERTS-1 data is generally very good. The data volume is large but reasonable, considering the extremely large area covered in a single scene. With only four channels (or possibly five in future missions), many facilities have computing capabilities which are adequate to handle and process these data.

The major advantages of ERTS-1 data are, (1) temporal coverage of the earth with good repeatibility, (2) large areal coverage, and (3) their multispectral nature. The principal limitations are, (1) lack of data over cloud-covered areas, (2) low ground resolution, (3) lack of a thermal infrared channel, (4) the length of time (18 days) between consecutive passes over a given area, and (5) the length of time between a request for data and its receipt by the user.

In general, ERTS-1 provides extremely useful data for many earth resources applications. This project has demonstrated the feasibility of specific applications to a wide variety of problems in the areas of inventory of natural resources and land use, monitoring of environmental quality, and providing geologic information. ERTS-1 data and the methods developed for their interpretation provide a valuable tool for regional management of natural resources and land use.

It is recommended that the resolution of the satellite scanner be improved to approximately 25 m and that a thermal channel be added to the satellite scanner. The repetitive coverage of the satellite should be increased to intervals of a week or less and the turn-around time between requests for data and receipt by the users should be reduced to two weeks for routine requests and 24 to 48 hours for special requests. A national central data processing network with several regional data centers should be investigated seriously and implemented as soon as possible; this could reduce the time required to get the data to users and thus encourage more agencies to become users.

An interactive display system should be used to aid in analysis and to reduce overall analysis time. Channel selection procedures should be employed to reduce data volume and analysis costs, unless adequate computing facilities and funds are available.

For the purpose of ground truth for ERTS-1 data processing, aerial photography should be obtained at altitudes of at least 5000 m above the ground surface. Care should be taken that aircraft missions are carried out at the desired time of the year and time of day, and on a course which covers the entire test site. The aircraft multispectral scanner should be calibrated and calibration information should be supplied to the user.

A multispectral scanner should be flown on the U2 aircraft. This platform could minimize the problems encountered with low-flying aircraft and would give a pixel with much greater resolution than that of ERTS-1. Consideration should be given to making the U2 into an operational system, such that flights could be requested by a variety of users.

Acknowledgements

The work reported herein was primarily supported by the National Aeronautics and Space Administration, Goddard Space Flight Center, under Contract NAS 5-23133. In addition to the ERTS-1 data supplied, the aircraft data acquired by NASA personnel were invaluable to the success of our research activities. Special appreciation is expressed to James Lindeman and James Weber of NASA-Houston for coordinating the U2 and C130 missions, and to Paul Alfonsi and Richard Dowd of NASA-Wallops for arranging the C54 missions and providing the photographic data. The efforts of Edmund Szajna for providing liaison as the Technical Monitor of this project are also appreciated.

Supplementary support was provided by the Space Science and Engineering Laboratory and its director, Paul Ebaugh, at The Pennsylvania State University. In addition, the contribution of significant amounts of unfunded computer time by the University is gratefully acknowledged.

The persons involved in the various aspects of the research described herein are identified by name in parentheses after the title of the sections in which their work is described.

In addition to the above persons, a special note of appreciation is given to Ms. Danielle N. Applegate for her services as computer programmer and to Ms. Nanna B. Bolling, as image analyst and for compilation, editing, and production of this report.

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CHAPTER 1

INTRODUCTION

In 1970, the Office for Remote Sensing of Earth Resources (ORSER) was established as an interdisciplinary group with the purpose of participating in various projects involving the use of remotely-sensed data of earth resources. These projects have involved personnel with backgrounds in agronomy, civil engineering, computer science, electrical engineering, forestry, geology, geophysics, hydrology, plant pathology, pattern recognition, regional planning, and soil genesis.

1.1 History of ORSER

ORSER was formed as a division of, and with financial support from, the Space Science and Engineering Laboratory (SSEL), which is a part of the Intercollege Research Program of The Pennsylvania State University (PSU). Administered by the Office of the Vice-President for Research and Graduate Studies, SSEL functions as a subunit of the Institute for Science and Engineering. A major purpose of SSEL is to give focus to research and graduate study in space-related sciences and engineering, to provide support services of a technical and administrative nature to programs operated in existing departments, and to administer funds for the support of new programs developed within departments on an interdepartmental basis. Major financial support for SSEL originally came from the NASA Office of University Affairs through the Sustaining University Program.

ORSER was established by SSEL to encourage interdisciplinary research activities involving remote sensing. A problems-oriented approach insures that this group functions in an interdisciplinary fashion. Each task is directly represented in the organizational structure, permitting associates from various disciplines to work together toward a common goal. The co-directors and the principal investigators from each task make up a coordinating committee which oversees current research efforts and encourages and develops future endeavors. The co-directors also meet periodically with the director and scientific advisory committee of SSEL for consultation, advice, and reports of progress.

Efforts of ORSER have been concentrated toward processing, analysis, and interpretation of multispectral remotely-sensed data, most of which have been supplied from NASA in both imagery and digital format. Although photointerpretation has been a vital part of the overall analytical process, emphasis has been on the use of digital computer algorithms for data processing.

1.2 Facilities

An extensive digital data processing system, using FORTRAN IV source language and the Remote Job Entry (RJE) system, has been developed by ORSER for use on the IBM/S370, Model 168, computer at The Pennsylvania State University Computation Center. Statistical information, pattern recognition routines, and a variety of analyses of remotely-sensed data can be produced. Computation cost efficiency has been emphasized throughout.

In addition to a Ramtek color display system and a Tektronix 4010 remote terminal with associated cathode ray tube (CRT) display and hard copy unit, the facilities include standard and high intensity light tables; Bausch and Lomb Zoom 70 and 95R stereoscope systems for viewing 70 and 248 mm films, respectively; a Bausch and Lomb Zoom transferscope (ZTS); an Old Delft scanning stereoscope; a microfilm reader; and a Diazo printer and developer. Research personnel also have access to a Saltzman projector in the Department of Geosciences and to a completely equipped photogrammetry and photointerpretation laboratory, including a Kelsh plotter, in the Department of Civil Engineering.

1.3 Experience

Although ORSER has been involved in a variety of projects funded by agencies such as the U.S. Army Corps of Engineers, the Susquehanna River Basin Commission, and UNICEF, emphasis has been placed on large interdisciplinary, projects funded by NASA: the ERTS-1 project, subject of this report, and the Skylab EREP project.

1.3.1 The ERTS-1 Project

On 1 June 1972, a contract was received from NASA for a two-year program in the analysis and interpretation of ERTS-1 data. The general objectives of this project, which is the subject of this report, were to:

1) ascertain the practical usefulness of the spatial and temporal data provided by ERTS,

2) develop interpretation techniques,

3) apply remote sensing in regional resource management,

4) provide graduate training and undergraduate instruction in remote sensing, and

5) evaluate the effectiveness of interdisciplinary research and university-industry related research.

The specific research objectives were to be met in the fields of:

1) digital processing and pattern recognition,

2) inventory of natural resources and land use,

3) geology and hydrology,

4) environmental quality, and

5) atmospheric effects and climatic mapping.

The investigator who was to perform the work involved with atmospheric effects and climatic mapping left the University shortly after commencement of ORSER's involvement with the ERTS program. There was no one else available to conduct the proposed work, hence, no further reference to this phase will be found in this report.

1.3.2 Other Projects

In addition to the ERTS-1 project, the following projects have been supported by outside contracts:

1. MITRE Corporation (11/6/72 - 12/31/73): provide interpretive and programming assistance for analysis of ERTS-1 data. MITRE made extensive use of the ORSER data processing system via long distance telephone hookup to the PSU Computation Center.

2. NASA (5/1/73 - 11/30/75): analysis and interpretation of data from the Skylab manned satellite missions. The initial contract called for geologic and mineral investigations; an extension of the contract involves investigation of new data processing techniques and land-use mapping.

3. UNICEF (1/1/74 - 6/30/74): provide data processing facilities and assistance for land-use mapping in India using ERTS-1 data.

4. U.S. Army Corps of Engineers (1/16/74 - 10/31/75): determine feasibility of using natural indicators (e.g., soil types, vegetative cover) from aircraft and ERTS-1 MSS data to map floodplain boundaries along the West Branch of the Susquehanna River.

5. Susquehanna River Basin Commission (6/28/74 - 6/30/75): provide land-use maps of 16 watersheds, covering an area of 14,500 km^2, in the Susquehanna River Basin by processing ERTS-1 data.

6. Spectral Data Corporation (for the U.S. Air Force) (7/1/74 - 12/30/74): collect ground truth for support of a corn crop yield prediction study; provide analysis of crop stresses; annotate aircraft photography over the test sites.

7. NASA (3/15/75 - 6/30/76): process ERTS-1 data for detection and monitoring of saline seeps in Montana.

1.4 Personnel

Mr. Paul Ebaugh, Associate Dean for Research, College of Engineering, is the director of SSEL. An associate professor of Electrical Engineering, Dr. George J. McMurtry, and an associate professor of Soils, Dr. Gary W. Petersen, serve as co-directors of ORSER. Other faculty active on the

ERTS-1 project include:

Dr. Shelton S. Alexander, Professor of Geophysics

Dr. F. Yates Borden, Associate Professor of Forestry

Dr. David P. Gold, Professor of Geology

Dr. Richard R. Parizek, Professor of Geology and Geophysics

Dr. Stanley P. Pennypacker, Assistant Professor of Plant Pathology

Dr. Brian J. Turner, Associate Professor of Forest Management

Dr. Harmer A. Weeden, Professor of Civil Engineering

The following faculty have had some involvement with ORSER, including proposal writing:

Dr. Gert Aron, Associate Professor of Civil Engineering

Mr. Monty Christiansen, Assistant Professor of Recreation and Parks and of Landscape Architecture

Dr. Peter W. Fletcher, Professor of Forestry

Dr. George A. Hussey, Systems Planning Specialist

Dr. Russell J. Hutnik, Professor of Forest Ecology

Mr. Raymon Masters, Instructor in Architecture

Mr. Glenn Steyers, Associate Professor of Landscape Architecture

Dr. Anthony V. Williams, Associate Professor of Geography

In addition to the above faculty, all of whom are at University Park, the following Commonwealth Campus faculty have participated in remote sensing projects under the direction of ORSER and with financial assistance from the Dean of Academic Instruction for Commonwealth Campuses:

Mr. Robert G. Balla, Assistant Professor of Engineering (Worthington Scranton)

Mr. Peter C. Bazakas, Assistant Professor of Geology (Ogontz)

Mr. John Kolesar, Professor of Engineering (Worthington Scranton)

Mr. Eva Tucker, Assistant Professor of Geology (Behrend)

Mr. John A. Vargas, Instructor in Environmental Sciences (DuBois)

Non-faculty personnel include:

Ms. Danielle N. Applegate, Computer Programmer

Dr. Daniel L. Bernitt, Research Associate, Computation Center

Ms. Nanna B. Bolling, Image Analyst and Technical Writer

Mr. Howard L. Heydt, Consulting Engineer, General Electric Company

Approximately 40 graduate students have worked on remote sensing projects in ORSER. Those who have been supported by funds from the ERTS-1 contract are listed below, along with their department and the degree on which they were working at the time. (Not all degrees were remote-sensing related.)

Agronomy

D. L. Henninger, PhD
G. A. May, PhD
T. W. Simpson, MS
A. D. Wilson, PhD

Civil Engineering

C. L. Kleeman, MS
L. E. Link, PhD

Electrical Engineering

W. L. Chren, MS
S. J. Chung, PhD

Forest Resources

J. E. Andersen, MS
H. M. Lachowski, MS
R. F. Masse, MS
B. F. Merembeck, MS
M. L. Stauffer, MS
D. N. Thompson, PhD
D. L. Williams, MS

Geosciences

C. E. Brown, PhD
M. F. Bucek, PhD
R. G. Craig, PhD
W. S. Kowalik, MS
M. H. Podwysocki, PhD
M. T. Roberts, PhD

Geophysics

J. L. Dein, PhD
M. A. Scanlin, MS
T. R. Schultz, MS
K. W. Volk, PhD

Plant Pathology

E. L. Fritz, MS

CHAPTER 2

DATA TYPES, HANDLING, AND PROCESSING

The various data types used in ORSER investigations and the methods of handling and processing these data are described briefly here. These methods were primarily developed in anticipation of and during work on the ERTS-1 project. Data processing methods are described in greater detail in discussion of the procedures used for accomplishing individual tasks.

2.1 Data Types

A summary of the remote sensing data types presently handled by ORSER may be found in Table 2.1. These data are discussed below, with emphasis on ERTS-1 data and aircraft underflight data flown by NASA for the ERTS-1 contract investigations reported herein.

2.1.1 ERTS-1 Data

The original standing order for ERTS-1 data was for scenes covering that portion of the Susquehanna River Basin which is located in Pennsylvania, bounded by the following coordinates:

Latitude	Longitude
4200N	7800W
4200N	7600W
4000N	7600W
4000N	7900W
4100N	7900W

When it was anticipated that ORSER would be working closely with state personnel, ERTS-1 data were requested to cover the entire state. On 3 December 1973 this request was granted, with some modifications, expanding the original standing order to cover the following two areas:

Latitude	Longitude
4210N	7900W
4210N	7600W
4000N	7600W
4000N	7900W
4210N	8030W
4210N	7900W
4100N	7900W
4100N	8030W

With the exception of a few minor irregularities, data quality has been excellent. Among the exceptions were the following:

Table 2.1: Remote Sensing Data Types Available in ORSER

Satellite or Aircraft, and Data Source	Approximate Altitude	Sensor	Spectrum Covered (Microns)	Approximate Color Range	Sensor Designation	Study Format	Approximate Ground Area Covered in One Image	Approximate Scale	Approximate Ground Resolution -- RS Unit (Meters)
Landsat-1 (ERTS-1) Goddard Space Flight Center Greenbelt, MD	900 km	RBV	.475-.575	Blue-green	Channel 1	248 mm color composites	34,200 km²	1:1,000,000	46
			.580-.680	Green-yellow	2				
			.698-.830	Red-near IR	3				
		MSS	.500-.600	Green	Channel 4	248 mm B&W transparencies and magnetic tapes	34,200 km²	1:987,000	80
			.600-.700	Orange-red	5				
			.700-.800	Red-near IR	6				
			.800-1.100	Near IR	7				
Skylab Johnson Space Flight Center Houston, TX	430 km	MS Camera	.5-.6	Green	S190A	70 mm pan	26,525 km²	1:2,920,000	30
			.6-.7	Orange-red		"			28
			.7-.8	Red-near IR		"			68
			.8-.9	Near IR		"			"
			.5-.88	Green-near IR		70 mm color IR			57
			.4-.7	Blue-red		70 mm color			24
						Also 248 mm pan, color & color IR for above	26,525 km²	1:700,000	Unknown
		Earth terrain camera	.4-.7	Blue-red	S190B	127 mm pan, color & color IR;	15,540 km²	1:975,000	Unknown
			.5-.7	Green-red		248 mm color	15,540 km²	1:475,000	Unknown
		MSS	.4-2.35 10.20-12.5	Blue-near IR Far IR (thermal)	S192	127 mm B&W transparencies and magnetic tapes	68.5 km wide strip	1:925,000	80
U2 Aircraft Ames Research Center Moffet Field CA	19,800 m	Cameras	.475-.575	Blue-green	1 or 11	70 mm pan	583-648 km²	1:450,000	18
			.580-.680	Green-yellow	2 or 12	"			
			.690-.760	Red-near IR	3 or 13	"			
			.510-.900	Green-near IR	4 or 14	70 mm color IR			
			.510-.900	Green-near IR	17 or 23	248 mm color IR	830 km²	1:130,000	Unknown
RB57 Aircraft Johnson Space Flight Center Houston, TX	18,300 m	Cameras	.440-.700	Blue-red	Film 101	248 mm color & color IR	195 km²	1:61,500	Unknown
			.500-.900	Green-near IR	103				
			.475-.585	Blue-green	105	70 mm pan	166 km²	1:233,000	Unknown
			.590-.710	Green-red	104	"			
			.700-.930	Red-near IR	106	"			
			.760-.900	Near IR	107	"			
			.500-.900	Green-near IR	108	70 mm color IR			
C130 Aircraft Johnson Space Flight Center Houston, TX	1525 to 4575 m	Cameras	.475-.585	Blue-red	Various	248 mm color & color IR	3.6-51.8 km²	1:6,000-22,000	0.3-0.9
			.450-.705	Blue-near IR	"				
			.590-.710	Green-near IR	"	70 mm pan	4.7-67.3 km²	1:22,000-120,000	0.9-9.1
			.700-.930	Near IR	"	"			
			.500-.900	Green-near IR	"	70 mm color IR			
		MSS	.340-13.00	UV through far IR (thermal)	24 channels	70 & 248 mm B&W transparencies and magnetic tapes	2.1-6.0 km wide strip	1:40,000-120,000	Unknown
C54 Aircraft NASA Wallops Island VA	2285 to 3810 m	I²S camera	.590-.700	Green-red	Lens 2	70 mm pan	5 km²	1:32,000	1.3-6.5
			.700-.930	Red-near IR	4	248 mm B&W	32-89 km²	1:22,850-38,100	1.2-7.8
		T-11 camera	.420-.750	Blue-red	Camera 1	248 mm color IR & 35 mm slides	7.5-38.7 km²	1:11,060-25,070	0.4-1.4
			.500-.900	Green-near IR	2				

1. Although scenes with a maximum of 70 percent cloud cover were requested, data from 80 to 100 percent cloud-covered scenes were received in some cases. On the other hand, a computer listing of all ERTS-1 data for Pennsylvania, obtained from NASA, revealed that occasionally data from 100 percent cloud-free scenes of portions of the Susquehanna River Basin were not sent. These were then obtained by retrospective order.

2. Although most data were received promptly, some difficulty was experienced in delivery of digital tapes within a reasonable time after the imagery had been received.

3. Banding of Channel 6 data, particularly noticeable in computer processing, often necessitated the exclusion of this channel in the early analyses. However, a method of recalibration developed by ORSER was used for correction of this problem in later analyses.

Several months after receipt of the first data, most problems of data flow and quality were either eliminated or minimized, resulting in an excellent collection of ERTS-1 data covering a large portion of Pennsylvania.

2.1.2 Aircraft Underflight Data

Two basic types of aircraft data were flown: one in the altitude range of 18,300 to 19,800 m (U2 and RB57) and the other in the range of 1520 to 4500 m (C130 and C54 aircraft) (see Table 2.1). Both the U2 and RB57 collected normal color, color IR, and black & white photography. In addition, some simulated ERTS MSS data were received from the early U2 flights. The C130 data included normal color, color IR, and black & white photography, as well as MSS data, in two formats: imagery and computer compatible tapes. Normal color and color IR photographs were supplied by the C54 aircraft, along with 35 mm slides for several flight lines. In many cases photography, with the exception of that from the C54, was supplied in both 70 and 248 mm formats. The mission numbers, dates flown, and kilometers of flight line data supplied, are listed in Table 2.2.

Most missions were flown well within the time tolerances stipulated in the investigation requirements and covered the area requested. In a few cases, however, critical time ranges were missed (due to weather or other factors) and, in one case, the Rothrock State Park area was flown instead of the Penn State Experimental Forest. A subsequent flight, however, corrected this error.

2.1.3 Other Data

Data were received from three Skylab sensors, the S190A and S190B camera systems and the S192 scanner (Table 2.1). These data, from two Skylab missions, have been useful not only in completing Skylab contract investigations, but for use as an intermediate scale level between ERTS-1 and aircraft data. Skylab S190B photography, for example, has been found useful

Table 2.2: Aircraft Support Missions for the ERTS-1 Project

Aircraft	Mission	Dates	Kilometers Flown
U2	71-070	2 Dec 71	455
	72-067	27 Apr 72	246
	72-094	7 Jun 72	262
	72-124	26 Jul 72	317
	73-009	23 Jan 73	1078
	74-016	5 Feb 74	3115
	74-060A	25 Apr 74	1660
	74-078	16 May 74	1368
	74-081	20 May 74	378
C130	207	20 Jul 72	756
	226	12 Jan 73	885
	230	15 Apr 73	708
	258-A	12 Dec 73	257
	258-B	12 Feb 74	829
	271	28 Apr 74	1287
C54	183-1	3 Jan 73	467
	183-2	10 Jan 73	483
	194-1	16 Apr 73	467
	227-1	13 Aug 73	113
	227-4	11 Sep 73	249
	227-5	19 Oct 73	225
	266-1	5 Sep 74	225

as a form of ground truth when processing ERTS-1 digital data, and the role of both S190A and S190B data in locating and verifying lineaments has been significant.

Two sets of aircraft data other than those supplied by NASA have been used. Under contract with ORSER, the Bendix Corporation flew several flight lines in central Pennsylvania carrying cameras with black & white and color film and an eight-channel MSS system. These data were used to gain experience with simulated ERTS-1 data before the satellite was launched. A set of 14-channel MSS data, with accompanying photography, was collected by University of Michigan aircraft and supplied by Dr. Harold T. Rib of the U.S. Bureau of Public Roads. These data, covering an area in Lancaster County, Pennsylvania, have been used in both pre- and post-ERTS-1 studies.

The ORSER laboratory contains an extensive map collection, including all USGS 7-1/2 minute and 15 minute quadrangle sheets and 1:250,000 maps, covering the entire state of Pennsylvania. The collection also includes aeronautical charts and various stream, physiographic, soil, and resource maps of the state. Soil survey and other county reports are available either in the ORSER office or in the offices of cooperating departments, where additional specialty maps may also be obtained. A complete set of reports from the Susquehanna River Basin study, conducted in 1970 by the Susquehanna River Basin Commission, is on hand, as well as numerous proceedings of symposia on remote sensing and related subjects. Ground truth data, collected by various professors and graduate students, are maintained in the offices and laboratories of these investigators.

2.2 Data Handling

Data handling within ORSER is a function separate from data processing. The latter involves the development of programs, specification of formats and procedures, and adaptation of these to remotely-sensed data. Data handling, on the other hand, is primarily a problem of management and control of the flow of data in daily operations, involving cataloging and storing of incoming data, preliminary processing in accordance with system requirements and formats, consolidation and integration of ground truth and other data with the remotely-sensed data, and preparation of data subsets.

2.2.1 Digital Data

With the exception of inactive tape storage, digital data handling is done by the Computation Center, without funding requirements. A Computation Center staff member serves in continuous liaison with ORSER investigators. All hardware is maintained and a considerable amount of routine software is supplied by the Center, which serves as a central storage facility, maintaining programs, subroutines, and subsets of data on magnetic tape files. These files are available at all times from terminals located on and off campus, some of which are reached by long distance telephone lines. ERTS, Skylab, and aircraft MSS data tapes are submitted to the Center (the "active file") when needed for subsetting, after which they are returned to ORSER storage (the "inactive file"). The location of each ERTS-1, C130, user, other data tape, is known by means of a cataloging system described in ORSER-SSEL Technical Report 18-73.

2.2.2 Photography and Imagery

Photographic and MSS imagery data are handled entirely within the ORSER laboratories. On receipt of such data, they are cataloged, annotated, and cross-referenced by a student assistant working under the supervision of the image analyst. When needed for a particular investigation, the photography or imagery is usually available within a few minutes, and may be studied using the light tables, stereoscopes, or zoom transferscope. These facilities, along with the annotation and cataloging system employed for photography and imagery, are described in detail in ORSER-SSEL Technical Report 18-74.

2.3 Data Processing

The use of satellite digital and imagery data; aircraft photography, imagery, and digital data; and other "ground truth" data sources, such as topographic and special maps, is integrated and coordinated in the recognition that such coordination is vital to significant investigative efforts. The "hybrid approach" to digital processing, described elsewhere in this report, was developed from this philosophy.

2.3.1 Digital Data Processing

The system for processing MSS digital tapes was developed for use by a wide variety of investigators representing many disciplines and having a wide range of experience and skill in computer usage. This system is described in detail in ORSER-SSEL Technical Report 9-74.

The automatic data processing facilities are primarily located at the Computation Center. A Remote Job Entry (RJE) system permits use of the IBM 370/168 from any of several remote terminals. An IBM 1401 computer is available at the Center, as well as an AGT-30 ADAGE graphics terminal and computer and a CalComp 564 plotter. Other digital systems, as well as extensive analog and hybrid processing equipment, are available elsewhere on campus. ORSER has recently installed a RAMTEK color TV display system which is interfaced with a Tektronix 4010 terminal and the RJE system. By means of this system, research results may be displayed in color at all stages of analysis, resulting in reduced analysis time and improved performance.

The IBM 370/168 is primarily dedicated to University research and education, but may be used by outside agencies as scheduling permits. Access to the computer is by one of three ways:

1) central and remote high-speed dispatch points operated by the Computation Center;

2) slow-speed RJE terminals, using IBM 2741, Tektronix 4010, or similar compatible terminals, supported by the user or by the Computation Center, including equipment at non-University Park locations tied in by long distance telephone connections; and

3) intermediate-speed remote batch terminals, such as the IBM 2780, supported by the user or the Computation Center.

The ORSER processing system for MSS data was developed for use with any of these entry points; however, RJE terminals are used for most developmental work and bulk output for final runs is directed from an RJE terminal to one of the high-speed terminal sites. Card decks are unnecessary, as data are input directly from the original MSS magnetic tapes, or from subset tapes, and data processing programs are kept in library files. Additional files for building control information or for storing output are also available.

2.3.2 Photographic and Imagery Analysis

The facilities for photographic and imagery analysis include various light tables, stereoscopes, a zoom transferscope, and film storage space. Three light tables with film reel mounts are provided for the study of transparencies and prints of various sizes, either as rolls or as individual frames. One of these tables permits simultaneous viewing of two reels of 248 mm film.

A Bausch and Lomb Zoom 95R stereoscope is available for use with 127 and 248 mm film in stereographic pairs. The zoom feature of this unit permits viewing at scales from 2.5 to 20X (or 5 to 40X with an attachment lens) with no adjustment of stereographic fusion necessary during the continuous change in scale. Each optical system can be rotated 360°, a highly useful feature for viewing images that are not in perfect alignment and for obtaining "false stereo" to enhance certain features, such as small streams. Each optical system also has a separate zoom train, hence a stereoscopic model may be obtained from imagery at two different scales. The stereoscope may be mounted on its own light table or used on the Richards variable-intensity light table, which is equipped with a bracket permitting movement of the entire unit in the X and Y directions.

A Bausch and Lomb Zoom 70 stereoscope, somewhat similar to the Zoom 95R stereoscope, is used for viewing 70 mm film. Although the entire unit can be rotated 360°, it does not feature rotation of the separate optical systems. Used with the rhomboid assembly, the unit will permit stereoscopic viewing at any scale from 10 to 30X with no adjustment of stereoscopic fusion necessary. With the single lens attachment (a feature not present on the Zoom 95R stereoscope) in place of the rhomboid assembly, the unit may be used for viewing single images, such as ERTS-1 scenes, at enlargements from 10 to 120X. Like the Zoom 95R, the Zoom 70 can be mounted on the variable-intensity light table, as well as used on its own small light-table stand with brackets for 70 mm film reels.

A Bausch and Lomb Zoom Transferscope permits projection of opaque or transparent images onto a plain surface or another opaque image, with 1 to 14X magnification in any direction or selectively in a single direction. With this instrument, a photograph can be projected onto a computer-generated character map with adjustment for the line and element distortion inherent in the high-speed printer output.

The laboratory is also equipped with an Old Delft Stereoscope and a mirror stereoscope with binocular attachment, for study of 248 mm film at magnifications of 1.5 and 4X, and 1 and 6X, respectively. A microfilm reader, a Diazo printer and developer, and a 35 mm slide projector are also provided.

A completely equipped photogrammetric and photointerpretation laboratory in the Department of Civil Engineering is also available to ORSER investigators, including a Kelsh plotter and an American Optical Delineascope, which was used to project 70 mm U2 photography onto computer output before the zoom transferscope was available. A Visucom overhead projector from the Division of Audio-Visual Services was also used for this purpose. An Itek reader-printer for 35 and 70 mm film, and a Saltzman projector for aerial photography are available in the Department of Geology and Geophysics. Additional equipment for collecting ground truth and other related information are found in the academic departments of the individual project investigators.

A wide variety of image reproduction facilities are available. Still Photography Services, of the Division of Instructional Services on campus, is staffed and equipped to provide professional, high quality, enlargements, contact prints, and slides, meeting all research and publication requirements. Several complete Xerox and Ozalid facilities are also available on campus.

CHAPTER 3

ERTS-1 CONTRACT RESEARCH: DATA PROCESSING AND PATTERN RECOGNITION

Research on the ERTS-1 project has been conducted in four areas: data processing and pattern recognition, inventory of natural resources and land use, geology and hydrology, and environmental quality. Descriptions of the individual projects conducted within these areas, using ERTS-1 and aircraft underflight data, are presented in this and the following three chapters.

In this chapter, we are dealing with data processing and pattern recognition. Throughout all the projects, the general objectives of developing interpretation techniques and ascertaining the practical usefulness of the spectral, spatial and temporal data provided by ERTS-1 have been pursued. Although computer processing of digital data has been emphasized, photointerpretation has been a vital part of the digital data analysis procedures and has been the basis for the lineament mapping project.

As defined in this chapter, data processing includes the specification of data format and processing procedures, development of methods and programs, and adaptation of these to the ERTS-1 data. Pattern recognition includes the implementation of algorithms which make decisions concerning the category or class to which a set of data should be assigned. Since pattern recognition frequently involves the preprocessing of data before they are classified and constitutes a major portion of any processing system for remote sensing data, data processing and pattern recognition have been combined as a single task in this project. Imagery and photographic analysis, an integral part of the hybrid approach to ERTS-1 digital data analysis, is also discussed in this chapter.

3.1 The Digital Data Processing System

One of the major accomplishments of the ERTS-1 project has been the development of a system for digital processing of MSS data. Many programs and procedures originally developed under funding from The Pennsylvania State University have been refined and expanded, and new programs have been developed for analysis of ERTS-1 and other MSS data.

3.1.1 System Characteristics (F. Y. Borden)*

All known MSS sources can conveniently be placed in the digital tape format designed by ORSER. A single tape may contain several files of data, and a file may be continued onto a second tape. There are

*This system is also described in ORSER-SSEL Technical Report 9-74.

four records within a file: identification, table of contents, MSS response, and history. Each MSS response record consists of a complete scan line, and scan lines are numbered and arranged in ascending order in the file. A working file will usually contain one or more small portions of the whole data set--the table of contents is particularly useful in such cases, avoiding costly searches for data not present in the file.

The system is couched in a multivariate framework. Each observation, identifiable by scan line and element number, consists of a vector with as many components as there are channels. At present, each vector is composed of either standard or transformed MSS response values. In the future, however, additional (non-scanner) data, such as topographic information, may be added.

Although the system is not in a conversational mode, where the user and the system dynamically interact during processing, each program accepts input control specifications and processes the MSS data according to these specifications. The specification format is identical for operation from an RJE terminal or by means of punched cards. Three primary considerations have determined program design: the University data processing environment, program library objectives, and costs.

A large general purpose computer is a definite advantage in efficient processing of the large data bulk from a multispectral scanner. The IBM 370/168, operating under OS and HASP in a batch environment, typically processes over 10,000 runs a day. ORSER must, of course, conform to the Computation Center system in its data processing; however, rather than a handicap, this requirement has often been an advantage. RJE access to the computer via telephone lines is an important factor in the programs designed by ORSER. Charges are based primarily on CPU time, and higher job priority is accorded to runs requiring smaller core, less time, and fewer records.

In the philosophy of ORSER program development, the human interpreter is essential to the classification of MSS data. The software should, therefore, be as interactive as possible. Emphasis has been on programs which minimize core use; run at tape speed; and return relatively small numbers of records, resulting in fast turn-around time to the interpreter at a remote terminal. A large number of commonly used programs, therefore, run in the small (140K) core. Working tapes kept in the active library contain subsets of scenes covering only the areas of interest, essentially eliminating the use of system time for bypassing unwanted tape records. Current turn-around time for most runs from a terminal is approximately two minutes. It is felt that larger and more complex programs would increase turn-around time and reduce interpreter interaction, needlessly increasing CPU costs.

A uniform control card structure, with many cards common to all programs, is used to reduce development costs, and many subroutines are common to all programs. By using these techniques, needlessly redundant program development has been eliminated and use of the programs is simplified, a particularly important aspect in an interdisciplinary environment where a number of users are not processing-oriented.

3.1.2 Program Descriptions and Documentation (F. Y. Borden, G. J. McMurtry, and D. N. Applegate)*

Program descriptions are entered into RJE batch and terminal (BAT) files and kept on disk storage; in this form, they can be processed by the FORMAT program, designed by Computation Center personnel to permit rapid editing and printing of text directly onto a system printer. This is particularly useful for program descriptions because it permits the addition of new control card and computational method descriptions as they are incorporated into the programs, and also serves as a method of recording program revisions, since the original description is edited by use of control cards, rather than by revising the original file.

A user's guide to the ORSER MSS digital data processing system is available as ORSER-SSEL Technical Report 10-75, which describes the pre-processing activities which should be completed before actual data processing begins and supplies complete descriptions of the programs with instructions for their use from an RJE system or from punched cards. Descriptions of the more commonly used RJE commands are given and sample RJE sessions, showing how program control cards and tape names are changed, are included. Commonly used control cards are described separately in the manual and listed by name only under the appropriate program. If, however, a control card in a program has the name of a commonly used card but differs in any way from the standard description of that card, it is described under the program to which it applies. Programs in current use include:

TPINFO	obtains information about tape contents from the internal label.
SUBSET	subsets satellite data onto a working tape, in ORSER format.
SUBAIR	subsets aircraft data onto a working tape, in ORSER format.
SUBTRAN	reformats to ERTS-1 format data supplied in various other formats and performs additional selected data manipulations.
NMAP	creates a brightness map from digital data.
UMAP	creates a uniformity map from digital data.
STATS & STCLASS	obtain basic statistics for user-defined small blocks of data.
PPD	classifies according to the parallelpiped method.

*Complete descriptions of the ORSER programs may be found in ORSER-SSEL Technical Report 10-75.

CANAL	uses the method of canonical analysis to derive an orthogonal transformation which maximizes category separability on as few axes as possible.
RATIO	performs classification and mapping based on the ratio of two selected channels of data.
MERGE	merges data from two different passes over the same area.
MAPCOMP	compares, element by element, two digital classification maps of the same ground area.
GMCLASS	makes geometric and scaling corrections to classified data and generates gray scale or color printer output.
CLASS & MINDIS	supervised parametric classifiers which classify data from a set of user-specified spectral signatures according to the angle or distance of separation.
CLUS	unsupervised classifier which develops a set of spectral signatures using a clustering algorithm.
NPAR	non-parametric classifier employing the linear discriminant function.
QUADNPAR	non-parametric classifier employing the quadratic discriminant function.
PARAM	parametric classifier based on a maximum likelihood decision rule.
LMAP	outputs a black and white line map scaled to user specifications on either a CalComp 564 plotter or a Tektronix 4010 CRT terminal.

3.1.3 The Digital Data Analysis Sequence (F. Y. Borden)*

The digital tape processing system for MSS data described here is regularly run for production and has been extended to meet the needs of various related projects. The system was designed to be easily augmented, typified by the addition of a number of supervised and unsupervised analysis and classification algorithms commonly used in ORSER investigations. The steps discussed in this section represent a typical digital analysis sequence, but many variations and other options are used in particular applications.

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*This system is described more completely in ORSER-SSEL Technical Report 9-74.

The first step in analysis of a previously unstudied area or series of targets is to select the targets and area of interest from maps or aircraft photography. Consultation of catalogs of imagery and digital tapes will indicate what data are available and their quality. Tapes corresponding to the selected scenes are chosen, the areas of useful data are specified, and the data for these areas are subset onto working tapes using the SUBSET program. (If this step has already been completed by an earlier user, the appropriate library subset tapes would be selected directly.) Subsetting accomplishes:

1) reduction of a large data set to small subsets containing only the data of interest,

2) reformatting of ERTS-1 or other MSS data to the common ORSER format,

3) doubling of data tape density from 800 to 1600 bpi thus doubling the data rate in subsequent use,

4) reduction of turn-around time,

5) higher priority of run assignments, and

6) reduction of computation costs.

The NMAP program is then run, using all channels or any subset of channels, to show the overall pattern of data. The norm of each multivariate vector is taken as the measure of brightness and converted to a percentage of the maximum possible value. This value is then translated to a mapping symbol. This process is repeated for every element in the data block specified by the user; thus, output from the NMAP program consists of a brightness map. The result is similar to a gray-scale map, without employing expensive and time-consuming techniques such as overprinting. Careful choice of mapping symbols, however, will yield a map with readily distinguished degrees of brightness. The NMAP program requires no prior knowledge of target spectral signatures or other characteristics, and the resulting map is useful for verification of area location and initial target identification.

Areas of local spectral uniformity are identified by means of the UMAP program. Using the euclidean distance between spectral signatures as the measure of similarity or dissimilarity, each element is compared with its nearest neighbors. If the largest distance is smaller than a value specified by user, then the symbol for uniformity is assigned to that element. One or more categories of uniformity can be mapped according to distances specified by the user. All elements with distances from their neighbors greater than those specified are mapped as contrasts. The map output shows the pattern of uniformity and contrasts from which the user can designate coordinates of training areas for supervised classifiers. It may also be used to determine high contrast boundaries between uniform areas.

Signatures and associated statistics are next obtained by the use of the STATS program, which computes the multivariate statistics for one or more training areas obtained from UMAP or similar output. The user designates, for each identifiable category, a training area by line and element coordinates and the program computes the statistics for all of the data which fall within the boundaries. The mean and standard deviation vectors for each category are found, and the correlation and variance-covariance matrices are computed, as well as the eigenvalues and eigenvectors of these matrices. Frequently, histograms for selected channels are also computed.

When most of the target categories have been identified by training areas, a classification run is made using the classifier or classifiers deemed most appropriate for the mix of targets under consideration. A variety of supervised classification programs are available, including parametric and non-parametric classifiers with either linear or quadratic discriminant functions. Unsupervised (clustering) algorithms are also available and used extensively. (Before classification, preprocessing programs for normalization, principal components, canonical analysis, and so on, may also be used.) The output of these programs is a digital character map in which each classification category is represented by a unique symbol. These maps are used primarily as working maps during the analysis of MSS data; they are inherently distorted in the length-to-width relationship because of the fixed number of lines and characters per unit of high-speed printer output.

Two programs have been developed for the production of distortion-free maps. The LMAP program, yielding output on the CalComp plotter or an RJE terminal with display (such as the Tektronix 4010), produces a finished copy line map with the following advantages over the high-speed printer output:

1) the map is orthographic and to a selected scale,

2) photographic overlays can be prepared for such a map (of importance in the comparison of classification results with corresponding imagery and related photography), and

3) the map is far more legible than a character map and of appropriate size for publication purposes.

The GMCLASS program transforms data from its original position in two-dimensional space to a unique position in another two-dimensional space by a linear matrix multiplication. The multiplying matrix can be adjusted by the user to:

1) correct for skew in the data,

2) give the same spacing between pixels in the vertical and horizontal dimensions,

3) yield a given map scale,

4) compensate for the distortion in the line and column spacing of the output device,

5) make fine corrections of a geometrical nature, and

6) rotate the data to a given geographic orientation.

The GMCLASS program then uses the DCLASS program to classify the transformed data and output the results in one of the following formats:

1) a standard character map,

2) a gray-scale map using overprinting on the IBM 1401,

3) a color tone-scale map using various color ribbons and overprinting on the IBM 1401,

4) a display on the RAMTEK color TV monitor, or

5) a photograph produced on a color recorder.

The approach employed for detection of changes between scenes, where a temporal dimension is involved, is similar to non-temporal analysis in many respects. The major difference is in the establishment of permanent training areas for analysis and classification. These must be selected and specified more carefully and with more refinement than when the temporal dimension is not of interest. The GMCLASS program is of assistance in such cases.

3.1.4 Hybrid Analysis (F. Y. Borden, H. A. Weeden, D. N. Applegate, and N. B. Bolling)*

After performing separate analyses of ERTS-1 data by photointerpretation and by computer processing of MSS digital data without the assistance of photointerpretation, it became apparent that each method had shortcomings which might be overcome if the methods were combined. In only a few cases could a feature be uniquely identified by the sole application of photo-interpretation techniques to ERTS-1 imagery. The use of U2, C130, and C54 photography has been found to improve these interpretation results, but photointerpretive techniques have not been completely satisfactory as a single means of analysis. Computer differentiation of targets from scanner data is far superior to that done by the human eye. Computation of areas from the digital data makes delineation of the areal extent of targets unnecessary and is far more accurate than planimetric methods at the scale of ERTS MSS imagery. Since the end result of processing ERTS-1 data is a map, the automated process of thematic mapping by computer is the most efficient. However, ground truth in the form of underflight data, and photointerpretation of underflight photography as well as of ERTS-1 imagery, are vital links leading to valid signatures for the thematic map. A marriage of these two disciplines, photointerpretation and computer processing, is essential for maximum utilization of ERTS-1 data. Thus, a method of ERTS-1 MSS data analysis, referred to as the "hybrid approach" was evolved. This approach, involving intimate interaction

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*This technique is described in detail in ORSER-SSEL Technical Report 13-73.

of the computer analyst and the photointerpreter, using aircraft photography or other forms of ground truth for comparison with the computer output, is described in ORSER-SSEL Technical Report 13-73. The Bausch and Lomb Zoom Transferscope is frequently used for this comparison.

3.2 Digital Data Processing Techniques

Of the many digital data processing techniques and procedures developed by ORSER, several were specifically an outgrowth of processing ERTS-1 data. These are discussed briefly here. Detailed descriptions of these and other techniques of MSS digital data processing are described in detail in ORSER-SSEL Technical Report 10-75. Where a particular technique is described in a separate report, this report is indicated in a footnote.

3.2.1 Cluster Analysis (B. J. Turner)*

The increasing availability of MSS remotely-sensed data from airborne and space platforms is making automated land-use and vegetative mapping a necessity. Mapping methods require that representative spectral signatures be obtained for each target of interest (land-use class, species type, etc.) and that each MSS response element then be classified according to the nearest target signature. One method for obtaining representative spectral signatures is cluster analysis.

The first approach to identifying an unfamiliar set of objects is to attempt to associate it with a known class of objects, thereby reducing the dimensionality of the unknown. If this fails because of the great variation among the unfamiliar objects, it may be instructive to subset these so that objects within a subset are more closely allied with one another than with any member of any other subset. If the subsets still cannot be associated with any known classes, at least it is helpful to know the structure associated with the set in order that initial attention can be concentrated on the more important problem of identifying the group, rather than on individual differences.

Cluster analysis is concerned with this subsetting problem. The basic premise of cluster analysis is that objects should be placed in the same group if measurements of variables associated with these objects are highly similar. This implies that there should be small variances within a group and large variances between groups. Furthermore, if one considers the value of each object as a point in multidimensional space, where each dimension represents a measured variable, then objects within a group should be close together and clearly distant from objects in other groups. Thus, the aim is to form subsets of the data that have high internal consistency and maximum separability from other subsets.

The clustering algorithm (CLUS), developed and used by ORSER, was influenced by a method suggested by Tryon and Bailey** for large numbers of observations. The first stage of this method, which they called

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*See ORSER-SSEL Technical Report 6-75 for a more detailed discussion.

**Tryon, R. C. and D. E. Bailey (1972) Cluster Analysis. McGraw Hill, N.Y.

"iterative condensation on centroids," requires that trial group centroids be set up and each point assigned to that group with which it has its smallest euclidean distance. After all points have been assigned, the centroid coordinates are computed and the process iterated until no change in allocation occurs.

