Research, Investigations and Technical Developments National Mapping Program 1985-1986

USGS Open-File Report 87-315

Department of the Interior
U.S. Geological Survey
National Mapping Division

UNITED STATES
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

RESEARCH, INVESTIGATIONS, AND TECHNICAL DEVELOPMENTS NATIONAL MAPPING PROGRAM 1985–86

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Reston, Virginia
1988

FOREWORD

This report provides general information on the research, investigations, and technical developments conducted by the U.S. Geological Survey's National Mapping Division. The Division collects, processes, and disseminates geographic, cartographic, and remote sensing information, digital data, and maps for the Nation. It also provides scientific and technical assistance and conducts research in the disciplines of cartography, geography, photogrammetry, remote sensing, surveying, and geodesy.

As the emphasis in the National Mapping Program shifts from standard graphic production to a digital mode of operation, a technological revolution is taking place. To keep pace with the changing emphasis, the National Mapping Division continues to expand the National Digital Cartographic Data Base. This data base contains multipurpose digital cartographic data to be used to produce standard and thematic map products and to support the increasing use of digital cartographic data in geographic information systems. The Division's research activities are primarily directed toward development of advanced digital cartographic systems and techniques, and development of improved remote sensing and spatial data handling techniques for earth resource applications.

The report covers projects and studies that will be of interest to all who are involved in the the advancement and application of the cartographic and geographic sciences.

Lowell E. Starr
Chief, National Mapping Division
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PREFACE

Summaries of selected research and development projects that were conducted in the Survey's National Mapping Division during 1985-86 are contained in this report for the first time, and several longer term research projects that were reported on in the 1983-84 report are brought up to date in this volume. The selected bibliography includes citations of papers and reports produced in the National Mapping Division during 1985-86. Primary responsibility for the generation of this report was undertaken by the Office of Research, and preparation for publication was accomplished by Sheila E. Martin, with major assistance from Cynthia L. Cunningham and Mary E. Graziani.

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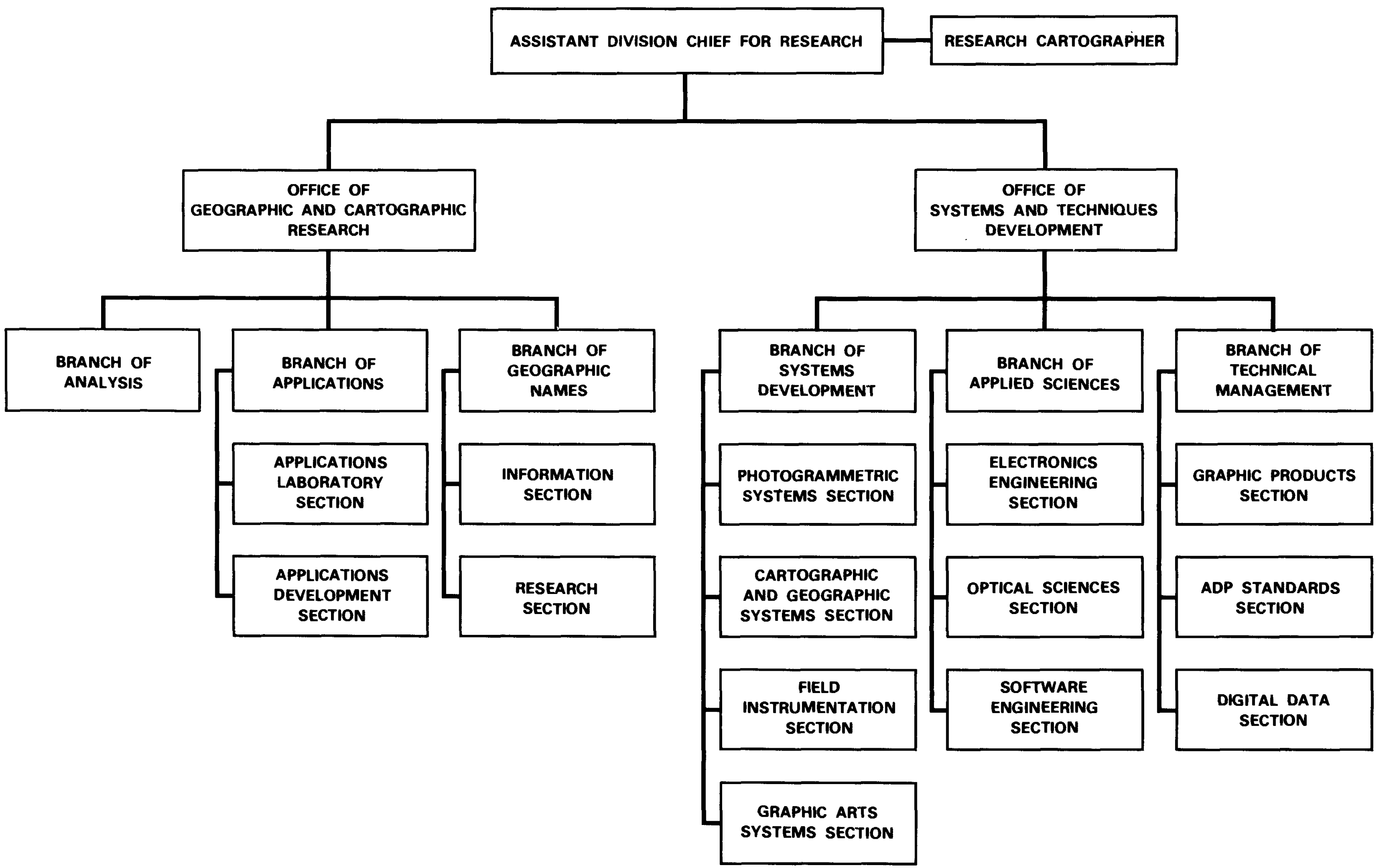