In the CLUS program, the initial centroids are computed from the first scan line in the specified block of data and from the user-supplied initial critical distance, θ_c. The vector of spectral data for the jth element within the ith scan line is designated as X_{ij}. The euclidean distance, θ, in p-dimensional space (assuming each observational vector X_{ij} has p elements) between X_{11} and X_{12} is computed. If this is less than θ_c, then the first centroid, $\bar{X}_1$, is calculated as the mean of vectors X_{11} and X_{12}. If $\theta > \theta_c$, then $\bar{X}_1 = X_{11}$ and $\bar{X}_2 = X_{12}$. Then X_{13} is attached to its nearest centroid $\bar{X}_1$ or $\bar{X}_2$, unless the distance between X_{13} and its nearest centroid is greater than θ_c, in which case a third centroid, $\bar{X}_3 = X_{13}$, is formed. The centroid is recomputed with each additional observation, and a "moving standard deviation of distance" is also computed. This procedure is carried out for every element in the first scan line, defining the set of initial or trial centroids on which the sample points are to be "condensed." It can be seen that the number of initial centroids is controlled by the initial critical distance; the larger the distance, the smaller the number of initial centroids.

After processing the first line in the specified block of data, only randomly-sampled points are used to complete the clustering process. Each sample point is located in turn on the data tape and is attached to the nearest centroid unless it deviates from this centroid by a distance greater than some multiple of the standard deviation, in which case a new centroid will be formed. If the point is accepted into an existing cluster, the mean vector and standard deviation are adjusted, and immediately adjacent points to the left and right along the scan line are tested to see if they are within the same cluster. If so, they are accepted and the centroid statistics are recomputed; if not, the next sample point is located. This technique makes use of the fact that there is a high probability that immediately adjacent observational points are spectral measurements of similar objects because of the spatial pattern relationships which exist in these data. The effect is to considerably augment the sample size at little additional computational cost.

After all sample points and their neighbors have been allocated, clusters represented by only one sample point are dropped. The remaining clusters are then tested to find if any overlap by one standard deviation. If so, the overlapping clusters are fused into one. The clusters are then sorted in descending order of their sample size. Clusters which have been formed from only a few sample points can be dropped (the user can specify the minimum proportional sample size for a cluster), and if there are still more than ten clusters remaining, the least represented clusters are dropped until only ten remain.

If the user now wishes to obtain a digital map of the same area, the tape is rewound and a character is assigned to each cluster spectral signature. Each observational element is assigned the character of the nearest cluster unless it is outside the nearest cluster by some user-supplied multiple of the angular standard deviation, in which case it is assigned a blank character. The matrix of characters so formed is output as a digital map.

3.2.2 Canonical Analysis (F. Y. Borden and H. M. Lachowski)*

A number of preprocessing and transformation methods are known and have been applied to remote sensing data. One method of particular interest is based on the multivariate statistical technique called canonical (or multiple discriminant) analysis. The primary objective of canonical analysis is to derive an orthogonal linear transformation which will emphasize the differences among the sample estimates of the means of several multivariate universes. In other words, the objective is to define new coordinate axes in directions of high information content useful for classification purposes. It then becomes feasible to select only those axes of highest information content and reject those with the lowest information content. Thus, canonical analysis becomes a technique for feature selection and reduction of dimensions in the processing and classification of MSS data. For this purpose, a canonical analysis program (CANAL) was developed for processing multispectral scanner data collected by aircraft or spacecraft scanners.

<u>The Principles of Canonical Analysis</u>. Consider several p-variate universes, say, h in number. Each universe may be conceived of as a swarm of points representing a particular category S_i $(i = 1,2,\ldots,h)$ in p-dimensional space, centered at a point characterized by a mean vector $\bar{X}_i$ and dispersed about this point in an ellipsoidal pattern characterized by the covariance matrix Σ_i. The universes under consideration overlap to a greater or lesser degree and the mean vectors are more or less distinctly separated.

A finite sample of observations can be obtained from each of the p-variate universes. Each sample of observations corresponds to a training set which is defined by the investigator and chosen to be a representative sample of data for a homogeneous category, that is, a category which has reasonably uniform characteristics differing from point to point within the target area only by random variability, as represented by the category covariance matrix Σ_i.

Each observation will be represented as a p-component vector,

$$X_{ij} = \begin{bmatrix} X_{ij1} \\ X_{ij2} \\ \vdots \\ X_{ijp} \end{bmatrix}$$

*A more complete description of canonical analysis may be found in ORSER-SSEL Technical Report 17-73.

where p is the number of channels for element j in scan line i. The sample mean vector for the kth category $(k = 1,2,\ldots,h)$ is $\bar{X}_k$. The sample covariance matrix for the kth category is $\hat{\Sigma}_k$.

Now let the desired canonical transformation be

$$Y_{ij} = CX_{ij}$$

where C is the q x p transformation matrix where $q \leq p$, and Y_{ij} is the transformed q-element observation vector

$$Y_{ij} = \begin{bmatrix} Y_{ij1} \\ Y_{ij2} \\ \vdots \\ Y_{ijq} \end{bmatrix}$$

If $q < p$, then the observation vector has been reduced from the p-dimensional X vector to the q-dimensional Y vector.

Let W be the combined covariance matrix for all the categories (commonly referred to as the "within - category" covariance matrix) computed as,

$$W = \left(\sum_{i=1}^{h} n_1 - h \right)^{-1} \left\{ \sum_{i=1}^{h} (n_1 - 1) \hat{\Sigma}_i \right\}$$

where $\hat{\Sigma}_i$ is the covariance matrix for category i, n_i is the number of observations for category i, and h is the number of categories. Let P be the "among - categories" covariance matrix defined as,

$$P = \bar{X} \bar{X}^T N - \frac{1}{\sum_{i=1}^{h} n_1} (\bar{X} n) (\bar{X} n)^T$$

where $\bar{X}$ is defined as a p x h matrix of all the category mean vectors, $\bar{X}_k$ $(k = 1,2,\ldots,h)$, that is,

$$\bar{X} = \begin{array}{c c} & \begin{array}{cccc} \text{cat. } 1 & \text{cat. } 2 & \cdots & \text{cat. } h \end{array} \\ \begin{array}{c} \text{ch. } 1 \\ \text{ch. } 2 \\ \vdots \\ \text{ch. } p \end{array} & \begin{bmatrix} \bar{X}_{11} & \bar{X}_{12} & \cdots & \bar{X}_{1h} \\ \bar{X}_{21} & \bar{X}_{22} & \cdots & \bar{X}_{2h} \\ \vdots & \vdots & & \vdots \\ \bar{X}_{p1} & \bar{X}_{p2} & \cdots & \bar{X}_{ph} \end{bmatrix} \end{array}$$

The annotation of this matrix indicates its category and channel organization. N and n are, respectively, an h x h matrix and an h x 1 vector of the number of observations in the categories, that is,

$$N = \begin{bmatrix} n_1 & 0 & \cdots & 0 \\ 0 & n_2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & n_h \end{bmatrix}, \quad n = \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_h \end{bmatrix}$$

W corresponds to the average covariance matrix for individual categories, while P corresponds to the covariance of the means of the categories. Thus, W represents the distribution of observations within categories, while P represents the spread in p-dimensional space between (or among) the categories.

After transformation, CPC^T is the among - categories covariance matrix for the transformed observations, Y, and CWC^T is the within - category covariance matrix. In order to meet the objective of finding C so that the differences among the categories are emphasized, CPC^T must be maximized, so that the diagonal elements of CPC^T (which are the variances of the transformed variables) are arranged in descending order. Then the axes (elements) with the largest values are assumed to have the greatest information content since they show the greatest spread (variances) among (or between) categories.

The matrix C can only be made to be unique if additional constraints are placed on it. The constraint that $CWC^T = I$, for I the q x q identity matrix, will suffice and, in addition, has the highly desirable effect that under this constraint the transformed variables will be independent and have unit variances. Maximization of CPC^T subject to $CWC^T = I$ is performed in the CANAL program and the resulting transformation matrix, C, is computed.

The possible rank, q, of the transformed discriminant subspace depends on the relative sizes of p, the number of elements in the X vector, and of h, the number of categories. If h - 1 is less than p, then h - 1 is the maximum possible rank of the discriminant space. For example, if two classes are used, their centroids will have to fit on a single line, the centroids of three classes will have to fit on a plane, four classes in a three dimensional space, and so forth. If, however, $(h - 1) \geq p$, it is possible to have as many as p canonical axes. If the smaller of p and h - 1 is quite large, one might decide to use less than the maximum number of axes for reasons of parsimony. In most cases, a reduced rank discriminant space yields adequate results when employed in classification. As the result of the transformation, the first canonical axis is assumed to represent the greatest separability achievable on one axis among all categories, the second axis represents the next greatest separability achievable for the remaining axes, and so on.

The CANAL Program. In the first part of the CANAL program, canonical analysis is performed on the data for all categories. In the second part, a classification method based on comparison of the euclidean distance between the input observation (unknown vector to be classified) and the stored references (category means) is used. Before the actual comparison takes place, the input vector is centralized; that is, the grand mean is subtracted from it. Each observation is then transformed using the linear transformation C, found in the first part of the program, and then classified. The decision rule applied is based on the comparison of euclidean distances, as follows: Y belongs to A if $|Y - \bar{Y}_i| < C_i$ and $|Y - \bar{Y}_i| < |Y - \bar{Y}_j|$ $(j = 1,\ldots,h;\ i \neq j)$. In this case, h categories are considered. Here C_i is the threshold value or limit for category i, $\bar{Y}_i$ is the sample mean for category i, and $\bar{Y}_j$ $(j = 1,\ldots,h)$ are the sample means for the remaining. This rule partitions the space into h + 1 regions (h categories plus "other"). The unknown observation is classified as belonging to category i if it is within the boundary limit defined by the threshold for category i, which is C_i. If it is outside all the h regions, the decision is made to classify the observation in the "other," or unclassified, category.

The procedure is different if the threshold value is not used. In this case, an unknown observation is classified as belonging to the category for which the euclidean distance is smallest, without other limitations. Every observation, therefore, is classified as belonging to a category, but this does not necessarily mean that the decision is a correct one. The thresholds are used mainly to avoid classification in one of the h categories when the likelihood of success is marginal.

Output consists of a classification map and two tables, showing various matrices computed during the canonical analysis and the distances of separation between all pairs of categories. By optional termination prior to the classification and mapping computations, the program may be run for the statistical information alone.

It has been found that a particularly useful product can be generated by a color film recorder or color TV display system when canonically transformed data for three axes (Y-variables) are used in the display. In these three axes, the majority of the discriminatory information is assumed to be recovered from the original MSS channels. The color recorder or display functions in essentially the same way that ERTS-1 image-generating equipment functions. The three axes can be thought of as corresponding to the three ERTS-1 MSS data channels which are used to produce color composite imagery. Each variable, or axis, is assigned to one of the three basic colors. For example, red may be assigned to Y_1, green to Y_2, and blue to Y_3. Since the range of the Y-variables does not usually correspond to the range of the recorder or display system, the Y-variables have to be translated and scaled. This is done, along with formatting the output for the film recorder, by the SUBTRAN program (see Section 3.2.3). Film recorder or color TV outputs are not classification maps. They are essentially color-coded displays of density slices from each of the three canonically transformed axes.

The color tones in the resultant display are useful in interpretation of the degree of importance of each axis in discriminating each category. For example, urban areas may have a high response in axis three (blue) but little response in the first two axes (red and green). In several applications, such color displays of canonically transformed data have proven helpful in the evaluation of confusion between various target types. They have also aided in determining the ability of each axis to discriminate among different targets.

3.2.3 Transforming MSS Data Into ERTS-1 Format (B. F. Merembeck, F. Y. Borden, and D. N. Applegate)*

ORSER has had the opportunity to process MSS data tapes in a variety of formats generated by several sources. Among these are:

1) 4-channel ERTS-1 data,
2) 22-channel Bendix scanner data obtained by the C130 aircraft from NASA-Houston in both MSS-DAS** and LARSYS II*** formats,
3) Reconofax IV thermal scanner data, and
4) 8-channel data obtained from a flight by Bendix Corporation (which was converted from analog to digital form by ORSER).

A number of ORSER programs can use data from one or more of these source

*This method is described in ORSER-SSEL Technical Report 11-74.

**MSS-DAS is the format system developed by NASA at the Johnson Space Center.

***LARSYS II is the format system used by the Laboratory for Applications of Remote Sensing at Purdue University.

tapes; hence, it is desirable, in the interest of convenience and efficiency, that these programs operate with a common data format and with subsets of the original data. The original SUBSET program, which generated working subset tapes in a common format from original source tapes, was developed to meet these requirements.

SUBTRAN, an extended version of the SUBSET program, was developed primarily in response to needs generated by use of the G.E. Image 100 project, described in the next section of this report. SUBTRAN performs all the functions of SUBSET, but has the following additional capabilities:

1. Output in ERTS-1 format. Data tapes are reformatted into ERTS-1 format by the sequence: SOURCE DATA FORMAT - ORSER FORMAT - ERTS-1 FORMAT. The result is a 4-channel tape in ERTS-1 format with 804 elements per scan line. Since the Image 100 system will accept only ERTS-1 format tapes at 800 bpi, SUBTRAN was originally developed to convert data to this format. However, other standard tape densities can also be generated.

2. Averaging. In order to facilitate comparison and to conform to the four channels available in the ERTS-1 format, channels exceeding this number (such as the 24 channels of the Bendix scanner) are averaged to approximate the channel responses of the ERTS-1 scanner.

3. Data transformation. This feature was originally intended for use with the canonical transformation matrix generated by the CANAL program, but any conformable matrix may be used. The transformation is of the form CX = Y, where C is an M row by N column matrix, X is the raw MSS vector of N channels, and Y is the transformed vector of M axes. Hence, C is a linear transformation which converts an N-channel raw MSS vector into an M-axes transformed vector.

3.2.4 Man-machine Interaction: The G.E. Image 100 System (B. F. Merembeck, F. Y. Borden, and General Electric Company)*

In accordance with the provisions of ORSER's contract with NASA, The Pennsylvania State University granted a subcontract to the General Electric Company for the purpose of processing MSS data on the Image 100 system. The objective of this investigation, conducted jointly by G.E. and ORSER, was to integrate the results of digital data analysis using:

1) the highly interactive Image 100 system having a moderate digital computer capability, and

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*Reports of this work by ORSER and by General Electric Company may be found in ORSER-SSEL Technical Reports 4-75 and 15-75, respectively; and in the M.S. thesis by J. E. Anderson.

2) the less interactive, but large capacity, high-speed computer capability at the University.

The task encompassed ERTS-1 and aircraft MSS digital data, conventional, as well as canonically transformed (all transformations were implemented by ORSER at the University). The following Image 100 pre-processing and analysis modes were employed:

1) geometric and radiometric scale factors,

2) 1-D training and classification,

3) N-D training and classification,

4) level slicing,

5) clustering, and

6) manual interpretation of multiband composite displays.

Experimental design and results. In preparation for the Image 100 sessions, selected aircraft data from the 24-channel Bendix scanner were averaged to approximate the responses of the four ERTS-1 channels and linearly transformed by a canonical transformation matrix, which converts a raw MSS element of N channels into a transformed element of M axes. The same transformation process was performed on selected ERTS-1 data sets.

The initial Image 100 session was held at Daytona Beach, Florida, on 9-10 February 1974. Primary concentration was focused on familiarization with the system, using data from a portion of an ERTS-1 scene covering the East Branch Reservoir of the Clarion River in northwestern Pennsylvania.* The second session, on 12-13 June 1974, was held at Beltsville, Maryland, as were all subsequent sessions. Data from ERTS-1 scenes from the Shamokin and Lancaster areas of Pennsylvania and from a scene in Texas were analyzed with both the 1-D and N-D classifiers.** Data from the Texas scene were also used to determine the effect of various radiometric scale factors on the channel means and variances for the same training area. It appeared that rather than being a linear effect, as assumed by G.E., a change in the radiometric scale factor changed the variance of the data by the square of the scale factor. This effect could be predicted statistically.

The only non-ERTS tape available at this second session contained aircraft data from the McElhattan area on the West Branch of the Susquehanna River, scanned at approximately 1500 m.*** The source of this tape was 12 channels of data from the Bendix scanner, in MSS-DAS format, which had been averaged by ORSER into four channels of data in ERTS-1 format with a

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*Scene 1028-15295, 20 August 1972.

**Scenes 1350-15190, 8 July 1973; 1080-15185, 11 October 1972; and 1146-16323, 16 December 1972, respectively.

***NASA C130 Mission 238, 15 June 1973, Flightline 4.

response range from 0.38 to 2.3 μm. The system accepted this tape, yielding excellent spatial resolution. The results approached photographic quality while simultaneously providing a data base in digital form. Photographs were taken of the face of the CRT and a working tape was left with G.E. personnel.

The third session took place 1-2 July 1974. One of the objectives of using the Image 100 system was to determine if canonically transformed data from both ERTS-1 and aircraft scanners would retain satisfactory information content while the speed of classification was improved. Hence, much of the data in this session, which was devoted exclusively to C130 aircraft scenes, were canonically transformed. The data were flown by NASA along sections of the West Branch of the Susquehanna River in Pennsylvania. They were all originally in MSS-DAS format and output after transformation in ERTS-1 format. The areas and data configurations involved in this session were:

1. McElhattan - altitude approximately 1500 m - Mission 238, 15 June 1973, Flightline 4 - 12 channels.
   a. Data from 12 channels averaged into 4 channels.
   b. Data from 12 channels canonically transformed onto 4 axes.
2. Pine Creek - altitude approximately 4500 m - Mission 230, 15 April 1973, Flightline 5 - 8 channels.
   a. Data from 4 channels output as 4 channels.
   b. Data from 6 channels canonically transformed onto 4 axes.
3. North Bend - altitude approximately 1500 m - Mission 230, 15 April 1973, Flightline 16 - 14 channels.
   a. Data from 12 channels averaged into 4 channels.
   b. Data from 14 channels transformed by the 4 eigenvectors associated with the 4 eigenvalues accounting for 98.2 per cent of the variability in the scene and output on 4 axes.
   c. Data from 14 channels canonically transformed onto 4 axes.

This was the first attempt at detailed analysis using aircraft data. The high spatial resolution permitted use of the displayed image alone to select training areas, and supplementary aircraft photography was unnecessary. The 1-D classification was performed on both the averaged and transformed data. Classification of the transformed data was faster and, in the case of non-homogeneous targets such as forests, more consistent than classification of non-transformed data. At the resolution afforded by the aircraft data, each pixel in a forest scene has an area roughly equal to one tree crown or less, at small look-angles of the scanning mirror. This results in very non-homogeneous response characteristics for forest data, and classification of non-transformed data both by ORSER methods and on the Image 100 was erratic. However, 1-D classification of the transformed data gave very good and consistent results when applied to the McElhattan scene.

Density slicing of the first canonical axis gave good classification of the areas of interest in both the McElhattan and North Bend scenes. In the Pine Creek scene, however, the second axis gave better delineation of the floodplain areas of interest. (This may possibly have been the result of misidentification of a forested training area next to the river, interpreted as floodplain. When this incorrect statistical information was input to the canonical analysis program, it conceivably could have caused the first axis to separate forest from non-forest land and water.) This success at uniform density slicing indicated that even better results could be achieved if the slicing levels for specific categories were initially determined by ORSER and then input to the Image 100 system. This was put on the schedule for the final session.

The N-D classifier was also run on the aircraft data. The high spatial resolution of the data resulted in alarms (categories) with orders of magnitude of 10^5 cells. With this number of cells in a single alarm, the search procedure of the N-D classifier becomes time-consuming and classification of the larger alarms was discontinued.

The fourth and final session on the Image 100 system took place 26 September 1974. Emphasis was placed on the analysis of canonically transformed ERTS-1 and aircraft data processed as follows:

1. North Bend - NASA C130 aircraft at 1500 m, Mission 230, 15 April 1973, Flightline 16 - 14 channels.

    a. Data from 12 channels of MSS-DAS data averaged into 4 channels in ERTS-1 format.

    b. Data from 14 channels of MSS-DAS data canonically transformed onto 4 axes and output in ERTS-1 format.

2. Whipple Dam State Park (Central Pennsylvania) - ERTS-1 Scenes 1459-15223 (25 October 1973) and 1297-15252 (16 May 1973) - 8 channels.

    a. Data from two scenes merged onto an 8-channel tape in ORSER format and then canonically transformed onto 4 axes and output in ERTS-1 format.

3. Gypsy Moth Infestation (Northeastern Pennsylvania) - ERTS-1 Scene 1350-15183 (8 July 1973) - 4 channels.

    a. Data from 4 channels canonically transformed onto 2 axes; the first axis then repeated three times and output with the second axis in ERTS-1 format.

4. Lockhaven (Central Pennsylvania) - NASA C130 aircraft at 1500 m, Mission 238, 7 July 1973, Flightlines 1 and 4 - 1 thermal channel.

   a. Repetition of 1 channel three times and the result output with a calibration channel in ERTS-1 format.

The desired levels for density slicing the axes of transformed data were initially determined by ORSER. The results were quite satisfactory, particularly for the gypsy moth and Whipple Dam scenes. Although signatures for moderately defoliated forest in the gypsy moth scene had not been developed to input to the canonical analysis program, it was known from earlier studies that the signature for moderate defoliation lay between the healthy and heavily defoliated signatures in the untransformed data. A density slice of the first canonical axis between the healthy and heavily defoliated intervals of the axis successfully mapped the moderately defoliated areas.

The results of work with the Image 100 to this point indicated that one of the most significant applications of canonical analysis is a color display of density slices of the first three axes of canonically transformed data, with one of the three primary colors used to represent each axis. In the Whipple Dam test site, for instance, red represented Axis 1, blue represented Axis 2, and green represented Axis 3. Topographic features were clearly shown. Gaps in and between ridges were recognizable, and slopes with a southeastern aspect appeared golden brown and those with a northwestern aspect appeared green. Whipple Dam and Stone Valley recreation areas were recognizable as yellowish-green areas. Agricultural fields, for which no spectral signatures had been generated, were seen in the display as tan and red areas. Similarly, clouds and a powerline right-of-way were also recognizable, even though they also had not been included in the original analysis. The presence of these three features in the display seems to be a direct result of the discriminatory power of canonical analysis. Another feature of interest was the vegetation pattern in the flatland areas of the scene. Coniferous vegetation, including plantations and recently cut areas shown on underflight photography and the Pennsylvania State Bureau of Forestry timber map, could be located accurately on the display. Conifers appeared green, with the lighter shades corresponding to a mixture of naturally-occurring coniferous vegetation and hardwoods. Darker green areas represented conifers in nearly pure naturally-occurring stands or in plantations, while pure stands of hardwoods appeared golden brown.

As a further system evaluation, in this final session, the cluster analysis algorithm of the Image 100 system was run on the averaged North Bend data. As with the N-D classifier, the high spatial resolution of the aircraft data resulted in large cell numbers in the alarm and the clustering was discontinued after 14 iterations.

Conclusions and Recommendations. In the following discussion, it should be borne in mind that the Image 100 system was in a state of continual development during all the sessions which have been described herein. Full written evaluations of the results, with recommendations, have been made by both G.E. and ORSER and issued as ORSER-SSEL Technical Reports 15-75 and 4-75, respectively. The conclusions and recommendations from ORSER's experience are summarized here.

It was found that the high-speed man-machine interaction capability is a distinct advantage of the Image 100. The color CRT is an excellent interface between the interpreter and the data. It is less abstract than other display systems such as computer character maps, and location and definition of training areas is a rapid interactive process.

One of the most significant applications of the Image 100 system is color display of density slices of the first three axes of canonically transformed data, resulting in a scene of high definition similar to an ERTS-1 color-composite image. The discriminatory power of canonical analysis has been shown to reveal features for which no spectral signatures have been generated. This capability, coupled with the high degree of machine-operator interaction possible on the Image 100 system, results in a powerful classification tool far exceeding the computer classification map.

The Image 100 system could be enhanced in two ways:

1. A method of determining local spectral uniformity would permit rapid and consistent training area delineations, reducing most of the time-consuming and expensive histogram slicing required with the 1-D classifier.

2. The interpreter should have the option of directly addressing cell areas by line and element coordinates. It should be possible both to input training area corner coordinates via the Tektronix keyboard, as well as to quickly recall the coordinates of previous training areas. Without this capability, results are not readily repeatable. It is too cumbersome to read coordinates off the CRT after visually defining a training area with the joystick. At $250 per hour, any hindrance in the system to rapid data input or access, must be considered a deficiency.

The dedicated computer provides a highly interactive system. Combined with the visual definition of the color CRT, it permits a rapid sequence of interpreter decisions. This advantage deteriorates, however, as processing becomes more complex. Time constraints are imposed by frequent paging to and from storage on the refresh disc, necessary because of the limited storage capacity of the minicomputer. This was a particularly significant deficiency when processing aircraft data. Large alarms resulted in lengthy processing during search procedures of the N-D and cluster analysis programs. During such processing, the system is not available for interaction with the interpreter. It would, therefore, be desirable to run the more sophisticated and complex programs on a large general purpose machine, where the processing time would be only a fraction of that required with the minicomputer. Results could be output directly to the system or to a tape which could be read into the system. Use of a large computer would minimize the bulk processing required of the minicomputer and increase the overall efficiency and capability of the Image 100 system. The interpreter would then have access to the interactive facilities of the Image 100 while bulk processing was being done externally. Charges for the IBM 370/168 used by ORSER are $360 per hour of CPU time; hence, the $250 per external clock hour for the Image 100 system further favors the large machine for bulk processing.

3.2.5 Correction of Banding in MSS Digital Data (F. Y. Borden)*

In the ERTS-1 instrument configuration, six banks of four-channel sensors record data simultaneously. In some cases, tapes were received on which data for some sensors were non-conformable with data from the rest of the sensors. The effect was first recognized as banding with a modulo of six in computer output maps. To investigate the problem, the NMAP program was extended to compute the mean and variance for each channel for each line modulo six. It was then apparent that the problem had to do with calibration or processing of the data by NASA. It was also evident that recalibration was possible, at least approximately, from the data alone.

After the sensors involved were determined from the NMAP program, the SUBSET program was extended to allow input of recalibration parameters for the offending sensor data. The following correction was then applied:

$$\hat{X}_{ijk} = \left[\frac{(X_{ijk} - \bar{X}_{k\ell})}{s_{k\ell}} * s'_{k\ell} \right] + \bar{X}'_{k\ell}$$

where

$\hat{X}_{ijk}$ is the recalibrated value for scan line i, element j, and and channel k;

X_{ijk} is the corresponding original value;

$\bar{X}_{k\ell}$ is the computed mean for channel k and for line ℓ = modulo (j, 6) + 1 taken from NMAP output;

$s_{k\ell}$ is the corresponding standard deviation;

$s'_{k\ell}$ is the recalibration standard deviation computed as the average of unaffected standard deviations for channel k based on NMAP output; and

$\bar{X}'_{k\ell}$ is the corresponding recalibration mean.

It was found that for one or two sensors, for one and sometimes two modulo six lines, the mean and standard deviation, or both, are not conformable with the rest of the data. A non-conforming mean or standard deviation results in banding if the offending channel is used in classification and

*This method is described in ORSER-SSEL Technical Report 22-73.

mapping. On two cloud-free days of the ERTS-1 overpass for Pennsylvania,* the data were of marginal utility because of banding resulting from non-conformable data in the third and fourth MSS channels. These channels are particularly valuable in analyses involving vegetation. Recalibration applied to these data sets resulted in a complete recovery of useful data.

It should be noted that the large-block approach used here does not work well for all banded data; however, recalibration parameters may be computed on a line-by-line basis in cases where the large-block method cannot be used. It should also be mentioned that, although NASA changed the software in its processing facility in April of 1973 to correct the banding problem, "reprocessed" tapes ordered a year later still displayed modulo-six banding.

To further analyze the banding problem, the SUBSET program was extended to output the 56-byte calibration table at the end of each scan line. Comparison of calibration wedges for two unbanded scenes, nine months apart, indicated that the sensors were quite stable over time.** Comparison of one of the unbanded scenes (May 1973) with one of the banded scenes (7 September 1972), however, was a different matter. The calibration wedge for the unbanded sensor was erratic -- a typical wedge for that sensor in the May scene was: 45, 40, 33, 14, 12, and 9, whereas a wedge for the sensor in the September scene was: 27, 10, 24, 19, 51, and 18, and there was no typical wedge.

3.2.6 Transference of ERTS-1 Spectral Signatures in Time and Space (B. F. Merembeck, F. Y. Borden, and D. N. Applegate)***

Following the successful application of the recalibration technique to solve the banding problem, an investigation was launched to determine if recalibration of data for all sensors from one scene to match the calibration of data for all sensors for another similar scene could be used to successfully transfer signatures from one scene to another. Two areas were chosen which were predominantly forested and had similar vegetation compositions. One was near the East Branch Reservoir on the Clarion River in northwestern Pennsylvania and the other was in the Stone Valley Experimental Forest in central Pennsylvania.**** The distance between the two sites is approximately 150 km and the two sets of data were recorded 17 days apart.

Spectral signatures for several vegetation categories were developed for the East Branch data, using supervised and unsupervised classification methods. Application of these signatures directly to unaltered Stone Valley

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*Scenes 1045-15243 (6 September 1972) and 1046-15295 (7 September 1972).

**Scenes 1028-15295 (20 August 1972) and 1297-15245 (16 May 1973).

***This method is described in ORSER-SSEL Technical Report 11-74.

****Scenes 1028-15295 (20 August 1972) and 1045-15243 (6 September 1972), respectively.

data resulted in exceedingly poor classification and mapping. However, when the East Branch site signatures were used on Stone Valley data recalibrated to match the means and variances of the data for the 24 sensors for the East Branch site, classification and mapping were quite successful.

Recalibration for the transference of signatures in time was also investigated. Data for a May overpass of the East Branch site* were recalibrated to agree with the August data for the site. Initially, application of the August signatures to the unrecalibrated May data resulted in complete failure. This was expected, since a spring scene was being mapped with a set of late summer signatures and the nature of the vegetation in the two scenes was very different. It would have been preferable to use a scene closer to the August 20 date, but another set of high quality summer data was not available for the area. Because the mix of channel averages for the May scene differed significantly from that of the August scene, and the largest difference was found in the vegetation of the two scenes, spring foliage from the May scene and summer foliage from the August scene were made equivalent in recalibration.

This resulted in successful classification of all categories in the May scene other than water, even to the point of indicating more coniferous understory along the streambeds, where the deciduous canopy had not yet leafed out. The water signature for the May scene did not classify the same body of water in the May data; however, recalibration forced this signature to be more, not less, different from the reference water signature.

Recalibration, as used here, requires no a priori information about the spectral signatures of the targets of interest. The only requirement is that the general mix of targets be similar for the two scenes. It is evident that recalibration represents an effective tool for the classification of large areas of similar target composition and for temporal comparisons of data sets from the same area.

3.2.7 Radiometric Value Conversion (L. E. Link)**

The effect of converting ERTS-1 MSS data to radiance values on the results of computer classification of those data were investigated using mean signatures for land-use categories from a scene in central Pennsylvania.*** Based on this preliminary work, the following conclusions were reached:

1. Conversion of ERTS-1 MSS signatures to radiance values was shown to be a potentially distinct advantage for classification and mapping of land use categories. Radiance values provided an average increase in angular separation of 2.1 degrees (approximately 11.3%) between the vectors representing the various land-use

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*Scene 1297-15245 (16 May 1973).

**This work is described in detail in ORSER-SSEL Technical Report 6-74 and 14-74.

***Scene 1009-15241 (1 August 1972) covering the area of Harrisburg, Pennsylvania categories, thus aiding in discrimination between these categories.

2. Conversion of ERTS-1 MSS signatures to radiance values may, in some cases, permit a particular feature previously defined by several signatures to be represented by a single signature, although this is heavily dependent on the true signature variability within the boundaries of the category definition. If the necessity for numerous signatures was created by bias, introduced by atmospheric or sensor-related phenomena, the use of radiance values may well be beneficial.

It should be noted that the true utility of the radiance conversion can only be assessed qualitatively, by applying the conversion to the signatures for each individual resolution element, executing the classification and mapping routines with these data, and then comparing the results to those obtained using the unmodified signatures.

Prominent temporal effects influencing the information content of remotely-sensed data were also investigated. Atmospheric haze, the variation in material reflectance characteristics, and effects associated with solar zenith angle were identified as the primary sources of temporal variations.

3.2.8 Statistical Examination of MSS Digital Data (R. G. Craig, R. R. Parizek, and J. C. Griffiths)*

ERTS-1 MSS digital data have been examined within a multivariate statistical framework. A subset of data** was chosen using geographical, logistical, informational, and statistical operational constraints, and sample pixels were selected by a random number generator. The objective was to obtain the maximum amount of information subject to the constraints of minimum dependence within the sample while ensuring that the sample is representative of the original data.

Each set of scan lines sampled was considered as a time series. Power spectrum analysis showed a cutoff in significant frequencies after about the 30th (of 256), thus indicating a minimum sample interval of 8 or 9 to specify the significant variation in the data. Bivariate spectra (coherence) gave similar results. The shape of the spectrum was remarkably similar in all series examined. This, however, did not suggest a parsimonious model for filtering.

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*This work will be described fully in the M.S. thesis by R. G. Craig, to be completed in 1976. Dr. Griffiths is Professor of Petrography at the University.

**Data from seven ERTS-1 scenes were used: 1389-15351 (16 August 1973), 1407-15350 (3 September 1973), 1425-15343 (21 September 1973), 1443-15340 (9 October 1973), 1461-15334 (27 October 1973), 1479-15333 (14 November 1973), and 1497-15332 (2 December 1973).

Analysis of these same series using the techniques of Box and Jenkins* again showed that all of the series could be represented by a single model, an ARMA (1, 1) with $\phi \simeq 0.67$ and $\theta \simeq -0.36$. This implies that the sensor data can be thought of as a near random walk embedded in an independent source of variation. The similarity to an IMA (1, 1) was used to determine a sample interval, and a value of about 10 was indicated. The Box-Jenkins model was then used as a filter to obtain quasi-white noise.

A further line of evidence concerning the sample interval was obtained by computing the Markov transition matrices for 1-step through 19-step transitions. The transition probabilities asymptotically approached equilibrium and appeared to be within five per cent of the equilibrium value at Step 10.

More traditional statistical analyses were also performed. The distributions (tested against a normal) showed significant (usually positive) skewness and were strongly leptokurtic. Using the chi-square test, the null hypothesis (normality) was rejected at the five per cent level in every case.

The information content of each scan line was calculated using the information transformation of Shannon.** The mean information content was 3.59 bits per symbol, suggesting that about twelve "levels" are present in the data. The standard deviation was 0.80.

Regression of the mean gray scale level versus the variance for the 196 scan lines showed that there is no significant linear relation within a single image. Comparison across all images, however, showed a significant linear relation. Each scan line was also analyzed by linear regression, and a significant linear trend was shown to be present. This could be of importance in estimating the spectrum.

After the images were digitally filtered, principal components analysis was performed across channels alone and across channels and days. Finally, a multiple regression trend surface of the major principal components was obtained and compared to the pattern of glacial drift in northwestern Pennsylvania. It appears that the patterns have approximately five per cent variance in common.

3.2.9 Digital Analysis of Lineament Patterns (M. H. Podwysocki and P. D. Lowman, Jr.)***

Three programs have been written in FORTRAN IV with the purpose of processing and summarizing the large number of primary observations of lineament and fracture trace orientation, length, and position, while varying

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*Box, G. E. P. and G. M. Jenkins (1971) Time Series Analysis Forecasting and Control, Holden-Day Company, San Francisco.

**Shannon, C. E. (1948) A Mathematical Theory of Communication. Bell System Technical Journal 27:379-423, 623-656.

***This work is described in detail in GSFC Document X-644-74-3. (Lowman is from Goddard Space Flight Center.)

the classification parameters in order that further statistical or structural analysis techniques might be applied.

The TRANSFORM program performs the initial data treatment, converting the fracture traces on the base map into a format acceptable for the AZMAP program. A cartesian coordinate system is established so that the beginning and end of each fracture may be indexed. Digitizing equipment, which automatically records coordinates either on computer cards or magnetic tape, is used to reduce the fracture map to a form usable by the program. The program treats each fracture as a vector in map space and generates parameters used in the classification techniques of the AZMAP program.

The AZMAP program uses data generated by the TRANSFORM program. In a mechanical sense, the program places an orthogonal grid over the map parallel to the designated X and Y map axes. The operator selects the area size (cell) over which the fractures will be summarized by specifying the X- and Y-axis grid cell size. The computer then scans all the fractures, determining whether each fracture falls within the grid cell, incrementing the cell by operator-supplied values in both the X and Y directions, until the total designated area has been covered. By incrementing at submultiples of the cell size, a sliding average technique may be employed.

Either of two summary techniques may be used. Subroutine MID counts the whole fracture as falling within the cell if its midpoint falls within that cell, while subroutine PART considers only that portion of its length which lies within the cell. The choice of either subroutine depends upon the grid cell size, the size of the linear features mapped, and the goals of the experiment. The operator also selects the number of azimuth classes into which the data will be summarized. Up to 90 classes may be specified, their values being incremented from 270 through 0 to 90 degrees. Thus, if a fracture trace lies within a specific cell, it is then added to the appropriate azimuth class within that cell, according to the subroutine selected, and a histogram is plotted. A chi square (X^2) test is performed on the resultant frequency-azimuth histogram for each grid cell, if desired, testing the distribution for randomness (i.e., a rectangular distribution, where all classes have an equal chance of occurring). Data are summarized both as density (total length of fractures within each cell) and frequency (number of fractures within a cell).

Using standard CalComp subroutines and hardware to produce rose diagrams from data generated on punched cards or magnetic tape in AZMAP, the ROSE program facilitates the presentation of the fracture data in a form suitable for qualitative interpretation of the spatial relationships between areas for tectonic analysis. The program produces rose diagrams suitable for map overlays for any number of map grid cells, plotting the rose at the midpoint of the cell along with the sum total of the values comprising the rose. Scaling factors are included within the program.

3.2.10 Skylab Photography as Ground Truth for ERTS-1 Digital Data Analysis (G. J. McMurtry and W. A. Chren)*

Digital MSS data from ERTS-1 were classified by supervised and unsupervised techniques, and the results verified with Skylab photography. An area along the Allegheny River just west of Oil City, Pennsylvania, was chosen because large visually uniform targets were present and unbanded cloud-free ERTS-1 data** were available. Skylab photography*** was initially used as ground truth because aircraft photography was not available; however, it was discovered that for the level of classification desired Skylab photography was a more efficient form of ground truth data--large areas were covered in a single photograph in sufficient detail for verification of the relatively broad categories desired.

Five land use classes were designated for the area: water, city (urban and suburban), agriculture, forest, and abused land (strip mines, construction sites, etc.). Each class was made broad enough to include the various conceivable subclasses. Hence, large critical distance values were used in the classification algorithms and several different training areas were used in defining each class. In some cases, it was necessary to establish separate training areas for the sub-classes, and then assign the resultant signatures to the same category symbol. For instance, deciduous, coniferous, and shaded trees were classified separately, but all were assigned the symbol for forest.

The classes were sufficiently large that the intensity map in conjunction with the Skylab photograph were sufficient to determine training areas--bypassing the usual intermediate step of a uniformity map. The Skylab photograph gave visual assurance of training area homogeneity.

USGS topographic maps were of assistance in differentiating some areas of confusion during the classification. For instance, a large number of city signatures were initially misclassified as abused land, because of the similarity between urban areas such as streets, oil bins, and railroad tracks, and areas of strip mining and construction. The details of such areas obtained from the topographic maps assisted in identification and proper classification of these features.

The classification performed here was relatively rapid and inexpensive, employing a minimum number of training areas to achieve an acceptable classification accuracy. Therefore, as a result of the wide range of diversity within the broad categories of city, disturbed land, and agriculture, the percentage of accurate classification was relatively poor (77%, 70%, and 78%, respectively). Better results could have been

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*This work is described in more detail in the M.S. thesis by W. A. Chren.

**Scene 1028-15295 (20 August 1972).

***Skylab 3, Orbit 30, S190B, Roll 85, Frame 342 (10 September 1973).

achieved with a significantly higher expenditure of time and funds. However, the forest category, with one training area for each of three relatively uniform classes, was classified with a high degree of accuracy (93%), and water, with only one training area, was next in accuracy (86%).

In conclusion, Skylab S190B photography was a very effective source of ground truth data on this project. Its resolution is ideal for use with ERTS digital data, since it is more detailed than the ERTS-1 data, but not as detailed as aircraft photography--the very high resolution of the aircraft photography can introduce needless confusion in the analysis of the much lower resolution ERTS data. The large areal coverage and excellent resolution of the Skylab photography permits very rapid comparison and verification of classifications from ERTS-1 data. Topographic maps are always helpful as ground truth; however, they are often out of date and, like aircraft photography, they frequently contain an over-abundance of detail. Thus, the Skylab S190B should be considered not only as a primary data source, but as an excellent source of ground truth for ERTS-1 digital data processing.

3.2.11 Printing and Reduction of Computer Maps (A. D. Wilson and R. E. Ackley)*

Computer-generated maps from ERTS-1 digital data have a nominal scale of 1:24,000, which is suitable for analysis or planning purposes. However, this scale is far too large for presentation or publication. A practical method was developed for photographic reduction of a 2.2 by 2.2 m computer map generated by the high-speed printer.

Symbols are carefully selected to obtain a gray-scale effect and the ink intensity is strictly controlled while printing out a map of a 23,000 km^2 area. The several resulting sheets of output are assembled and a 20 by 20 cm glossy photograph is taken. The result is a small-scale gray-tone map, obtained without costly overprinting and on which the mapping symbols can still be identified. The resolution of the original ERTS-1 data is retained while areas of regional importance are represented in a size convenient for publication. The techniques used are available in any well-equipped photographic studio.

3.3 Imagery Processing

ERTS-1 images and aircraft and Skylab photography have been processed in a variety of ways to assist in direct interpretation and in use of the data as "ground truth" for digital analysis. Several methods developed under the ERTS-1 contract are described here.

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*This technique is described in detail on ORSER-SSEL Technical Report 3-74. Mr. Ackley is associated with the Still Photography Services on the University Campus.

3.3.1 Diazo Printing (W. S. Kowalik)*

ERTS-1 color composites equivalent to those supplied from NASA have been made with the help of a Diazo developer (Model 202) and printer (Model 101). These two units, equally useful for making color composites and black line copies of ERTS, Skylab, and aircraft transparencies, have been a significant element in streamlining research efforts and data cataloging operations.

Early in the ERTS-1 project, an attempt was made to make ERTS-1 color composites using the Ozalid capabilities available in the College of Engineering at the University. Some success was achieved, but it was not possible to reproduce results from one day to the next. The large amounts of time and materials necessary to produce a usable color composite eventually discouraged these attempts. The problem here was twofold: 1) the variation in density of ERTS-1 transparencies from one scene to the next, making each scene essentially an entirely new "experiment" and 2) the variation in results due to the sensitivity of the large Ozalid machine to heat and humidity--a composite made on a dry hot day would be entirely different from one made from the same set of transparencies on a cool wet day, even with use of identical materials and exposure times. These problems were solved by the purchase of the desk-top Diazo developer and printer.

Color composites were made from two different types of .003 clear colored polyester sheets: Escochrome, from Diazo Specialty Company (Beltsville, MD) and GAF, from GAF Corporation (New York). The following colors were most successful in duplicating the color composite quality of the NASA product:

ERTS-1 Transparency	Escochrome Film	GAF Film
Channel 7	Cyan	Blue
Channel 5	Magenta	Red
Channel 4	Yellow	Yellow

The GAF film produces more brilliant colors, closer to those of the NASA product. However, the Escochrome film lies flatter after development and, hence, is more easily handled in constructing composites.

Five ERTS-1 single channel density standards were established in order to determine exposure time:

Standard 1 (lightest)	1046-15301-7
Standard 2	1080-15183-7
Standard 3	1079-15131-7
Standard 4	1046-15301-5
Standard 5 (darkest)	1080-15183-5

*This technique is described in ORSER-SSEL Technical Report 11-75.

A graph for the standards was developed from which the exposure time for any transparency can be estimated. To use the graph, the transparency to be copied is compared with the standards and a visual estimate is made of its density with respect to one of the standards. Then the exposure time, which may be from 3 to 30 minutes, is estimated from the position of that standard on the graph. Using this method, a color composite can be made by a technician in less than an hour--often while other work is being performed during the waiting periods.