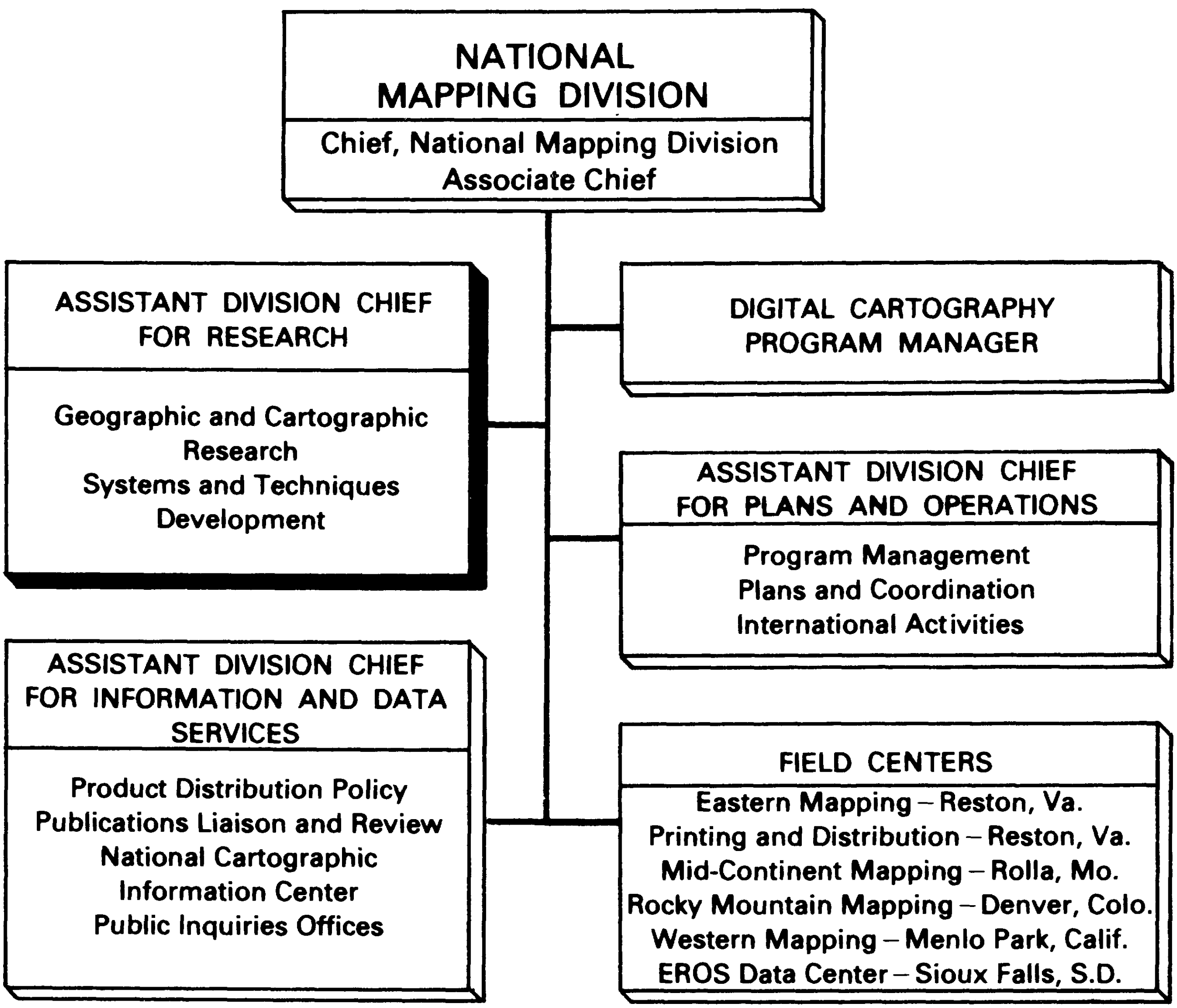
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U.S. customary units used in this report may be expressed as metric units by the use of the following conversion factors.