This method is not limited to the production of standard color composites of three channels in the colors indicated. The method lends itself to various possibilities of color enhancement for specific features. Single channel images of the same ERTS-1 scene from two dates, for example, have been composited for analysis of gypsy moth damage in Pennsylvania,* and such temporal composites would undoubtedly also be useful to study features such as crop pattern changes, urban growth, and flood damage.

Another highly useful aspect of the Diazo equipment is the rapid production of black line paper images from transparencies of any kind. Such copies are extensively used in the ORSER cataloging system, in that a Diazo copy of the Channel 7 image of each scene is kept in a loose-leaf notebook for ready reference. In this way, a "first look" capability is provided of the scenes available for analysis, and such factors as cloud cover, and snow cover can be immediately determined. In addition, black line reproductions of ERTS-1, Skylab, and aircraft scenes have been supplied within a few minutes, to use for reference during a project. For instance, these images of Channel 7 ERTS-1 scenes are routinely used to outline a study area before computer analysis of the digital data, and several mosaics of such scenes have been used in Pennsylvania lineament studies.**

3.3.2 Mosaics, Enlargements, and Overlays

Mosaics of ERTS-1 transparencies in Channel 7, reproduced as Diazo black-line paper prints, have become standard reference material in ORSER. Utilizing the most recent cloud-free scenes available at the time, these mosaics have been used to plot lineament distributions, for displays, for reference to determine appropriate areas of study, and for a multitude of related purposes by individual investigators.

Mosaics have also been made from contact and enlarged photographic prints of ERTS-1 scenes. These have been used most frequently in geological investigations, where both mosaicked and individual enlargements have been used for lineament and terrane analyses. Negative print enlargements of ERTS-1 images have been used to enhance features such as water bodies,

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*See the discussion of gypsy moth damage studies in this report and in ORSER-SSEL Technical Report 22-74.

**See the discussions of mosaics and of lineament analyses in this report and in ORSER-SSEL Technical Reports 1-74, 10-74, 5-75, 12-75, 13-75, and 14-75.

strip mines, and urban areas. It has been found that overlaying a positive transparency of one channel and a negative of another (principally combinations of Channels 5 and 7) serves to further enhance these features. This technique was used with moderate success in a land-use study (see Section 4.1).

Enlargements of aircraft photography have also been made. Many of these have been used for comparisons with computer output from ERTS-1 and aircraft data. Others have been used in connection with aircraft-oriented projects. Recently, Skylab photography has also been used for comparison with ERTS-1 images and computer classification maps, for comparisons of lineaments with those plotted on ERTS-1 scenes, and in independent projects.

Most imagery/photography comparisons with computer output are made with the aid of the Bausch and Lomb Zoom Transferscope. In some cases, it is necessary to enlarge an image or reduce the size of the computer output to stay within the magnification limits of this instrument. However, in most cases, a direct "optical overlay" is possible with use of the transferscope, thus avoiding the necessity of making difficult and costly reproductions to scale. The stretch factor in this instrument greatly facilitates comparison of an aircraft photograph with a distorted longitudinally-stretched computer printer output map.

In some cases, the Saltzman projector, available in the Geology Department, has been used to project enlarged ERTS-1 images onto a table, where features of interest could be delineated and the result later used as overlays for aircraft photographs or scaled computer output. Projection of 35 mm slides has been used in a similar fashion. In the development of the hybrid approach, 70 mm U2 transparencies were projected directly onto computer output to assist in selection of training areas.

A Nikon camera with a full set of attachments and lenses is used with a large camera stand and the Richards high-intensity light table to make 35 mm slides of any transparent image or photograph. A macroscopic lens and Ektachrome ASA 64 film are usually used for this purpose. A reflected light system is used to take photographs of prints and other illustrative materials, such as graphs and computer output.

3.3.3 Reconnaissance Mapping (H. A. Weeden and N. B. Bolling)*

A method of reconnaissance mapping from aerial photographs has been developed. Although directed primarily toward the engineer, this method is readily adaptable and useful for a variety of investigative efforts, and has been used with both ERTS-1 and Skylab scenes, as well as with aircraft photography.

Attempts to use this method with ERTS-1 imagery were not entirely satisfactory, due to the small scale and poor resolution of the images. It was found that, although a variety of features were easily seen on the images, it was not possible, even on enlargements, to trace or outline

*This method is described in detail in ORSER-SSEL Technical Report 17-75.

significant units with acceptable precision. However, an orientation toward broader mapping units, and definition of such units adapted to the scale of ERTS-1 images, would more likely yield positive results. With some redefinition of parameters, mapping of Skylab scenes offers a great deal of promise.*

The method of analysis involves the following steps:

1) review of the literature and other sources of information on the area;

2) definition of objectives;

3) selection of parameters;

4) choice of map symbols;

5) detailed and careful stereoscopic study of pairs of overlapping photographs with available means of magnification; and

6) constant awareness that photointerpretation is always to some extent a subjective process, in that data from several sources and of varying importance (tone-texture-color on the photographs, information from other data sources, the interpreter's knowledge of the area and experience with similar areas, etc.) are evaluated in the interpretive process.

The result is a photograph overlay with areas outlined and identified by a five-part symbol denoting: (1) landform, (2) soil type, (3) slope, (4) position of water table, and (5) depth of soil cover.

3.3.4 Zoom Transferscope

The Bausch and Lomb Zoom Transferscope offers an opportunity to optically overlay computer-generated thematic map output and satellite images. Computer map output has a distorted scale, resulting from the difference in line and element spacing of the printer. This distortion can be overcome by the stretch capability of the transferscope, making it an ideal instrument for image output comparisons. However, the approximate scale of the computer output is 1:24,000, whereas the scale of an ERTS-1 image is approximately 1:1,000,000. This disparity exceeds the scale-matching limit of the transferscope. An intermediate scale, therefore, has been approached from two directions.

Black and white 2X enlargements of ERTS-1 images are made, resulting in a scale of approximately 1:500,000. Strips of computer output are then reduced, by Xeroxing, to one quarter of their original scale, or approximately 1:96,000. The disparity in scale of the two forms of data is then well within the capability of the transferscope and computer output can readily be matched to the ERTS-1 image. The distortion still inherent in the reduced computer map is easily overcome by the stretch capability of the transferscope.

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*See ORSER-SSEL Technical Report 16-75.

CHAPTER 4

ERTS-1 CONTRACT RESEARCH: INVENTORY OF NATURAL RESOURCES AND LAND USE

Significant results have been attained in mapping land use, agricultural croplands, forest resources, and vegetative cover. In most cases, the final product is a computer-generated thematic map. The classification categories selected for such a map depend upon the geography of the area, the purpose of the project, and the detail required. Relatively few categories may suffice for large areas, such as major river basins and watersheds. For smaller heterogeneous areas, however, classification requires more detail and considerable ground truth and aircraft data for support and verification of categories.

4.1 Land Use Mapping of a Heterogeneous Area (H. A. Weeden, F. Y. Borden, D. N. Applegate, and N. B. Bolling)*

The Harrisburg area of Pennsylvania was a natural choice for initiating a land use study; there are a variety of land use types in the vicinity and excellent ERTS-1, U2, and other ground truth coverage were available early in the project.

Data from an October ERTS-1 scene** were subset onto working tapes and the NMAP and UMAP programs were run for selection of the first set of training areas. From the two resulting maps, the most easily recognized targets from spectrally homogeneous areas with widely separated geographic locations were chosen. (The Susquehanna River is an excellent example of such a target--see Figure 4.1.) These targets were then positively identified by projecting a U2 photograph of the area (Figure 4.2) onto the NMAP output. Scale distortions of this printer-generated map, however, prevented proper registration of the photograph over areas of the output larger than 25 cm^2 (corresponding to a ground area of approximately 1.0 km^2). Therefore, a distribution of positively identified targets throughout the study area was required in order that adjacent portions of the scene could be sequentially brought into proper registration. (Later development of programs for scaling and correction of distortion has eliminated this difficulty in data comparison.)

As thematic maps were produced, using the STATS and DCLASS programs, they were refined and new training areas were chosen by comparison with the U2 photograph. These maps were produced in separate categories (such as all vegetation) for ease of checking. The number and variety of targets

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*This study is fully described in ORSER-SSEL Technical Report 14-73. The hybrid approach, which was an outgrowth of this study, is described in ORSER-SSEL Technical Report 13-73.

**Scene 1080-15185 (11 October 1972).

Figure 4.1: Enlargment of a portion of the Channel 7 ERTS-1 image of the Harrisburg area. (Image 1080-15185, 11 October 1972. 1 cm equals approximately 3.6 km.)

Figure 4.2: Black and white enlargement of a portion of the U2 color IR photograph of the Harrisburg area. (Flight 72-124, Sensor 14, Frame 34619. 1 cm equals approximately 0.71 km.)

was thus expanded with respect to both type and extent of geographic separation. This cyclic operation was repeated until all uniform areas of sufficient size to define training areas for the STATS program were identified. The DCLUS program was then applied to find signatures for areas of small size and spectral inhomogeneity. Most of the training areas chosen for this program were first selected by the photointerpreters from the U2 photograph, after which line and element coordinates were determined from the computer output. (The industrial and suburban categories, for example, were developed in this way--Figure 4.3.)

The U2 photograph was again used to verify the DCLUS output. The resulting classification was generally excellent; however, two areas of difficulty were evident. One of the areas mapped as suburban was seen on the U2 photograph as also including a considerable number of agricultural fields. Apparently the mixed character of a suburban area, consisting of roofs, lawns, shrubs, and streets, resembles a mixture of small or long and narrow fields. One can see on Table 4.1, for instance, that the signature for this category, suburb confusion (Number 2) and that for field (Number 3) do not have a wide separation, whereas the separability of Category 1 (river) from the other categories is quite large, implying no problem in classifying this category correctly. A similar problem was encountered with Categories 4 and 5, which occurred consistently as a mixture in the output.

Table 4.1: Distances of Separation for Several Categories Used in Mapping the Harrisburg Area

Name	Number	1	2	3	4	5
River	1	0.0	31.8	31.5	14.2	31.4
Suburb confusion	2	31.8	0.0	1.1	18.3	14.2
Field	3	31.5	1.1	0.0	18.0	13.8
Industry 1	4	14.2	18.3	18.0	0.0	17.7
Industry 2	5	31.4	14.2	13.8	17.7	0.0

Although these two categories were relatively widely separated, and thus retained as separate entities, they were assigned the same symbol, in order to obtain a uniformly mapped area on the output.

The thematic map at this stage was too refined and confusing to the reader. Therefore, some categories were combined, as was done for the industrial areas, and stray symbols were suppressed, using the CLEAN program option. A careful review of map objectives served as a guide to the final number of categories to be mapped. Figure 4.3 is the final map, output on the CalComp plotter to eliminate the distortion inherent in a character map from the 1403 printer. The output also included a table expressing the percentage of the area mapped for each category.

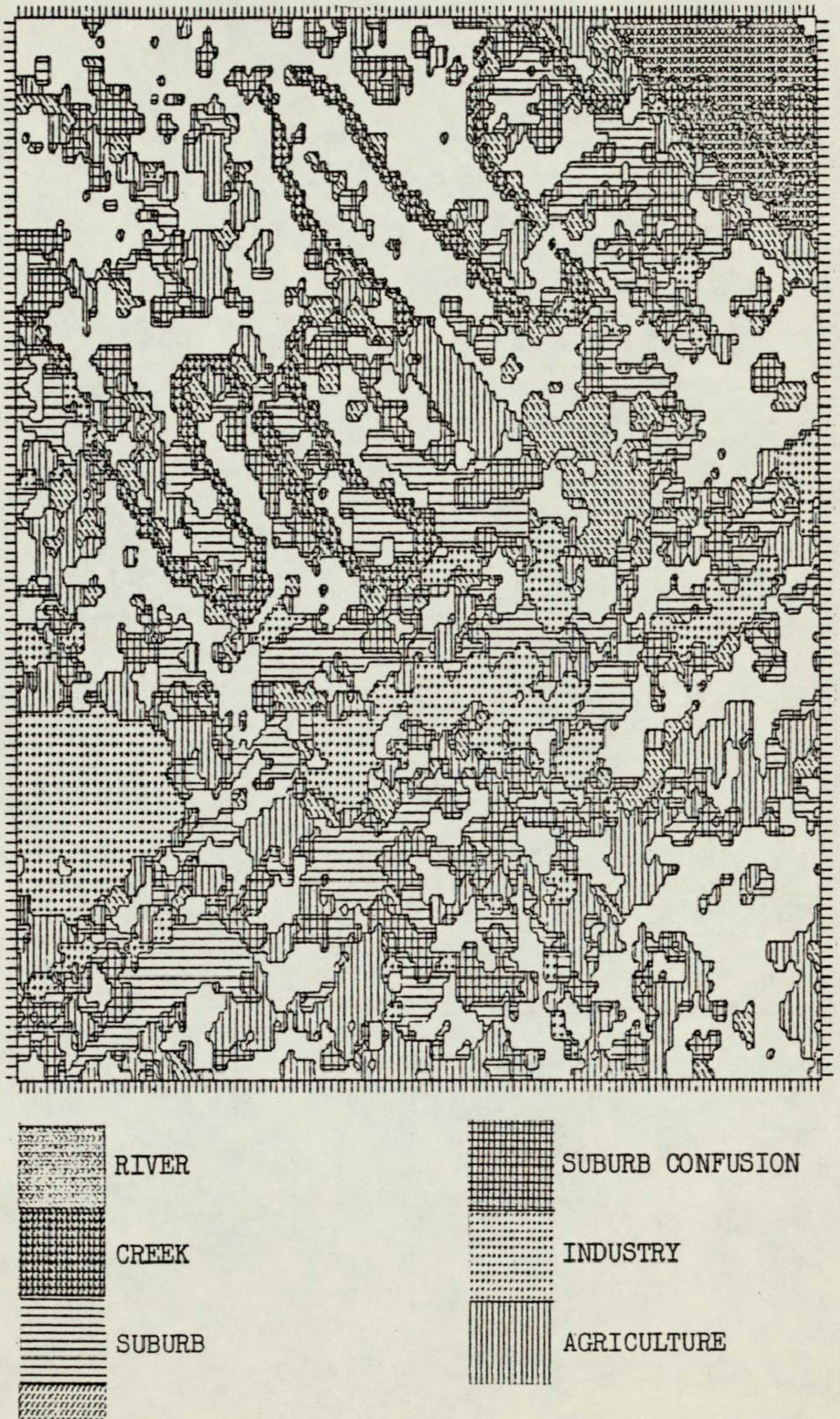

Figure 4.3: Classification map of all categories in the Harrisburg area. (Plotted on the CalComp plotter, using the LMAP program. 1 cm = approximately 0.56 km.)

4.2 Agricultural Land Use Mapping

Land use mapping of Pennsylvania agricultural areas was studied with data from two physiographic provinces. The first study was in Lancaster County, in the Piedmont Province, and the second was in Cumberland County, in the Ridge and Valley Province. In the second study, an investigation was made of three methods of analysis: photointerpretation of imagery in various formats, digital analysis, and interactive analysis using the G.E. Image 100 system.

4.2.1 Lancaster County (G. W. Petersen and A. D. Wilson)*

An area was selected for analysis within Lancaster County, in southeastern Pennsylvania, where the field size is generally small (1.5 to 4 ha), with livestock and major crops of corn, hay, small grains, and tobacco. The soils are residual, derived largely from limestone, shales, and sandstones, and the climate is humid. The topography is characterized by broad valleys separated by ridges of sandstone and shale, and the area is bisected by many small streams. The native vegetation is of mixed oaks, or oaks and hickory.

The test site had been covered by low altitude photography (1500 to 4500 m) on a seasonal basis, and by high altitude photography (19,000 m) on a periodic basis. In addition to ground truth data from these flights (predominantly by C130 and U2 aircraft), maps and county reports were consulted for topographic, geologic, and soil information, and field data were collected on visits to the area in conjunction with the ERTS-1 overpass.

As this was the first site selected for a study of agricultural land use using ERTS-1 data, an October scene** (the first clear one available of the area) was selected for study, although fall does not present optimum conditions for the study of agricultural land use. Initially, the Channel 7 positive transparency was overlaid on a map at the scale of 1:1,000,000 to locate the town and highway networks, and possible target areas were selected for computer analysis. After the data for the study area were subset, brightness and uniformity maps were output and training areas were selected for analysis by the STATS program. The results of using these STATS signatures with the DCLASS program, however, were inconclusive.

The unsupervised classifier, DCLUS, was then employed. Five widely separated categories were delineated by this method. The first two were related to forested sandstone ridges, which agreed very closely with vegetated areas indicated on the USGS topographic maps. The third category corresponded closely to bodies of water, such as swamps, farm ponds, and streams. The last two categories occurred in cultivated areas. One

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*This study is described in ORSER-SSEL Technical Reports 25-73 and 23-74.

**Scene 1080-15185 (11 October 197).

of these categories had a high response in Channels 5 and 6, and was tentatively identified as bare soil. Areas which did not fall into any of these categories were not mapped.

The DCLUS program was then used to subclassify some of the five categories and to establish signatures for some areas which had not yet been mapped. By this method, the water signature was further subdivided into four categories: clean water , two categories of dirty water, and vegetated water. Although a number of additional categories were established within the forested and cultivated areas, they presented a pattern too complex for clear identification from the ground truth available at the time. Individual fields could not be mapped, partially because of the wide variety of agricultural practices, including contour plowing. Aircraft data were an invaluable aid in analysis of the DCLUS output. The true complexity of the land use patterns of Lancaster County became evident from these photographs, and the problems of mapping these patterns from ERTS-1 data were clarified.

It appeared from this study that the use of ERTS-1 digital data for automatic mapping of broad land use categories was feasible. Forest land, cultivated land, and water were classified within 10,000 ha of very complex land-use patterns.

4.2.2 Cumberland County (G. W. Petersen and A. D. Wilson)*

The complicated nature of agricultural patterns in Pennsylvania requires detailed analysis of selected areas within an ERTS-1 scene. To investigate three ways of conducting such an analysis, ERTS-1 data were selected for an area of approximately 1225 km^2 in the vicinity of the town of Shamokin.** Ground truth available for this area included:

1) USGS 7-1/2 minute topographic maps;

2) an October 1969 ASCS 1:63,000 photomosaic;

3) ASCS 1969 aerial photographic prints at a scale of 1:12,000;

4) C130 aerial photographs at scales from 1:6000 to 1:120,000, flown in December of 1973 and February and April of 1974, as color positive, color IR, and black and white multispectral transparencies; and

5) U2 aerial photographs at scales from 1:130,000 to 1:450,000, flown in February of 1974, as color, color IR, and black and white multispectral transparencies.

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*This study is described in ORSER-SSEL Technical Report 20-74.

**Scene 1350-15190 (8 July 1973).

In an effort to delineate land use classes, various photographic products were made from the ERTS-1 images. These included enlargements to scales ranging from 1:500,000 to 1:140,000, using 70 mm negatives from the four bands of the ERTS-1 scene. Although one could delineate small streams, rivers, strip mines, forested ridges, and agricultural areas on these enlargements, it was not possible to discern individual agricultural fields. A positive-negative approach was then attempted, superimposing a negative transparency from Channel 5 on a positive transparency from Channel 6. This combination was enlarged to 1:140,000. However, delineations within agricultural areas were still not possible.

In areas such as this, where much greater resolution is required, it is necessary, therefore, to use digital tape data. In this case, 500 scan lines were selected with 690 elements in each line, for a total of 345,000 pixels. The width of a scan line is approximately 79.1 m and the width of each element is 57.3 m, hence, each pixel is approximately 0.45 ha in size. Using an unsupervised classification procedure, the following categories were delineated: (1) forest land with northern aspect, (2) forest land with southern aspect, (3) valley trees, (4) wheat, (5) corn, (6) alfalfa/grass/pasture, (7) disturbed land, (8) built-up areas, (9) strip mines, and (10) water. These responses were used to produce a digital map at a scale of approximately 1:20,000. In general, the classification was accurate, although some misclassification did occur and there were a few instances where signatures were derived but it was not possible to determine the category into which the signature should be placed. These problems were a result of the complex nature of land use in Pennsylvania, where several types may occur within a given pixel. Another difficulty encountered was that the response from a similar target can vary within a scene. Such differences could be due to physiological variations, such as different stages in maturity of vegetation. Even with due consideration of these problems, however, digital processing is still necessary in an area such as Pennsylvania. This is the only system that has a great enough resolution to delineate fields. The speed of the analysis and the ability to obtain summaries of the areal coverage of the various categories are also decided advantages of this approach.

Land use delineations were also made using the G.E. Image 100 interactive analysis system. Although the thematic maps produced on this system generally agreed with the categories delineated on the line printer output from the digital analysis, a few categories were misclassified. For example, too much of the area was classified into grasses and alfalfa. This was probably a result of the signature extraction technique, where the categories are determined by looking at a small number of representative pixels, rather than a large number, as is done with the ORSER system. Hence, the statistical validity of the signature may be in question.

The effectiveness of any of these analysis systems would have been greatly enhanced by the use of temporal data. Subsequent studies have worked with data from two or more scenes merged onto a single data file. Thus, for a given pixel there may be 8, 12, 16 . . . channels of data, rather than the four channels of a single scene. Spatial corrections and alignment of the pixels is necessary, but, once this is accomplished, considerably more information is available to the user.

4.3 Mapping Forest Resources

Three studies have specifically involved the mapping of forest resources in Pennsylvania. Although each study had a somewhat different emphasis, in all three instances classification of sun vs. shade (and/or hill aspects) and conifers vs. hardwoods was highly successful. In the latter case, the most difficult differentiation was shaded hardwoods vs. conifers. Aircraft photography was used throughout as ground truth data; in the case of the Penn State Experimental Forest, an actual ground survey was also conducted.

4.3.1 Allegheny National Forest (B. F. Merembeck and F. Y. Borden)*

In an effort to map open forest areas, two sites in northwestern Pennsylvania were investigated. The first was in the vicinity of the southern branch of the Allegheny Reservoir (the "Kinzua" area) in Warren County, and the second was in the vicinity of the reservoir on the East Branch of the Clarion River (the "East Branch" area) in Elk County. Both areas are heavily forested, with open patches of low vegetation throughout. Location within both sites on the ERTS-1 image** was facilitated by the presence of reservoirs and streams. The large number of clouds over the scene, however, caused considerable trouble throughout the investigation.

Supervised, unsupervised, and partially supervised approaches were attempted in this investigation. The partially supervised approach proved to be by far the most fruitful, and is recommended for study of scenes in which there are many shadows and numerous targets with varied characteristics. U2 flight 72-094 photography, flown 7 June 1972, was used for verification of targets.

In preparation for supervised analysis of the Kinzua area, an initial run of the NMAP program revealed an immediate problem with clouds and cloud shadows. In spite of numerous adjustments of parameters, only the reservoir could be mapped. Comparison with the U2 photography revealed that not a single open area had been mapped. The terrain is hilly and the 9:30 AM sun angle created a very complicated light and shadow pattern. The further complicating pattern of numerous clouds and cloud shadows made interpretation of the NMAP output virtually impossible. A UMAP output revealed further that an area of road and vegetation patterns, which could be seen on the U2 photographs and would have given a number of excellent training targets, was under clouds. These difficulties led to the choice of the East Branch site for further study.

The initial work with the Kinzua area had given some indication of the parameters to use for an NMAP run of the East Branch area. However, even with further "fine tuning" of the parameters, only gross features and a very few open areas were mapped on the NMAP output. The UMAP

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*This work is discussed in greater detail in ORSER-SSEL Technical Report 21-73.

**Scene 1028-15295 (20 August 1972). This was the best quality scene of the area for which imagery and tape data were available at the time.

program run on data from this site mapped very few uniform areas, except water. In spite of these poor results, however, the UMAP and NMAP outputs were superimposed on a light table and small areas, averaging 10 to 20 map elements, which appeared to have the greatest likelihood of being open vegetative sites, were outlined and submitted as training sites to the STATS program.

Output from the STATS program and the first DCLASS map revealed that none of the areas mapped corresponded with an open area shown on the U2 photograph. However, eight of the training areas had reasonably non-dispersed histograms, indicating that each was a signature for a valid, but unknown, feature. Comparison with the U2 photograph indicated that the signatures were related to large targets, such as sections of forest, creekside vegetation, and the reservoir. Further inspection of the forest signatures in the Channel 6 data revealed that their values were in ascending order, left to right on the map, and then repeated themselves. It was apparent that the signatures progressed from the creek, up the northwest aspect of a hill, over the hill, and down the southeast aspect to another creek or valley. The U2 photograph showed a similar pattern; however, sun angle differences between the two scenes prevented detailed comparison.

The successful mapping of hill aspect and creeks at this stage made it possible to precisely locate open areas within the test site. It was apparent that the supervised mapping procedure was not suitable for areas of this small size; hence, the unsupervised method involving the DCLUS program was the next step. An initial run of the DCLUS program on data from a relatively large area yielded three forest signatures very similar to those obtained from the STATS program. However, considerable confusion was still evident among the smaller targets.

Frequently, in using the DCLUS program for small targets, a signature in a fairly small block may not be classified, regardless of the critical distance used. In this case, there are three procedural options:

1. Increase the number of sample points and leave the size of the block the same. In this case, the number of mapping symbols and categories must also be increased.

2. Decrease the size of the block and keep the number of categories and symbols as they were. This seems to be a better alternative. However, to use very small blocks, the location on the map must be precisely known—often the choice of a relatively large preliminary block (four to five times the size of the intended target area) will serve to locate the smaller target block. An additional advantage in decreasing the size of the target block is the reduction in computer time used in multiple runs to determine the proper critical distance.

3. Decrease the size of the block and increase the number of mapping symbols and categories.

Option 2 was chosen, which was, in essence, "partial supervision" of the DCLUS program in that very small areas known to be open areas of vegetation were selected for analysis.

A distinct advantage of using the DCLUS program is that, in addition to obtaining a signature, the optimum critical distance can be estimated by watching the change in symbol clustering with changes in critical distance from run to run. This feature has proven quite valuable in mapping small areas. If the critical distance is set too small, the whole target, except for one or two points, may suddenly disappear into the forest categories. This is probably due to the relatively large effect of borders on small targets, causing the elements near the border with adjacent areas to disappear when the critical distance is too small. If the critical distance is too large, the symbols are scattered all over the map on both large and small targets.

Having determined a working methodology for obtaining signatures from the DCLUS program for the study area, additional signatures were defined. The final result was a set of 25 signatures defining 10 categories: three hill aspects, clouds, cloud shadows, open areas, areas of thin vegetation, hemlock, creeks, and water. Most features over 10 ha in area were mapped.

Having developed signatures for clouds and cloud shadows at the East Branch site, a brief attempt was made to use these signatures for the Kinzua data. The initial results seemed promising. However, investigation of signature transference in time and space by recalibration (see Section 3.2.6) was underway at this time, promising far better results.

4.3.2 Penn State Experimental Forest (B. J. Turner and D. L. Williams)*

In order to determine the limitations of ERTS-1 data with respect to the classification of forest types, a site was chosen within The Pennsylvania State University Experimental Forest, an area of approximately 1800 ha for which ample ground truth was available and on-site inspection was convenient. The forest includes many small plantings of various coniferous species, as well as several natural forest types, including oak-hickory, hemlock-hardwood, Virginia pine, and table mountain pine. It offered, therefore, a wide range of forest targets of sizes down to the resolution of the data elements.

ERTS-1 digital data tapes from a September and a January scene were analyzed.** Both supervised and unsupervised classification methods, used with data from the two scenes, were able to discriminate between conifers and non-conifers with considerable accuracy. Results from both scenes were even more successful, however, when the RATIO program was used with Channel 4 and Channel 7 data. (The discriminating ratio in both cases was set from information derived from the DCLUS program.) The resulting classification maps were compared with each other and with photography from U2 underflights made in June 1972 and January 1973.

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*This work is described further in ORSER-SSEL Technical Reports 16-73 and 12-74.

**Scenes 1045-15243 (6 September 1972) and 1171-15245 (10 January 1973).

Comparisons were also made with a 1965 vegetative cover map supplied by the Pennsylvania Wildlife Research Unit.

The results of these comparisons indicated that coniferous forest types could be easily differentiated from non-coniferous types, in areas of 3 ha or more, by a variety of classification methods in both summer and winter data, but further differentiation within these groups was hazardous. There were a few cases of confusion; in particular, some areas were classified as coniferous in the winter data and as hardwood in the summer data.

The next stage in analysis, therefore, was to refine the mapping by merging the data from the two scenes, yielding seven channels of information (Channel 6 in the September scene exhibited banding and was not used in analysis). The category for pine plantations was assigned the same symbol for both the January and the September RATIO maps. These two maps were then superimposed on a light table and the symbol areas matched as closely as possible. It was determined that the September data differed from the January data by +68 scan lines and +81 elements. Using the MERGE program, which combines the data on an element-by-element basis, data from the two scenes were then subset together onto a working tape. (Registration of the data from the two scenes was simplified because rotation was unnecessary.) The result was an eight-dimensional vector of each observational element, instead of the four-dimensional vector of a single ERTS-1 scene. These expanded vectors were then handled by the classification programs as if the data originated from an eight-channel scanner.

A supervised classification procedure was used to process the combined data and the road system of the area was transferred to the character map from ground truth data. No major discrepancies in classification were found. It was discovered that the areas which had appeared as coniferous in the winter scene and hardwoods in the summer scene (and had appeared as a separate category in the merged data) consisted of hardwoods with a hemlock understory. The conifers would obviously be obscured by the hardwoods in summer but evident after leaf fall. The following six categories, based on nine spectral signatures, were differentiated in the classification map: hardwoods, shaded hardwoods, conifers, hardwoods with hemlock understory, fields, and water.

The character map was converted to a plotter line map, using the LMAP program (Figure 4.4), and the scale was adjusted to facilitate comparison with USGS 7.5-minute quadrangle maps. In order to verify the results in the field, 40 points were randomly located on the map and visited in the field. At only one point was there disagreement, yielding an estimated accuracy of 97 per cent.

4.3.3 Rothrock State Forest (J. E. Andersen and F. Y. Borden)*

Rothrock State Forest is located in Huntingdon County, Pennsylvania,

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*This work is described in detail in the M.S. thesis by Andersen.

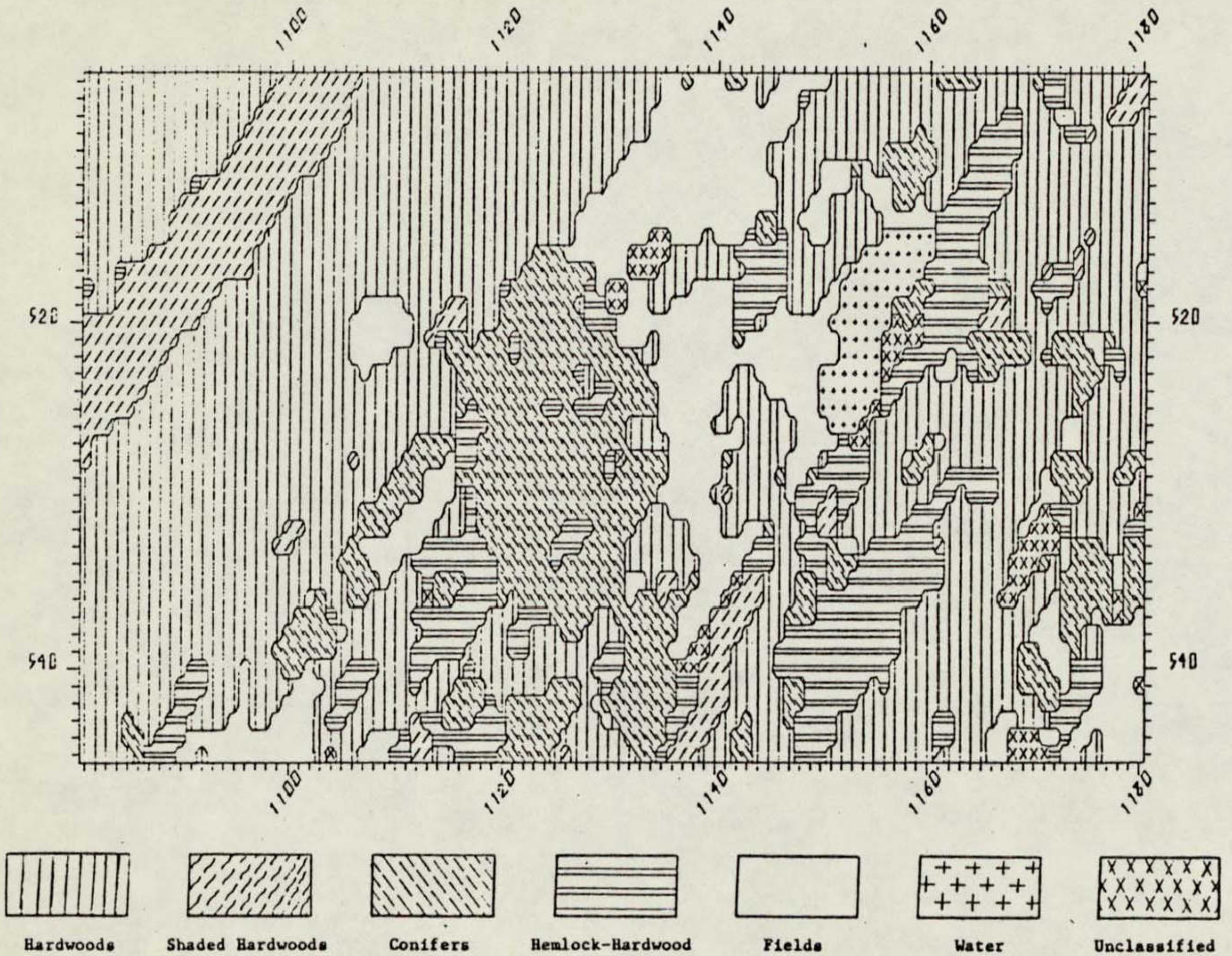

Figure 4.4: LMAP printout of the classification map for the Penn State Experimental Forest.

approximately 16 km southwest of the University Park campus. The 8100 ha study site, chosen for its variety of forest types, includes areas of private ownership, as well as portions of the state forest. Whipple Dam Recreation Area is located approximately at its center. The objective of this investigation was to evaluate the extent of forest type differentiation possible, using ERTS-1 data and the existing ORSER programs.

Flights of the C130 aircraft from 15 April 1973 and 12 February 1974 (Missions 230 and 271, respectively) served as ground truth. However, since neither flight covered the entire study area, USGS 7.5-minute quadrangle maps were consulted as additional ground truth and to provide information regarding the spatial orientation of major topographic features located in and around the test area. They were also used to locate training areas, since their scale was approximately the same as the printer output classification maps generated during the course of the investigation. Timber maps of Rothrock State Forest, furnished by the Pennsylvania State Bureau of Forestry, were used as a source of detailed ground truth against which all results were checked.

The initial investigation was directed toward analysis of data subset from an October scene.* It was expected that the characteristic fall coloration of hardwood species would facilitate separation of hardwoods from conifers. Fifteen training areas, representing the major cover types found in the test area, were defined and the STATS program was used to calculate their statistical parameters. At this point, two different analytical approaches were taken.

The first approach was based on the DCLASS euclidean distance classifier. In this case, coniferous species were delineated from hardwood species in most instances; however, some confusion in classification existed between shaded hardwoods and conifers, as well as between conifers and certain areas of sunlit hardwoods. The second analytical approach used canonically transformed data. Although classification results from this approach were similar to those obtained from the untransformed data, there were two significant differences: the confusion between shaded hardwoods and conifers had been reduced and, in addition to hardwoods and conifers, the geographic distribution of rhododendron was mapped fairly accurately.

Data from a May scene** were then merged with those from October. UMAP output from these eight channels of data led to the addition of six new categories. The 21 categories at this stage were then processed by the STATS program and the category statistics used as inputs to the DCLASS and CANAL programs. The resulting classification maps were markedly improved over those using only the October data. There was still confusion, however, between shaded hardwoods and conifers, especially in the valleys. This difficulty was most prominent on the DCLASS map.

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*Scene 1459-15223 (25 October 1973).

**Scene 1297-15252 (16 May 1973).

CANAL separability statistics indicated that several training areas probably represented the same category. These statistically similar targets were combined and the remaining 18 categories were input to the STATS program for analysis. The resulting statistics were then input to the CANAL program to determine if the 18 combined training areas were separable. It was found that two training areas were not entirely separable, but the overlap was too small to justify combination.

DCLASS classification with these 18 categories proved to be quite accurate, with much of the shadow problem removed. Whipple Dam Recreation Area was delineated correctly, as was a clearcut area to the north and east of it. Agricultural fields, for which no spectral signatures had been developed, were correctly classified as belonging to the "other" category, as were clouds which were present in the May data. Confusion between coniferous species and hardwood overstory with a rhododendron understory was also reduced.

Canonically-transformed ERTS-1 data from the Whipple Dam area were also classified using the DCLASS program. Results indicate that classification was quite accurate, both for single season MSS data and for merged data, and that the discriminatory characteristics of the transformed data are much greater than those of the original data in spectral coordinates. The confusion between plantations and conifers, present to some extent in the DCLASS output, was virtually removed. Plantations were accurately delineated within coniferous surroundings, as well as where they occurred in the open and within hardwood stands. Delineation of evergreen understory appeared more accurate than in the DCLASS map. Rhododendron were located quite accurately over the entire test area, and areas located away from the training sites were delineated with reasonable accuracy. Based on the results obtained in this investigation, canonical analysis appears to be very helpful in delineating forest cover types in areas with mountainous topography and/or heterogeneous vegetation.

Canonically-transformed data and classification results based on these data were also displayed on the G.E. Image 100 system. Although this system is highly interactive and has many advantages (see Section 3.2.4). Its limitation to eight classification categories was a distinct restriction for this study. Certain completely separable categories had to be grouped, resulting in the loss of potentially valuable information and an undesirable increase in within-category heterogeneity.

4.4 Land Resources Mapping in Mountainous Terrain (T. W. Simpson)*

A May and an October ERTS-1 scene** of an area of mountainous terrain in northcentral Pennsylvania were selected for land resource mapping by computer analysis. The objective of this study was to determine a procedure for developing spectral response patterns useful in preparing land resource maps in rugged mountainous terrain.

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*The details of this study are described in the M.S. thesis by Simpson.

**Scenes 1297-15245 (16 May 1973) and 1459-15221 (25 October 1973).

Using a combination of supervised and unsupervised procedures, six categories were classified from the May data and five from the October data. Merged data from the two scenes yielded the same six categories as the May data, but resulted in fewer misclassifications. The categories were: depressions, wetland, upland, northwest slope, southeast slope, and floodplains (not identified on the October classification).

In order to determine their accuracy, the three classification maps were compared to several soils and topographic maps at 1090 randomly-selected locations. Two additional maps, one digital and one interpretive, were produced and sampled for each of the three data sets to determine if any change in accuracy would result from, (1) limiting the number of pre-defined spectral units, and (2) interpretation of the original computer-classification map by an experienced land resource interpreter.

The results indicated that combined cluster and statistical analyses produced the most useful spectral response patterns for identifying land resources. Classification of the October scene showed an increase in accuracy over that of the May scene; however, the merged data yielded the greatest accuracy. It was shown that useful land resource maps of rugged mountainous terrain can be prepared from satellite MSS data, and that interpretation of the maps by an experienced resource mapper can increase their value.

CHAPTER 5

ERTS-1 CONTRACT RESEARCH: ENVIRONMENTAL QUALITY

The periodic nature of ERTS-1 data acquisition presents an ideal opportunity for monitoring the effects of environmental changes in land-use potentialities. The possibilities of such monitoring have been investigated for three sources of environmental stress: mining, industry, and gypsy moths.

One of the most serious environmental problems facing Pennsylvania is that of strip mining for coal. Extensive areas have been stripped, and effective and efficient methods are required to monitor the extent of this work and the effectiveness of reclamation and re-vegetation projects. Digital mapping of stripped areas from ERTS-1 data, using ORSER programs, has demonstrated that quantitative monitoring of the location and extent of strip mining activity is feasible, and that working maps of mines and coal refuse piles can be produced for use by field personnel involved in reclamation and pollution control.

Damage to vegetation by industrial pollutants and gypsy moths also represents serious environmental problems. The effects of air pollution on vegetation surrounding a zinc smelter have been investigated, using ERTS-1 digital data, and gypsy moth defoliation has been mapped by both visual interpretation of ERTS-1 images and processing of the digital data.

5.1 Environmental Effects of Coal Mining

Large areas of Pennsylvania have been stripped for coal, and innovative methods are needed to monitor the growth of mines and spoil piles as well as to determine the effectiveness of reclamation projects. Digital processing of ERTS-1 data has shown that stripped areas and coal refuse accumulations can be mapped effectively, and that some areas affected by acid mine drainage can be mapped as well.

5.1.1 Anthracite Refuse (D. N. Thompson and F. Y. Borden)*

A portion of the southern and middle fields of the anthracite coal region of eastern Pennsylvania was selected for study for several reasons: (1) the coal fields are relatively compact areas with well-defined boundaries, (2) the fields are representative of regions seriously affected by mining, (3) they have been the subject of several studies which could be helpful in verification of computer-classification results, and (4) the portion of the fields to be studied was confined to a single ERTS-1 scene,** from which data were used throughout this study.

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*This work is described in detail in ORSER-SSEL Technical Reports 20-73 and 12-74.

**Scene 1080-15195 (11 October 1972).

The eastern tip of the Southern Anthracite Field was selected for initial investigation. This relatively small area, which includes the city of Hazelton, is bounded by mountain ridges and includes towns with locally extensive refuse accumulations; substantial segments of the surrounding land have been stripped for coal. Output from the NMAP program clearly delineated the mountain ridges and the Lehigh River valley, permitting accurate orientation with respect to features seen on the USGS 7 1/2-minute topographic maps. UMAP output was then used to select initial training areas thought to represent categories such as reservoirs, coal refuse accumulations, silt basins, towns, strip mines, and several vegetation types. Since no underflight photography was available, few targets could be identified unequivocally. The first trial classification maps were produced by processing the data with the DCLASS program, using the signatures generated by the STATS program. Thereafter, because known target areas could not be defined by photointerpretation, most additional category-defining signatures, for small areas of interest, were developed using the DCLUS program. The categories thus defined were identified by inference from the pattern of their spectral response and by reference to the topographic maps. A profusion of signatures was developed in this manner and reduced to manageable proportions by grouping those with very small calculated distances of separation. These signatures were then added to the original classification categories and additional digital maps were produced. This procedure was iterated several times, with particular emphasis on correct mapping of coal refuse and silt, until a reasonably satisfactory map of the area was obtained.

The study was then extended to a second area, adjacent to the first and just northwest of the town of Jim Thorpe. All known coal refuse piles and silt basins, identified from topographic maps and from previous studies of the area, were mapped as either refuse or silt. However, there was some confusion between these two materials, since they are similar in composition and color and differ primarily in texture. Nearly black spoil piles of carboniferous rock were also frequently mapped as refuse, since they consist of the same geologic material as most of the coal refuse and have, therefore, a very similar reflectance pattern. Although such inaccuracies are not desirable, the consequences may not be serious since the same environmental and reclamation problems are involved in each case.

One area mapped as coal refuse seemed anomalous because it was located on the opposite side of a ridge from any other evidence of mining. Because its spectral signature, determined by cluster analysis, was intermediate between those of coal refuse and water (Figure 5.1), it was tentatively identified as a lake with muddy water. Although no impoundment showed on the topographic map, subsequent field inspection confirmed the existence of a newly constructed dam and lake. Other small areas, classified as water on the digital map, but not seen on the topographic maps, were determined to be water-filled abandoned strip mine pits.

All known refuse piles and silt basins were mapped successfully in the two areas. Water bodies were easily identified, including several not shown on the topographic maps. All towns and cities were also mapped correctly and four-lane highways could be discerned where they traverse forested areas. Some strip mine spoils were still mapped as coal refuse

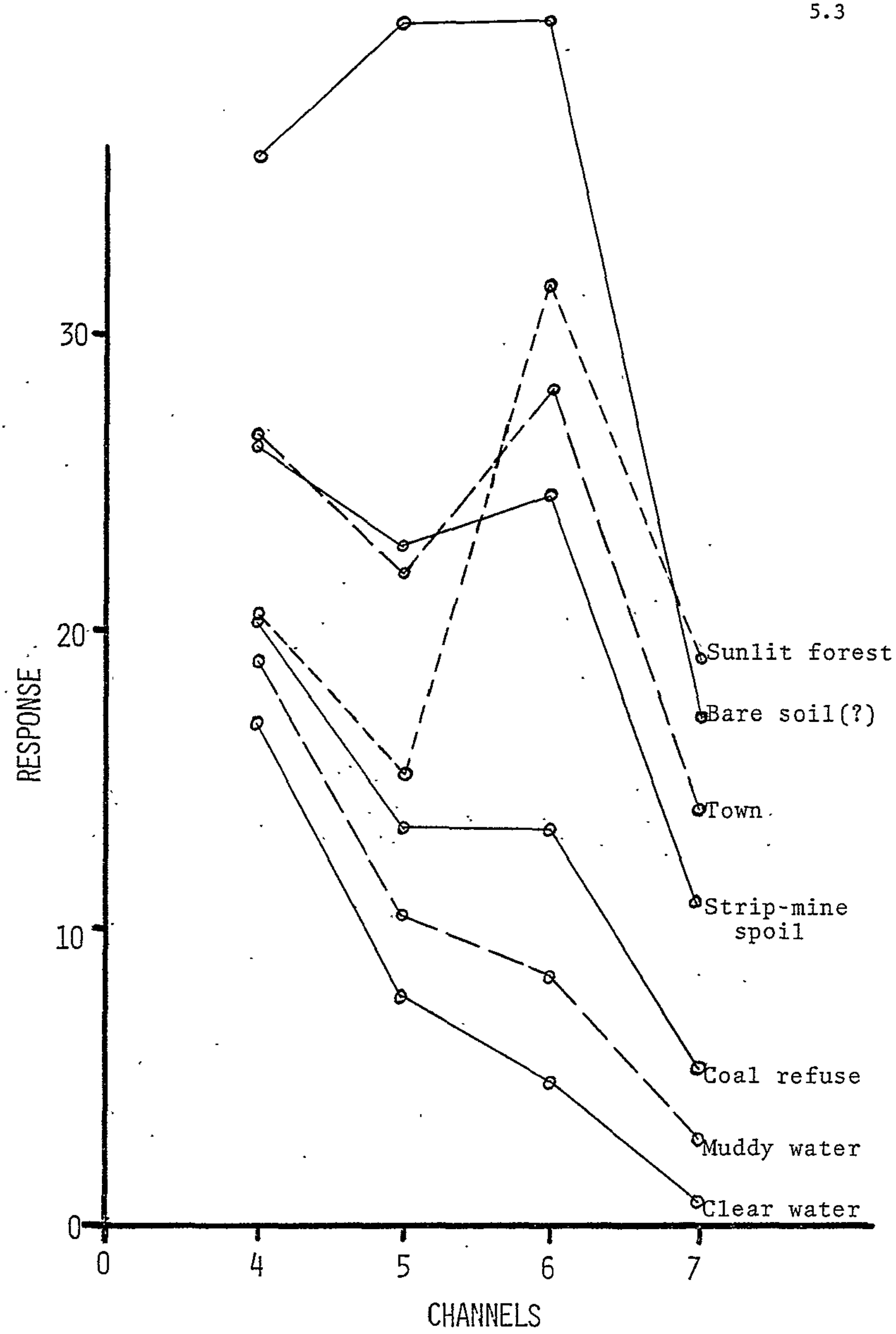

Figure 5.1: Representative spectral patterns for several major categories in the anthracite coal district.

in the second area; however, the extent of this problem could not be evaluated without underflight photographic coverage. Although towns were mapped almost entirely correctly, some strip mines and much farmland were also mapped as towns. On the other hand, the inverse of this incorrect classification was not a difficulty, as strip mine and vegetation symbols rarely occurred in anomalous places.

After the initial small area investigations, an area encompassing the Eastern Middle, Western Middle, and Southern Coal Fields was subdivided into 27 mapping blocks; each approximately 11.3 by 13.7 km. The same classifier and categories as in the preliminary investigation were used to produce digital maps of each block. However, because of the large distance between blocks, substantial portions were not classified in the first run, and there were many seemingly anomalous classifications. The cluster analysis procedure was employed in these cases to identify additional categories, and several signatures obtained in a study of the Harrisburg area (which overlaps the southwestern tip of the coal region) were added to the list of categories. As the set of signatures was expanded and refined, additional maps were produced and features such as towns, lakes and reservoirs, mountain ridges, and coal refuse accumulations, were identified by correlation with the topographic maps. The final list of categories (Table 5.1) included 59 distinct spectral signatures, representing 14 mapping categories.

Throughout the 27 blocks, the classification results were significantly improved over those of the original two blocks by the use of the additional spectral signatures. (A map of one of the blocks is shown in Figure 5.2.) Comparison with the topographic maps indicated that all major urban areas and mountain ridges were correctly classified throughout the area. Classification of many of the refuse banks and silt basins was verified from earlier studies of the anthracite region. Classification of some additional deposits, not mentioned in these studies or shown on the topographic maps, was verified by field inspection. It appeared, however, that the extent of individual coal refuse banks and silt basins was exaggerated in some cases--probably, as a result of the misclassification of strip mine spoil as refuse, as discussed earlier.

The additional signatures representing coal refuse and water, developed in order to correct misclassifications over the widened area of investigation, caused some refuse and silt deposits to be mapped partially as water. This problem could probably have been resolved by further refinement of the signatures. The three-way confusion among some strip-mines, towns, and agricultural areas, encountered in the preliminary phase of this study, was made less serious by selective elimination of those signatures which caused the most confusion. Additional signatures for urban and industrial areas clearly mapped virtually all towns and cities, but some farming and partially reforested strip mines were still classified as towns. The problem seems to be that all three categories are mosaics of vegetation and some dissimilar material: roofs and pavement in towns, bare soil on farmland, and bare spoil in strip mines. It is unlikely that the problem can be resolved by further refinement of the signatures. Techniques such as merging data from two or more seasons, thus making use of the temporal dimension, are more likely to lead to a solution.

Table 5.1: Categories and Spectral Signatures for the Anthracite Region

Signature Number	Category	SPECTRAL SIGNATURE Channels 1	2	3	4
1	Clear Water	16.79	7.57	4.79	0.69
2	Turbid Water	16.40	8.16	5.87	1.42
3	River Water 1	16.36	8.63	8.96	3.43
4	Muddy Water 1	20.12	15.67	10.10	1.98
5	River Water	18.31	9.90	6.03	0.89
6	Muddy Water 2	18.76	10.38	8.33	2.86
7	Muddy Water 3	19.08	11.92	11.08	3.92
8	Muddy Water 4	23.85	14.23	7.88	1.54
9	Refuse 1	20.88	14.43	12.34	4.42
10	Refuse 2	20.23	13.39	13.32	5.26
11	Refuse 3	21.77	15.59	14.73	5.84
12	Refuse 4	19.73	12.99	11.04	3.66
13	Refuse 5	24.37	19.50	17.11	6.49
14	Silt 1	18.49	10.79	9.79	3.26
15	Silt 2	16.50	9.58	11.33	4.58
16	Stripmine 1	24.44	19.50	18.80	7.69
17	Stripmine 2	29.20	26.66	24.92	9.92
18	Stripmine 3	26.10	22.82	24.55	10.79
19	Stripmine 4	32.62	31.46	31.70	14.77
20	Stripmine 5	30.58	29.42	28.33	11.65
21	Stripmine 6	21.02	15.47	18.47	8.54
22	Industry 1	28.75	24.50	22.92	9.00
23	Industry 2	26.97	21.87	20.70	8.74
24	Industry 3	42.00	38.00	30.33	11.33
25	Bare Soil	36.00	41.33	42.50	17.00
26	Town 1	33.21	28.67	30.12	13.32
27	Town 2	25.23	19.48	21.46	9.70
28	Town 3	27.57	22.38	26.62	12.69
29	Town 4	24.56	20.51	27.33	14.08
30	Town 5	24.50	19.26	23.74	11.42
31	Town 6	24.05	18.97	26.45	13.61
32	Town 7	21.26	13.78	26.08	14.70
33	Town 8	24.81	18.08	27.73	15.00
34	Town 9	30.14	27.14	37.14	19.00
35	Town 10	26.40	21.80	28.20	13.90
36	Road 1	28.82	25.45	30.73	15.32
37	Road 2	26.50	23.18	30.64	16.02
38	Road 3	27.42	23.47	31.68	16.84
39	Brush 1	25.08	19.77	30.19	16.27
40	Brush 2	24.41	19.62	32.64	18.50

Table 5.1 (Continued)

Signature Number	Category	SPECTRAL SIGNATURE Channels 1	2	3	4
41	Brush 3	22.44	20.11	30.56	17.33
42	Brush 4	23.14	18.97	30.06	16.97
43	Vegetation 1	20.42	15.12	31.80	18.99
44	Vegetation 2	19.61	15.12	29.62	17.86
45	Vegetation 3	19.65	14.01	25.43	14.25
46	Vegetation 4	21.46	16.85	27.62	15.31
47	Vegetation 5	18.14	12.81	23.86	13.81
48	Vegetation 6	19.34	12.46	26.48	15.33
49	Vegetation 7	20.52	12.96	27.31	16.11
50	Vegetation 8	19.18	17.00	25.27	14.27
51	Vegetation 9	20.96	16.48	33.41	20.20
52	Vegetation 10	20.93	15.99	36.47	22.17
53	Vegetation 11	22.12	17.97	39.72	24.19
54	Vegetation 12	19.92	13.44	38.87	24.29
55	Vegetation 13	27.81	25.14	36.09	19.12
56	Vegetation 14	20.15	14.43	20.83	10.69
57	Vegetation 15	18.27	12.05	18.64	9.52
58	Swamp 1	18.39	12.72	20.56	11.94
59	Swamp 2	18.44	10.50	13.59	6.53

Figure 5.2: Line map of a portion of the anthracite area showing targets of major interest. (Scale: 1 cm = 720 m.)

The feasibility of using ERTS-1 data to map coal refuse has been demonstrated in this study. It is evident that with ground truth verification and the use of more advanced techniques, such as data merging, working maps can be produced for use by field personnel involved in reclamation and pollution control.

5.1.2 Strip Mines and Acid Mine Drainage Effects (S. S. Alexander and J. L. Dein)*

The objective of this study was to determine if ERTS-1 MSS digital data could be used to map coal strip mines and areas adversely affected by acid mine drainage. A training site near Kylertown, Pennsylvania, was selected where both old and new strip mines are found, where significant areas of vegetation are affected by acid mine drainage, and for which a variety of ground truth data was available in the form of geophysical and geological surveys and aircraft photography. A September ERTS-1 scene** was chosen for analysis.

Using both supervised and unsupervised procedures, it was found that the unsupervised procedure of cluster analysis provided the best definition of categories. Not only was it possible to identify stripped areas unambiguously, but sub-classifications were found to represent trenches, backfills, recent workings, and areas cleared for future stripping operations. In addition, certain areas of dead, dying, or stressed vegetation caused by acid mine drainage and not visible on the ERTS image, were distinctly classified and correctly located spatially.

It was found that the training area signatures could be used to classify similar features in another part of the ERTS-1 scene. Although there were some differences in detail, strip mines and some of the effects of acid mine drainage on vegetation were still mapped effectively. Comparison of results for ERTS-1 passes a day apart*** revealed that the signatures for forests, fields, and strip mine features were clearly reproduced even though the two images differed in brightness and quality.

Comparison of results for the same area, with data from a different season,**** showed distinct differences in the forest and field categories, while the strip mine features remained essentially unchanged. However, the difference between strip mine signatures and those of the surrounding areas in the spring scene was not great, implying that early spring is a poor season to use for mapping strip mine features. The fact that the strip mine features appear to give season-invariant signatures implies that these signatures can be used to verify classifications where ground truth is scant or unavailable, and that spectral signatures developed for strip mines in one season can be used to classify these features with data from a different season.

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*This work is described further in ORSER-SSEL Technical Report 23-73.

**Scene 1045-15240 (6 September 1972).

***This comparison was made with data from Scene 1046-15295 (7 September 1972).

****Scene 1243-15253 (23 March 1973).

It is concluded that digital processing techniques with ERTS-1 MSS data can be used to monitor the extent and location of strip mining activity and certain areas of acid mine drainage effects on vegetation and, therefore, these techniques can be used to assess the effectiveness of reclamation and pollution abatement procedures.

5.2 Industrial Pollution

Pollution from industrial and power installations in Pennsylvania is a growing problem. Two studies were initiated to determine to what extent ERTS-1 data could be used to monitor pollution effects from such installations. The first study involved the effect of air pollution from a zinc smelter on the surrounding vegetation. The other was designed to monitor the effect of a nuclear power plant on the local environment. In this latter case, however, only the preliminary studies could be completed, as the power plant did not become operational within the duration of the ERTS-1 contract.

5.2.1 Air Pollution Damage to Vegetation (E. L. Fritz and S. P. Pennypacker)*

The study area, a narrow valley near Palmerton, Pennsylvania, has been the site of a zinc smelter since 1898. During periods of low wind speed and stagnant air, pollutants are trapped in this valley--with detrimental effects on the surrounding vegetation. Oxides of zinc, lead, cadmium, copper, and sulfur are released from the smelter during the roasting and sintering process. Stack tests in 1970, conducted by the Pennsylvania Department of Health, measured a total sulfur dioxide emission rate of 635 to 681 kg/hr or 15.4 tonnes per day. The daily zinc emmissions ranged between 6.3 and 9 tonnes per day. Within an 0.8 km radius of the smelter, zinc concentrations were found to be as high as 80,000 μg per gram of air-dried soil.

As a result of logging and burning, the forests surrounding Palmerton are all second growth. Approximately 468 ha of bare soil area may be attributed to accumulations of high levels of zinc. Larger areas of altered plant communities exist because of sulfur ioxide pollution and zinc in the soil. Areas adjacent to the bare soil sites support very little plant life. The only plant in relative abundance is the winter annual Arenaria Patula Michx. In other areas, the only trees present are sassafras (Sassafras albidum Nutt.) and black gum (Nyssa sylvatica Marsh.) with widely scattered scrub oak (Quercus ilicifolia Wangenh and Quercus prinus L.). The trees are stunted and there is very little undergrowth. At a distance beyond 0.8 km from the smelter, the forest exhibits a somewhat more normal appearance, although the stands of oak are thin, the leaves are small, and there is less undergrowth than normal.

Cluster analysis of the digital data for portions of a July ERTS-1 scene** for the Palmerton site revealed that the area could be divided into

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*See ORSER-SSEL Technical Report 19-74 for a full discussion of this study.

**Scene 1350-15190 (8 July 1973).

four distinct categories: (1) healthy forest, (2) less healthy forest (thinner, with less undergrowth), (3) forest in poor condition (mostly sassafras and black gum trees with a few scattered oaks and no undergrowth), and (4) barren soil with severe erosion and Arenaria patula as the only vascular plant growth.

Although ground truth revealed very striking differences between two stands of white pine (Pinus strobus L.), these differences could not be seen from analysis of the ERTS-1 data. Elimination of possible interference from herbaceous undergrowth and deciduous trees, obtained by cluster analysis of merged data from a winter scene* with the summer scene, still did not provide separable spectral signatures for the two stands.

The results from this study show both the value and the weakness of ERTS-1 data in the analysis of the effect of air pollution on vegetation. The data are valuable for evaluation of vegetative conditions where large areas of damage occur and the damage is severe enough to cause a high contrast between damaged and healthy vegetation. The data studied here, for instance, produced a map accurately delineating areas where vegetation has been limited by the presence of zinc, defining four zones. On the other hand, the resolution of the data is not sufficient for detailed evaluation of vegetative conditions or for study of the small areas of damage often attributed to air pollution, such as investigated here in the case of the two white pine stands.

5.2.2 Pollution by a Nuclear Power Plant (S. S. Alexander)**

The objective of this study was to monitor the effects of power plants on the local environment and, in particular, to follow the temporal changes induced by the installation and activation of the nuclear power plant on Three-Mile Island in the Susquehanna River near Harrisburg, Pennsylvania. The delay in activation of this power plant, however, limited the amount of work which could be completed on this task.

ERTS-1 scenes and C130 underflight photography at two altitudes (1500 and 4500 m) were examined for this area as they became available and it was found that the power plant installation was easily identified at each altitude. These data provided information on the pre-activation conditions at various scales for Three-Mile Island and vicinity. Apart from the bare soil areas resulting from construction of the plant and associated buildings, there were no discernible effects of the plant on the surrounding areas at this stage, as expected.

Because of the availability of repeated ERTS-1 coverage during each season in the pre-activation period, it will be possible to monitor the local and regional effects induced on the environment both spatially and temporally when the plant is put into production and to compare these effects to the pre-activation seasonal data. Among the expected direct perturbations are: increased cloud cover and fog, reduced flow

*Scene 1116-15192 (16 November 1972).

**This project could not be completed because the Three-Mile Island plant was not activated before the end of the ERTS-1 contract. Therefore, a technical report was not written.

in the Susquehanna River and higher water temperatures locally and downstream from the plant, alterations in stream life around and downstream from the plant, effects on soil moisture content and vegetation, and effects on land use patterns in the surrounding areas.

We believe that these effects could have been effectively detected and mapped, both spatially and as a function of time, from ERTS-1 data. Analysis of the MSS digital data, in particular, would have provided detailed and quantitative indications of changes in the spectral signatures of the area, including the river. Ultimately, the environmental effects induced by conventional and nuclear power plants can be compared, and the extent of these effects determined as a function of the average power produced. Such results will be useful in planning for future power production to achieve maximum output with minimal undesirable side effects.

5.3 Gypsy Moth Damage to Vegetation

The delineation of gypsy moth damage to vegetation was studied from two vantage points. In the one case, photointerpretive techniques were used with merged ERTS-1 images using Diazo transparencies; in the other, the digital data were processed using unsupervised classification techniques. Both studies were initiated in response to the discovery of an apparently distinct indication of gypsy moth damage to forests on the ridges of northeastern Pennsylvania, seen on images from two July ERTS-1 scenes.* The data for these scenes were collected on a clear day at the height of defoliation.

5.3.1 Photointerpretation (W. S. Kowalik)**

Close inspection of images from the July ERTS-1 scenes* revealed that interpretation of defoliation from either the single channel black and white positive transparencies or the standard NASA color composites would not be straightforward. Defoliated tracts, urban areas, strip mines, and poorly drained areas within the Scranton/Wilkes-Barre coal field all have similar tones on the Channel 6 and 7 images. On individual transparencies of Channels 4 and 5, defoliated areas blend with strip-mined, urban, and agricultural areas. Defoliation on the standard NASA color composites is not easily resolved from bordering agricultural areas or from strip mines and the Scranton/Wilkes-Barre coal field.

In an attempt to achieve less speculative interpretation than possible with the standard images, color temporal composites were made using a Diazo printer and developer. By superposition of transparencies of the non-defoliated scenes in one color over transparencies of the defoliated scenes in another color, the defoliation becomes color-coded.

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*Scenes 1350-15183 and 15190 (8 July 1973).

**This work is described in detail in ORSER-SSEL Technical Report 22-74.

After some experimentation, it was determined that blue transparencies of the two defoliated July 8 Channel 7 scenes and red transparencies of two October 11 Channel 7 scenes* could be combined for interpretation of defoliation. Color addition of primary red and blue results in violet, providing maximum separation of areas of no change from the reds and blues of changed areas. The depiction of defoliation on these composites agreed very well with spot-sampled defoliation estimates in Monroe, Pike, and Northampton Counties.

Deep blue areas on the Channel 7 composites represented a range of defoliation from 70 to 100 per cent, whereas areas of light blue with tinges of violet represented areas ranging from 15 to 70 per cent defoliation. The boundaries of these areas could be located with a maximum error of a few hundred meters.

Of course, all other relative tonal changes between the two dates (mainly agricultural fields and clouds and their shadows) were also evident on the temporal composites, but these did not interfere significantly with the interpretation. Clouds were circled before analysis, and agricultural areas were eliminated on the basis of field patterns. Urban areas, strip mines, coal fields, and most agricultural areas were clearly differentiated from defoliation. Shadows were more pronounced on the October scene than on the one from July; however, awareness of this fact during the interpretation was sufficient to minimize misinterpretation.

Visual interpretation of temporally composited color Diazo transparencies of ERTS-1 images appears to be a practical method for detecting and locating areas of widespread defoliation.

5.3.2 Digital Data Processing (D. L. Williams and B. J. Turner)**

Portions of the two July 8 scenes*** depicting gypsy moth defoliation were chosen for digital analysis and the data were subset onto a working tape. Unsupervised cluster analysis procedures were chosen for classification, with the intent of using supervised classification where necessary to verify uniformity and variability in the signatures obtained.

No difficulty was encountered in developing signatures using the DCLUS program. Color IR aerial photography and other supporting ground truth information were used to verify the classifications. Table 5.2 lists the 12 categories and their spectral signatures. Those of particular

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*Scenes 1080-15183 and 15185 (11 October 1972).

**This work is described in detail in ORSER-SSEL Technical Report 5-74.

***Scenes 1350-15183 and 15190 (8 July 1973).

interest represent healthy forest (0 to 30% defoliated), moderate defoliation (30 to 55% defoliated), and heavy defoliation (60 to 100% defoliated). Although the responses for these three categories are similar in Channels 4 and 5, significant differences can be seen in Channels 6 and 7, corresponding to the degree of defoliation. The signatures accurately identified 98 percent of the study area.

Table 5.2: Spectral Signatures of the 12 Categories Developed During the Gypsy Moth Defoliation Analysis

	SPECTRAL RESPONSE			
	Ch. 4	Ch. 5	Ch. 6	Ch. 7
Water	27.83	19.00	17.25	5.21
Wetlands	33.00	24.00	31.00	14.00
Swamp 1	32.51	22.77	24.67	9.90
Lake edge	32.50	22.75	32.75	15.00
Siltwater	35.60	24.93	21.57	6.74
Swamp 2	33.32	24.26	26.71	11.31
Swamp 3	31.63	21.46	22.33	8.61
Swamp 4	33.02	22.98	21.02	5.23
Swamp 5	29.03	19.22	23.67	9.25
Healthy Forest	34.79	24.61	51.47	28.52
Moderate Defoliation	34.44	25.04	46.38	24.80
Heavy Defoliation	34.08	25.47	41.30	21.08

A training area encompassing three experimental plots aerially sprayed with Dylox was of particular interest throughout the investigation. These plots were easily identified on the ERTS-1 image (1350-15183), the character maps, and on color IR photography supplied by the U.S. Forest Service. They had also been plotted on topographic maps by the Pennsylvania Bureau of Forestry. All defoliation levels were represented in the vicinity of these plots: areas which had received the maximum spray application were relatively healthy, while the surrounding unsprayed forest was generally heavily defoliated. Certain areas within and around these plots, where the application of spray was not as heavy, showed moderate degrees of defoliation.

The results shown on Figure 5.3 indicate that ERTS-1 digital data can be used to discriminate between two degrees of defoliation and healthy vegetation in northeastern Pennsylvania, and that computer processing methods can be used to map the severity of defoliation and compute the areal extent of each category.

5.3.3 Evaluation

The digital processing of areas defoliated by gypsy moths nicely complements the photointerpretive approach. While the photointerpretive

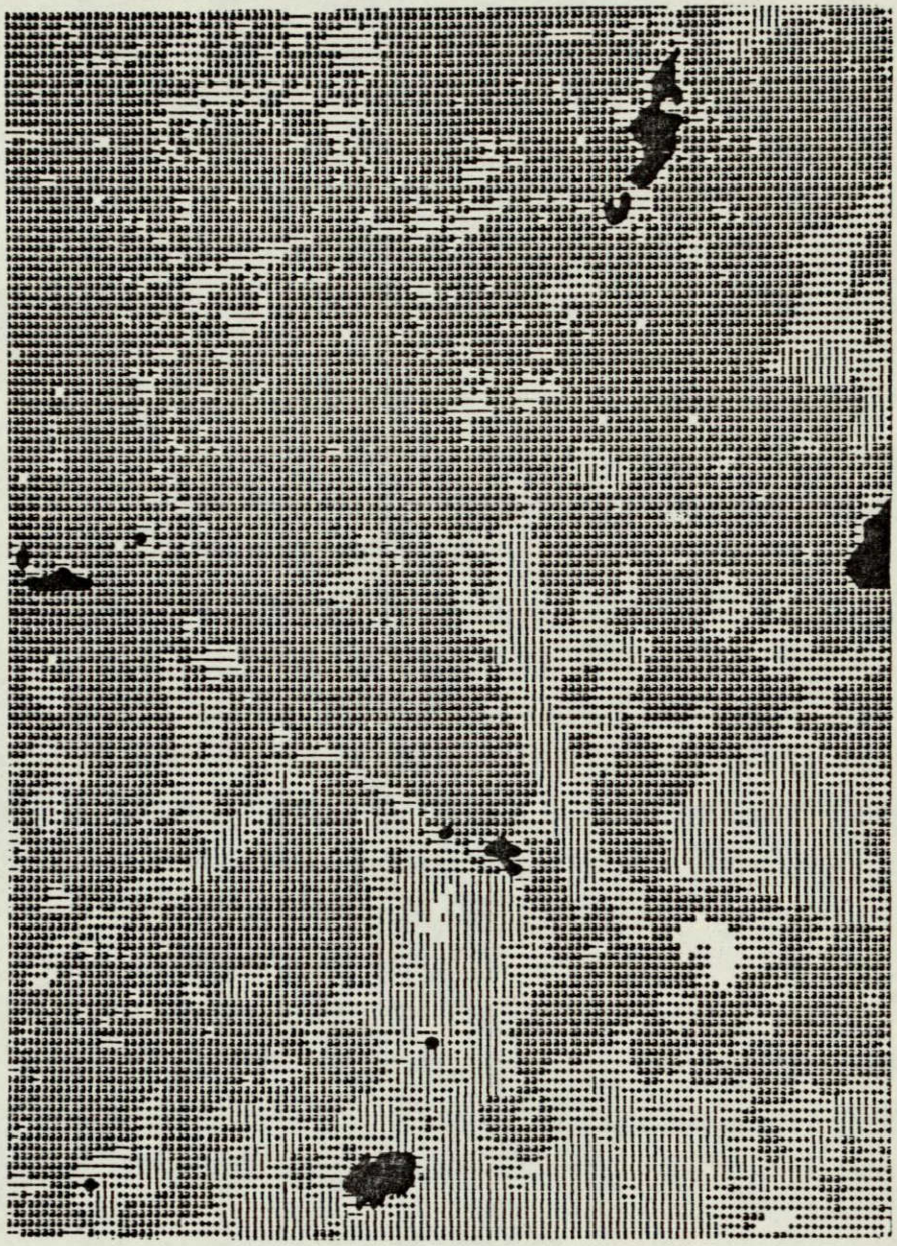

Figure 5.3: Character map derived from spectral signatures shown in Table 5.2. Dylox spray plots appear in lower half.

Legend

Heavy defoliation	@
Moderate defoliation	+
Healthy forest	I
Swamp	-
Water	Solid black

approach provides a quick and inexpensive method of delineating general areas of defoliation, digital processing provides a much more quantitative evaluation of both the areal extent and the degree of defoliation. This suggests that, not only for gypsy moth defoliation studies but for many other environmental problems, a combination of the two methods may be a very useful analytical technique.

A major advantage of using ERTS-1 data is the wide areal coverage in a single scene. Present methods of mapping gypsy moth damage involve light aircraft with observers experienced with the local geography mapping the extent of defoliation directly onto topographic maps. This method is heavily dependent on the keenness of observation and depth of knowledge of the observer. Because of the necessity of covering vast areas in a short time span, the same observer cannot be used throughout, so differences between observer interpretations of defoliation levels can be substantial. This may be compounded by errors in judgment brought about by the fatigue and air discomfort of the observer, and by the amount of refoliation which can occur over the time necessary to map the total area. Maps from satellite data are free of such operator variations and substantial areas can be monitored in a single pass; e.g., a third of Pennsylvania was covered in one day by ERTS-1.

A critical factor in any defoliation detection and mapping scheme, however, is timing. Satellite data at 18-day intervals is not sufficient. Defoliation and refoliation move as waves, often a week or two apart; in addition, many areas—such as eastern Pennsylvania—are frequently cloud-covered. Cloud-free coverage on at least a weekly basis would be necessary to routinely and effectively use satellite data for analysis of gypsy moth damage to Pennsylvania forests.

CHAPTER 6

ERTS-1 CONTRACT RESEARCH: GEOLOGY AND HYDROLOGY

Painstaking synthesis over many years has provided regional, state, national, and global geologic maps. However, the synthesis of features on one scale does not guarantee that a larger feature will necessarily be apparent on the smaller scale maps that have been generated. Artifacts in mosaicking, poorly known scaling laws, and inconsistent conditions (variable sun angle, albedo, seasons, etc.) of data collection are more likely to obscure than enhance subtle features. The advent of ERTS-1, however, presented an unparalleled opportunity for analysis on a small scale of a large body of data gathered under consistent conditions.

Physiographic and structural provinces are spectacularly displayed on ERTS-1 scene mosaics. Geologic bedrock structures are clearly evident and formation contacts can sometimes be traced for hundreds of kilometers. Many regional features previously obscured by the detail of higher resolution data can be seen.

ORSER geologists have concentrated on the study of linear features seen on ERTS-1 images. Numerous earlier geologic studies have shown fracture traces, seen on aircraft photography, to be strongly correlated with groundwater resources. A few segments of lineaments (linear features on a scale of tens to hundreds of kilometers long) had been seen on mosaics of aircraft photography as well. ERTS-1 imagery, however, has revealed for the first time the abundance and wide distribution of lineaments across the State of Pennsylvania. These features exert a strong control on topography and have been shown to be significantly correlated with groundwater occurrence, hence, development of water supplies. ORSER investigations indicate that some lineaments appear to localize mineral deposits as well. A knowledge of lineament location is highly relevant to the planning of engineering projects and is critical in the location of facilities such as nuclear power plants, dams and reservoirs, mines, and quarries.

Summarization of lineament orientation by frequency, length, and degree of expression (using ORSER-developed programs), and comparison with lineaments seen on Skylab scenes, has shown an interpreter bias against detecting lineaments near the sun azimuth and near the scan line direction. This points out the desirability of satellite passes at various times and in various directions for maximum lineament detection.

Lineaments and other geologic features revealed for the first time by the wide view of ERTS-1 are contributing significantly to knowledge of the earth's structures and processes. A large number of geologic projects, initiated by ORSER and others, have been stimulated by the data from ERTS-1. Further ground truth correlation, in an effort to determine the full practical significance of these newly identified features, is essential.

6.1 Regional Geologic Mapping (D. P. Gold, M. D. Krohn, R. R. Parizek, and S. S. Alexander)*

The methodology of regional geologic mapping from ERTS-1 data has been continually developed as experience in interpreting the data has been gained. Criteria used in mapping like areas (visual similarity in tone, spatial patterns, or texture) are classified according to whether they represent a direct or indirect manifestation of the bedrock condition. In forested areas such as Pennsylvania, a knowledge of the indirect indicators is important for geologic interpretations even though their relationship to the bedrock conditions may not yet be understood. The main mapping criteria used here are the boundaries or interfaces which separate areas of different tone, texture, or pattern. Whereas irregular boundaries generally result from differences in land use (arable land versus forests), smooth and regular boundaries commonly reflect geologic control, especially where layered rocks are involved. Combinations of these two relationships (e.g., forest cover over untillable rocky areas) enhance contrast and interpretability, if the correlation can be made and the cause identified from ground truth data. For example, the diabase sills in eastern Pennsylvania show up best on Channel 5 images because their overlying forest cover stands in contrast to the surrounding cultivated fields.

Three criteria were used to select geographic areas for evaluation: the availability of good ground truth data, the presence of underlying rocks with clear lithologic contrast, and the presence of abundant faults. The areas chosen were:

(1) the Traissic Basin of eastern Pennsylvania and associated diabase sills (the Great Valley),

(2) the Anthracite Basin around Scranton,

(3) the Precambrian inliers of the Reading Prong,

(4) the Martic Line north of Philadelphia,

(5) transgressive long lineaments through Mount Union and Tyrone, and a similar lineament through McAlevy's Fort and Port Matilda,

(6) transgressive lineaments in the South Mountain area, and

(7) short and intermediate lineaments, for orientation and density comparisons, in various parts of the state.

6.1.1 Visual Interpretation

A mosaic of ERTS-1 images of Pennsylvania was prepared using the first available cloud-free scenes. Physiographic and structural provinces were displayed spectacularly on this mosaic, and the resolution achieved revealed

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*This work is described further in ORSER-SSEL Technical Reports 1-74 and 2-74.

some linear formation contacts for hundreds of kilometers. Bedrock structures showed up well, especially on Channel 7 images of midwinter scenes, even where not accentuated by topography or vegetation. On Channel 5 imagery enlarged to a scale of 1:250,000, the contacts of some lithologic boundaries in eastern Pennsylvania could be placed with an accuracy of 400 meters, with respect to the 1960 Geologic Map of Pennsylvania; and much of this error may have been a result of transferring the boundaries from the imagery to the base map.

Mapping of superimposed structural features such as faults, particularly along the northern end of the Traissic Basin, was disappointing. While the margin of the Reading Prong could be traced from tonal and land use variations, the faults shown on geologic maps were not everywhere apparent on the imagery. On the other hand, accurate mapping of the Triassic diabase sills and dikes was facilitated by vegetation enhancement. In Pennsylvania, little bedrock is sufficiently well exposed to exhibit a direct spectral response. Fracture and drainage patterns, and tonal variations, however, serve to distinguish certain rock types; and most contacts are reflected indirectly in the condition and type of overlying soil, vegetation, and land use.

A zone encompassing two previously unidentified faults, confined to Cambro-Ordovician aged carbonate rocks of Centre County, Pennsylvania, and mapped for an extent of at least ten miles, was interpreted as a lineament from ERTS-1 scene enlargements. The faults were oblique to stratigraphic strike and to fold axes, as well as to the strike of reverse faults, and exerted strong control on topography. The fault relationship may have been obscured by the complex land use pattern in the area, a region containing a mixture of woodland, farms, and urban sprawl.

Mapping and analysis of lineaments in this study were continued on a later mosaic of the state and on enlargements of ERTS-1 scenes. This work is described in the section on lineaments.

6.1.2 Digital Data Processing

To test the effectiveness of detailed discrimination of geologic features, ERTS-1 imagery and computer compatible tapes from an October scene* were analyzed. The Great Valley of southeastern Pennsylvania, seen on this scene, was chosen as a training area for several reasons:

(1) it encompasses five contrasting lithologies in three physiographic provinces,

(2) the geology is well known,

(3) aircraft underflight data were available, and

(4) it is currently undergoing rapid urban growth and development.

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*Scene 1080-15185 (11 October 1972).

The following geologic relationships were visually determined on enlargements of the imagery, in the four channels, to a scale of 1:250,000:

(1) diabase ridges were differentiated from folded sandstone ridges,

(2) Cambro-Ordovician carbonates were partially separated from the upper Ordovician Martinsburg Shale,

(3) lineaments were observed to trend from north to northwest, and

(4) the trace of the main thrust fault bounding the displaced carbonate sequence was identified.

Using the standard ORSER sequence for processing MSS digital data tapes, character maps were generated from a euclidean distance classification program. Most spectral signatures for this map were derived from a cluster analysis technique, although a few larger areal features, such as water bodies, could be defined from homogeneous training areas. Comparison of the classification maps with image enlargements indicated that the spectral signatures were indicative of the geologic features where these were enhanced by land use and vegetation patterns. Although linear geologic features are difficult to identify or classify with computer techniques, they are readily identified by visual analysis of image enlargements.

6.2 Lineaments

Perhaps the most encouraging and unexpected characteristic of ERTS-1 imagery is the number, distribution, and patterns of unspecified linear features which can be seen. Geologists have long recognized the presence of straight to slightly curved linear features on the earth's surface. These vary from systematic and non-systematic joints, a few to tens of meters in length, to lineations several to tens of kilometers long which have no obvious field expression and are visible only on mosaics of aerial photographs and now on satellite images. To distinguish among features recognizable on aerial photographs, Lattman* defined a "fracture trace" as a "natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs and expressed continuously for less than one mile." Those greater than one mile (1.6 km) in length were termed "lineaments."

A considerable amount of work has been done with joint traces, with joint orientation studies in the field, and, since 1957, with fracture traces. Using ground-based and NASA-aircraft data, as well as those from ERTS-1, at least six scales of linear features have been recognized by ORSER geologists. A single mechanism, possibly related to stress fields

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*Lattman, L. H. (1958) Techniques of Mapping Geologic Fracture Traces and Lineaments on Aerial Photography. Photogrammetric Engineering 24:568-576.

imposed on a drifting continental plate, may explain the origin of these features on all scales. It has been shown here that these fractured zones act as conduits or zones of increased permeability, channeling fluids in the shallow crust. The movement of ore-bearing fluids at depth could also have occurred within these zones.

Many lineaments which transgress regional structural grain, and even physiographic province boundaries, have been discovered from visual examination of ERTS-1 MSS bulk-processed images. ORSER geologists, who have studied aerial photographs and conducted field work for years in central Pennsylvania, have mapped some lineaments and portions of others from high-quality aerial photograph mosaics and from aircrafts. However, not until ERTS-1 images became available did they recognize the great number and trend of many of the major lineaments of the state.

Linear features are detectable on ERTS-1 images and mosaics, as well as on aircraft photography, as lines or bands defined by alignments of valleys, wind gaps, and water gaps, and by straight stream segments, linear tonal patterns, and aligned field boarders reflecting topographic and land use variations. Many are subtle features, especially in areas of low relief, and the tonal contrast may vary along their length. Lineaments of particular orientations may be enhanced by a low sun angle, particularly in mountainous areas. Shorter linear features (up to a few kilometers in length) are best seen on aerial photographs or ERTS-1 image enlargements. However, enlargement may render lineaments over 100 km in length less obvious.

Lineament mapping from ERTS-1 digital tape data is difficult because of the variation in expression along the trace of the lineaments and the diversity of geology and land use areas transected; and because of the difficulty of distinguishing lineaments from man-made linear features, such as highways and power lines, and artifacts of data collection, such as scan lines. Because the human eye is more sensitive for mapping these features than any machine processing of ERTS-1 data tried so far, ORSER has concentrated on visual approaches. Computer programs have been developed, however, for the analysis of lineament length and orientation (see Section 3.2.9).

The following sections describe the various studies of lineaments which have been conducted by ORSER, using ERTS-1 data, the characteristics of those features which have been determined during these studies, and the relationship of those features to geologic structure, and various engineering and prospecting problems.

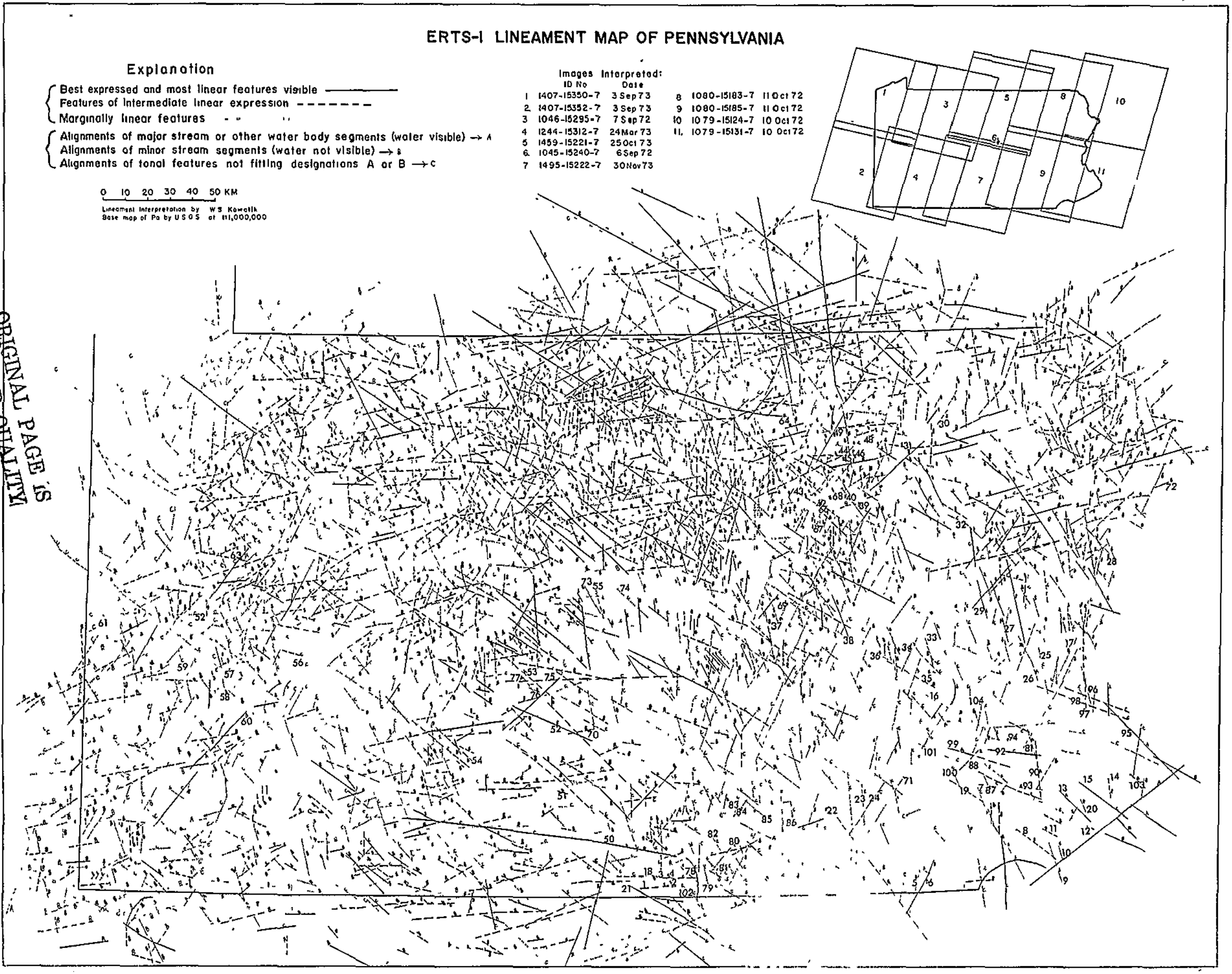
6.2.1 Lineament Map of Pennsylvania (W. S. Kowalik and D. P. Gold)*

Lineaments were mapped on individual ERTS-1 Channel 7 positive transparencies in standard format and compiled in a laydown mosaic at the same scale (approximately 1:989,000). The individual frames used and their positions in the mosaic are indicated in the top right-hand corner of the map (Figure 6.1).

The lineaments were mapped on a light table (transmitted light) and interpreted on a subjective ordinal scale of quality, linearity, and

*This work is described further in ORSER-SSEL Technical Reports 5-75 and 13-75.

Figure 6.1: Lineament map of Pennsylvania interpreted from ERTS-1 Channel 7 transparencies. Dotted, dashed, and solid lines denote lineament classes and letters indicate the various components of each lineament (see text for further explanation). Numbers indicate mineral deposits associated with individual lineaments (see Section 6.6).