Multiply	By	To Obtain
feet	0.3048	meters
statute miles	1.609	kilometers

U.S. metric units used in this report may be expressed as U.S. customary units by the use of the following conversion factors.

Multiply	By	To Obtain
meters	3.281	feet
kilometers	0.6214	statute miles

ABBREVIATIONS AND ACRONYMS

ALMRS	Automated Land and Minerals Record System
AMRAP	Alaska Mineral Resource Assessment Program
ANSI	American National Standards Institute
APTS	Aerial Profiling of Terrain System
AVHRR	Advanced Very High Resolution Radiometer
BLM	Bureau of Land Management
CCB	Configuration Control Board
CRAIGES	Cartographic Reproduction and Interactive Graphic Editing System
CTOG	Contour-To-Grid software
CUSMAP	Conterminous U.S. Mineral Assessment Program
DEM	Digital Elevation Model
DLG	Digital Line Graph
DMA	Defense Mapping Agency
DN	digital number
EDC	EROS Data Center
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FACS	Feature Attribute Coding Standard
FGEF	Federal Geographic Exchange Format
FICCDC	Federal Interagency Coordinating Committee on Digital Cartography
FLIS	Federal Land Information System
GD	Geologic Division
GIS	Geographic information system
GLORIA	Geological Long-Range Inclined ASDIC
GNIS	Geographic Names Information System
GPM	Gestalt Photo Mapper
GPS	Global Positioning System
IDIMS	Interactive Digital Image Manipulation System
IMODES	Interactive Map Overlay, Digitizing, and Editing System

LAMPS	Laser-Scan Automated Map Production System
LAS	Land Analysis System
LBR	Laser Beam Recorder
LITES	Laser-Scan Interactive Editing Station
MIPS	Mini-Image Processing System
MOSS	Map Overlay and Statistical System
MSS	multispectral scanner
NAD	North American Datum
NASA	National Aeronautics and Space Administration
NAVD	North American Vertical Datum
NCIC	National Cartographic Information Center
NDCDB	National Digital Cartographic Data Base
NCDCDS	National Committee for Digital Cartographic Data Standards
NGS	National Geodetic Survey
NHAP	National High-Altitude Photography Program
NOAA	National Oceanic and Atmospheric Administration
PROSYS	PROduction System Software for DLG processing
RETSAM	Reviewing, Editing, and Tagging Software for Automated Mapping
RMSE	root-mean-square error
SCS	Soil Conservation Service
SES	Standalone edit system
SIR	Shuttle Imaging Radar
SPOT	Systemé Probatoire d'Observation de la Terre
TM	Thematic Mapper
UCLGES	Unified Cartographic Line Graph Encoding System
UPPS	Universal Projection Plotting Software
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator
WRD	Water Resources Division

RESEARCH, INVESTIGATIONS, AND TECHNICAL DEVELOPMENTS NATIONAL MAPPING PROGRAM 1985–86

INTRODUCTION

The report is organized into major subject areas of digital cartography, geodetic surveys, image mapping, image processing, remote sensing, and geographic information systems. It is evident throughout the report that the application of digital cartographic concepts is leading not only to automated map production, but to the merging and analysis of cartographic and other earth science data in digital form--the essence of modern geographic information systems.