ERTS-I LINEAMENT MAP OF PENNSYLVANIA
Explanation
Best expressed and most linear features visible
Features of intermediate linear expression
Marginally linear features
Alignments of major stream or other water body segments (water visible) → A
Alignments of minor stream segments (water not visible) → B
Alignments of tonal features not fitting designations A or B → C
0 10 20 30 40 50 KM
Lineament interpretation by W S Kowalik
Base map of Pa by U S G S at 1:1,000,000
Images Interpreted:
ID No Date
1 1407-15350-7 3 Sep 73
2 1407-15352-7 3 Sep 73
3 1046-15295-7 7 Sep 72
4 1244-15312-7 24 Mar 73
5 1459-15221-7 25 Oct 73
6 1045-15240-7 6 Sep 72
7 1495-15222-7 30 Nov 73
8 1080-15183-7 11 Oct 72
9 1080-15185-7 11 Oct 72
10 1079-15124-7 10 Oct 72
11 1079-15131-7 10 Oct 72

expression from one to three, where class three lineaments are the straightest and best expressed. On the map, these classes are represented by a dotted line (class 1), dashed line (class 2), and solid line (class 3).

In addition, each lineament was categorized by the components of its composition as: (A) straight segments of major streams, i.e., where water is visible; (B) straight segments of minor streams, particularly alignments of these segments; and (C) alignment of tonal features; e.g., swampy patches, small streams, vegetation, and wind gaps. This classification is descriptive only; genetic relationships are incidental to the mapping scheme.

The overlays from each image mapped were checked against 1:250,000 topographic maps and linear features clearly corresponding to cultural artifacts, such as roads, power lines, pipe lines, field boundaries, plough patterns, and trails were removed from the final compilation. Topographic features along which cultural features have been built were retained as lineaments, however. Lineaments along primary lithologic contacts were avoided, but those representing secondary or imposed structures, such as the trace of dikes or faults, were included. Where available, Skylab S190B photography was used to verify the plots.

After the lineaments were digitized for computer processing, three FORTRAN IV programs were written to sort the data by lineament length and by degree of expression and type, and to plot their orientation. In addition, two programs were written to provide CalComp plotter line maps at desired scales. By this means, the lineament map was enlarged to the scale of the Stream Map of Pennsylvania (1:380,160)* on which all known metallic mineral localities, mineral prospects, and abandoned and working mines had been plotted.

It is believed that the lineaments remaining on the final map of Figure 6.1 have structural significance. However, summarization of lineament orientation by frequency, length, and degree of expression, and comparison with lineaments seen on Skylab photographs, indicate a bias is present against detecting lineaments near the sun azimuth and near the scan line direction. It can be seen in Figure 6.2 that the ERTS-1 histogram shows a double peak to the northwest whereas the Skylab histogram shows a single broad peak in that position. The double ERTS-1 peak appears to be primarily a function of the lack of lineaments detected parallel to the sun azimuth. The Skylab histogram also shows a decrease of lineaments detected parallel to its sun azimuth.

Geologists mapping lineaments should be aware of illumination and scan line biases prior to interpreting lineament distributions. Use of repetitive spring, fall, and winter satellite images for interpreting lineaments in a particular area should reduce the sun azimuth bias.

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*Higbee, H. M. (1965) Stream Map of Pennsylvania. Agricultural Experiment Station, College of Agriculture, The Pennsylvania State University, University Park, Pa. 16802

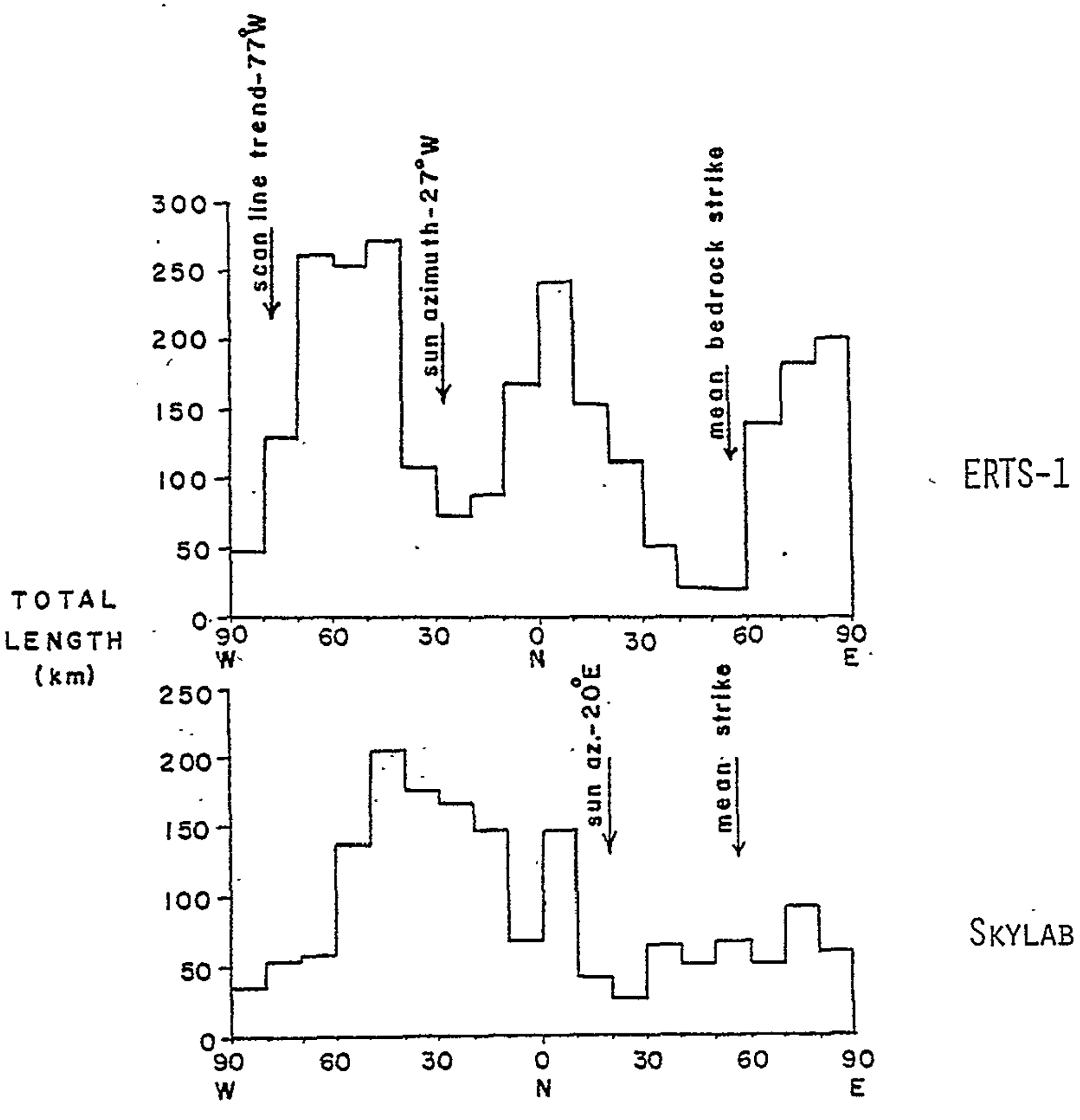

Figure 6.2: Summed length-versus-orientation histograms for ERTS-1 and Skylab lineament interpretations.

Lineament degree of expression is also somewhat dependent on these biasing factors and is not necessarily a measure of the extent of structural disturbance underlying the lineament.

6.2.2 Scale (D. P. Gold, R. R. Parizek, and S. S. Alexander)*

Three scales of lineaments have been recognized: 1.6 to 8 km, 8 to 80 km, and 80 km to a few hundred kilometers long. Lineaments on a sub-continental scale are anticipated. There seems to be an inverse relationship of length to abundance and density. Lineaments appear to have a consistent relationship to fold and fault axes, are generally straight features, cut across physiographic provinces, and are not influenced by faults. Their linear nature, regardless of topography, suggests they are the surface expression of near-vertical fractures or fracture zones. They transgress rocks of all ages in Pennsylvania. They are not obscured by blankets of residual and transported soil, or even Pleistocene glacial drift. These deep-seated features apparently imprint themselves on younger deposits in a systematic manner and are themselves inherently old. Major lineaments, for example, can be traced from Precambrian metamorphic and igneous rocks through overlying Paleozoic sedimentary rocks and into the down-faulted sediments and diabase sills of the Triassic Basin. They must represent either rejuvenated fractures, a "tectonic inherence" from the underlying crustal rocks; or a recently imposed fracture system, as might be expected from stresses associated with a drifting lithospheric plate.

Some "lineaments" are actually fault traces, in that lateral offsets in individual rock layers can be established. Many major faults previously mapped transverse to regional stratigraphic or structural strike in Pennsylvania appear on ERTS-1 images. Some previously unmapped faults have also been identified, and more should become evident with further study. Recently, the probable motion, deduced from first arrival directions of both the P and S waves, for an earthquake near Philadelphia, was combined with lineament directions mapped from ERTS-1 imagery to locate the most probable fault plane.**

A preliminary look at the problem of scale as it affects lineaments and fractures in other areas has been made. A link in mechanism between joints; fracture traces; and short, intermediate, and long lineaments; is suggested. Their identification is apparently also related to scale. A study of these relationships is a major objective of ORSER's on-going research. It is planned to systematically map the lineaments and fold axes of Pennsylvania on a scale of 1:250,000. A tectonic map of the state will then be developed, with the aid of existing structural data provided by the Pennsylvania Topographic and Geologic Survey.

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*Lineament scales are discussed further in ORSER-SSEL Technical Reports 1-74 and 10-74.

**The seismic data were compiled by Dr. Shammus of the Geophysical Section of the College of Earth and Mineral Sciences, The Pennsylvania State University, in cooperation with seismologists from the Lamont Geophysical Observatory of Columbia University, New York.

6.2.3 Correlation with Ground Truth (D. P. Gold, R. R. Parizek, and S. S. Alexander)*

The problems of optimum viewing scale and elevation of vantage point, so marked in plotting lineaments on aerial photographs, have been all but eliminated through the ERTS-1 and Skylab programs. A number of relationships require investigation, however, concerning the nature and significance of lineaments. Among these are:

(1) the nature of the structural features that underlie lineaments, their width and depth, and the genesis of lineaments and other structures of larger and smaller scale;

(2) accurate ground location of lineaments observed on satellite images, to permit direct observation and use in field studies; and

(3) the establishment, under controlled conditions, of the significance of lineaments to geologic and engineering applications.

Fracture traces and lineaments are commonly straight and unaffected by topography; hence, they are considered surface manifestations of vertical to near-vertical zones of fracture concentration. Although occasionally curved, lineaments are apparently independent of regional structural trends. In the Ridge and Valley Province of the Appalachians, for example, lineaments have been mapped across folded bedrock with vertical dips. There is no evidence of offset of beds on either side of a fracture trace or lineament, even when beds are thin, distinct, and relatively well exposed. The same is true where fracture zones have been seen on outcrops. It has been observed in cross-section that fracture traces are underlain by:

(1) relatively few closely spaced joints which cut one or more beds but do not cut overlying or underlying beds,

(2) relatively few closely spaced joints which cut all beds exposed at a given location, or

(3) hundreds of closely spaced fractures which give the rock a brecciated appearance.

With the exception of scale, the resemblance of lineaments to fracture traces is striking. Lineaments observed on ERTS-1 images have many of the morphological characteristics of fracture traces, although they are longer, wider, exert a major influence on topography, and are not at all obvious in the field because of their scale.

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*Further discussion relevant to the material in this section may be found in ORSER-SSEL Technical Reports 1-74 and 10-74.

It may be seen, from careful examination of ERTS-1 and Skylab scenes, that one of the most pronounced expressions of lineaments is the alignment of topographic features, such as wind and water gaps, upland sags and depressions, and segments of stream and river valleys. Selected straight valley segments, particularly, smaller tributary valleys, have been shown to be controlled by zones of fracture concentration. Such valleys have abrupt, sometimes nearly right angle, turns at fracture trace intersections, resulting in an apparent meander pattern in youthful, incised streams. Parizek has shown that fracture zones heavily influence stream patterns in carbonate and other valleys of the central Appalachian Mountain region. On adjacent uplands, solution along zones of fracture concentration results in subsidence of unconsolidated soils. This produces lines of shallow depressions, and, in carbonate terranes, aligned perched ponds and sinkholes. Master joint sets, together with zones of intersecting fracture concentrations and bedding plane openings, have been shown to produce irregular offsets in new tributaries.

Lineaments from 1 to 10 km in length, recognized prior to the ERTS-1 program, show a pattern of valley development control similar to that of fracture traces but on a larger scale. Lineaments 10 to 100 km in length, recognized only recently on ERTS-1 images, show identical relationships. It appears safe to conclude, therefore, that they control valley development for the same reason that shorter lineaments, fracture traces, and fault zones do; namely, that they are underlain by zones of fracture concentration which facilitate differential chemical and physical weathering and control secondary permeability and porosity development.

Positive verification of the significance of lineaments to the performance of water wells, foundations, tunnel and mine roofs, and so on, must be made on a case-by-case basis, with comparison of a number of similar situations located on and off lineaments. It is easy to design the necessary verification studies; however, their implementation is hampered by the lack of high quality field data and the opportunity for repetitive observations--especially in humid regions characterized by a thick soil cover, dense vegetation, and variable geology.

A field study of a cross-section of the Tyrone - Mount Union Lineament is described in the next section. Subsequent sections describe several studies to determine the relationship of lineaments to specific areas of geologic, economic, and engineering concern.

6.3 A Field Study of Lineaments in Cross-Section (M. D. Krohn and D. P. Gold)*

Construction on a portion of the Route 220 bypass at Tyrone, Pennsylvania, revealed highly variable bedrock conditions suspected to be related, in part, to lineaments transecting the ridge at the construction site (Figure 6.3). Existing geologic maps are too small in scale

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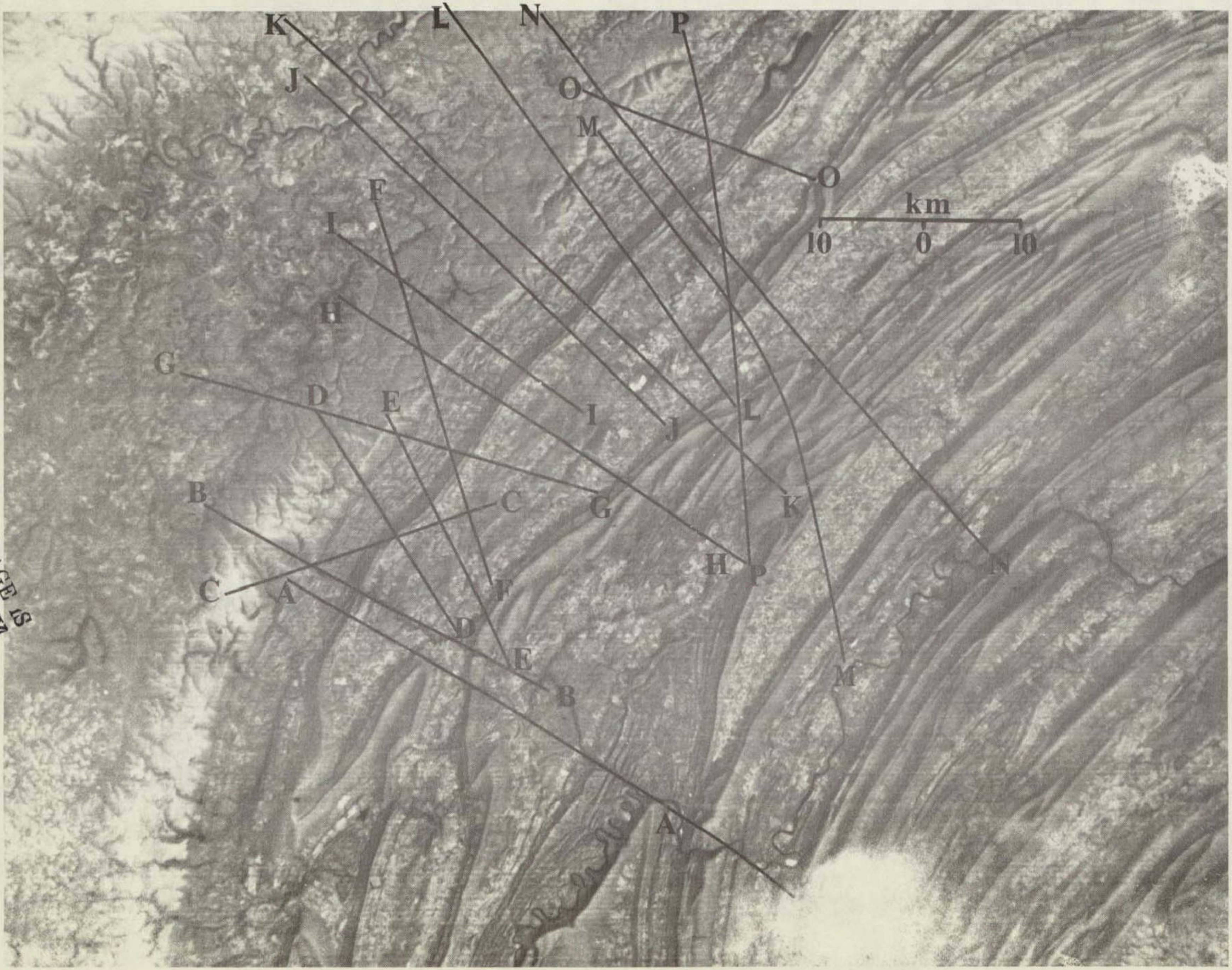
*This study is described further in the M.S. thesis by M. D. Krohn.

Figure 6.3: Enlargement of ERTS-1 scene with lineaments plotted across Bald Eagle Mountain. Lineaments CC and DD intersect on the crest of Bald Eagle Mountain; the construction site extends approximately 5 km south of the intersection of Lineament BB with the ridge, along its northwestern flank. (Scene 1243-15253, 23 March 1973, Channel 7.)



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to predict such conditions, and poor exposures in Bald Eagle Valley, especially in lower hill slopes, render geological mapping a difficult and imprecise task. The construction site presented an excellent opportunity to study lineaments in cross-section.

The new highway, northeast of Tyrone, parallels Bald Eagle Mountain along its western flank from the village of Bald Eagle to south of Grazierville. It spans three lineaments (AA, BB, and CC of Figure 6.3). Structurally, the western flank of Bald Eagle Mountain represents the steeply dipping northwest limb of the Sinking Valley Anticline. By analogy with the overturned beds where Route 322 crosses the ridge to the northeast, the overturned beds exposed in the road cuts are not anomalous; however, the degree of fracturing and faulting encountered was far greater than indicated on the geologic map.* Two zones of poorly drained and friable material coincided with the trace of Lineaments AA and CC (Lineament DD may also be involved near its intersection with CC). The road cuts in these localities remained unstable; hillside creep was active and small landslides developed on the graded slopes, especially during spring thaw and runoff, and after heavy and prolonged precipitation. A large volume of material had to be excavated from the site at its intersection with Lineament AA (the Tyrone - Mount Union Lineament).

The excavations about 1 km southwest of the village of Bald Eagle (close to the intersection of Lineaments CC and DD) exposed Helderberg Limestone, Oriskany Sandstone, Marcellus Shale, a fault, and two zones of fractured rocks. The geology was mapped in a plane-table survey on a scale of 1:1200 and updated as bedrock was excavated or contacts uncovered by construction.

Along the exit ramp north to Route 350 and the village of Bald Eagle, the following sequence of steeply dipping to overturned beds were encountered:

(1) coarse to medium grained sandstone,

(2) grey limestone (fragmental and fossiliferous in places),

(3) brown-weathered shale grading down-section into black shale, and

(4) highly friable sandstone overlain by talus near the northern end of the roadcut.

The sedimentary contact between the sandstone and limestone is well exposed; these beds represent the Oriskany and the Helderberg Formations in faulted contact with the younger Marcellus Shale member of the Hamilton Formation. This fault, which strikes northeast across the road, is transverse and exhibits right-lateral separation. A ridge offset to the east with the right sense of displacement is apparent on the ERTS-1

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*Butts, C., F. M. Swartz, and W. Bradford (1939) Tyrone Quadrangle, Atlas of Pennsylvania, No. A96. Fourth Pennsylvania Geological Survey.

imagery, as well as on Skylab and U2 aircraft photography.* Approximately 200 m further north, friable sands from the brecciated Oriskany Formation (probably the Ridgeley Sandstone Member) were exposed at the base of the roadcut and overlain by deep talus. This zone extends approximately 100 m into talus near the northern end of the embankment.

The sandstone was saturated with water in several places, promoting a quick condition. Hillside creep was active and small slumps were common. A large part of the bank had to be excavated when it threatened to slide. It was further evident that this zone was a conduit for groundwater when the concrete roadbed cracked and heaved approximately 30 cm. Test holes drilled through and adjacent to the roadbed revealed a rise in the piezometric surface of approximately 1 m with artesian water flow.

It is evident that the fractured materials represent zones of high porosity and permeability. These zones collect and channel groundwater and result in the development of landslides on artificial slopes. Furthermore, there appears to be good correlation of these zones with lineaments seen on the ERTS-1 imagery.

6.4 Lineaments and Geologic Structure (D. P. Gold, W. S. Kowalik, R. R. Parizek, B. L. Weinman, and S. S. Alexander)**

Lineaments represent a significant new class of structural element, one which may generate a resurgence of studies of global fracture patterns and may tie into studies of plate tectonics. The ERTS-1 program has spurred further investigation of a theory, offered by Moody and Hill in 1956,*** to account for the size and frequency of linear features on all scales. This theory is being developed by Drs. Gold, Parizek and Alexander in an effort toward dynamic analyses of stress distribution.

The longest lineaments (Figure 6.4) detected on ERTS-1 images are probably tear faults, as defined by Gwinn† in the Paleozoic strata overlying the basal Appalachian decollement (Figure 6.5). They

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*Skylab 3, Orbit 14, 5 August 1973, S190A, Roll 21, Frames 191 and 192. Skylab 4, Orbit 73, 4 January 1974, S190A, Roll 55, Frame 317. U2 Mission 016, 5 February 1974, Sensor 23, Frames 6120 and 6121. U2 Mission 060A, 25 April 1974, Sensor 17, Frames 8127 and 8128.

**With two exceptions, further information concerning the work discussed in this section may be found in ORSER-SSEL Technical Reports 1-74 and 13-75. The relationship of lineaments to joint orientations is discussed in TR 12-75, and the thermal springs study is discussed in the M. S. Thesis by Weinman (in preparation).

***Moody, J. D. and M. J. Hill (1956) Wrench Fault Tectonics. Bulletin, Geological Society of America 67:1207-1246.

†Gwinn, V. E. (1964) Thin-Skinned Tectonics in the Plateau and Northwestern Valley and Ridge Province of the Central Appalachians. Bulletin, Geological Society of America 75:863-900.

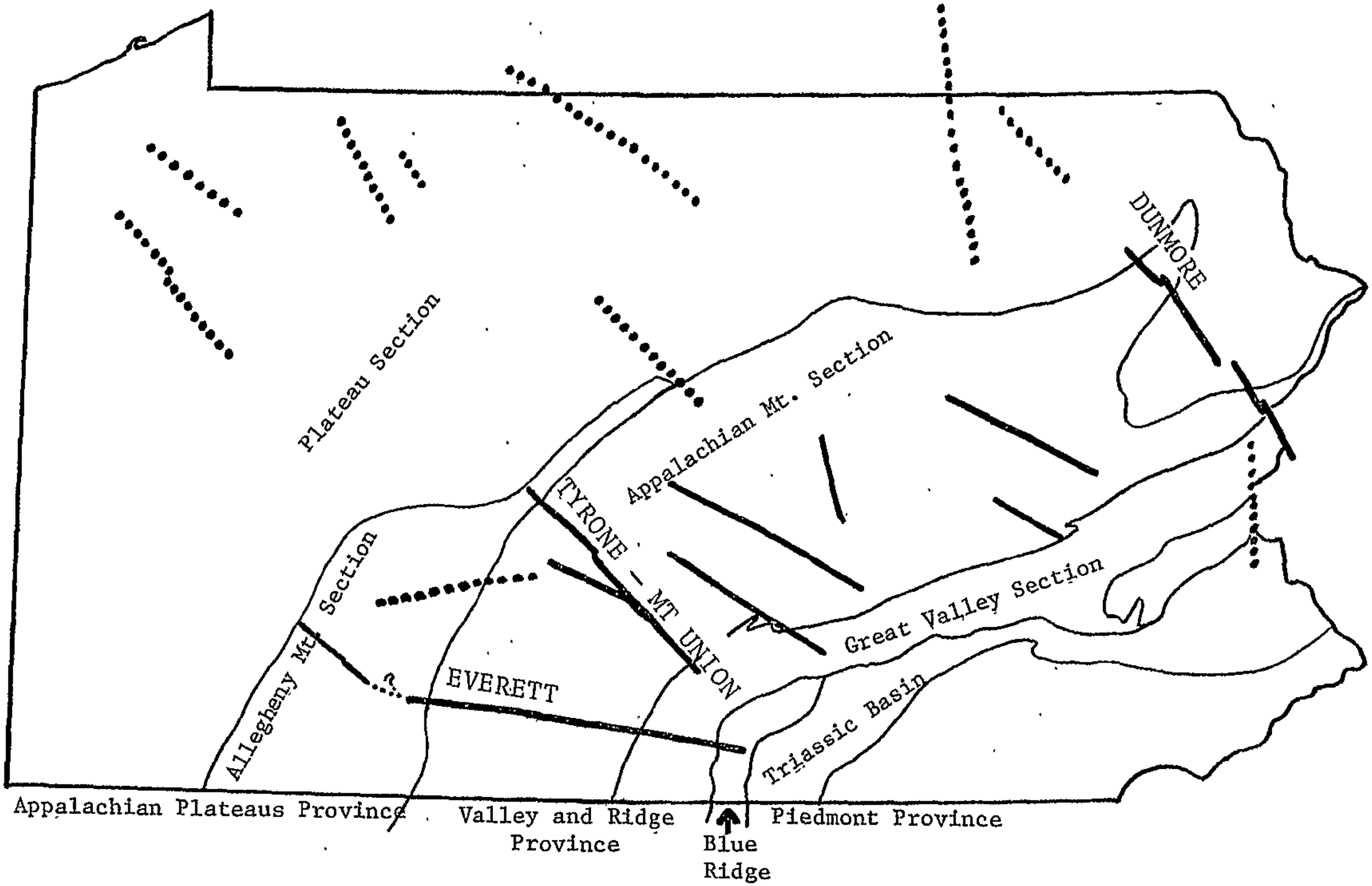

Figure 6.4: Distribution of the longest lineaments identified in Pennsylvania from ERTS-1 images. The solid lines represent the best expressed "Gwinn-type" lineaments, and the dotted lines are possible "Gwinn-type" lineaments.

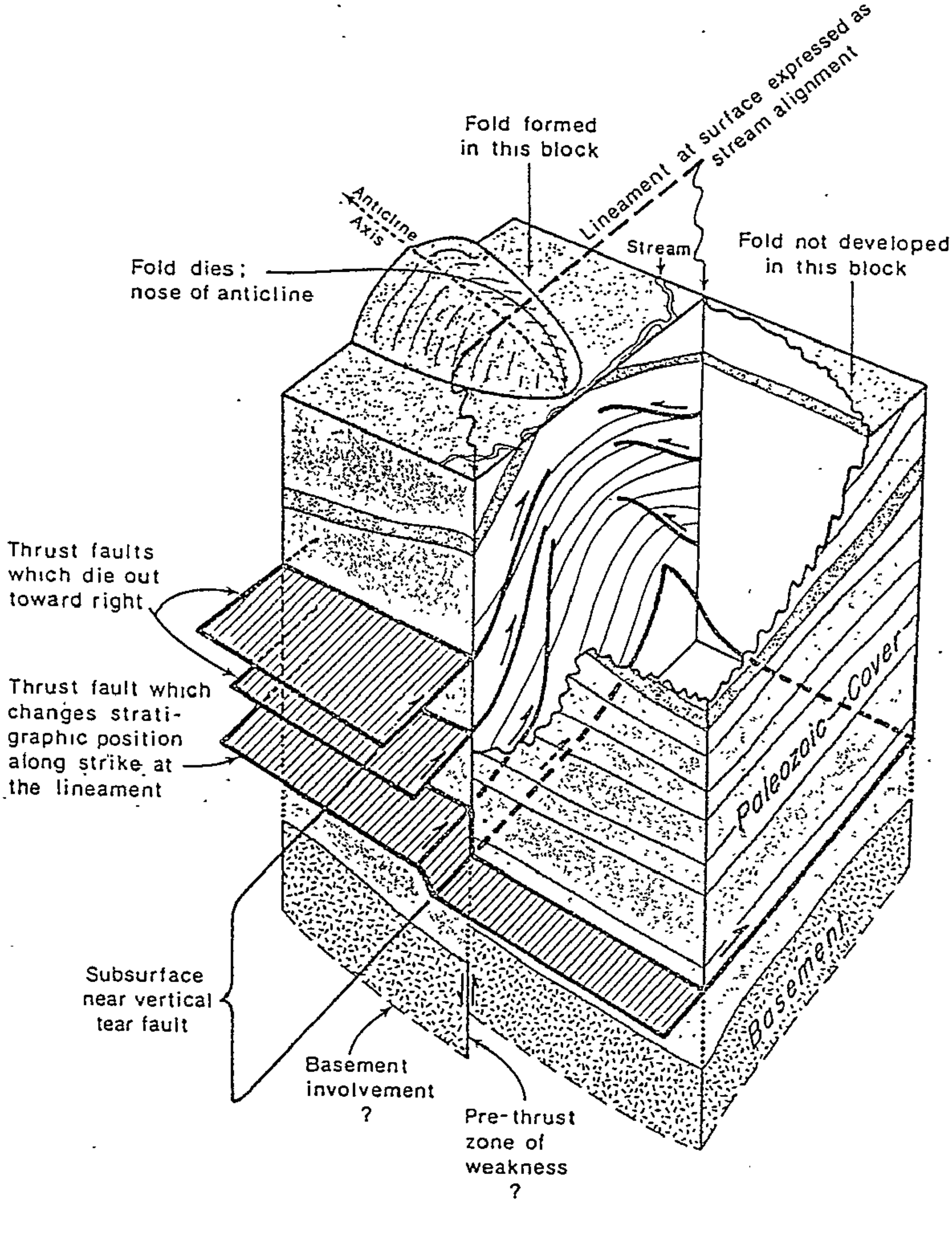

Figure 6.5: Idealized block diagram showing the postulated three-dimensional structure of a "Gwinn-type" lineament. These lineaments are thought to represent the boundary between semi-independent thrust blocks.

characteristically pass along the noses of plunging folds. These may also be basement related, as they appear somewhat analogous to two lineaments described in Alabama by Drahovzal et al.* which are evidently basement-controlled. One of these in Pennsylvania, the Everett Lineament, if extended across part of the Great Valley, also traverses the Blue Ridge, suggesting that the basal decollement extends below the Blue Ridge toward the east.

Many shorter lineaments trending across strike may be related to tears in upward splaying thrusts. The passage of many probable buried tear faults through wind and water gaps indicates that the gaps are points of structural weakness and are not randomly located, as theories of drainage superposition contend.

The origin of shorter lineaments may be more consistent with a tensional than a shear model. A study of the coincidence in direction, regardless of scale, of joints, fracture traces, and lineaments, in an area of the Allegheny Plateau in central Pennsylvania, has suggested a mechanical relationship among these features. Lineaments mapped from a portion of an ERTS-1 image** and a Skylab photograph*** were compared to major shale-joint and coal-cleat orientations in the area of the Snowshoe and Renovo West USGS 7-1/2 minute quadrangle maps. The joint directions tended to coincide with the strike of fracture traces and lineaments, rather than lying at acute angles--as would be expected if there was a second order relationship between the surface linear features and joints. It seems likely that joints and lineaments in undisturbed strata are differently scaled effects of a continuous range of natural linears of similar origin. It has been frequently observed that there is an apparent inverse relationship between joint frequency and bed thickness when other factors, such as lithology and degree of tectonic deformation, are constant. Thus, lineaments may be produced by body forces acting on mega-layers of the earth's crust in much the same fashion that fracture traces may be produced in structurally coherent thicknesses of strata. These same forces, at much higher frequencies, may also provide joints parallel to the larger lineaments in individual lithologic units.

In a study of an area of folded rocks east of Harrisburg, Pennsylvania, in the Ridge and Valley Province, the intermediate and shorter lineaments appear to be conjugate with an angle of about 30° to a northwesterly trending axis. These shorter lineaments, spaced about 1 km apart, cut across regional primary structure and often across major physiographic province boundaries as well. Except for those coincident with known faults, the three-dimensional physical nature of lineaments is unknown. However, by analogy with fracture traces, it is speculated that they are underlain by concentrations of fractured and jointed rocks and represent zones of deformation or movement between "jostling" crustal blocks.

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*Drahovzal, J. A., T. L. Neathery, and C. C. Wielchowski (1973) Significance of Selected Lineaments in Alabama. Third Earth Resources Technology Satellite - 1 Symposium, Technical Presentations 1(A):897-918.

**Scene 1459-15221 (25 October 1973) Channel 7.

***Skylab 4 (4 January 1974) S190B, Roll 91, Frame 324. The Skylab photograph was used to compensate for the illumination bias in the ERTS-1 Scene.

They transgress rocks from Precambrian to Triassic age and, although they are partially blanketed by Pleistocene glacial drift, they are not obscured by it. They must, therefore, be either a rejuvenated crustal fracture system impressed on the younger rocks as active crustal "joints," or they represent deformation in response to a widespread and pervasively imposed stress field, as would be expected from a drifting North American crustal plate. Joint frequency studies have lent support to this latter hypothesis.

A Channel 7 ERTS-1 image* revealed that two lineament zones cross one another at the location of the only thermal springs in Pennsylvania. These springs, situated in Paleozoic strata in the central Appalachians, most likely do not have a volcanic source; hence, their origin has long been of interest to geologists. The lineaments are expressed morphologically as water gaps and as the surface expression of dikes, faults, and known zones of fracture concentration. If these lineaments overlie fracture zones which extend to depths proportional to the length of the lineament, then they would be expected to influence groundwater flow in the Warm Springs area--providing not only deep circulation paths for groundwater, but exercising control over the discharge location of the springs. The occurrence of cold and warm springs within 1 km of one another in the same geologic outcrop in this area substantiates this possibility. It is postulated that the fracture zones underlying the lineaments may provide channels for deep percolation and return of groundwater, resulting in the warm springs phenomenon. ERTS-1, Skylab, aircraft underflight, and thermal IR data are being used in an effort to determine the mechanism responsible for the springs.

A preliminary examination of the relationship of lineaments observed on the ERTS-1 mosaic to such aeromagnetic intensity maps as are available for Pennsylvania revealed a distinct difference between the correlation in the western and eastern portions of the state. In western Pennsylvania, where the lineaments appear to connect magnetic lows, the magnetic anomalies are thought to be basement controlled. In the eastern portion of the State, the anomalies are highly concentrated and tightly intertwined, with no visible relationship between lineaments and the magnetic patterns. The implication of these differences has not yet been studied.

It is evident that the lineaments seen on ERTS-1 images have had a profound influence on geologic thinking and have stimulated a wealth of new interpretations of global tectonics. The task remains to establish the true nature of these linear features through careful and detailed study of data at all scales, as well as in the field.

6.5 Lineaments and Groundwater (R. R. Parizek)**

A considerable amount of work over the last 17 years has established the nature of fracture traces and their significance in engineering and

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*Scene 1243-15253 (23 March 1973)

**This work is being continued on EREP Contract NAS 9-13406, after which a technical report will be issued.

groundwater exploration studies. Since data have been available from ERTS-1, analogies have been noted between fracture traces and lineaments, and it has been concluded that structures which underlie lineaments tend to permanently fix master drainages in a vertical plane.

Parizek has proposed the basic principle that valley environments favor increased local and regional permeability development in a wide variety of carbonate and other terranes and represent, therefore, excellent sites for potential high-capacity wells. The realization that joints, zones of fracture concentration, and fault zones localize valley development and, hence, contribute to secondary permeability and porosity development, supports this conclusion.

Many factors, however, combine to influence well yields at a particular location. Comparison of yields from a few wells and springs on or off a lineament will not suffice to establish a significant relationship, even though a strong inference may have been established. Several variables also influence the depth and extent of weathering and permeability development--factors which are of importance in engineering foundation studies, mine and tunnel roof stability analyses, and similar investigations, as well as in groundwater prospecting.

To date, more than 2000 water wells which lend themselves to analysis have been inventoried by various workers within Pennsylvania. This has resulted in no more than 800 wells which have been available for conducting controlled pumping tests. The data points, obtained under similar pumping test conditions and known field conditions, have been compiled and used in the analysis of well yields to determine the significance of lineaments. They have been ranked by topographic and geologic setting, well radius, depth, duration of testing, and similar factors. Yields have been standardized to a common well radius, depth of penetration, and pumping duration.

Because of the many factors which influence well yields within a given rock unit, a number of conditions must be satisfied to conclusively prove a relationship between lineaments and permeability development. A critical condition is the precise location of lineaments on the ground, for which ERTS-1 images do not have sufficient resolution and aircraft underflight photographs have too large a scale. A helpful factor in development of this study, therefore, was the availability of Skylab photography, although the limited coverage of the Skylab scenes prevented their use in many cases.

One method by which the relationship between lineaments and permeability development may be determined is to analyze all wells available within a given region for which construction details are known and tests can be conducted under controlled conditions, and for which the number of influencing variables is limited or kept constant. Here one relies upon the probability that as the number of well control points increases the likelihood also increases that wells will fall within all combinations of conditions that influence permeability development. Unfortunately, a number of well points must fall within each combination of conditions being tested for significance before one can conclusively prove which of the many possible factors influence the yields and the extent to which each contributes. Time-consuming studies using this approach have been completed within four regions in Pennsylvania and the significance of geologic variables contributing to permeability development determined. These studies included the influence exerted by fracture trace and non-fracture trace related structures.

A more efficient method of study to achieve early benefits and to establish the significance of fracture trace and lineament-related bedrock structures is to keep as many variables constant as possible, thereby reducing the number of data points required in the analysis. Ideally, wells should be drilled, completed, and developed under identical conditions, and located within a single rock type under one topographic and structural setting. Only the lineament/non-lineament variable should be permitted to vary. However, this experimental design could not be strictly adopted because existing well control data had to be relied upon in the study. Therefore, yields were tested for wells on and off lineaments and either within a single rock type or within a series of associated rock types, with all other factors, such as well depth, diameter, topography, fracture traces, and dip of beds permitted to vary.

Well Yields from a Single Rock Type. Well yield data were obtained from the Upper Sandy Dolomite Member of the Gatesburg Formation, of Late Cambrian age, in a selected area of Nittany Valley in central Pennsylvania. Wells were located on fracture traces, at fracture trace intersections, and remote from fracture traces; within beds of various dips, ranging from 0 to 30°, and in a variety of topographic settings. They were considered to be on lineaments if they fell within a 1 km wide belt, as defined from the ERTS-1 or Skylab scene,* and off lineaments if they fell beyond this assumed width. The yield data were adjusted for depth of saturated rock penetrated or exposed below the casing.

Some wells were highly productive regardless of whether they were on or off lineaments (according to the definition established). These most typically fell on fracture traces or at fracture trace intersections. It was evident that a positive benefit can be derived by combining both fracture traces and their intersections with lineaments, wherever possible, when locating wells for maximum yield.

Well Yields in Folded and Faulted Sedimentary Rocks. Controlled pumping tests were conducted on 59 domestic and farm wells within a 155 km^2 test area in the Valley and Ridge Province. The wells were completed in the partially folded and faulted rocks of either the Trimmers Rock Sandstone or the Catskill Formation, of Devonian age. They penetrated sandstone, siltstone, shale, or interbedded siltstone and shale beds. The data were obtained under controlled testing conditions and adjusted to a common well radius, depth, and duration of testing.

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*ERTS-1 Scene 1045-15243 (6 September 1972) and Skylab 4 (4 January 1974) S190B, Roll 91, Frame 323.

When the wells were initially ranked as on or off fracture traces with an assumed width of 13.3 m, there appeared to be no significant difference between the yields of the two categories of wells. Subsequently, however, zones of fracture concentration exposed on bedrock escarpments 95 to 120 km to the east were mapped and the width of fracture concentrations measured at 9 stations. The average width was found to be 10.3 m. When these wells, together with ten intentionally located fracture trace wells, were ranked again, using this width, it was found that those located on these newly-defined fracture traces had significantly higher yields than the other wells tested. These results indicate the importance of directly penetrating zones of fracture concentration for increased yield and knowing the width of controlling structures revealed by fracture traces. An incorrect assessment of width will easily lead to an incorrect conclusion concerning the significance of fracture traces in groundwater prospecting and even abandonment of the procedure; and, by analogy, the same should hold true for lineaments. Hence, ORSER geologists are concentrating on field studies designed to determine the underlying fracture pattern and width of lineaments in various rock types.

In order to determine the influence of topography on well yield, the region was subdivided into upland, valley wall, and valley bottom settings. Two distinct populations were obtained, indicating that wells located in valley bottoms have significantly higher yields than those located in valley wall or upland settings. Segments of most valleys in the study area define fracture traces; hence, the valleys must be largely structurally controlled. Joints, plus weathering along these joints, probably are much more extensive and better developed in the valley bottoms than in the walls or uplands, resulting in a greater flow of water to wells. Other factors also contribute to higher well yields in the valley environment, but they were not isolated here.

It also appeared that valley bottom wells have more variable yields than wells in the other two settings. It was apparent that a lineament related valley was one of the factors responsible for the variable yields in valley bottom wells. A plot of the yields showed that there were two distinct populations present: one consisting of wells located on two lineaments in a valley at Klingerstown Gap and the other consisting of the remaining valley bottom wells (Figure 6.6). This finding was reinforced when valley bottom wells located on fracture traces were compared with valley bottom wells located adjacent to or remote from fracture traces: the valley bottom wells off fracture traces appeared to be more productive than those located on fracture traces. However, when all data from wells located opposite the Klingerstown water gap were eliminated, these results were reversed.