Several projects are of special interest. These include the Division's MARK II digital system development; production of the GLORIA sonar image atlas of the Exclusive Economic Zone; Global Positioning System activities, the Chernobyl, U.S.S.R., image analysis; the 1:250,000-scale Landsat image map of Denali National Park and Preserve, Alaska; and the numerous applications of geographic information systems.

MARK II: THE NEXT STEP IN DIGITAL SYSTEM DEVELOPMENT

The National Mapping Division has begun a major new system development effort called MARK II that has as its goal the implementation of advanced technologies and production procedures that will satisfy projected requirements of the National Mapping Program through the year 2000. At that time, it is planned that the National Digital Cartographic Data Base (NDCDB) will be fully operational. These data will represent the 7.5-minute, 1:24,000-scale map series, as well as other smaller scale series, and will be the central focus of the Division's mapping activities. To accomplish that ambitious goal, a series of developmental tasks are being implemented to (1) expand and improve mass digitization capabilities; (2) modify data structures to support increased content and access requirements; (3) develop digital revision capability; (4) develop product generation capability for standard, derivative, and digital products; (5) improve quality control; and (6) support advanced analysis and applications. Development of the MARK II system has begun, and implementation over the next few years will lead to full production of 1:24,000-scale digital data in the early 1990's.

To accomplish the year 2000 goal and to provide an orderly implementation of newly developed capabilities, the MARK II production system has been divided into four functional components, each under a component manager and designed to address a specific portion of the production process. Each of these components has been further subdivided into a series of development modules consisting of a set of defined and assigned tasks.

Data Production Component: The data production component addresses all phases of data collection, editing, processing, quality control, and revision prior to entry of data into the NDCDB. This component is the largest and most complicated portion of the system to be developed. It includes the requirement to develop efficient mass digitization and automatic feature-recognition capabilities for traditional cartographic symbolization and the requirement to develop methods for feature extraction from imagery.

Data Base Component: The data base component is designed to implement improvements in the NDCDB to enable a central data repository to support substantially all of the Division's production activities. In order to do this, the development of two levels of data bases is planned: (1) operational data bases located in each production center to support ongoing center production and product generation requirements, and (2) an archival data base to provide a central repository for data to support the operational data bases. These data bases will be linked with high-speed data communication systems to transfer data between data bases and to support the public sale and distribution of products.

Product Generation Component: The product generation component is designed to provide a capability for producing a variety of standard and derived digital and graphic products directly from the NDCDB. The first phase of this component deals with product definition, system design requirements, and software development. The second phase addresses system procurement and testing. Integration of newly acquired capabilities with existing production systems will achieve an initial operating capability for generation of both graphic and digital products. The third phase will increase capabilities for the production of all products by integrating technologies derived from other programs. By 1996, the Division will have the capability of producing standard and derivative products directly from the NDCDB.

Production Management Component: The production management component is designed primarily as an interface between the MARK II production system and the National Mapping Program production requirements and authorization systems.

MARK II Management: Management and development of the MARK II effort is being accomplished within the current organizational structure of the Division rather than by establishing a separate organization. The only new position that has been established is the Program Manager for MARK II developments. This position has been placed within the research staff with full responsibility for the overall coordination and management of the development effort. The effort has been divided into components and modules, and component management has been assigned to existing staff offices. Module responsibilities have been assigned throughout the Division, with 60 percent of the work assigned to mapping centers and 40 percent assigned to staff offices.

The design, development, and implementation of the MARK II system represents a major development activity within the U.S. Geological Survey that will exploit state-of-the-art mapping technology resulting in a highly responsive digital cartographic production system. Attainment of this goal will allow the Division to be responsive to national requirements for up-to-date cartographic data and map products that are produced more quickly and efficiently.

DATA PRODUCTION COMPONENT

Hypsography and Hydrography DLG Collection

Use of Laser Line-Following Equipment in Digital Production Operations

Digitizing of the hypsographic and hydrographic information contained on the more than 50,000 published 7.5-minute quadrangle maps will be a major method for adding Digital Line Graph (DLG) and Digital Elevation Model (DEM) data to the NDCDB. In 1985, the Division acquired two Laser-Scan Automated Map Production Systems (LAMPS) to expedite hypsographic DLG production.

The laser-scaning systems perform data collection and editing through a dedicated minicomputer. The hardware for each system consists of a Lasertrak (semi-automatic digitizer), a Laser-Scan Interactive Editing Station (LITES), and a Digital Equipment Corporation VAX 11/750 computer system. The standard software package includes data capture, cartographic editing, and data manipulation programs.

Production procedures for DLG and DEM projects are virtually identical through the major portion of the hypsography production flowline. The major steps are pre-digital preparation, Lasertrak setup and digitizing, editing, and DLG/DEM processing.

Predigital preparation: The Lasertrak digitizes sections of a 7.5-minute quadrangle from reduced film negatives of the original source material. The maximum image size on the reduced negatives is 2.7- by 3.8-inches. The area at map scale that can be digitized is determined by the photographic reduction factor, which is influenced by the minimum line width on the source material and the density and complexity of the contour lines. A set of master registration points are combined with the original source materials during the production of film positive copies. The copies are then annotated with additional information prior to the photographic reduction process.

Lasertrak setup and digitizing: Each reduced negative is projected onto a display screen on the Lasertrak at a 10X enlargement. The digitizing sequence is controlled by the operator, who selects and codes the feature to be digitized and monitors the progress of a red-reading laser digitizing the line. Multiple DLG codes and contour elevations may be added to each feature as it is digitized. When the operator accepts the digitized line, a blue-writing laser paints out the line on the display screen to make the capture of remaining features easier, especially in areas of dense linework.

Editing: The operator corrects digitizing errors or adds additional information at the interactive editing station. Errors in digitizing, such as loops within a feature, are automatically identified by software; however, the operator must interactively correct the error. Spot heights, missing lines, and supplemental or auxiliary contours are added at the high-precision digitizing table. The sections of the quadrangle are joined in a batch process that requires little additional interactive editing.

DLG/DEM processing: At this point in the production flowline, the procedures for producing DLG and DEM data diverge. The DLG processing programs consist of a combination of utility programs and special-purpose software run on the VAX 11/750 in batch mode and the PROduction SYStem (PROSYS) software on the Gould computer. PROSYS provides all final data structuring and verification of DLG files. To produce DEM data, the Laser-Scan file is converted into the format required by the Contour-to-Grid (CTOG) software that is operational on a Perkin-Elmer computer system. The resulting DEM is processed through the DEM Viewing System for data verification prior to being forwarded to the NDCDB for indexing and storage. Future DEM production will use the hypsography DLG data directly from the NDCDB.

Raster Scanning Techniques for Digital Production

Efficient production procedures have been developed that utilize raster scanning and editing technology for the collection of hypsographic and hydrographic data for DLG and DEM production.

The Scitex Response 280 System provides for rapid, precise data collection using a large-format, rotating drum raster scanner. Data collected with this scanner are processed using raster and vector data manipulation software at interactive edit stations. These systems, located at each of the four mapping centers, have been in use for several years, primarily for the Division's 1:100,000-scale data collection effort done in support of the U.S. Bureau of the Census. The 1:100,000-scale map separates were designed with digital collection in mind and therefore used an optimal symbol set for automatic data capture. The Survey's 1:24,000-scale series contains a more traditional selection and variety of symbology that makes digital data collection a more complex process.

Production procedures for 1:24,000-scale data collection of hypsography and hydrog- raphy are similar to those used for the 1:100,000-scale data collection project. The major steps include prescan preparation, raster scanning, raster editing, raster-to- vector conversion, attribute tagging, and DLG processing.

Prescan preparation: For scanning, a scale-stable composite is made using the appropriate map separates for the category of data being collected. Where possible, features are color composited to allow for automatic attribution. In all cases the composite is annotated in color at those points where raster editing is necessary. This allows rapid access to these locations during subsequent editing. Where the separates are of poor quality or the feature symbology is extremely interrupted, re-inking on the composite is done.

<u>Raster scanning</u>: The Scitex Color Scanner is located at the Eastern Mapping Center in Reston, Va., and all composites are shipped there to be scanned. The standard scan is done with a resolution of 750 lines per inch and takes 1 to 2 hours. The resulting scanned data are returned to the mapping centers on magnetic tape.

<u>Raster editing</u>: This step occupies over half of the total collection time and is designed to provide a set of clean, continuous lines for vectorization. The raster pattern is read from magnetic tape to the edit station disk and checked for completeness of coverage. A neatline is generated for editing purposes. The pattern is then searched for annotation marks. Interactive editing is done to remove unwanted linework (contour numbers, depression ticks, etc.), to clear out areas where the linework may have coalesced, and to close up any remaining breaks in the original linework. Where appropriate, line colors are changed to identify individual feature types. Isolated hydrographic point symbol locations (springs, wells, etc.) are collected during the editing and their linework removed from the raster pattern. Spot elevations for hypsography are collected on a separate system using manual digitizing techniques.