Two explanations have been offered to account for the higher yields at Klingerstown Gap. Somewhat permeable and saturated floodplain sediments are known to occur in the area. These can serve as a source of vertical recharge to underlying joints and fractures, supplying water to wells cased into bedrock and tested for yield in this setting. However, all pumping tests were of short duration and these influences should not have been brought into play. A more likely explanation is

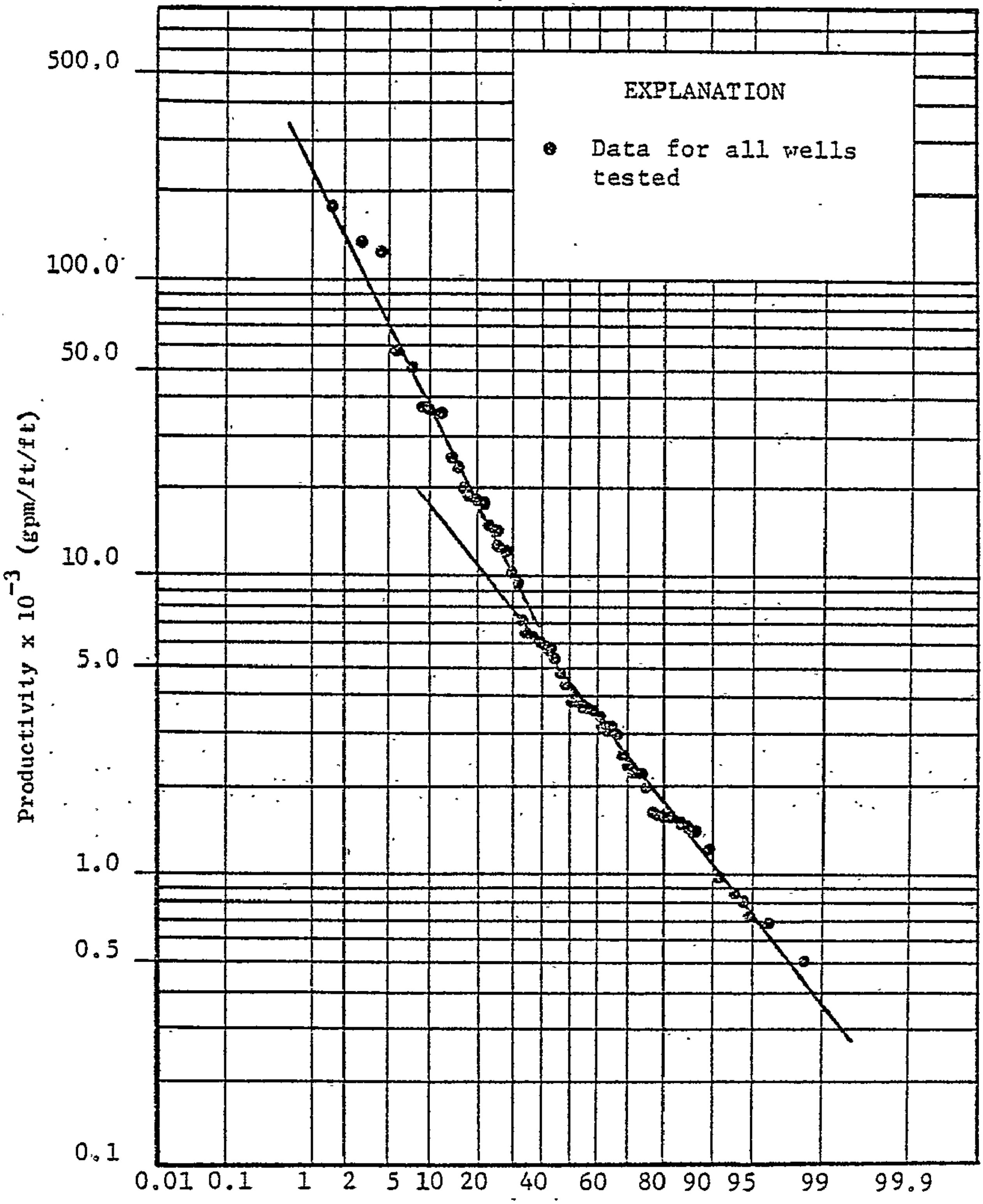

Figure 6.6: Productivity frequency graph for 59 wells located in folded shale, siltstone, and interbedded shale and sandstone of Devonian age. The break in slope reveals that two distinct populations are being sampled. Nearly all wells which define the high-yield population are located on one of two lineaments at Klingerstown, Pennsylvania. (Productivity in ℓ/sec/m/m may be obtained by multiplying gpm/ft/ft by 0.679.)

that the Klingerstown wells are located opposite a water gap controlled by a regional zone of fracture concentration, revealed by lineaments mapped on ERTS-1 and Skylab scenes. Alignment of the water gap with segments of the master stream and adjacent tributaries, and topographic breaks in nearby uplands, reveal structural controls on the gap. The width of these structures and the exact position of the lineaments with respect to the wells are not precisely known, but a zone 1 km wide would encompass all the wells tested for yield in the gap. It is significant that the Klingerstown wells are among the most productive wells in the entire study area.

Further support for the significance of lineaments in groundwater prospecting can be obtained from scattered wells located opposite, or within, other water gaps. Two wells at Spring Bank and several at Potters Mills, Pennsylvania, were drilled opposite lineament-controlled water gaps and showed comparatively high yields when compared to other wells drilled into the same formations at immediately adjacent locations remote from lineament-controlled water gaps. Three wells drilled near Shingletown, Pennsylvania, in an underdrained, lineament-controlled, valley and on fracture trace intersection sites, are among the most productive wells ever drilled in the region and completed in the Nittany Dolomite of Ordovician age.

Although various geologic and hydrologic factors other than lineaments could account for the yield differences observed here, and additional field study is necessary, success to date indicates that ERTS-1 data are a significant aid in groundwater exploration. It is apparent also that knowledge of the distribution of zones of fracture concentration and high permeability has implications for investigations of oil and gas migration and leakage, as well as for groundwater prospecting and any other geologic or engineering investigation concerned with groundwater movements and occurrence.

6.6 Lineaments and Metallic Ore Deposits (D. P. Gold, W. S. Kowalik, and M. D. Krohn)*

The results of recent mineral exploration in central Pennsylvania suggest that the megascopic fracture pattern of the Appalachian Mountain system may have had a controlling influence on the location of metallic sulfide occurrences. To explore this possibility further, the lineament map of Pennsylvania was compared with the distribution of known metallic mines and mineral occurrences in the state. Of 383 known mineral occurrences, 116 show a geographic association with 1 km wide lineaments, 25 are found at the intersections of two lineaments, and one lies at the intersection of three lineaments. The Perkiomen Creek lineament, in the Triassic Basin of southeastern Pennsylvania (Lineament 90 on Figure 6.1) is associated with nine copper-iron occurrences. The Tyrone-Mount Union Lineament, a marked topographic feature over 160 km long in central Pennsylvania (Lineament 53 on Figure 6.1) is the locus of seven lead-zinc occurrences within three separate host lithologies, one copper occurrence, and at least

*Further discussion of the ore deposit study may be found in ORSER-SSEL Technical Report 14-75. The Bald Eagle Mountain study is discussed in the M.S. thesis by M. D. Krohn.

three known fault zones. Thirteen other lineaments are associated with three, four, or five mineral occurrences each.* Eleven mines with production exceeding $1,000,000, and 23 mines with production less than that figure, lie on 1 km wide lineaments. These distributions strongly suggest a genetic relationship--particularly, where large numbers of mineral occurrences lie along a single lineament.

Discrete areas of finely-fractured and brecciated sandstone float along the crest of Bald Eagle Mountain, in central Pennsylvania, have been found to be potential sites of sulfide mineralization, as evidenced by the presence of barite and limonite gossans. The negative binomial frequency distribution of the brecciated float supports the interpretation of a separate population of intensely fractured material. Such zones of concentrated brecciated float have an average width of 1 km with a range from 0.4 to 1.6 km and, where observed in outcrop, have subvertical dips. Direct spatial correlation of the ERTS-1 derived lineaments and the fractured areas on the ridge is low; however, the mineralized and fractured zones are commonly parallel to, but offset from, the lineament positions (Figure 6.7). This systematic dislocation might be a result of an inherent bias in the float population or might be the product of the relative erosional resistance of the silicified material in the mineralized areas.

Further work with surface and subsurface structural expression of lineaments will be necessary to define and separate lineaments genetically, and to sort out those most likely to be mineralized. The results shown here should encourage further field study of lineaments in varied terranes. Such studies, combined with more accurate lineament plots, such as would be available from Skylab-type photography, should result in a map which would be a valuable prospecting tool.

6.7 Lineaments and Non-Metallic Deposits

Little is known of the relation between lineaments and non-metallic deposits in Pennsylvania, and this was not a significant thrust in the investigations conducted for this contract. Nevertheless, a study was conducted to determine if there was a possible relation between clay deposits and lineaments, and a program has been initiated to study the relation between coal distribution and lineaments.

Clay Deposits.** White kaolinitic clay deposits in the Gatesburg Formation of central Pennsylvania were compared to linear features seen on ERTS-1 images and aerial photography in order to test the hypothesis that the feldspathic horizons are weathered to kaolinite only where groundwater percolation and weathering have been enhanced by rock fractures. Clay occurrences were mapped on 7-1/2 minute quadrangle maps from Bedford

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*Lineaments 1, 2, 10, 12, 15, 29, 47, 58, 60, 65, 83, 88, and 95 on Figure 6.1.

**A short report on this project has been issued as ORSER-SSEL Technical Report 26-74.

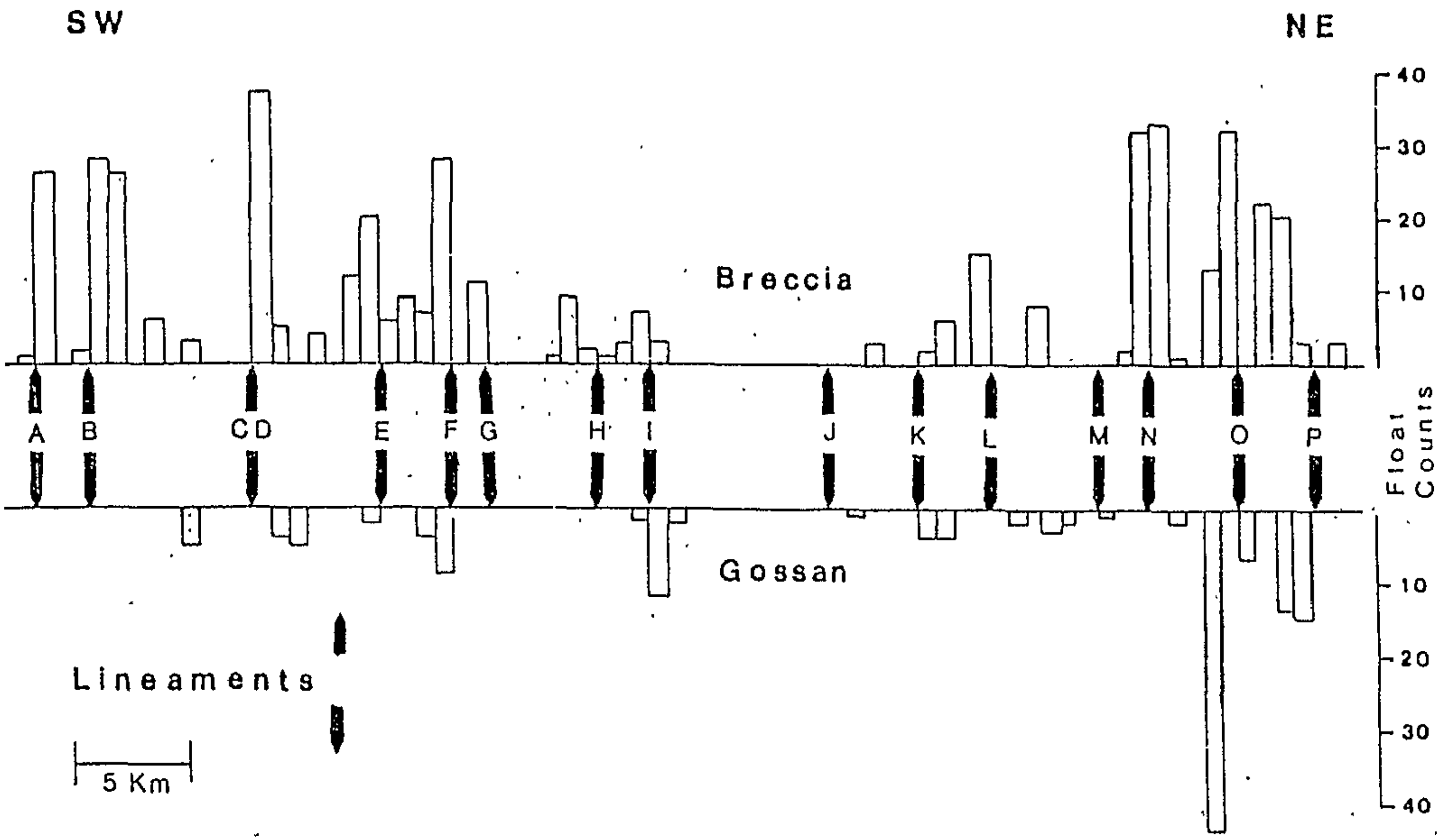

Figure 6.7: Histogram showing the spatial relationship of brecciated and gossan float to the position of lineaments crossing Bald Eagle Mountain. (The lineaments are plotted on Fig. 6.3.) Each bar represents the sum of two sample localities and is equivalent to 0.8 km along the ridge crest. Lineament C-D (see Fig. 6.3) represents the intersection of two lineaments at the ridge crest.

to Lamar and the lineaments transferred to the maps from the ERTS-1 imagery* and the aircraft photography** by means of a Saltzman projector. Of 22 deposits, only two had lineaments transecting them. In terms of mineralogy, petrography, and distribution of the various clay types, these deposits did not differ from the remaining twenty. At one clay location, not transected by linear features, a significant amount of kaolinite had altered to gibbsite, indicating local conditions of severe leaching. If lineaments or fracture traces have an influence on clay genesis in the region, the photography and imagery should have revealed them at this locality. It is concluded from the study of these deposits that factors such as bedding attitudes, initial rock porosity, and local topography are more influential in enhancing percolation in the area of study than is fracturing manifest as fracture traces and lineaments.

Coal Deposits. Investigations are being conducted in three areas of Pennsylvania to determine the influence of lineaments seen on ERTS-1 images, on coal distribution, coal quality, and mining problems related to rock structure. Two of the study areas involve bituminous coal deposits on the Allegheny Plateau, near Ebensburg and near Clearfield, and one is in the anthracite field of the Scranton/Wilkes-Barre area. Bethlehem Steel Corporation has been contacted for data on several underground mines, and ground truth is presently being collected in several localities.

6.8 Lineaments and Engineering Problems

Lineaments manifest themselves in all terranes in Pennsylvania and elsewhere, and cut across rocks of all ages and all degrees of fold/fault complexity. Preliminary data strongly indicate that lineaments will be useful in foundation engineering studies wherever increased weathering, porosity, and permeability development are significant--such as in planning tunnels, mines, and exploration and grouting programs for structures such as dams and foundations.

Not only are lineaments significant in the stability of engineering structures, but the placement of structures such as oil and gas reservoirs and nuclear power plants with respect to lineaments is a critical consideration. Accurate, large-scale lineament maps are essential for choosing sites with low probability of leakage and tectonic activity.

Increased soil moisture and perched groundwater and surface water bodies are frequently aligned along lineaments in areas where residual soils are well developed above carbonate bedrock. Lineaments should be useful, therefore, in delineating areas in carbonate terranes which are likely to experience surface drainage problems, sinkhole formation, settlement, and contribute to phenomena such as landslides. A study of the relationship of lineaments to a series of landslides in Pennsylvania is now in progress.

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*Scene 1243-15253 (23 March 1973).

**The aircraft photography used in this study was supplied in part by NASA C130 aircraft and in part by the USDA.

CHAPTER 7

DIGITAL DATA PROCESSING COST ANALYSIS

Computer and personnel time are the two major elements in the cost of analyzing and interpreting ERTS-1 digital data. Computing costs can be partitioned into those for spectral signature development and those for processing bulk data after the signatures have been developed. The major personnel cost is associated with the development of signatures, since remote sensing analysts and interpreters are required for this phase. Far less personnel time is required for bulk processing of data when classifying a large area, although analysts and interpreters remain closely involved in evaluating the products.

In the Susquehanna River Basin test site in Pennsylvania, two characteristics dominate the analysis and interpretation of ERTS-1 data: the diversity of targets and their small size. Compared with other areas, where these characteristics are less pronounced, signature development presents a greater challenge and is, therefore, likely to be more costly. The time involved in signature development is also contingent upon the nature of the particular problem to be solved and the cost is difficult to specify categorically for this reason.

7.1 Processing and Analysis

The costs of processing and analysis of ERTS-1 data presented here have been determined on the basis of experience on this project. These costs are typical for the production of a land cover map of an area in the range of 500 to 10,000 km^2 in Pennsylvania. They are based on the development of approximately 40 spectral signatures resulting in a final map showing 12 to 15 different categories. These costs also include correction of the data to a north-south orientation and scaling of the standard computer printout to 1:24,000. Color and gray-scale printouts are not included, but these would increase the total cost by less than ten per cent. Under these assumptions, a typical cost per square kilometer is $1.75, as follows:

Computation	$0.40
Salaries and Overhead	$1.05
Miscellaneous (including travel to collect ground truth)	$0.30
Total:	$1.75 per square kilometer

Overhead costs are based on the University rate of 75 per cent of salaries. Obviously, a different overhead rate and other variables, such as travel distances for collection of ground truth, would affect the above figures. Travel represents a very small portion of the above total, since the test sites were in close proximity to the University.

Computer run costs are based on the standard rates charged at the Computation Center of the University (e.g., 10¢/sec CPU time). The ORSER MSS computer analysis methods are designed for signature development based on short computer runs on small subsets of data, hence, they emphasize the minimization of computation costs. Computation costs per square kilometer may be broken down approximately as follows:

Subsetting of data	$0.01
Signature development	$0.11
Classification of area	$0.11
Final map product	$0.17
Total:	$0.40 per square kilometer

In subsetting, data from the original tape or from a previous subset are selected for the areas to be mapped and recorded on a separate tape. Subsequent processing with this subset tape avoids costly bypassing of unwanted data during signature development, as would be the case if the original tape were used in the analysis. Signature development costs will vary according to the heterogeneity of the area and the number of classes for which spectral signatures are desired. It is assumed that the training area used for signature development will be much smaller than the entire area to be classified and mapped. The apparently high cost of final map production includes correction to north-south orientation and scaling of the output.

The costs presented here represent a conservative analysis; it is strongly believed that they can be substantially reduced in a more production-oriented environment. It must be kept in mind that these figures are based on work performed in a university research organization and include extensive interpretive analysis. Reduction of these costs by 30 to 50 per cent would appear realistic. Some of the ways such a reduction could be achieved are listed here:

1. Signature development costs can be reduced by using fewer categories and spending less time on analysis by experts in various disciplines. These steps would reduce costs with some reduction in mapping accuracy, but the trade-off would be readily acceptable in many cases.

2. In mapping large areas (greater than 10,000 km^2), signature development costs may be reduced by using the same signatures for classification over larger areas, i.e., using signature transfer techniques.

3. In areas with large uniform mapping targets, signature development will be considerably less expensive than in the typical Pennsylvania area of small and heterogeneous targets.

4. A more efficient organization of the ORSER programs would place the correction of orientation and scaling in the SUBSET program, rather than having these procedures as separate programs. This would facilitate analysis and signature development and result in cost savings.

5. If the data were in a north-south orientation on the original tapes, the cost of re-orientation could be eliminated (although it presumably would be transferred to the producer of the tapes, i.e., NASA).

6. The salary costs given in this analysis include graduate students, supporting staff, and supervising faculty on research projects. They are, therefore, relatively high and could be cut significantly in a production setting.

7.2 Data Acquisition

It should be noted that no allowance is made for the cost of data acquisition in the cost analysis presented here. At current rates, however, the cost of purchasing data tapes for a single ERTS-1 scene of 34,225 km^2 is only \$200, or approximately \$0.005 per square kilometer. This figure is obviously negligible, even though two or three scenes may be required to cover a relatively small area. (The cost of launching the satellite and operating the NASA data processing facility is not included, but would obviously not be negligible.)

The acquisition of aircraft underflight photographic data would be a more significant cost. Such data are extremely valuable as a source of ground truth in signature development. Their acquisition cost is not evaluated here, but it could be substantial in many cases.

7.3 System Development

These calculations of analysis and processing costs have not taken into account development of the ORSER digital computer processing system. The system is designed to be easily used for processing ERTS-1 and any other satellite or aircraft MSS digital data. While it is difficult to determine exactly what system development costs at ORSER have been included, and how they have been divided among the sources of financial support, an indication of the relative contributions from the various sources may be obtained from the following summary, showing the total computation costs for ORSER from 1970 through 1974. These figures include data analysis, as well as system development, but experience indicates that the development and analysis costs have been about equal during that time period. The distribution of these costs for the various funding sources is not available, but the ratio of development to analysis costs on projects supported by the University can be assumed to be higher than for the other funding sources shown. It should be noted that these figures show only computation costs and do not include associated personnel or other costs.

NASA ERTS-1 project	\$ 9,200
Other contracts	\$16,700
The Pennsylvania State University	\$93,500
Total computer cost:	\$119,400

It is obvious from these figures, and from the material contained in the sections of this report describing research results and data processing, that The Pennsylvania State University has provided a major portion of the system development funds, as well as extensive computer support for analytical and interpretive work on the ERTS-1 project.

7.4 Equipment

Signature development was greatly assisted by laboratory equipment purchased almost entirely from University funds. These funds totalled $22,400 from 1970 through 1975. No contract funds were used to purchase equipment.

7.5 Cost-Benefit Considerations

No attempt has been made here to provide a cost-benefit analysis for the reasons listed below:

1. Since the primary goals of this project were directed toward the development of a workable processing system and demonstrating the feasibility of using ERTS-1 data in a variety of applications, the benefits derived are very subjective at this stage and costs are virtually impossible to quantify.

2. The cost analyses presented here are based on a university research environment and, therefore, it is difficult to make accurate estimates of what costs would be in a production environment.

3. Indications of the costs of current methods used by the state and federal agencies for mapping and analyses, using traditional data sources, are incomplete; thus, comparisons are difficult to make. For example, the cost of ground truth collection by persons already in the field is often not included in the overall cost of a particular mapping project.

However, it is evident that for many of the types of applications investigated on this project, the economic and societal benefits of using ERTS-1 data are well worth the cost. Further cost reduction for production purposes is promising, and should make the cost-benefit picture attractive.

CHAPTER 8

DATA EVALUATION

An evaluation of the ERTS-1 and aircraft underflight data is presented here in the light of ORSER experience and as an outcome of the various projects involved in the evaluation of these data.

8.1 ERTS-1 Data

ERTS-1 is an excellent remote sensing platform which generates a tremendous volume of data. Large areal coverage, repeatability, and the multispectral nature of the scanner result in a valuable data source.

8.1.1 Imagery

In Pennsylvania, ERTS-1 imagery is most useful for delineation of large features, such as forested ridges and agricultural valleys. Individual agricultural fields, usually less than 4 ha in size, cannot be delineated on the imagery. However, isolated small features down to 2 ha in size, such as bodies of water and strip mines, are readily discernible if they have sharp boundaries. Areas of population in excess of 50,000 are clearly visible on Channel 7 imagery, and individual towns of half that population can frequently be seen in certain settings.

In some cases, subtle but large scale terrain features, such as lineaments, have been clearly identified for the first time on ERTS-1 imagery. Enlargement up to a scale of 1:140,000 is of assistance in such interpretation in some cases, but the graininess resulting from further enlargement degrades the image beyond the point of usefulness.

ERTS-1 imagery lends itself well to broad regional mapping of physiography, geology, and land use. It is uniquely suitable for delineation of large, but subtle, geologic features.

8.1.2 Digital Data

Processing of ERTS-1 digital data has been very successful for a variety of applications in Pennsylvania. Land cover maps delineating forests, bare soil, cultivated land, populated areas, strip mines, and water bodies have been produced to various scales; including 1:24,000, which forms a direct overlay to a USGS 7-1/2 minute topographic map.

Some difficulties have been encountered in areas of complex land use patterns, such as small irregular agricultural fields and contoured and strip-cropped larger fields. To adequately delineate a land cover type, its extent must be larger than the area covered by four contiguous pixels. The complex pattern of agricultural fields in Pennsylvania reduces the usefulness of the ERTS-1 scanner data for mapping crop types because pixels frequently bridge field boundaries, causing classification difficulties.

Occasionally, however, the average response value of a pixel is advantageous in an area with a complex land cover pattern. For instance, a floodplain, which is a subtle feature defined by a variety of characteristics, could not be consistently defined from data supplied by the high resolution aircraft scanner; however, with the averaging effect of the ERTS-1 pixels, the floodplain was clearly delineated.

Several problems were encountered in mapping vegetation. Frequently, the response of a single vegetative type varied within a given ERTS-1 scene due to shadow differences, and seasonal variations caused difficulties between scenes of different dates. Seasonal differences, however, were an advantage in separating deciduous and conifer forest stands. Timing is particularly important in some specific studies. For instance, if an insect infestation or disease epidemic is to be monitored, it is essential that the data be acquired within a narrow time interval. In most instances, the 18-day cycle of ERTS-1 is not adequate for such monitoring, especially under Pennsylvania weather conditions.

Targets such as strip mines pose another type of problem: although they are distinctly different from their contiguous surroundings, they are extremely variable in their own response. A variety of targets, such as open pits, bare spoil banks, and spoil banks in various degrees of re-vegetation, comprise strip mines. A large signature bank, therefore, is required to map such a composite target.

The merging of digital data from two or more scenes can greatly add to the temporal dimension, improving the separability of various classes. This is especially useful for determining vegetative and land use changes.

8.2 Aircraft Data

The ERTS-1 investigations reported herein depended heavily on aircraft photographic data as "ground truth"; and the lack of such coverage for a particular area was a severe handicap in establishing the validity of signature interpretations. In addition, both photographic and digital aircraft data have been used alone in several studies, and the photography has been extensively consulted by students and both University and non-University investigators. Repeated seasonal coverage was of particular aid in the analysis of temporal changes and for close temporal proximity to ERTS-1 scenes. The ORSER-developed "hybrid approach" to data processing has been built around aircraft data as a check on the accuracy of classification during the processing of ERTS-1 MSS data. When possible, study sites were selected on the basis of the availability of aircraft data for the area.

Mission planning is an important consideration in the aircraft program. Because of the limited area covered and the high cost per square kilometer, considerable care must be taken in selection of test sites. Once the sites are selected, the aircraft mission must be conducted exactly according to the flight plans, especially in cases where timing is an important factor.

8.2.1 Photography

The photographic data was excellent. In just a few cases occasional camera malfunction resulted in double exposures or overexposure. Documentation for the photography was generally excellent. The photography acquired at 1525 and 4575 m had extremely good resolution but the area covered by the flight lines was limited. If one relates resolution to area covered, it appears undesirable to fly missions at altitudes less than 4500 m above the ground and probably for most missions an altitude of 6000 m or more would be desirable.

High altitude photography (19,800 m with the U2) is a very valuable data source. Such photography gives a synoptic view of an area sufficient in size to make regional planning decisions. The resolution of this data is very good and in many instances it would substitute for the low altitude photography with very little loss of information.

8.2.2 Digital Data

A considerable amount of time was spent in reformatting and analysis of the C130 digital data. The major problems were as follows:

1. The information supplied was very inadequate, necessitating a great deal of trial-and-error work to determine the tape format.

2. Mirror imaging made additional programming necessary to reformat the data once the original format was decoded.

3. The data were not calibrated and calibration information was generally unavailable or incomplete. Therefore, internal variations in the performance of the scanner could not be removed; nor could variability of the data and its effect on the classification results be evaluated.

4. The data tapes were frequently inconsistently and inadequately labeled. Often area designations were not indicated, and there was no way to determine what was on the tape without processing it. In a shipment of 40 tapes covering a large number of areas, this represented a distinct loss of efficiency. When data for a single large area were sent on a series of tapes, the same start and stop times were indicated on each tape, making it impossible to determine which portion of the area was represented by an individual tape. Simply numbering the tapes in the sequence of the data within the area would have saved large amounts of time for the investigators.

5. Malfunction of critical channels on the scanner was a serious problem in several investigations, resulting in the loss of valuable data.

The large volume of data collected by an airborne MSS system at low altitudes has a significant influence on the data processing procedures. At an altitude of 4575 m, the ground resolution element, or pixel, of the aircraft scanner is approximately 9 m on a side, while at an altitude of 1525 m it is approximately 3 m on a side. Therefore, 59 and 488 aircraft pixels, respectively, are required to equal the ground area of a single ERTS-1 pixel. In other words, the respective data volume (for a single channel) of aircraft MSS digital data is 59 and 488 times that of ERTS-1 data for a given area of the earth's surface.

Another factor contributing to the large volume of data is the number of channels under consideration. In contrast to the 4 channels of the ERTS-1 scanner, the aircraft scanner has 24 channels, of which a maximum of 14 were available for this study. Using 14 channels increases the data volume by 3.5 over that of ERTS-1. Therefore, the total volume of aircraft scanner data collected at altitudes of 4575 and 1525 m is approximately 200 and 1700 times greater, respectively, than the volume of data collected by the ERTS-1 scanner for the same ground area. It is important to note, however, that although the greater number of channels multiplies the data volume, it does not increase the computer processing time by the same proportion as does the greater number of pixels per unit area.

The large volume of aircraft MSS data involved in the study of even moderately-sized ground areas requires appropriately large computation facilities. Computers of inadequate size and speed may impose constraints when research-derived techniques are applied to problems on a routine basis outside the original research facilities. The computer facility at The Pennsylvania State University imposes no limit on data volume; therefore, all good-quality data could be utilized.

MSS imagery of selected channels, provided by NASA, was helpful for locating the approximate position of an area of interest on the computer compatible tape. However, because of the large data volume, estimation of line and element numbers must be more precise than is necessary for ERTS-1 data. For this reason, as well as because of labelling problems described earlier, location of a specific area within a single data tape was difficult.

By far, the most limiting factor in this study was the great amount of time required to analyze the vast amount of data required to cover a relatively small ground area. A user-interactive analysis system with a cathode ray tube viewing device would significantly reduce the time and costs of an investigation using aircraft MSS data. (ORSER has recently acquired such a system but it was not available during the course of this investigation.) A system of this type, when linked with a large computing facility, can be used to quickly locate specific study areas and evaluate data quality, as well as to conduct the actual analyses in a much shorter period of time. A device of this nature can also more easily display a larger area than can be displayed using conventional computer line printers.

Whenever multispectral scanner data is to be collected and analyzed, it is essential that the flightlines are accurately flown, since relatively small deviations from planned flightlines may mean the area under investigation has not been adequately covered. Platform stability is also very important in that seemingly minor variations in altitude and scanner attitude influence pixel size and geometric location in a non-uniform manner. Irregular distortion resulting from changes in the scanner viewing angle can also create difficulties in applying a signature developed on a target in one part of the scene to targets in another part of the scene.

8.3 Recommendations

Experience with this project has led to two basic recommendations to improve the quality and utility of satellite and associated data and data processing.

8.3.1 Reduced Delivery Time to Users

The current delivery time of four to 10 weeks between placement of a request and receipt of the data is not satisfactory. Many potential users, including federal and state agencies, have expressed the feeling that, to be useful, the data must be available to them within 10 days or even within 48 hours, in some cases.

8.3.2 Improved Resolution

The need for MSS data with better resolution than available from ERTS-1 is apparent. Such a need is seen in Pennsylvania, for example, where agricultural fields are relatively small and often elongated. Current ERTS-1 resolution (on the order of 80 m) is not sufficient to map such areas. On the other hand, low altitude aircraft MSS data, with a resolution of 3 to 9 m, are of such large quantity that handling and processing problems become severe. It is, therefore, recommended that systems be designed to acquire data with a resolution on the order of 20-30 m. Future satellite systems may be designed with such capability, but it is also suggested that serious consideration be given to placing a multispectral scanner system on high-altitude aircraft (U2 and RB57). These stable platforms have considerably greater flexibility, and can cover specific areas at irregular times. Such capability could be extremely valuable.

CHAPTER 9

INTERDISCIPLINARY RESEARCH

One of the general objectives of the ERTS-1 project was to evaluate the effectiveness of interdisciplinary research in terms of management procedures and the role of a strong data processing group in sustaining such research. This evaluation is given here by first summarizing our approach to interdisciplinary research and then highlighting several points which experience has shown to be important for the success of such a research unit.

9.1 Approach

Interdisciplinary research may be defined as integrated research performed by experts with different disciplinary backgrounds working together, while multidisciplinary research involves experts working separately to solve different aspects of a single problem. ORSER has operated primarily as an interdisciplinary group on the ERTS-1 project, although a significant amount of multidisciplinary research has also been conducted.

Data processing is perhaps the greatest source of interdisciplinary activity within the group. Not only do photointerpreters and computer programmers work with one another and with other investigators, but all ORSER personnel are involved in the development and use of processing and classification programs.

Various other aspects of the ORSER structure also encourage and facilitate interdisciplinary research. A principal factor is a deliberate coordination of efforts within the faculty research group. Although the co-directors (an Associate Professor of Electrical Engineering and an Associate Professor of Soils Genesis and Morphology) perform essential administrative duties, long-term planning takes place during regular meetings of the investigators as a group.

To insure that this group functions in an interdisciplinary manner, a problems-oriented approach has been taken: each problem or task is directly a part of the organizational structure. Thus, rather than dividing projects among disciplines, associates from the various disciplines work together toward a common goal throughout each project. Regular seminars enable investigators to present their work and interpretations to the rest of the group. Interaction in these seminars encourages communication among the investigators, prevents duplication of effort, and generally improves the quality and effectiveness of the research efforts.

Although there is a tendency on the part of faculty members to also pursue multidisciplinary research, it is interesting to note that some of the greatest interdisciplinary activity involves graduate students assisting the various faculty investigators. The educational and research results from this standpoint have been extremely gratifying, and it can be reasonably assumed that, through such projects, the activity of these students after their graduation will be more broad-based and interdisciplinary than that of their predecessors.

It should be noted that the success of any interdisciplinary activity, particularly within a university, will be heavily dependent upon the cooperation and interest of the administration of the institution. The financial and administrative support tendered by the administration at the University has been a significant contribution to the success of ORSER. Although it is often difficult to categorize the individual sources, it seems appropriate here to mention the major roles of three levels of administrative organization which have been instrumental in this support.

1. Department heads have cooperated in releasing time for faculty members to participate in interdisciplinary remote sensing research, often without the department receiving financial return proportional to the faculty time involved. Cooperation at both the departmental and dean's level has provided laboratory and office space, as well as research facilities.

2. Further financial and administrative assistance at the dean's level has been generously provided by the Space Science and Engineering Laboratory, an intercollegiate office directed by Paul Ebaugh, Associate Dean for Research in the College of Engineering.

3. Support from the Intercollege Program in the Office of the Vice-President for Research and Graduate Studies has been clearly demonstrated by the grant of large amounts of unfunded time on the University's computer system and by the provision of funds for the purchase of equipment. This program has also provided general funding and administrative support and created an atmosphere that encourages interdisciplinary research.

These sources of support and encouragement have been vital to the success of ORSER and would, undoubtedly, be an essential ingredient for the operation of any similar interdisciplinary group.

Experience has shown that there are many advantages and some common problems encountered in interdisciplinary research. Some of the more salient of these are discussed in the following sections. Although presented primarily from the University research point of view, most of these points would be relevant to government agencies or private industries as well.

9.2 Advantages

The advantages of interdisciplinary research vary with each situation. However, there are several advantages that are not only related to the ERTS-1 project, but which appear to be basic to any interdisciplinary project within a university.

1. Interdisciplinary projects provide increased opportunities for faculty participation in research. Faculty are frequently unable to obtain funding for research when proposals are submitted individually, because the work proposed must necessarily be limited in scope. Interdisciplinary teams can propose to undertake more meaningful problems on a larger scale.

2. Participation in interdisciplinary research results in improved teaching and relevance in classroom instruction. Such participation broadens faculty understanding of problems and techniques available for their solution. This experience provides valuable background for making classroom instruction more relevant to the student.

3. Strong interdisciplinary programs enhance the reputation of a university. This results in greater visibility and, consequently, the attraction of higher quality students and faculty. Though the visibility is directed toward the university as a whole, when generated by interdisciplinary programs, it may frequently also draw attention to specific departmental strengths within the university.

4. Interdisciplinary research is frequently applied research. Persons with various backgrounds and areas of expertise join together to apply their knowledge to the solution of a common problem. The result is that faculty and graduate students are working on real-world problems.

5. Interdisciplinary research helps the university to participate directly in the solution of societal problems. The great wealth of knowledge and technical expertise residing within the university is more readily available to help solve some of the more critical problems facing the nation.

6. Interdisciplinary research acquaints faculty and graduate students with other disciplines and their importance in solving problems. It creates opportunities for greater interaction between the "hard" and "soft" sciences and calls attention to the varied aspects of a problem which must be considered in its solution. The resulting increase in appreciation for the relevance of other disciplines frequently breaks down traditional barriers between them.

7. Interdisciplinary research makes the technical solution to problems more visible to the public. When combined with other considerations and approaches, technology appears to be less mysterious and frightening, and its role in problem-solving is more readily placed in a perspective which is understandable and reasonable to the public.

8. Participants in interdisciplinary projects develop a better understanding of and appreciation for the various administrative procedures within their own institution. The participants must necessarily become acquainted with how other university administrative units (e.g., university departments) differ in their procedures and the reasons for the difference. These include budgetary, personnel, and many other administrative procedures.

9. Personal satisfaction is achieved by participation in interdisciplinary projects. There is great satisfaction in being a contributor to a team working on significant problems. The wide variety of professional contacts and the opportunity to apply individual expertise in new and different ways makes participation in interdisciplinary research an interesting and worthwhile experience.

9.3 Common Problems

Just as there are many benefits to be gained from involvement in interdisciplinary research, there are also several problems which the participants in such projects may encounter. Although few of these have been of a serious nature, all of them have been experienced to some degree in the operation of ORSER.

1. Proper recognition of the individual and his contribution is difficult. The visibility of the individual participant is generally not high, either within or outside his own institution. This is due to many factors, e.g., most publications will have several authors, only one or two persons will be listed as principal investigators on interdisciplinary projects, and individual participants are frequently working away from their home departments.

2. There are high risks and various uncertainties associated with faculty participation. In addition to the other problems which face the faculty member from the standpoint of recognition, promotion, and tenure, he must also consider that continued funding of the project is dependent upon many factors over which he may have little or no control. These vary from the quality of work of other members on the project to the discontinuance of funding on high-cost interdisciplinary projects. In addition, the individual faculty member may not be free to pursue a chosen direction of investigation because it does not contribute directly to the interdisciplinary goal. There is also the chance of weakening his professional reputation; traditionally, it has been expected that a researcher will become more narrow and specialized, thus, getting more deeply into his own discipline, rather than broadening into new areas outside that discipline.

3. Criticism by more discipline-oriented peers is often severe. Some peers look with suspicion at faculty involved in interdisciplinary projects. There is often a lack of understanding and appreciation of the individual's role in interdisciplinary research, and this, combined with the fact that the participating faculty member frequently does not spend much time in his home department, may result in the belief that the individual is neglecting professional responsibilities in his own discipline.

4. Publication in acceptable journals presents special problems. Papers resulting from interdisciplinary projects are normally multi-authored, leading to greater recognition for the institution than for the individual contributors. It generally takes a longer time to obtain research results and to prepare them for publication; and, because of their applied nature and the wide spectrum of topics involved, these results are not always suitable for publication in refereed journals of the traditional disciplines (which tend to publish more theoretical work in narrow fields of endeavor). In the case of remote sensing, however, new journals, such as Remote Sensing of Environment; and the change in emphasis (and even title) of established journals, such as Photogrammetric Engineering becoming Photogrammetric Engineering and Remote Sensing, are increasing the opportunities for publication in refereed journals.

5. Reward criteria, particularly in terms of promotion and tenure, are generally not well identified and established. There must be recognition by the university of the extra frustrations, higher risks, and increased time demands imposed by participation in interdisciplinary research. Without procedures for proper recognition and reward, young faculty members may feel that such research is not a good way to establish themselves professionally, and they may not want to be involved until they are tenured. Universities need to recognize and reward technical and managerial competence for those involved in interdisciplinary research and thereby enlarge the scope of faculty professional activities.

6. The research problems are not always well-suited for graduate thesis work. This is particularly true for doctoral work, where one of the requirements is that the thesis show an original contribution on the part of the student. It is often difficult for a doctoral candidate to show that the work is solely his, and if the thesis is evaluated in one of the traditional departments, it may be criticized as being too broad and not sufficiently deep in the discipline. This problem is not as severe for students on a masters degree program. Naturally, if suitable thesis topics cannot be defined, it is difficult to attract graduate students to work on these projects. Similarly, the interest of the faculty will be

hard to maintain if the problems are not of sufficient academic interest and if qualified graduate students cannot be attracted to work on them.

7. The cost is high. Even though the cost of interdisciplinary research is normally lower than if the same work were performed in several separate projects (if, indeed, this could be done), it is still higher than most individual research efforts. Since many agencies have limited funds and generally like to "spread the wealth," it is often difficult to obtain support for large interdisciplinary projects. Reluctance to fund such projects is increased by the fact that final results are relatively long-term and immediate results are not always obvious.

8. Project Proposals are difficult to evaluate. Evaluation of interdisciplinary proposals is difficult and good procedures for such evaluations have not yet been established. The fact that evaluators often have strong disciplinary backgrounds increases the difficulty of establishing such procedures.

9.4 General Observations and Recommendations

All the advantages and disadvantages of conducting interdisciplinary research within a university have been experienced to some degree by ORSER personnel, although the advantages have far outweighed the disadvantages. Research on the ERTS-1 project have led to the following observations and recommendations:

1. Interdisciplinary research is most effective when it is initiated by a group within the faculty. In other words, the effort should be initiated by the faculty, rather than the administration. In this way, the group assembled to perform the work will be composed of faculty who are there because they are genuinely interested, rather than because they believe their department head or dean wants them to be involved. Compatibility, interest, and cooperation within the group are essential ingredients of success.

2. Leadership will be most effective when it comes from within the group. Unfortunately, there are always administrative chores which must be performed when group projects are undertaken. Coordination of the effort, equitable distribution of the available funds, maintenance of good communication, coordination and assistance in report writing, and liaison with the supporting agency and university administration are all functions which must be performed by someone within the group. The leadership may be shared, depending on the project, but the responsibility must be clear. The administrative organization of the group will vary according to the projects involved and the policies and procedures of the university. The smaller the group,

the less formal the organization needs to be, and, generally, faculty respond better to an informal approach, since this is more consistent with the traditional concept of academic freedom. Within ORSER, for example, the lack of a staff specifically employed for management and administrative purposes causes some administrative inconvenience and inefficiency; however, this advantage is believed to be more than offset by the advantage of faculty control of direction and planning.

3. University administrative policies and procedures must be conducive to the conduct of interdisciplinary research. Restrictions must be minimal and lines of communication between departments, colleges, and central administration must be open. At Penn State, the Intercollege Program facilitates the establishment of programs such as ORSER, but the cooperation of departments and colleges is also necessary for successful operation.

4. If the interdisciplinary group is to have stability, it must be supplied with a basic and continuing source of funding. It is very important that sufficient basic funding exists to maintain a critical nucleus of personnel, facilities, and services at times when contract funding may be reduced. Once disbanded, an interdisciplinary group is difficult to revive, because the individuals make various commitments which cannot be broken.

5. University-based interdisciplinary research groups must be careful not to be placed in direct competition with industry. Because interdisciplinary research is frequently of an applied nature, it is often involved in areas which are also the concern of industry. The university, however, must not be placed in a position of direct competition with industry, particularly, if it is the recipient of public funds for its operation. There is a fine line dividing reasonable university research areas and those in which a university should not be involved. The basic criterion should perhaps be whether or not the problem under consideration is of sufficient academic importance to warrant university involvement, and whether the university is uniquely qualified--by reasons of its combination of disciplines and facilities--to solve the problem.

   A related matter is that of providing services. As interdisciplinary groups develop procedures and methods for approaching problems, their services are likely to be sought by state agencies, industry, and others. For example, ORSER has been frequently contacted in the area of MSS digital data processing. A university certainly does not wish to be uncooperative, and it should provide such services if it is uniquely in a position to so; but, again, care must be taken not to operate in competition with industry. It is also important to avoid accepting requests for services to such an extent that the time involvement for the staff and facilities detracts from educational and research responsibilities.

In summary, on the basis of experience with the ERTS-1 project, we feel that interdisciplinary research is an exciting and effective way to approach many of today's real-world problems. It is a way in which the great potential of the modern university can be directed toward the improvement of our society. It is highly beneficial to the participating faculty and graduate students, and to the university itself. If the projects are such that the best faculty and graduate students are attracted, and as long as the faculty feel that their participation is properly recognized, then university interdisciplinary research is an interesting, challenging, and worthwhile endeavor.

CHAPTER 10

RELATED RESEARCH

Many research projects not directly part of the ERTS-1 contract work have been stimulated by the availability of ERTS-1, Skylab, and aircraft data, and by the facilities and experience provided by ORSER in the academic community. Some of these projects are summarized in this chapter.

10.1 Data Processing

Two of the five projects described below were initiated in preparation for the ERTS-1 contract. The others are representative of the range of ORSER data processing studies and technique development which have not been directly related to the ERTS-1 project.

10.1.1 Analog to Digital Conversion of MSS Data*

The objective of this investigation was to design a system which would directly accept analog data from FM magnetic tape recordings produced by the Bendix eight-channel multispectral scanner, sample the analog data, convert those samples to digital numbers, arrange those digital values into standard ORSER format, and output the data onto digital magnetic tape in the standard IBM System 360 nine-track tape mode of 32-bit words written in 800 bits-per-inch density.

The design was restricted to implementation on systems available at the University. In order to maintain a high degree of accuracy in the measurement and sampling of the spectral response of the subject, simultaneous sampling was considered advantageous over simple multiplexing, in which each channel is sampled as it is input to the analog-to-digital converter, no two channels ever being sampled at the same instant.

The conversion was implemented on the hybrid computer, operated by the Hybrid Computer Laboratory of The Pennsylvania State University, consisting of a Digital Equipment Corporation PDP-10 digital computer and an EAI 680 analog computer mated by a special interface unit to translate data and control signals from one computer to the other. Sampling and conversion of the MSS data are controlled by a digital program. Prior to this project, the maximum sampling speed available was limited by existing subroutines to approximately 11,000 samples per second.

A new subroutine was developed in order to achieve a sampling rate approaching the hardware maximum. Sampling rates for eight channels of data were increased to 19,544 samples per second (2443 samples per second per channel) in fast core and 17,496 (2187) in slow core. The new

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*This work is described in greater detail in ORSER-SSEL Technical Report 24-73.

subroutine was also designed for simultaneous sampling of all channels utilitzing a constant sampling rate, or an adaptive sampling rate such as that required to geometrically correct multispectral scanner distortions. Three operations are required to convert the raw digital number data to the specified ORSER format before they are ready for storage on magnetic tape:

1) scale change and axis translation;

2) fitting the data to the required format and reversing the order of the samples, so that output maps will have the standard point of view; and

3) reduction of the data storage requirement by a factor of four, by packing four consecutive 8-bit words into one 32-bit word.

A second subroutine improves the speed of writing onto magnetic tape by at least a factor of four. The simplicity of both of these new subroutines increases programmer flexibility.

There are five advantages of the conversion over simple bulk digitizing:

1. The more precise control of analog signal sampling by the hybrid system fits the data into the coordinate system more accurate than does simple digitizing.

2. The final product from the hybrid system can be written in the format required by any user system.

3. The conversion is strictly a software system, requiring no specialized equipment for implementation. It can, therefore, be easily altered to new specifications.

4. The system permits geometric corrections of the MSS data as they are being sampled.

5. The analog computer permits preprocessing of the data before conversion.

Upon completion, the system was used to convert 13 flightlines of analog data flown by Bendix Corporation. The data were originally recorded on one-inch magnetic tape at 60 ips with an Ampex FR 1600, 14-track wide-band FM tape recorder with a cutoff frequency of 200 kHz at that speed. They were re-recorded onto half-inch magnetic tape with an Ampex FR 1300, seven-track FM tape recorder at the Bendix ground station in Ann Arbor, Michigan. At 60 ips, the FR 1300 has an upper cutoff frequency of 20 kHz.

The Bendix scanner senses eight spectral bands. The eight analog signals, plus a synchronization signal, fit easily on the 14-track recorder, but there are two signals too many for the available seven-track unit. To resolve this problem, two seven-track tapes were made from the original 14-track recording, each containing only six data channels and the synchronization channel. The four data channels estimated to contain the most information appear on both tapes. These analog tapes were converted to digital data and then merged on the IBM 360, resulting in 97.25 per cent efficient use of the computer while the program was in the digitizing phase.

The immediate objective of this work was to digitize the Bendix data; however, the conversion system is suitable for digitizing other aircraft data as well. There are a number of extensions of this investigation which could prove useful. The preprocessing of analog data prior to sampling and conversion could be treated as a feature extraction problem. The concept of non-linear sampling to compensate for scanner geometry could be carried further by using actual terrain contour information, instead of assuming the terrain to be flat.

10.1.2 Comparison of Preprocessing and Classification Techniques*

The objective of this research was to develop and compare various preprocessing and classification techniques for pattern recognition applications to MSS data. The data used were collected in 1969 by the University of Michigan aircraft over southeastern Pennsylvania, and were made available to Penn State by Dr. H. T. Rib of the Federal Highway Administration.

Trainable classifiers implementing various discriminant functions were studied, and linear and quadratic discriminant functions were selected for implementation. Training was achieved by adjustment of parameters within the discriminant functions, based upon known sets of MSS observations (training sets). Eight different pattern classes (concrete, asphalt, grass, trees, crops, and three soil classes) were chosen, with 50 to 60 patterns per class in the training set. Classifiers were categorized with respect to type of training employed, as well as discriminant function form. Parametric and non-parametric classifiers were used. Parametric classifiers train on the statistical parameters of the training set. Non-parametric classifiers assume a discriminant function with unknown coefficients. These coefficients are adjusted by a correction rule contingent upon the classification of the patterns in the training set. The four classifiers implemented were:

1) a parametric classifier with linear discriminant function (MINDIS),

2) a parametric classifier with quadratic discriminant function (PARAM),

3) a non-parametric classifier with linear discriminant function (NPARMAP), and

4) a non-parametric classifier with quadratic discriminant function (QUADMAP).

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*This work is described in greater detail in ORSER-SSEL Technical Report 15-73.

Principal components analysis and data normalization were chosen as the preprocessing options to the classification programs. The implemented classifiers were run using the following options: unpreprocessed data; principal components analysis using 13, 6, and 2 components; and normalized data. Comparisons were made between preprocessing and classifier results in the areas of separability of the training set, accuracy on the test set, computation speed, and overall appearance of the output site map.

All classifiers reached an acceptable level of separation (as evidenced by training set classification) and accuracy (as evidenced by test set classification). The technique of initially running classifiers with crude classes and then inspecting the site map in collaboration with aerial photographs and soil maps proved to be excellent for refining pattern classes. This procedure was a forerunner of the more formalized hybrid approach, developed later. Considering computation time, the classifiers with the more complex discriminant functions (quadratic) were slower than those with less complex discriminant functions (linear). Non-parametric classifiers generally took longer during the training phase than did parametric classifiers. Assumptions of initial weight values near the pattern class means permitted the non-parametric classifier with linear discriminant function to train faster than the same classifier with the initial weight values assumed at a greater distance from the class means.

Principal components analysis provided a means of dimension reduction while maintaining an acceptable level of classification accuracy. When the number of principal components (6) corresponded to 99 per cent of the total variance, class separation and classification accuracy was comparable to using all the dimensions or principal components (13). However, in general, there was an obvious deterioration in class separation and classifier accuracy accompanying dimension reduction below the value corresponding to 99 per cent of the variance.

The results of data normalization as a preprocessing technique were not conclusive. However, it is apparent that classification with normalized data is comparable to, and in some instances better than, classification performed with unpreprocessed data. Some indication also exists that data normalization may remove unwanted noise.

Overall site map appearance was best for the classifiers employing linear discriminant functions; however, class boundaries were best defined by quadratic discriminant functions. Asphalt was the most misclassified class of the eight selected.

All classification training procedures used in this research were supervised methods; that is, the user selected the pattern classes himself before classifying the data. The dimension reduction and corresponding classification accuracy of principal components analysis should also be compared with other feature selection methods, such as canonical analysis, divergence, and Bhattacharya distance.

On the basis of separability, accuracy, speed, site map appearance, and ease of implementation, the classifiers employing the linear discriminant function appear to be comparable to--and at times superior to--classifiers using the quadratic discriminant function. There are certain cases where the quadratic discriminant function has a definite advantage, for instance, in defining class boundaries. A study of the statistical and physical nature of the data proved to be an excellent aid in the selection and implementation of classifiers and preprocessing techniques, and in the interpretation and analysis of corresponding results.

It must be concluded that no single preprocessor/classifier combination is universally optimal. A knowledge of the physical aspects of the classification problem (ground truth) along with careful statistical analysis is essential for proper pattern recognition.

10.1.3 Sensitivity of Normalized Classification Procedures for Floodplain Soils Studies*

In an effort to determine the sensitivity of normalized classification techniques for application to floodplain soil studies, spectral signatures, in the form of multi-variate vectors, were synthesized for various soil moisture, soil type, solar zenith angle, and atmospheric attenuation conditions. These signatures were normalized for the various parameter combinations and used to calculate the angle subtended by selected vector pairs, in order to examine the sensitivity of this procedure for classifying soil types and soil moisture conditions.

The results indicated that normalized techniques appear to be adequate for classification of gross soil types; however, soil moisture condition classification may be marginal for clay soils. It was also shown that solar zenith angle and atmospheric attenuation can significantly influence the classification results.

10.1.4 Subsetting Scanning Densitometer Data Into ORSER Format

Data from an Optronics Scanning Densitometer located in the High Voltage Electron Microscope laboratory at the University of Wisconsin, have been subset into ORSER format. A color infrared U2 photograph of an area in Wisconsin was scanned at 100 and 50 μ densities four times; the first time using no special filters, and the other times using a 5500 Å, a 6800 Å, and a TIFFEN Photar 47B Series 7 blue filter, respectively. Data from each scan of the photograph were output to a separate file on magnetic tape. The SUBSET program was modified to input a file of data and output it in ORSER format. All 100 μ density data were subset and then merged, using the MERGE program, resulting in four channels of information. Using NMAP, a brightness map was made of the area, and it was successfully matched to the photograph. These data will be classified into various land cover types and then into a hydrologic model, using ORSER routines.

10.1.5 A Survey of Image Enhancement Techniques**

A survey of current image enhancement techniques was conducted, over

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*This work is described in greater detail in ORSER-SSEL Technical Report 14-74.

**The results of this survey are given in ORSER-SSEL Technical Report 17-74.

a two-week period, for the Office of Geographic Programs, Earth Science Division, Office of Naval Research, Arlington, Virginia. Most of the information contained in the resulting report was gathered during visits to six major organizations in the Washington, D.C., area and from personal conversations with ONR personnel. The organizations visited were: Central Intelligence Agency, Arlington,Va.; NASA Goddard Space Flight Center, Greenbelt,Md.; U.S. Army Engineer Topographic Laboratories, Ft. Belvoir,Va.; IBM, Gaithersburg,Md.; Naval Intelligence Support Center, Suitland,Md.; and General Electric Company, Beltsville,Md. Omission of other organizations was due to lack of time, and in no way reflects adversely on the value of their work.

After a general discussion of image enhancement, the various methods of enhancement are described in detail in the report. Photographic enhancement (film processing, multispectral photography, chemical processing, neutron radiation, displays and viewers), and enhancement by electronic data processing (data format, digital enhancement, analog enhancement, coherent light enhancement, displays) are discussed. Particularly noteworthy in photographic enhancement are the use of Agfa Contour film and chemical methods for enhancing underexposed images, and the neutron radiation technique. The principal limitation to photographic enhancement is the time required for processing.

Many quantitative techniques, including digitization of photographs and electronic image sensing methods, are now available for processing extremely large amounts of data in very short periods of time. Because data originally in digital form are not degraded upon processing, a high order of image generation can be performed without loss of resolution. Analog processing is faster than digital, although its accuracy may be lower. Electro-optical techniques are still new, but hold promise as good approaches to image enhancement and processing. Electronic data processing systems with good visual displays are highly desirable: when man-machine interaction is efficient, the enhanced properties can be readily observed and altered. Cost is the chief drawback of electronic data processing and enhancement. However, considering the large amounts of data requiring processing in many cases, the cost/benefit ratio is low.

10.2 Land Use Mapping

In addition to those conducted on the ERTS-1 contract, land use mapping projects have been conducted on contracts with other government agencies, such as the U.S. Army Corps of Engineers and the Susquehanna River Basin Commission. Pilot land use mapping studies have also been completed for various agencies, and graduate degree programs have involved land use mapping and related studies both within and outside of Pennsylvania. Some of these projects are described below.

10.2.1 Floodplain Delineation*

An investigation was conducted for the U.S. Army Corps of Engineers

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*This project is described in greater detail in ORSER-SSEL Technical Report 1-75.

to determine if floodplain boundaries could be delineated by applying automatic computer processing techniques to aircraft-collected MSS data, using natural indicators as criteria, such as differences in vegetation, moisture, and soils. Test areas were chosen along the West Branch of the Susquehanna River, in central Pennsylvania, representing naturally forested sites and sites featuring predominantly agriculture. MSS data were collected at two aircraft altitudes (1525 and 4575 meters) and in two seasons (April and June). Fourteen channels of a 24-channel scanner were operational during the flights, covering the electromagnetic spectrum interval between 0.38 and 8.0 μ. The uncalibrated data sets of the individual channels were screened, with those of obviously poor quality excluded from the analysis. Computer analysis results from both the agricultural and the forested areas were checked against the Corps of Engineers 100-year frequency floodplain boundary and the Soil Conservation Service Boundary between floodplain and non-floodplain soils. In addition, the agricultural test areas were studied on aerial color photographs by a photointerpreter, and the computer analysis results checked against the photointerpretation analysis results. Both areas were also field checked.

In the agricultural areas, the results were not sufficiently conclusively to delineate a continuous floodplain line. Verifiable indications of breaks between floodplain and non-floodplain areas were apparent within relatively small portions of the test areas exhibiting a uniform land cover. However, these were also areas where the photointerpreter was confident of his floodplain delineation. In one instance, the computer classification results indicated a soils drainage category in disagreement with the SCS soil classification; this category was later determined to be correct by field checking. In general, the bare soils of April made the spring data more useful in detecting soils differences than the June data.

Classification differences in the forested areas could be related not only to the various species, but also to differences in crown closure or canopy density. These variations may be a result of species composition, site quality, or cultural practice. With the exception of a river birch community, it was not possible to distinguish individual species. Only in the area of river birch did the computer-classified floodplain boundary and that of the Corps of Engineers correspond. Topography and aspect were distinct problems in classifying forested areas. The June data were more effective for classification than the April data, due to the presence of foliage, but only the low altitude June data set was useful in floodplain delineation.

On the basis of this investigation, the following recommendations were made:

1) aircraft collected MSS data should be calibrated prior to analysis;

2) the data should include the thermal infrared region of the electromagnetic spectrum;

3) missions should be carried out precisely at the desired time of year and time of day, and on a course which covers the entire floodplain;

4) channels should be carefully selected to reduce the data volume and analysis costs, unless adequate computing facilities and funds are available; and

5) an interactive display system would aid in the analysis and reduce overall analysis time.

The results of this study indicate that, given the current state-of-the-art in aircraft MSS data collection and analysis techniques, delineation of floodplains in complex areas such as central Pennsylvania using aircraft MSS data to identify natural indicators, is not promising. However, an extension of this study, involving ERTS-1 MSS data, appears to be yielding more promising results.

10.2.2 Land Use Mapping of 14 Watersheds*

At the request of the Susquehanna River Basin Commission, a study was undertaken to use ERTS-1 MSS data to classify and map 14 watersheds, covering 14,500 km^2 within the Susquehanna River Basin. One of the important results of this study was the determination of the extent to which signatures from one area could be transferred to another.

Within the first watershed mapped, and using data from a single ERTS-1 scene, signatures were developed on a small training area and transferred to an adjacent area with only minor misclassifications. However, the larger variety of agricultural land found in the second area necessitated the development of several new signatures. Third and fourth transfers, within the same scene, were equally successful. A fifth transfer of signatures was made to data from a scene recorded 18 days later by ERTS-1, for an area adjacent to the other five (to complete the watershed map). Only one category was successfully transferred, necessitating the development of a new signature bank. However, transfer of the entire set of 48 signatures developed from the first ERTS-1 scene to a watershed 55 km to the south of the first and in the same scene, was highly successful. Only ten new signatures had to be developed and most of these were for commercially developed and urban areas. In the case of several other watersheds in the scene, of a simpler nature than those described above, the initial set of signatures developed from the small training areas mapped the entire watershed with little difficulty.

The final product from this project was a set of 1:24,000 land cover maps of the 14 watersheds, indicating seven categories: bare soil, hayland and grasses, stubbleland, woodland, water bodies, urban areas, and disturbed land. The land area in each category was determined for each watershed.

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*This project is described in more detail in the Ph.D. thesis by G. A. May, and ORSER-SSEL Technical Report 21-74.

10.2.3 Land Use Mapping in Hill County, Montana*

The Hill County site is located in the Hard Winter Wheat Belt of the Northern Great Plains. The region is entirely agricultural, with major crops of winter wheat, spring wheat, and barley, in two-year rotation with summer fallow. Individual fields range from 16 to 40 ha in size. Fields are usually either 800 m or 1.6 km long, with widths from 80 m to 400 m.

The general objective of this study was to see how well the ORSER classification system would work in an area where land use patterns were larger and more regular than in Pennsylvania. The specific objective was to produce a thematic map of two test sites, depicting the following categories: stubble, fallow, native grassland, planted pasture, farmsteads, roads, railroads, and water bodies.

The following categories were obtained for the final map:

1. Summer Fallow: One signature mapped the majority of fields known to be in summer fallow. Four additional signatures were developed, each capable of mapping portions of known summer fallow fields.

2. Stubble: This category required four signatures. It is not known whether these signatures are indicative of particular crop types.

3. Water: Four of the five signatures in this category mapped out the storage reservoir of Fresno Dam. The difference among these signatures could be attributed to increased sediment and shallower water encountered away from the dam area. The fifth signature located the water storage reservoirs at the community of Kremlin, as well as numerous farm ponds and depressions.

4. Vegetation: This signature mapped grassy strips less than 6 m wide between summer fallow fields. A considerable area of grazed, short grass, vegetation was also improperly classified as stubble or summer fallow around Fresno Dam.

5. Range and prairie: Areas of dense or ungrazed grassland were mapped with either the range or the prairie signature. The prairie signature was predominant, and the range signature was required to "fill in the blanks."

6. Cut bank: Gullies carrying runoff water to Fresno Dam were located predominantly with the cut bank signature, which mapped eroded areas.

These signatures successfully defined the categories of the area in the final land use map with one exception: an area of grazed, native short grass vegetation was mapped as stubble and summer fallow. The location

*This project is described in detail in ORSER-SSEL Technical Report 25-73.

of farmsteads could often be inferred by small groupings of vegetation, prairie, and cut bank signatures. Loose bare soil (summer fallow) was differentiated from crusted bare soil. It was not possible to make valid separations within the summer fallow categories, possibly because of bad scan lines within the data. Five categories of water were defined, with differences related to sediment content and depth.

To determine the validity of these categories over a larger area, 390 km^2 were mapped. No obvious improper classification resulted. The field patterns remained regular, alternating between summer fallow and stubble. The Milk River, flowing out of Fresno Dam was discernible, as was a creek flowing into the Milk River.

The successful and easily obtained results from this study helped to verify that it was the complexity of field patterns and topography which created problems in processing Pennsylvania data for land use classification, and not difficulties inherent in the ORSER data processing system.

10.2.4 Spectral Signature Selection for Mapping Bare Soils*

Laboratory soil signatures and signatures derived from aircraft multispectral scanner data were compared in this study. The MSS data were flown for Harold Rib of the Federal Highway Administration, by aircraft operated by the Willow Run Laboratory at the University of Michigan. ORSER programs were used to classify the data and produce a thematic map for three soil types. Soil samples from the area were then collected and a computer program was developed to determine the scan line and element number of these sampling locations. The samples were analyzed on a spectrophotometer and the resultant soil spectral signatures were corrected for atmospheric attenuation and solar radiation at the time the MSS data were collected. The corrected laboratory data were then used to map the three soils, using the method applied to the MSS data. Comparison of the two maps resulted in the following conclusions:

1. It was possible to accurately assign a scan line and element number from the MSS data to each field sampling location.

2. Using 12 channels in each case and critical angles for the laboratory-derived signatures of three times those used for the MSS signatures, it was possible to produce 90% agreement between the two signature sets for maps of three soil sites.

3. For both the laboratory-derived and the MSS signatures, it was possible to accurately map a siltstone-derived soil and differentiate it from the other two soils. However, the remaining two soils could not be adequately separated, as they were both shaley in character (one was formed from shale and the other from a shaley limestone).

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*This work is described in greater detail in ORSER-SSEL Technical Report 3-75.

4. In the cases of both the laboratory and the MSS data, signatures derived from only seven channels (3, 4, 5, 7, 9, 10, and 11) yielded approximately the same results as those derived from 12 channels.

5. Subdivisions in channels 12 (1.0 to 1.4 μ) and 13 (2.0-2.6 μ) would have enhanced the spectral differences of the soils and facilitated classification separations.

10.2.5 Land Use Mapping in Erie County, Pennsylvania*

A pilot study was conducted for the Environmental Protection Agency to determine the feasibility of mapping land use in the Great Lakes Basin area utilizing ERTS-1 data. A portion of the Lake Erie shoreline in Erie County, Pennsylvania, was mapped using data from ERTS-1 scene 1029-15352 and the ORSER computer programs NMAP, UMAP, DCLUS, AND STATS. Ground truth included a soils map mosaic constructed from the Erie County Soil Survey Report, at a scale of 1:20,000; USGS 7.5 minute quadrangle maps; and field knowledge of the area.

The following results indicated that it is feasible to map the Great Lakes Basin area using ERTS-1 data:

1. Small streams were clearly defined by the presence of trees along their length in predominantly agricultural terrain.

2. Field patterns were easily differentiated from forested areas and dairy and beef farms were differentiated from other farmlands (no attempt was made to identify crops).

3. Large railroad lines and major highway systems were identified.

4. The city of Erie and several smaller towns were identified, as well as residential areas between these towns, and docks along the shoreline in Erie.

5. Marshes, forests, and beaches within Presque Isle State Park were correctly identified, using the DCLUS program.

6. Bay water was differentiated from lake water, with a small amount of misclassification.

10.2.6 Land Use Mapping in Luzerne County, Pennsylvania

The Economic Development Council (EDC) of northeastern Pennsylvania had undertaken the task of producing a land use map of their seven county region. Members of EDC contacted ORSER to see if a land use map could be

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*This work is described in more detail in ORSER-SSEL Technical Report 24-74.

accurately and efficiently produced from remote sensing data. ORSER personnel worked closely with EDC in a pilot study to develop a list of land use categories which could be mapped.

A land use map was produced for a selected site in Luzerne County. Members of ECD reviewed the map and made a request for several changes. Several revised land use maps were then produced for the site and reviewed by EDC. The major categories on these maps were: agricultural land, strip mines, forested areas, water bodies, and urban areas.

EDC was pleased with the results of this study, and indicated a desire to obtain similar land use maps of their entire seven-county area. However, since sufficient funding was not available within the time period of interest, the study was discontinued.

10.2.7 Corn Crop Yields

Under subcontract to Spectral Data Corporation, ORSER assisted in a U.S. Air Force project to predict corn crop yields before harvest, using photographic techniques. Bi-weekly field visits were made by ORSER agronomists to seven test sites with reports on crop condition. Tonal patterns on aircraft photography were investigated and causes and severity of stress were investigated. Soil and weather data were supplied to SDC by the U.S. Air Force. Yield sampling was conducted prior to harvest for several stressed and non-stressed areas within each test site. A computer compatible tape of digitized photography of the test sites has been supplied to ORSER by the Air Force. It is planned to analyze this tape when time and funds become available.

10.3 Earth Sciences

Geologic thinking has been profoundly stimulated by the availability of ERTS-1, Skylab, and aircraft data. The significance of scale in geologic investigations has come under increasing consideration, and the results of earth processes on a continental scale can, for the first time, be viewed holistically. In addition to the specific studies conducted for the ERTS-1 project, the broader aspects of the significance of satellite data to geologic thinking have been considered by ORSER geologists, as indicated in the following two sections.

10.3.1 Geologic Applications for Remote Sensing Techniques

Various aspects of remote sensing and its application to the problems of geology and natural resources were discussed in a report published in <u>Earth and Mineral Sciences</u> (Vol. 43, No. 7, April 1974), put out by the College of Earth and Mineral Sciences at the University.* In this report, the electromagnetic spectrum, natural and synthetic detectors, radiometers and spectrometers, active and passive responses, attenuation phenomena, imaging methods (scanners, cameras), and techniques (digital and photographic), were reviewed. Imaging platforms and systems were compared (Table 10.1), relating geologic features and map type to six orders of

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*This report has also been issued as ORSER-SSEL Technical Report 10-74.

Table 10.1: Summary of Available Remote Sensing Data for Pennsylvania and Relative Cost of Acquisition

Platform	Approximate Altitude	Approximate Area Sensed in km^2	Approximate Scale[a]	Sensor	Coverage of Pennsylvania	Relative Cost of Mosaic: Frames	Man-Yrs.	Cost[b]
ERTS-1	900 km	34,200	1:1,000,000	RBV camera and MSS	Complete and repetitive	14	1.5	$75,000
Skylab	430 km	15,540	1:700,000	Camera and MSS	Selected areas			
U2 aircraft	19,800 m	830	1:125,000	Camera	Selected areas			
C130 aircraft	1525 to 4575 m	1.6 to 52	1:6000 to 1:120,000	Cameras and MSS	Selected areas			
C54 aircraft	1525 to 4575 m	3.9 to 52	1:6000 to 1:44,000	Cameras	Selected areas	938[c]	11	$730.000
Various aircraft	1830 and 3050 m	7.3 and 20	1:12,000 and 1:20,000	Camera	Complete, USDA; selected areas for engineering studies	20,000[d]	44	$1,100,000

[a]Standard 248 mm format.

[b]Based on a 14-frame mosaic of Wyoming (NASA exhibit).

[c]Higher altitude.

[d]Lower altitude.

Table 10.2: Optimum Scales and Corresponding Sensing Platforms for Mapping Deformation and Geotectonic Phenomena*

Structural Scale and Order	Natural Scale and Size of Feature	Types of Phenomena	Types of Maps	Platform and Medium of Observation
Gigascopic 1	1:50 million >1000km	Continental or oceanic plates, seismic plates	Globes; world-wide and continental geologic, tectonic and seismic maps.	Seismic networks (long waves) Space probes; vidicon, scanner, radiometer (visible, IR & gamma ray) Various satellites (visible & IR)
Megascopic 2	1:1 million 10 km to 1000 km	Mountain belts, basins, island arcs, rift valleys structural provinces, plutons, megalineaments, craters.	Large globes; continental, national, state geologic, tectonic and seismic maps.	ERTS, vidicon photography & scan imagery (visible & IR) Skylab & Intelligence satellites; photography and scan imagery (visible & IR)
Macroscopic 3	1:1000 10 m to 10 km	Folds, faults, lineaments, craters volcanoes, dikes, fracture traces, etc.	Regional, geological and structural maps; fabric diagrams.	Aerial photographs and scan imagery (visible, IR, radar)
Mesoscopic 4	1:1 1 cm to 10 m	Folds, faults, cleavage, joints, bedding, geologic contacts.	Detailed geologic and structural maps; fabric diagrams.	Life-size fieldwork (visible IR, radar, gamma rays) seismic, acoustic, gravity, and magnetic stations
Microscopic 5	1000:1 10 microns to 1 cm	Micro-fractures, deformation lamellae, grain size.	Micro-fabric orientation diagrams.	Microscope (visible, IR, electron, etc.)
Submicroscopic 6	100 million:1 1 angstrom to 10 microns	Lattice defects.	Crystal structure charts.	X-ray, electron microscope

*Larger-scale maps are produced from the higher orders of observation and smaller-scale maps from the lower orders. The arrows on the right indicate the range in scale: a) upward into the unshaded region by synthesis (integration and mosaicking) of the primary observations, and b) downward into the shaded region by analysis (enlarging and enhancing to the limit of resolution).

scale and the optimum observation platform. The scales, gigascopic (>1000 km), megascopic (10 km to 1000 km), macroscopic (10 m to 10 km), mesoscopic (1 cm to 10 m), microscopic (10 μ to 1 cm), and submicroscopic (1 Å to 10 μ), and their practical range of extension by mosaicking or enlarging were compared (Table 10.2) for use in the solution of problems of synthesis and analysis. The available remote sensing data for Pennsylvania and the relative costs of acquisition of such data were summarized (Table 10.1).

10.3.2 Application of Remote Sensing to Tectonics

Analysis of remote sensing data, particularly those from ERTS-1 and Skylab, has revealed a number of large-scale (>50 km) intra-plate features which had not previously been identified or had only been partially mapped from ground-based geological and geophysical observations. These synoptic data are especially well-suited to surface manifestation studies of intra-plate tectonics over large areas, including presently active features, as well as "fossil" imprints of older stress systems. Remote sensing techniques and accurate hypocenter determinations from existing and planned regional seismic monitoring networks provide a promising approach for mapping the spatial extent of zones of geologically recent deformation and for inferring the associated stresses. This combined approach is especially desirable for areas of relatively low seismicity, such as the eastern United States. Examples from the eastern United States are being studied with emphasis on Pennsylvania and nearby areas.

10.4 Environment

ERTS-1 data have made a notable contribution toward the solution of environmental problems. Two environmental studies undertaken by ORSER, in addition to those done on the ERTS-1 contract, are described here.

10.4.1 Saline Seeps*

At the request of the Earth Survey Applications Division at Goddard Space Flight Center, a study was initiated to determine if ERTS-1 data could be used to detect and map saline seeps in Montana. A ground truth trip to the study site revealed the character, extent, and location of the seeps.

Initially, spring and fall ERTS-1 data were analyzed separately. It was hoped that salt crusts in the spring and indicator plants (salt tolerant weeds) in the fall could be used equally effectively to map the seeps. However, very poor mapping results were obtained in both cases.

Data from the two seasons were then merged and the resulting eight channels of data classified. The final map correlated well with a subsequent field check. Although all the seeps classified were present in the field, many seeps with an area of less than 1 ha were not shown on the classification map. It was concluded that these small areas were beyond the ERTS-1 MSS resolution limit.

*A report on this work is not yet completed.

It is evident that saline seeps can be efficiently and accurately mapped, within the resolution capability of the sensor, by merging spring and fall ERTS-1 data. Data from a single spring or fall scene, however, are not sufficient to reliably map such seeps.

10.4.2 Coal Mine Drainage

A service contract is being negotiated with the Pennsylvania Department of Environmental Resources, The Pennsylvania State University, and the consulting engineering firm of Skelly and Loy of Harrisburg, Pennsylvania. The demonstration study, funded by the Environmental Protection Agency on a matching basis with the Department of Environmental Resources, is designed to demonstrate that the connector-well method of abating pollution derived from abandoned or active deep mines is feasible and cost-competitive with existing abatement techniques. Lineament intersections mapped on various scales using ERTS, Skylab, and aircraft data will serve as the sites for up to four connector wells planned in this pilot demonstration study. The concept demonstrated here is receiving widespread interest and it is expected that the EPA will soon fund demonstrations of mine dewatering techniques for abatement of pollution from active mines.

The project objectives are as follows:

1. To select a field site where a small scale demonstration study can be conducted and, if successful, expanded to abate a significant amount of pollution derived from coal mine drainage.

2. To demonstrate the concept that connector wells can be used to reduce leakage to abandoned and active deep coal mines using a gravity-drainage well scheme in a favorable hydrogeologic setting.

3. To demonstrate that ground water can be drained from aquifers above deep coal mines and recharged to deep aquifers underlying mines for a prolonged period of time without excessive losses in flow rates.

4. To design a well system which will prevent channelization of drainage from the mine environment to the underlying aquifer along the well bore.

5. To demonstrate that the volume of acid mine drainage discharged from the deep mine is reduced, and the water quality improved, after four or more demonstration wells have been completed in the test site.

6. To determine the optimum number, spacing, and cost of connector wells required to bring about a significant reduction in mine water discharge.

7. To determine the hydrogeologic data requirements necessary to select mines where this abatement procedure may be adopted for routine use.

8. To develop cost/benefit data demonstrating that this procedure is economically viable as a mine drainage control method.

9. To develop a set of procedures for site selection and implementation of this technique for expanding its usage in the abatement of drainage from active and abandoned mines.

10.5 Skylab Investigations

ORSER is presently under contract with NASA for investigations involving the use of Skylab data (Contract Number 9-13406). The two projects described here have been completed on this contract to date.

10.5.1 Photointerpretation of Skylab Data*

Skylab scenes from three different areas in Pennsylvania were studied for their potential application to terrain analysis. The study was conducted in two parts: First, photography from the S190A and S190B sensors were compared, with the result that the S190B color positive film was selected as the best in overall quality for terrain analysis. Terrain analyses of the three study areas were then made, using the S190B photography. The summarized results are as follows:

1. Relief differences of 185 to 245 m could be detected, with some indications of lower relief features from shadows and vegetation.

2. Regional geological features could be delineated from topography, and from patterns of drainage, vegetation, and cultural features. Regional strike and dip were indicated, but should be verified by ground truth.

3. Water and wind gaps, and drainage larger than second order were clearly visible. Changes in drainage density were an important indicator of geology.

4. Color and tonal changes gave inconclusive evidence of soil and underlying bedrock. Tonal differences clearly differentiated forest vegetation from cultivated fields. In some cases, concrete highways could be differentiated from asphalt on the basis of tone. Tonal differences in water bodies indicated the presence of silt.

5. Textural differences were used to identify urban, suburban and industrial, and agricultural land uses. The presence of utility and railroad rights-of-way, quarries, and large industrial buildings required aircraft underflight photography for verification.

*This work is described in detail in ORSER-SSEL Technical Report 16-75.

6. Field patterns could easily be seen, although crops could not be identified. The level of generalization at which soils could be mapped compared well with soil association maps prepared by the Soil Conservation Service.

10.5.2 Land Use Classification from Skylab MSS Data*

Using ORSER computer programs, each of the 22 channels (13 bands) of Skylab multispectral scanner data were evaluated with respect to the quality of data in each channel and their suitability for classification. Permanent training areas for future channel evaluation were then located and sample areas of a scene were mapped. A scene including the town of Freeport, Pennsylvania, and a portion of the Allegheny River was selected as having a desirable mixture of target types.

Channel evaluation was based on visual examination of brightness maps generated from individual channels of data. The evaluation included recognition of target patterns, obvious banding problems, garbled data, etc. Only definitely useless channels were eliminated from further analysis. Eighteen channels were considered of usable quality. Sixteen of these were used in processing and a total of 21 signatures were obtained. Eight signatures were developed from uniform blocks on the uniformity map output, and 14 were developed from clustering program output. The signatures fell into 6 basic categories and classified more than 90 percent of five scenes. These categories were: open agricultural land, forest, water, open non-agricultural land, urban areas, and disturbed land.

Accuracy was determined from a USGS 7.5 minute quadrangle map. Although this is not adequate for such determination, large scale aerial photography was lacking for the area of study.

The next objective of this study was to process the data by means of canonical analysis, with a view toward improvement of classification, reduction of data bulk, and determination of the value of each band for classification of various targets. Statistical information for each of the 22 signatures was obtained from the STATS program, and training areas for specific targets were defined. The new signatures, number of observations, and variance-covariance matrixes for the signatures were obtained and used as input to the CANAL program. The objective here was to maximize the separability of the categories (the transformation will usually also reduce the within-category variance). It was determined that, after transformation, the first three axes (linear combinations of the original channel values) contained 98.83 percent of the total data variance (see Section 3.2.2); hence, only the first three axes were for classification. Thus, canonical transformation is a form of feature selection, resulting here in an 81.25 percent reduction in data bulk.

After canonical analysis, 8 additional signatures were obtained, using the cluster analysis algorithm. The final 29 signatures generated 8 land use classes: water, forested, open vegetation, low grassy, central urban, residential urban, strip mines, and factories and disturbed soil. A scaled and colored computer output map of the scene was generated.

*Portions of this work are described in detail in ORSER-SSEL Technical Reports 2-75, 18-75, and 19-75.

CHAPTER 11

RELATED ACTIVITIES

Many of the activities carried on by ORSER are not directly associated with research. Nevertheless, their development was a direct outgrowth of the general objectives of the ERTS-1 contract. These efforts are summarized below, and developed in more detail in the following sections of this chapter.

<u>Education</u>. ORSER has been involved not only with graduate and undergraduate students, but with the education of faculty at the University and other institutions, government and industrial personnel at a number of levels, and the general public.

<u>University and Government Relations</u>. Through attempts to interest the state government at various levels in the potential offered by remote sensing techniques, a great deal has been learned about the needs and interests of the Commonwealth and where remote sensing may be useful for purposes such as resource management.

<u>University and Industry Relations</u>. Subcontracts utilizing ERTS-1 and aircraft data analysis techniques have been fulfilled with two industries, MITRE Corporation and General Electric Company; and proposals have been submitted for joint efforts with HRB-Singer Corporation. Proposals submitted by several other companies have indicated ORSER as a sub-contractor.

11.1 Education

The involvement of ORSER in educational activities has been significant and varied. For instance, in an effort to acquaint the University branch campus faculty with the latest in remote sensing techniques, several such faculty members have been assisted with research projects involving the use of ERTS-1 data and ORSER computer capabilities by long distance telephone lines. One such project involves the extension of the mine refuse study initiated on the ERTS-1 project (described in Section 5.1.1), and another involves a study of water quality around Presque Isle, on Lake Erie.

Two graduate level courses, taught by project staff members, are a direct result of ERTS-1 activities and the availability of the remote sensing data, facilities, and analysis techniques:

<u>Forestry 597: Remote Sensing of Earth Resources</u>, taught by Dr. F. Y. Borden, involves the technology and applications of remote sensing of earth resources. Emphasis is placed on computer analysis of multispectral scanner data acquired by spacecraft and aircraft. Prerequisites include basic calculus and one course in statistics. The lectures cover the following topics: introduction to remote sensing, data collection systems, preclassification analysis and processing, classification and mapping, and applications. The practicum covers:

imagery, photography, and other support materials, use of the remote job entry system, use and organization of tapes, use of pre-classification and classification programs, map making and interpretations; and individual projects. Each student selects a study site and a set of digital data for analysis. He develops his classification techniques for the site during the practicum, completing a land use map or equivalent project by the end of the term.

Geology 546: Photogeology, taught by Dr. D. P. Gold, deals with remote sensing techniques and terrain analysis for geological interpretations. It is designed to acquaint students with remote sensing systems and to develop photointerpreter skills in deducing surficial and bedrock conditions from diagnostic stream density and drainage patterns, landforms, and structure. Emphasizing the photointerpretive aspects, this course complements Forestry 597, which deals with digital processing. Prequisites include basic physics, structural geology, and geomorphology. In the first part of the course there is a literature and data search assignment and an oral presentation by the student on specific remote sensing topics. In addition to standard reference materials, MSS imagery and digital data available in ORSER files are used as resource material. The second part of the course reviews the history and development of aerial photography and photogeology, the fundamentals of photogrammetry, and the use of photo-keys for geologic interpretation and the instrumentation necessary for making quantitative geologic measurements. Photointerpretive skills are developed by analyzing terrains exhibiting a variety of bedrock types, conditions, and climatic settings. Students work with stereoscopic pairs of aerial photographs to produce contour maps and measured altitude of tilted strata. The student is given wide latitude in selecting a term project, and is encouraged to tie this project into a thesis program.

In addition to the courses described above, approximately a dozen other courses offered by various departments at the University are dominantly concerned with remote sensing and/or photointerpretation techniques. Several of these courses are taught entirely, or in part, by ORSER staff members. In others, ORSER personnel have been invited to present guest lectures and to conduct laboratory sessions in remote sensing. Graduate students working on ERTS-1 projects have frequently chosen remote sensing topics for term papers and class presentations as well. Materials such as the C54 35 mm slides have been requested for use in several course presentations.

Weekly or biweekly seminars have been conducted almost every academic term. Presented largely for the benefit of ORSER investigators, to assist them in keeping up with the field and with the results of their fellow staff members, these seminars have attracted faculty and graduate students from many departments. In some cases such visitors have subsequently invited staff members to lecture in their classes, or have commenced projects involving remote sensing data and assistance from ORSER.

Several seminars have been presented at other universities as well. Among these are Cornell University, the University of Georgia, and Virginia Polytechnic Institute and State University. ORSER personnel have also assisted in conducting short courses and workshops at Penn State, the University of Georgia, Yale University, and NASA Houston. While on sabbatical leave to the University of Wisconsin, Dr. Petersen assisted in teaching two courses in remote sensing and worked on two projects involving ERTS-1 data and ORSER-developed analysis techniques. He gave several seminars on remote sensing topics, as well as presentations before general audience groups.

ORSER has become a significant source of data, facilities, and expertise utilized by undergraduate students, as well as graduate students and faculty. As a result, it has become necessary to carefully regulate the use of data and equipment to assure that they would be available for research use when needed. Undergraduate term projects involving ERTS-1 and aircraft data have been as varied as mapping the historic Pennsylvania canal system and doing a crop study on an area in South America (in this case, the ERTS-1 microfilm library was consulted to enable the student to request the appropriate scenes from the EROS Data Center at Sioux Falls).

ORSER-SSEL Technical Reports (see Appendix A) have become significant educational tools. Several students have become aware of the data and facilities available through the file of these reports kept in the undergraduate library on campus. Although the reports are available through NTIS, requests are frequently directed to the authors, and copies have been sent to faculty, graduate students, and businesses in several foreign countries, as well as throughout the United States.

Visits by the general public have been frequent as a result of educational programs featuring ERTS-1 scenes and ORSER personnel on radio and TV, newspaper publicity, and publications and publicity issued by the University's Office of Public Information. Various displays, such as those included as part of the NASA program for high schools, held in Blair County, Pennsylvania, have also held the public interest. Talks on remote sensing and ERTS-1 have been given to general audience groups as close to home as the State College Lions Club and as far away as a high school group in South Africa. Dr. McMurtry was invited to address the Pennsylvania Earth Sciences Teachers Society--an indication of the growing interest of high school educators in remote sensing. A color film, "To Water by Air," prepared by Dr. Richard Parizek and shown to a large variety of audiences, stresses the importance of groundwater as an alternative to surface water sources, and discusses the use of satellite and aircraft data sources to map lineaments and fracture traces as the key to groundwater supplies.

There is little doubt that the variety of educational activities which have grown out of ORSER's involvement with the ERTS-1 project has done much to heighten the awareness of Penn State students and faculty with respect to the true significance of the ERTS-1 program. These activities have been a significant educational influence in the lives of many others as well.

11.2 Presentations

Presentations represent a major activity related to work on the ERTS-1 project. These have taken various forms, including status reports to NASA, both formal and informal. Several presentations were made to groups of officials in the state government, in an effort to interest the Commonwealth of Pennsylvania in using remote sensing techniques as an aid in the solution of many of the state's problems in fields such as agriculture, hydrology, and engineering.

Presentations have also been given to other governmental groups, such as the New Jersey Department of Environmental Protection and the Tennessee Valley Authority. Conferences, symposia, and professional society meetings have been part of the agenda of many investigators, both faculty and graduate students. Many talks and discussions on remote sensing have been held with non-professional groups as well.

11.2.1 NASA Symposia

The following papers have been given at symposia and conferences sponsored by NASA:*

<u>Symposium on Significant Results obtained from the Earth Resources Technology Satellite - 1</u>

ANALYSIS AND APPLICATION OF ERTS-1 DATA FOR REGIONAL GEOLOGICAL MAPPING
D. P. Gold, R. R. Parizek, S. S. Alexander

THE USE OF ERTS-1 MSS DATA FOR MAPPING STRIP MINES AND ACID MINE DRAINAGE IN PENNSYLVANIA
S. S. Alexander, J. L. Dein, D. P. Gold

INVESTIGATIONS OF AN URBAN AREA AND ITS LOCALE USING ERTS-1 DATA SUPPORTED BY U2 PHOTOGRAPHY
H. A. Weeden, F. Y. Borden, D. N. Applegate, N. B. Bolling

MAPPING OF AGRICULTURAL LAND USE FROM ERTS-1 DIGITAL DATA
A. D. Wilson, G. A. May, G. W. Petersen

IDENTIFICATION AND MAPPING OF COAL REFUSE BANKS AND OTHER TARGETS IN THE ANTHRACITE REGION
F. Y. Borden, D. N. Thompson, H. M. Lackowski

CLASSIFICATION OF ERTS-1 MSS DATA BY CANONICAL ANALYSIS
H. M. Lachowski, F. Y. Borden

<u>Third Earth Resources Technology Satellite - 1 Symposium</u>

PENN STATE ORSER SYSTEM FOR PROCESSING AND ANALYZING ERTS DATA
G. J. McMurtry, F. Y. Borden, H. A. Weeden, G. W. Petersen

<u>Earth Resources Survey Symposium</u>

APPLICATIONS OF SATELLITE PHOTOGRAPHY AND MSS DATA TO SELECTED GEOLOGICAL AND NATURAL RESOURCES PROBLEMS IN PENNSYLVANIA
S. S. Alexander, D. P. Gold, W. S. Kowalik, M. D. Krohn, R. R. Parizek

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*Most of these papers are available as ORSER-SSEL Technical Reports--see Appendix A.

11.2.2 Other Reports to NASA

In October of 1973, ORSER participated in the ERTS-1 Investigation Status Conference, held at Goddard Space Flight Center. Five staff members were involved in presentations given to the Environmental and the Interpretations Techniques Panels. In addition to information regarding the results of ERTS-1 data processing, both panels were given descriptions of ORSER's use of aircraft data supplied by NASA and ground truth data available. Cooperation with government agencies was described and a cost-benefit analysis was given.

Environmental Panel Presentation. Results presented to the Environmental Panel, with color slides, covered the following fields: geology and hydrology; inventory of natural resources and land use (mapping agricultural and other land use, surveying forest resources and vegetative cover types); and environmental quality (mapping strip mines, acid mine drainage effects, and anthracite refuse; surveying insect damage to vegetation).

Interpretive Techniques Panel Presentation. Using illustrations from several research projects, the three forms of ORSER interpretive techniques were described: image interpretation using photointerpretive techniques; MSS data processing (the graphics CRT remote terminal was demonstrated, operating from a standard telephone hookup with the Penn State Computation Center); and the hybrid approach to interpretation, in which photointerpretation and data processing techniques are combined to maximum advantage. Two additional topics were discussed: MSS data banding corrections and their extension in classification, and augmenting ERTS-1 MSS data with digitized ground truth map data.

11.2.3 Presentations to State Government

Late in February of 1974, ORSER gave a presentation in Harrisburg to the Department of Environmental Resources (DER). Present were 17 members of that department in such diverse fields as resources programming and flood recovery. Also present were personnel from the Pennsylvania Department of Transportation (PennDot), the Department of Commerce, several regional planning commissions, several institutions of higher education, and various federal agencies. Remote sensing in general was described, with particular attention paid to the ORSER system for processing data. Results of processing ERTS-1 data to date were described, and suggestions were made of areas in which the state might be interested in using remote sensing to solve current problems.

It was explained in the discussions that ORSER considers the field of remote sensing to be in an applied research stage, that is: (1) the concept has been proven, (2) some research remains to be done, (3) applications are being sought, and (4) large areal coverage is obtained quickly at decreasing cost, making remote sensing an essential tool in future land use and environmental management.

It was emphasized that ORSER is seeking increased interaction with local, state, and federal agencies for the following purposes: (1) to identify real world problems for which remote sensing solutions may be helpful,

(2) to educate and train government personnel in the use of remote sensing data and their potential applications, and (3) to help agencies develop working systems using remote sensing techniques for natural resource, environmental, and land use management purposes.

The following services were offered to agencies of the Commonwealth of Pennsylvania: (1) training and education in the form of short courses, seminars, presentations, etc.; (2) use of ORSER facilities, such as the tape and imagery libraries, photointerpretation equipment, and remote terminal access to the computer; (3) opportunity to specify aerial photographic coverage by flights out of Wallops Island, Va. (NASA), and Rome, N.Y. (Griffis AFB); (4) analysis and interpretation of specific problems defined by the agencies, assisted in part by NASA (a proposal for such assistance was submitted to NASA); (5) advice in the applicability of remote sensing systems, methods, techniques, and equipment.

In addition to the presentation described above, ORSER personnel have made presentations to, and held discussions with, numerous state agency personnel. Among these were a presentation to the Pennsylvania House of Representatives Committee on Energy, the Susquehanna River Basin Commission, and several regional and local planning commissions.

11.3 Publications

Most papers published by ORSER staff members (Appendix B), as well as portions of graduate student theses (Appendix C), have also been issued as ORSER-SSEL Technical Reports (Appendix A). In some cases, the report and publication (or thesis section) differ in minor details (e.g., one may be a slight updating of the other), and in other cases one report may be an updating of another (this is especially true of the Data Users Manual). In all, 16 publications (4 in referred journals), 3 Ph.D. theses, 5 M.S. theses, one M.S. paper, and 42 technical reports have been a direct result of the ERTS-1 project. In addition, the project has contributed substantially to 7 publications (1 in a refereed journal), 1 Ph.D. thesis, 5 M.S. theses, one M.S. paper, and 13 technical reports.

11.4 Professional Activities

Faculty and staff members associated with ORSER have had increased opportunities for professional activities as a result of their remote sensing work. Some examples of these activities are listed here.

Drs. Borden and McMurtry participated in a NASA working group and panel on the applications and requirements review for the Synchronous Earth Observation Satellite (SEOS).

Dr. McMurtry, during two weeks of Active Duty for Training as a Naval Reservist in the Office of Geographic Programs, Earth Sciences Division, Office of Naval Research, Arlington, Virginia, prepared a survey of current image enhancement techniques.*

Dr. Petersen participated in the development and instruction of an intensive course on remote sensing techniques for Lockheed and NASA.

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*This survey has been issued as ORSER-SSEL Technical Report 17-74.

He is a member of the Remote Sensing Panel of the Agricultural Research Institute, and was, for two years, chairman of the Committee on the Use of Remote Sensing in Soil Surveys, a committee of the North-East Soil Survey Work Planning Conference.

Dr. Alexander was program chairman for the 1975 American Geophysical Meetings which included, in part, a symposium entitled: Sample of Skylab Results on Earth Resources Experiments. This symposium consisted of invited papers, one of which was by Drs. Alexander, Gold, and Parizek, with three graduate students.

Dr. Gold served on the Geology Review Panel for the November 1972 ERTS-1 Symposium. He was asked to serve on a similar Landsat and Skylab review panel in June 1975, but had to decline. He is presently Chairman of the session on Pattern Recognition with Earth Data for the 14th International Symposium on the Application of Computer Methods in the Mineral Industries, to be held in 1976. On a lecture tour of southern Africa, he delivered six lectures on "Sputnik to Skylab," which included a review of the ERTS-1 program. He also visited the U.N. geological team working on remote sensing techniques for lineament and fracture trace analyses of Lesotho.

Dr. Pennypacker attended the Symposium on the Ecological Interpretations of Remotely-Sensed Data at the First International Congress of Ecology, The Hague. While there, he visited with Drs. Frinking and Zadoks of the University of Wageninger, who have been determining the feasibility of using ERTS-1 data for detection of plant diseases in The Netherlands.

Drs. Weeden and Gold, and Ms. Bolling, are writing portions of the text: REMOTE SENSING IN GEOLOGY, edited by A. R. Gillespie and B. S. Siegal, Jet Propulsion Laboratory, California Institute of Technology, and published by John Wiley and Sons, Inc. The chapter by Dr. Weeden and Ms. Bolling is on Interpretations and Applications of Aerial Photography; the one by Dr. Gold is on Structural Geology.

Dr. Petersen spent the 1974-1975 academic year as a visiting professor at the University of Wisconsin, teaching and participating in research on the applications of remote sensing to land use and water resources management. Throughout this year, he worked closely with personnel of the Institute for Environmental Studies, an interdisciplinary teaching and research organization at the University of Wisconsin; the Soils Department of the University of Wisconsin; the Southeastern Wisconsin Regional Planning Commission; and the Wisconsin Department of Natural Resources.

Two research projects were initiated with the University of Wisconsin, during Dr. Petersen's stay. It is anticipated that these studies will be continued by ORSER under a cooperative agreement. One of these studies involves the detecting and monitoring of hydrologically active source areas, using remote sensing techniques. Several study sites have been selected. High and low altitude aerial photography, as well as aircraft thermal imagery, will be used.

The objective of the second investigation is to determine if data digitized from aerial photographs can be classified to produce land cover maps. A 70 mm AMPS photograph (taken on an RB57 mission) has been spectrally filtered and digitized, using the Optronics Scanning Microdensitometer at the University of Wisconsin. The digitized spectral data have been placed on a computer tape and mailed to The Pennsylvania State University for preliminary analysis. Work has begun on the various data calibration corrections necessary before a final land cover analysis can be accomplished.

Eleven graduates of Penn State, who have worked with ORSER, have been placed in remote sensing positions in government and industry, enhancing their opportunity for professional advancement.

11.5 Interactions with State Agencies

ORSER has had considerable interaction with several agencies of the Commonwealth of Pennsylvania. The first contact was a visit from the Pennsylvania Geological Survey for discussion and imagery perusal. In November of 1972, ORSER personnel were invited to Harrisburg to the Director of Planning and Research for the Pennsylvania Department of Environmental Resources (DER) to give a presentation to representatives from various agencies and to discuss plans for participation in a state program for the use of ERTS-B data in implementing the statutory and regulatory requirements of Pennsylvania. A proposal was developed outlining an interdisciplinary investigation of the application of ERTS-B data to natural resource and environmental problems in Pennsylvania. This proposal was submitted to NASA by DER. ORSER's role in the proposed work was to assist the Commonwealth in the development of its own processing systems utilizing input from satellite, aircraft, and ground truth sources. When the project was not funded, inquiries to NASA revealed that it rated high in the technical evaluation but was rejected because the state did not indicate intention to fund a portion of the proposed work.

ORSER maintained its liaison with the state by, again, going to Harrisburg, in February 1974, and outlining how remote sensing could be used by various agencies. This one-day session was attended by representatives from 39 federal and state agencies (see Section 11.2.3). Considerable interest was generated, prompting visits to the University by personnel from the Pennsylvania Department of Transportation (PennDOT), DER, The Office of State Planning and Development (OSPD), and by the governor's science advisor. These visits included tours of ORSER facilities, examination of imagery and photography, and discussions with staff members. On several occasions, imagery or photographs were reproduced to fill requests from various agencies.

These discussions with state personnel led to the development of another proposal, entitled "Transfer and Utilization of the Technology for Monitoring and Evaluating Earth Resources in Pennsylvania," which was submitted to the Pennsylvania Science and Engineering Foundation (PSEF). The Pennsylvania State University had agreed to make a $42,000 per year contribution to this project. However, due to budgetary restrictions, the state agencies involved did not feel that funds could be committed. Nevertheless, the state, and in particular PSEF, indicated its willingness to contribute funds toward a project for which there was sufficient additional support from other sources, e.g., NASA, other federal agencies, and the University.

State agency personnel continue to express interest in remote sensing, and further discussions have been held with the Departments of Transportation, Agriculture, and Environmental Resources; the Bureau of Scientific and Technological Development; and the Governor's Energy Council. ORSER personnel have also been asked by OSPD to review the "Interim Land Policy Statement" for Pennsylvania.

Despite repeated interaction and continued expressions of interest, ORSER has not been able to obtain support from the state. Conversations with other remote sensing research groups, however, indicate that funding for applied research projects on remote sensing is at a low level in most states and that our experience in Pennsylvania has not been unique. Nevertheless, ORSER retains the hope that continued contact with state agencies will result in joint activities and attract the needed federal funding necessary to support these activities.

11.6 Visitors and Inquiries

Receiving visitors and answering inquiries has become a major activity within ORSER. This is a very time-consuming part of our activities, but one which is felt to be necessary from the standpoint of increasing the public's awareness of remote sensing and fulfilling Penn State's responsibilities to the public as a land grant university. The specifics of these visits and inquiries vary, but they include viewing imagery, seeking advice on the use of remote sensing, simply finding out what is meant by remote sensing, discussing possible projects, seeking information regarding use of the data processing system, requesting copies of reports, requesting completion of survey questionnaires on remote sensing activities, and inquiring about specific details in technical reports. A partial list of visitors and sources of inquiries is given below, to provide some indication of the breadth of this activity.

<u>County planning commissions</u> from Bucks, Clinton, York, Franklin, Clearfield, Lackawanna, and Huntingdon Counties in Pennsylvania.

<u>Regional planning and development groups</u>, including the Susquehanna Economic Development Authority, the Tricounty Conservancy of the Brandywine, the Economic Development Council of Northeastern Pennsylvania, and the Northwest Planning and Development Commission of Pennsylvania.

<u>State agencies</u>, including the Pennsylvania Department of Transportation, the Office of State Planning and Development, the Pennsylvania Department of Agriculture, the Pennsylvania Department of Environmental Resources, and the Pennsylvania Geologic Survey.

Federal agencies, including the U.S. Geological Survey; the Susquehanna River Basin Commission; the Soil Conservation Service (field soil scientists, state office personnel, and the Cartographic Division in Hyattsville, Md.), the National Park Service, the U.S. Army Corps of Engineers; the Environmental Protection Agency; the Great Lakes Basin Commission; the U.S. Forest Service; and NASA facilities at Lewis, Goddard, Langley, Mississippi, Houston, and Ames.

Commercial firms, such as HRB-Singer Corporation; General Electric Company; Dames & Moore, Inc.; Gilbert Associates; Michael Baker, Jr., Inc.; Moody and Associates; Energy Resources Company, Inc.; MITRE Corporation; Consolidated Natural Gas Service Company; Todd Giddings and Associates; Bethlehem Steel Corporation; and Earth Satellite Corporation.

Penn State departments and personnel, including course instructors seeking information and data for lectures and research, students seeking project materials, etc.

Universities other than Penn State, including Cornell, Harvard, MIT, Wisconsin, North Carolina State, and Syracuse.

Professional personnel from foreign countries, including teaching and research staff from universities, government agencies, and research organizations in The Netherlands, Israel, India, Australia, Germany, Canada, South Africa, Bulgaria, and Switzerland.

The UN Food and Agricultural Organization, which has approached ORSER concerning assistance to the Peruvian and Indian governments in developing their remote sensing capabilities.

Others, including personnel from the Pennsylvania Technical Program, the Academy of Natural Sciences, the Penn State Hike and Bike Club, Hawk Mountain Sanctuary, and individual geological and agricultural consultants.

There have also been special visitors, such as Captain Paul Weitz, of the U.S. Navy, Penn State graduate and Skylab astronaut, who gave a seminar on Skylab and answered questions from students and staff.

Many requests for information have been handled by mailing ORSER-SSEL Technical Reports (see Appendix A).

11.7 Outside Use of the ORSER Data Processing System

The ORSER data processing system has gained wide recognition for its efficiency, speed, low cost, and accuracy. As a result, many people outside of Penn State have become users of this system, and many more make inquiries about its use. Users of the system either obtain access to computation system directly, or purchase ORSER software to install on their own systems.

Long distance access. These users are connected to the Computation Center at Penn State by long distance commercial telephone lines. They have an IBM compatible terminal at their home location and can operate the ORSER system and receive standard output there. The data must first be sent to the Computation Center, usually by mail. The MITRE Corporation and Dames & Moore, Inc. have utilized the ORSER system in this manner and NASA-Goddard is currently such a user.

Purchase and local installation. These users purchase the programs from Penn State and install them on their own local computers. ORSER and Penn State accept no responsibility for the proper installation or use of these programs or for interpretation of any results from their use. No responsibility is assumed for maintaining these programs or for informing the user when changes are made at ORSER. Even with the above qualifications, several institutions and agencies have obtained and installed these programs. Reports indicate that the users have generally had success, with few or no problems with installation or use of the programs.

The following groups have received copies of ORSER programs:

Cornell University, School of Civil and Environmental Engineering

Italian Embassy, Delegation of the European Commission

North Carolina State University, School of Design

Texas School of Technology, Department of Mathematics

U.S. Department of Agriculture, Washington, D.C.

University of Georgia, School of Forest Resources

Harvard University (in cooperation with MIT) for a United Nations Food and Agricultural Organization project.

University of Zurich, Geographic Institute, Switzerland

Federal Institute of Technology, Zurich, Switzerland

EURATOM - an interdisciplinary working group in the European Common Market

CHAPTER 12

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

As a result of the work on the ERTS-1 project, ORSER believes that it has achieved significant results in four technical and/or applications areas: 1) data processing and pattern recognition; 2) inventory of natural resources and land use; 3) geology and hydrology; and 4) environmental quality. The results in each of have been discussed in Chapters 3 through 6 and are summarized briefly below. In addition, an analysis of the costs of obtaining such results has been made (Chapter 7).

ORSER's involvement in the ERTS-1 project has also: (1) demonstrated the effectiveness of an interdisciplinary approach to remote sensing analysis and interpretation (Chapter 9); (2) stimulated several other projects, including work for user agencies (Chapters 10 and 11); and (3) provided training for graduate students which has broadened their outlook, provided them with an opportunity to apply their knowledge to real-world problems, and increased their opportunities for employment upon graduation (Chapter 11).

Finally, ORSER's experience not only with ERTS-1 but also aircraft and Skylab data has resulted in an overall evaluation of the applications and limitations of the various data types (Chapter 8), and a preview of the future for remote sensing and ORSER (Section 12.4).

12.1 Summary of Results

The results of the four specific tasks undertaken on the ERTS-1 project are summarized below. Conclusions and recommendations drawn from these results, and from experience with the many related aspects of the overall projects, are presented in Sections 12.2 and 12.3, respectively.

12.1.1 Data Processing and Pattern Recognition

The full potential of high-quality data is achieved only with the application of efficient and effective interpretation techniques. An excellent operating system for the handling, processing, and interpreting ERTS-1 and other MSS data has been achieved on this project. Programs for processing digital data are implemented on a large non-dedicated general purpose computer located at The Pennsylvania State University Computation Center. A data processing system has been developed which is capable of producing statistical information, performing pattern recognition routines, and generating maps and other types of analyses of remotely-sensed data. Computation cost efficiency has been emphasized throughout. Non-University users have access to this system by means of remote terminals connected by telephone lines to the Computation Center. Although emphasis has been placed on processing digital data, ORSER has routinely utilized a hybrid approach, in which photointerpretation is an essential overall part of the analysis and interpretation process. The availability of high quality aircraft underflight photography is, therefore, an important source of ground truth for purposes of verification and interpretation of digital processing results.

Several options are available for digital analysis of the data, and both supervised and unsupervised algorithms may be used for classification purposes. Unsupervised cluster analysis has been shown to be extremely helpful in development of spectral signatures for classification in areas of small size or spectral non-homogeneity. A canonical analysis algorithm has been implemented which performs a linear transformation of the data; this transformation emphasizes the differences between classes in the transformed dimensions and may also be used as a technique for reduction of dimensions in processing and classification, thus, reducing both the time and cost of analysis. Experience with the General Electric Image 100 system effectively demonstrated the potential value of combining the advantages of speed and image enhancement of a highly interactive display system, such as the Image 100, with those of a large capacity and flexible processing system, such as that developed by ORSER on the large general purpose computer.

Many specific programs and procedures have been developed for analysis of both digital data and imagery. Several of these are discussed briefly in this report and all are completely documented in ORSER-SSEL Technical Reports (see Appendix A). Among these technical reports can also be found documents describing the cataloging of both imagery and digital data and a comprehensive manual describing in detail the use of all computer programs in the ORSER system.

12.1.2 Inventory of Natural Resources and Land Use

Significant results have been attained in mapping land use, agricultural croplands, forest resources, and vegetative cover. The categories of land use classified and mapped depend upon the geographic location, the detail required, and the types of land use of interest. In most cases, the final product is a thematic map generated by computer processing.

When mapping areas such as major river basins and watersheds, relatively few categories may suffice. In mapping large portions of the Susquehanna River Basin, for example, seven land categories were used: water, urban, disturbed land (e.g., strip-mines, quarries), pasture, cropland, forest, and "other." In smaller heterogeneous areas, classification has been performed in greater detail. Categories mapped in these cases have included golf courses, suburban areas, industrial areas, and shopping centers. Such detailed classification is obviously more difficult and requires adequate ground truth and aircraft data for support and verification.

Agricultural areas have been mapped in several portions of central and southeastern Pennsylvania. In central Pennsylvania, a brief comparison was made among techniques of photointerpretation from the imagery, digital analysis, and interactive analysis with the General Electric Image 100 system. Agricultural areas in Pennsylvania present special problems with ERTS-1 data because of the small size and irregular shape of fields, due to agricultural practices adapted to the terrain. The resulting complex spatial patterns generally do not provide more than a few pixels of spectral uniformity. Nevertheless, by careful and detailed analysis, mapping of such areas has been shown to be feasible.

Forest cover types have been analyzed in several areas of the state. Hardwoods, conifers, hardwoods with conifer understory, rhododendron, and open areas over 10 ha in size have been differentiated. Merging of data from winter and summer scenes has been very useful in defining these classes. Progress has been made with the problem of aspect--a significant difficulty in central Pennsylvania--and signatures have been successfully transferred from one study area to another with only minor changes necessary.

12.1.3 Geology and Hydrology

Painstaking synthesis over many years has provided regional, state, national, and global geologic maps. However, the synthesis of features on one scale does not guarantee that a larger feature will necessarily be apparent on the smaller scale map generated. Artifacts in mosaicking poorly known scaling laws, and inconsistent conditions (variable sun angle, albedo, seasons, etc.) of data collection are more likely to obscure than enhance subtle features. The advent of ERTS-1, however, has presented an unparalleled opportunity for the analysis of a large body of data on a small scale, gathered under consistent conditions.

Physiographic and structural provinces are spectacularly displayed on ERTS-1 MSS image mosaics. Geologic bedrock structures show up well and formation contacts can sometimes be traced for hundreds of kilometers. Large circular structures and regional features, previously obscured by the detail of higher resolution data, can be seen.

The study of lineaments and fracture patterns has been the focus of concentration for ORSER geologists. Numerous earlier geologic studies have shown fracture patterns and the few lineaments seen on aircraft photography to be strongly correlated with groundwater resources. ERTS-1 imagery has revealed for the first time the abundance and wide distribution of lineaments across the state of Pennsylvania. These features exert a strong control on topography and have been shown to be significantly correlated with groundwater supplies. A map prepared by ORSER indicates that in some cases lineaments appear to localize mineral deposits as well. A knowledge of lineament location is also highly relevant to the planning of engineering projects and is critical in the location of facilities such as nuclear power plants.

Summarization of lineament orientation by frequency, length, and degree of expression (using ORSER-developed programs) and comparison with lineaments seen on Skylab scenes has shown a bias against detecting lineaments near the sun azimuth and near the scan line direction.

Lineaments and other geologic features revealed for the first time by the wide view of ERTS-1 are contributing significantly to knowledge of the earth's structures and processes. A large number of geologic projects, initiated by ORSER and others, have been stimulated by the data from ERTS-1, and are continuing, with heavy concentration on ground truth correlation in an effort to ascertain further the practical significance of these newly identified features.

12.1.4 Environmental Quality

The periodic nature of ERTS-1 data acquisition presents an ideal opportunity for monitoring of the effects of environmental changes on land-use potentialities. ORSER has investigated the possibilities of such monitoring in three major areas, that of coal strip mining, coal refuse problems, and damage to vegetation caused by insects and pollution.

One of the most serious environmental problems facing Pennsylvania is that of strip mining for coal. Extensive tracts of land have been stripped and effective and efficient methods are required to monitor the extent of this work and the effectiveness of reclamation and re-vegetation projects. Digital mapping of such areas has shown that characteristic spectral signatures of stripped areas persist over different seasons, some areas of vegetation affected by acid mine drainage can be mapped, and digital mapping with MSS data can be used to monitor quantitatively the extent and location of strip mining activity.

Another serious environmental problem is the surface accumulation of wastes from coal mining and processing. Such refuse piles contribute both silt and acid pollution to streams. Located either within or very close to towns and cities, they frequently catch on fire, polluting the air with sulfur dioxide and posing a real danger to nearby populations. Coal refuse is potentially a valuable resource; however, effective reclamation programs require the development and periodic updating of inventories on a regional scale. The feasibility of using ERTS-1 data to map coal refuse has been demonstrated, and it appears that working maps could be produced for field personnel actually involved in reclamation and pollution control.

Insect and air pollution damage to vegetation are also serious environmental problems in Pennsylvania. Two successive summers of heavy insect defoliation can kill most hardwoods, and softwoods can be killed by a single defoliation. The Pennsylvania Bureau of Forestry estimated that 857,000 acres of Pennsylvania forest were defoliated by gypsy moths during the summer of 1973, more than twice as much as was defoliated during 1972. Seventy-nine per cent of that area was heavily defoliated. Accurate monitoring of defoliation is an aid in determining the magnitude of the problem and in investigating and developing control and conservation procedures. Using both imagery and digital data, ORSER investigators have demonstrated how ERTS-1 data can be used to monitor gypsy moth defoliation. The effects of air and soil pollution on vegetation surrounding a zinc smelter have also been investigated, resulting in a map showing four categories of forest condition.

12.2 Conclusions

Several conclusions have been drawn as a result of the work on this ERTS-1 project. Although individual conclusions are undoubtedly biased by the particular backgrounds and interests of ORSER personnel, taken as a whole they are believed to be reasonably well balanced due to the interdisciplinary nature of the project.

The primary value of ERTS-1 imagery is in making broad regional interpretations, such as delineation of physiographic and generalized land use features and geologic mapping. Of special value is the visibility of large, but subtle, features, such as lineaments, which are obscured by the details found in data of higher resolution.

Detailed mapping with quantitative analysis and evaluation is best performed using ERTS-1 digital data. Both spectral and spatial resolution within the limits of the ERTS-1 system can be preserved at all stages of the analysis. Areas of 4 ha or larger can be regularly classified, and in many cases smaller areas may be identified, depending on scene contrast and other factors.

A hybrid approach to the interpretation of MSS data appears to be highly desirable. In the case of ERTS-1 data, this involves extensive use of photointerpretive techniques applied to aircraft underflight photography for purposes of verification and interpretation of the digital data processing results.

Due to the large area covered by ERTS-1 data and the nature of the problems to which such data are most suitably applied, an interdisciplinary team is recommended for most interpretations.

The quality of ERTS-1 data is generally very good. The volume of data is large, but reasonable, considering the extremely large area covered in a single scene. With only four channels (and even with possibly five in future missions), many facilities have computing capabilities which are adequate to handle and process these data.

The major advantages of ERTS-1 data are: (1) temporal coverage of the earth with good repeatability, (2) large areal coverage, and (3) their multispectral nature.

The principal limitations of ERTS-1 data are (1) lack of data over cloud-covered areas, (2) low ground resolution, (3) lack of a thermal infrared channel, (4) the length of time (18 days) between consecutive passes over any given area, and (5) the length of time between a request for data and its receipt by the user.

In general, ERTS-1 provides extremely useful data for many earth resources applications. This project has demonstrated the feasibility of specific applications to a wide variety of problems in the areas of inventory of natural resources and land use, monitoring of environmental quality, and providing geologic information. ERTS-1 data and the methods developed for its interpretation provide a valuable tool for regional management of natural resources and land use.

12.3 Recommendations

The following recommendations are suggested for future satellite and aircraft missions:

1. The resolution of the satellite scanner should be improved to approximately 25 meters.

2. The repetitive coverage of the satellite should be increased to intervals of a week or less.

3. The turn-around time between requests for data and receipt by the users should be reduced to two weeks for routine requests and 24 to 48 hours for special requests.

4. A thermal channel should be added to the satellite scanner.

5. Care should be taken that aircraft data collection missions are carried out at the desired time of the year and time of day, and on a course which covers the entire test site.

6. The aircraft MSS scanner should be calibrated and calibration information should be supplied to the user.

7. For the purposes of ground truth for ERTS-1 data processing, aerial photography should be obtained from altitudes of at least 5000 m above the ground surface.

8. The photography obtained by the U2 aircraft is extremely useful, yielding coverage of extensive areas with a resolution acceptable for most uses. Consideration should be given to making the U2 into an operational system, such that flights could be requested by a variety of users.

9. A multispectral scanner should be flown on the U2 aircraft. This platform could minimize the problems encountered with a low-flying aircraft and would give a pixel with much greater resolution than that of ERTS-1.

10. Channel selection procedures should be employed to reduce data volume and analysis costs, unless adequate computing facilities and funds are available.

11. An interactive display system (such as a color cathode ray tube system) should be used to aid in the analysis and to reduce overall analysis time.

12. A national, central data processing network with several regional data centers should be investigated seriously and implemented as soon as possible. This could reduce the time required to get the data to users and thus encourage more agencies to become users.

12.4 Outlook for Remote Sensing and ORSER

Both the short-term and long-term outlooks for programs involving the remote sensing of earth resources appear to be bright. A second ERTS (now called Landsat) was launched in January 1975, and Landsat-C has been approved for launching in 1977. A fourth satellite, Landsat-D, is currently being designed. The Heat Capacity Mapping Mission (HCMM) is scheduled for launch in 1977. The Synchronous Earth Observations Spacecraft (SEOS) program is well into its advanced planning stages.

The Committee on Remote Sensing Programs for Earth Resources Survey (CORSPERS) of the National Research Council released a report in 1974 and the Space Applications Board (SAB) released a report in 1975, both of which recommended continuation of, and improvement in, current remote sensing programs and placement of particular emphasis on acquainting potential users with the operational prospects of such programs. Of particular note was the recommendation by CORSPERS that all earth resources data processing be converted to digital techniques. A large central data processing network with several regional and local data centers was also proposed. The SAB report recommends systems be developed for transmission of data to users within three to five days (as opposed to the current 3-4 week interval).

Congress has been very favorably impressed with the successes of the ERTS program and, in fact, caused the Office of the Management of the Budget (OMB) to reverse its position and recommend budget approval for Landsat-C to the President. The SAB report recommended that any new federal land use legislation take into consideration the possibilities of acquiring data by the use of remote sensing from aircraft and space.

Remote sensing appears to be in the applied research stage of development. Although shown feasible, considerably more research is needed to develop advanced techniques, systems, and methods for making remote sensing programs cost-effective. This obviously requires funding as well as identification of applications by users and closer interaction between these users and the research groups involved.

A combination of positions taken by NASA and various federal and state agencies has led to perhaps the major constraint in obtaining funding for remote sensing projects. NASA has launched the satellites and provided funding for basic research to prove the feasibility of remote sensing applications, but user agencies at the state and federal level were expected to provide funding for actual applications. The potential user agencies, on the other hand, have taken the position that they will not, or cannot, provide funds for research, and they have not yet been convinced that the programs are sufficiently cost-effective to warrant funding support.

There are strong indications that this impasse is being recognized, and that funding for such applied research will be more readily available. Indication of a shift in NASA's position is given by two examples. First, in requesting funds for Landsat-C, James Fletcher, NASA Administrator, is reported to have explained to OMB and the President that Landsat-C was to be an "experimental" system and not "operational," thus recognizing that much research and developmental work remains to be done. Secondly, NASA has begun to support many projects with specific applications in mind in an attempt to show potential users at the state level the operational importance of remote sensing programs. In addition to position shifts by NASA, other more user-oriented federal agencies are showing signs of supporting some of the necessary applied research. Such agencies include the U.S. Bureau of Mines, the U.S. Geological Survey, and the Appalachian Regional Commission.

Both the CORSPERS and SAB reports discuss the lack of state and other user activity, and CORSPERS suggests that the two major reasons are: (1) uncertainty that remotely sensed data will continue to be collected, and (2) the need for data with better spatial resolution and unawareness of the potential usefulness of the data available. A third reason is undoubtedly the present relatively high cost of the information produced. The first reservation is certainly becoming less serious with the announcement of approval for Landsat-C and the importance which Congress is giving to earth resources programs. The problem of spatial resolution is one which has two answers:

1. At the satellite altitudes required for synoptic coverage, there will always be a physical limitation to the resolution attainable, but improvements can be expected in all programs and are planned for Landsat-C (where the RBV system will have about twice the resolution (± found on Landsat-1 and Landsat-2).

2. State users are becoming more aware of the uses of data with current Landsat (ERTS) resolutions; states are also becoming aware of the remote sensing capabilities of other systems, such as high-altitude aircraft (U2).

A good example of increasing awareness, and appreciation for potential cost savings, is shown in the following excerpt from the SAB report: "The Water Resources Planning Act of 1965 stipulates that a national inventory be made biannually. To date only one inventory has been made and it was less than satisfactory. . . . Currently another national inventory is underway at an appropriated cost of $605 million. Representatives of the water resource management community involved in the study estimated that the actual cost of the inventory will be about twice the amount appropriated if conventional means of data collection are used. They estimated that a significant part of these data costs could be saved if space-based remote sensing were added to current capabilities."

Funding opportunities should increase in the near future, although they may have to be more deliberately sought than in the recent past. Federal agencies including NASA, USGS, EPA, USDA, and NSF are expected to continue supporting research in remote sensing, while regional agencies such as ARC and SRBC are interested in supporting demonstrations of the applicability of remote sensing techniques to problems in their regions. State agencies are less likely to provide major research support, although they can be expected to be more willing to share costs on projects having direct applications to problems of current state concern. The greatest single deterrent to the use of remote sensing by state agencies in Pennsylvania has probably been an over-selling of ERTS-1 potential. The ramifications of this are still observable, but gradually being overcome. Agencies expected to be particularly interested in remote sensing in Pennsylvania are the Department of Agriculture, the Department of Environmental Resources, and the Office of State Planning and Development. ORSER has had considerable interaction with several of these agencies in the past, and while success in obtaining funding support has not been attained, there remains the hope that joint activities might attract support at the federal level -- particularly if the state agencies and the University can show a willingness to share in the costs.

ORSER anticipates that future research activity on its part would involve any or all of the following:

1. Continued program development including:

    a) making the ORSER system more user-oriented and operational;

    b) developing and implementing more pattern recognition techniques; and

    c) developing and implementing image enhancement techniques.

2. Evaluation of spectral bands for optimum combinations in sensors.

3. Development and implementation of methods for inclusion of other types of data with spectral data, i.e., expansion of the data base used for classification.

4. Use of other types of remotely sensed data, e.g., thermal IR, SLAR.

5. Greater use of data collected from aircraft.

Undoubtedly, an important phase of any future ORSER activities will be informing the public and potential users of the valuable earth resources information available through remote sensing.

In conclusion, although funding of ORSER activities is approaching a low level in the immediate future, the outlook for obtaining substantial outside support and undertaking new projects must be considered to be good. There will have to be a greater attempt to obtain funding for tasks which are more discipline-oriented than the ERTS-1 project, but it is believed that such tasks can maintain an identity with remote sensing and be properly conducted as ORSER activities, e.g., the anticipated project on lineament analysis. Large interdisciplinary projects will be difficult to obtain because of their necessarily high cost and because effective methods of evaluating interdisciplinary proposals have not yet been developed. However, opportunities will continue to be available (e.g., HCMM and Landsat-C), and it is believed that the interdisciplinary nature of ORSER hould, therefore, continue in its effectiveness.

Appendix A

ORSER-SSEL Technical Reports

Reports Resulting from the ERTS-1 Project

9-73 INTERDISCIPLINARY APPLICATIONS AND INTERPRETATIONS OF ERTS DATA WITHIN THE SUSQUEHANNA RIVER BASIN: RESOURCE INVENTORY, LAND USE, AND POLLUTION
Principal Investigators: G. J. McMurtry and G. W. Petersen
(ERTS Type II Report for 1 June 1972 through 30 May 1973)

10-73 PROGRAM DESCRIPTIONS
F. Y. Borden, D. N. Applegate, B. J. Turner, H. M. Lachowski, and J. R. Hoosty
(Out-of-date, material is included in TR 10-75.)

11-73 ERTS AND AIRCRAFT MULTISPECTRAL SCANNER DIGITAL DATA USERS MANUAL
F. Y. Borden, D. N. Applegate, B. J. Turner, H. M. Lachowski, and J. R. Hoosty
(Updated by TR 16-74 and 10-75.)

12-73 STORAGE AND RETRIEVAL OF ERTS AND UNDERFLIGHT IMAGERY
N. B. Bolling
(Updated by TR 18-74.)

13-73 DEVELOPMENT OF THE HYBRID APPROACH TO DATA PROCESSING
H. A. Weeden, F. Y. Borden, D. N. Applegate, and N. B. Bolling

14-73 LAND USE MAPPING
F. Y. Borden, H. A. Weeden, D. N. Applegate, and N. B. Bolling

16-73 SURVEY AND INVENTORY OF FOREST RESOURCES
B. J. Turner and D. L. Williams

17-73 CANONICAL ANALYSIS APPLIED TO THE INTERPRETATION OF MULTISPECTRAL SCANNER DATA
H. M. Lachowski and F. Y. Borden
(Out-of-date, updated material is included in TR 10-75.)

18-73 CATALOGS FOR REMOTE SENSING DIGITAL DATA TAPES
F. Y. Borden, H. M. Lachowski, and D. N. Applegate

19-73 PROCESSING OF REMOTE SENSING DATA
G. J. McMurtry, S. J. Chung, and N. B. Bolling
(Updated by TR 9-74.)

20-73 MAPPING OF ANTHRACITE REFUSE
D. N. Thompson and F. Y. Borden

21-73 INVESTIGATION OF VEGETATIVE COVER CONDITIONS
B. F. Merembeck and F. Y. Borden
(Updated by TR 12-74.)

22-73 CORRECTION OF BANDING IN MSS DIGITAL DATA
F. Y. Borden
(Updated by TR 11-74.)

23-73 ACID MINE DRAINAGE AND STRIP MINES
S. S. Alexander and J. L. Dein

25-73 AGRICULTURAL LAND USE MAPPING
A. D. Wilson and G. W. Petersen
(Updated by TR 23-74.)

1-74 ANALYSIS AND APPLICATION OF ERTS-1 DATA FOR REGIONAL GEOLOGIC MAPPING
D. P. Gold, R. R. Parizek, and S. S. Alexander

2-74 GEOLOGIC INVESTIGATIONS OF THE GREAT VALLEY IN PENNSYLVANIA
D. Krohn and D. P. Gold

3-74 GRAY SCALE PRINTING AND PHOTOGRAPHIC REDUCTION OF LARGE AREA COMPUTER GENERATED MAPS
A. D. Wilson and R. E. Ackley

5-74 COMPUTER ANALYSIS AND MAPPING OF GYPSY MOTH DEFOLIATION LEVELS IN NORTHEASTERN PENNSYLVANIA USING ERTS-1 DATA
D. L. Williams and B. J. Turner

6-74 PRELIMINARY INVESTIGATION OF THE EFFECT OF CONVERSION OF ERTS DATA TO RADIOMETRIC VALUES ON THE PERFORMANCE OF THE PSU REMOTE SENSING CLASSIFICATION ROUTINES
R. E. Link, Jr.

7-74 A METHOD OF SPECIFYING REMOTELY SENSED UNITS FOR SOIL SAMPLE POINTS
G. A. May, G. W. Petersen, F. Y. Borden, and D. N. Applegate

8-74 INTERDISCIPLINARY ANALYSIS AND INTERPRETATIONS OF EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS) DATA
G. J. McMurtry
(Updated by TR 9-74.)

9-74 THE PENN STATE ORSER SYSTEM FOR PROCESSING AND ANALYZING ERTS AND OTHER MSS DATA
G. J. McMurtry, F. Y. Borden, H. A. Weeden, and G. W. Petersen

10-74 APPLICATION OF REMOTE SENSING TO NATURAL RESOURCE AND ENVIRONMENTAL PROBLEMS IN PENNSYLVANIA
D. P. Gold, S. S. Alexander, and R. R. Parizek

11-74 TRANSFERENCE OF ERTS-1 SPECTRAL SIGNATURES IN TIME AND SPACE
B. F. Merembeck, F. Y. Borden, and D. N. Applegate

12-74 CLASSIFICATION AND MAPPING OF COAL REFUSE, VEGETATIVE COVER TYPES, AND FOREST TYPES BY DIGITAL PROCESSING ERTS-1 DATA
F. Y. Borden, B. F. Merembeck, D. N. Thompson, B. J. Turner, and D. L. Williams

14-74 SENSITIVITY OF NORMALIZED CLASSIFICATION PROCEDURES FOR FLOODPLAIN SOILS
L. E. Link, Jr.

16-74 ERTS AND AIRCRAFT MULTISPECTRAL SCANNER DIGITAL DATA USERS MANUAL
F. Y. Borden, D. N. Applegate, B. J. Turner, H. M. Lachowski, and J. R. Hoosty
(Updated by TR 10-75.)

18-74 STORAGE AND HANDLING OF SATELLITE AND AIRCRAFT IMAGERY IN ORSER
N. B. Bolling

19-74 SATELLITE DETECTION OF VEGETATIVE DAMAGE AND ALTERATION CAUSED BY POLLUTANTS EMITTED BY A ZINC SMELTER
E. L. Fritz and S. P. Pennypacker

20-74 INTERPRETATION OF PENNSYLVANIA AGRICULTURAL LAND USE FROM ERTS-1 DATA
G. W. Petersen and A. D. Wilson

22-74 INTERPRETATION AND MAPPING OF GYPSY MOTH DEFOLIATION FROM ERTS-1 TEMPORAL COMPOSITES
W. S. Kowalik

23-74 TECHNIQUES FOR DELINEATION AND PORTRAYAL OF LAND COVER TYPES USING ERTS-1 DATA
G. W. Petersen and A. D. Wilson

26-74 APPLICATION OF ERTS IMAGERY TO THE STUDY OF RESIDUAL KAOLINS
R. W. Pollok

4-75 PROCESSING ERTS AND AIRCRAFT MSS DATA WITH THE GENERAL ELECTRIC IMAGE-100 SYSTEM
B. F. Merembeck and F. Y. Borden

5-75 LINEAMENT MAP OF PENNSYLVANIA
W. S. Kowalik and D. P. Gold

6-75 APPLICATIONS OF CLUSTER ANALYSIS IN NATURAL RESOURCES
B. J. Turner

9-75 RELATION OF LINEAMENTS TO SULFIDE DEPOSITS: BALD EAGLE MOUNTAIN, CENTRE COUNTY, PENNSYLVANIA
M. D. Krohn and D. P. Gold

10-75 SATELLITE AND AIRCRAFT MULTISPECTRAL SCANNER DIGITAL DATA USERS MANUAL
F. Y. Borden, D. N. Applegate, B. J. Turner, H. M. Lachowski, B. F. Merembeck, and J. R. Hoosty

11-75 DIAZO PRINTING OF ERTS COLOR COMPOSITES
W. S. Kowalik

12-75 COMPARISON OF SKYLAB AND LANDSAT LINEAMENTS WITH JOINT ORIENTATIONS IN NORTHCENTRAL PENNSYLVANIA
W. S. Kowalik

14-75 LINEAMENTS AND MINERAL OCCURRENCES IN PENNSYLVANIA
W. S. Kowalik and D. P. Gold

15-75 REMOTE SENSOR DIGITAL IMAGE DATA ANALYSIS USING THE GENERAL ELECTRIC IMAGE 100 ANALYSIS SYSTEM (A STUDY OF ANALYSIS SPEED, COST, AND PERFORMANCE)
General Electric Company, Space Division

17-75 RECONNAISSANCE MAPPING FROM AERIAL PHOTOGRAPHS
H. A. Weeden and N. B. Bolling

Reports from Related Projects

15-73 COMPARISON OF PREPROCESSING AND CLASSIFICATION TECHNIQUES AS APPLIED TO MULTISPECTRAL SCANNER DATA
J. R. Hoosty and G. J. McMurtry

24-73 ANALOG TO DIGITAL CONVERSION AND PROCESSING OF MSS DATA USING A HYBRID COMPUTER
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15-74 THE USE OF REMOTE SENSING AND NATURAL INDICATORS TO DELINEATE FLOODPLAINS--PRELIMINARY FINDINGS
S. C. Sollers, G. W. Petersen, D. L. Henninger, and F. Y. Borden
(Updated by TR 1-75.)

17-74 A SURVEY OF IMAGE ENHANCEMENT TECHNIQUES
G. J. McMurtry

21-74 LAND USE MAPPING IN THE SUSQUEHANNA RIVER BASIN
G. A. May and G. J. McMurtry

24-74 LAND USE MAPPING IN ERIE COUNTY, PENNSYLVANIA--A PILOT STUDY
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1-75 FLOODPLAIN DELINEATION USING AIRCRAFT DATA
D. L. Henninger, M. L. Stauffer, H. A. Weeden, and G. W. Petersen

2-75 PRELIMINARY SKYLAB MSS CHANNEL EVALUATION
D. M. Barr and F. Y. Borden

3-75 SPECTRAL SIGNATURE SELECTION FOR MAPPING BARE SOILS
G. A. May and G. W. Petersen

16-75 PHOTOINTERPRETATION OF SKYLAB PHOTOGRAPHY
H. A. Weeden, C. Kleeman, S. Daelhausen, and G. Hesler

Appendix B

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Appendix C

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