<u>Raster-to-vector conversion</u>: Scitex proprietary software is used to perform the conversion of the clean raster linework pattern to a set of continuous vector line strings. Where feasible, automatic attribution is carried out based on line color. Because of the extensive variety of hydrographic features that appear on the 1:24,000-scale maps, it is currently not efficient to use these conversion techniques for hydrography at that scale. Conversion is more easily performed on the hypsography overlay because of its limited set of attribute codes and simple linework.

<u>Attribute tagging</u>: For hypsography data, there are two available paths for tagging the elevation information to the vector data sets. The Scitex software provides a collection of elevation tagging tools that allow both batch and interactive tagging. In the batch mode, the spot elevations collected separately are used to automatically tag those contour lines that are within a specified tolerance of the spot elevation location. Those lines that remain untagged are then tagged by interactively building height paths between known contour lines over the untagged lines. The system uses the height path to identify the line strings and tags them with the correct elevation.

Alternatively, the semiautomatic contour tagging software available on some Division Intergraph systems can be used to attach the elevation values to the contour data. With this program, high and low elevations along the four edges of the data set are specified and then an interactive batch-tagging subroutine attributes interior contour lines.

Hydrography data are usually most effectively tagged with attributes by using either the Interactive Map Overlay, Digitizing, and Editing System (IMODES) software or the Reviewing, Editing, and Tagging Software for Automated Mapping (RETSAM) software available on the Division's Intergraph systems.

DLG processing: For either data category, regardless of the tagging method used, the data sets are processed through PROSYS software on the Gould computer to produce a structured DLG for entry into the NDCDB. Subsequent combination of the hypsography and hydrography DLG's can be done with software to produce a high quality DEM.

Quality Control of Digital Line Graph Data

Several new techniques for quality control of DLG data have been developed. These techniques include improvements in (1) generating the topological structure of the line graphs, (2) checking attribute codes, (3) detecting and correcting errors in geometry, and (4) checking data for completeness prior to entry into the NDCDB. These improvements consist primarily of new software in the DLG production system called PROSYS. Some of these new production software capabilities include:

- The ability to detect very short lines or gaps in lines. These conditions are usually generated during the vectorization of raster-scanned linework.
- The ability to realign a neatline or analytically generate a new neatline for a quadrangle-based DLG.
- New versatility in the determination of the topological relationships among the node, line, and area elements in the DLG.
- The use of production control flags during data processing. These flags ensure that the correct procedures are executed in the proper order.

New techniques were also developed to assist in checking attribute codes applied to the node, line, and area elements. A rule-based review system was developed to check for logical consistency of attribute codes applied to line graph elements of a hydrography file. These checks help to detect both attribute coding errors and missing line elements. In addition, new plotting techniques were introduced using a color electrostatic plotter to display the attribute codes applied to area elements of a file. These plots assist in detecting coding errors. Finally, new software was developed to detect a variety of data entry errors and validate the large quantities of DLG's prior to entry into the NDCDB.

Development of Relational Integrity Checks as a Quality Control Tool for Production of Digital Line Graph Files

Until recently, validation of DLG files has been exclusively a manual procedure. Positional, content, and classification attribute accuracy are verified almost entirely by visual inspection of hard-copy plots and computer listings. The ongoing development of relational integrity checks within MARK II is a significant step toward automating quality control procedures that are complex in nature, repetitious, and labor intensive.

A relational check is defined as any test that identifies conditions or relationships that must exist, are unlikely to exist, or should never exist. These relationships are defined by combinations of elements (lines, nodes, and areas) and (or) attributes. The attributes used to define a relation may be the result of classification, position, topology, or any combination of these. Relational rules are rigorously tested to ensure cartographic validity. They are designed to accurately identify and report only invalid or highly suspect relationships. Rules are acceptable in a production environment only if they can detect invalid or suspect conditions with a minimum accuracy of 85–90 percent.

DLG files are increasingly being used for sophisticated modeling and analytical applications that require a high degree of internal file consistency. The use of relational integrity checks permits further automation of the quality control process and will result in higher quality DLG files.

Development and Implementation of PROSYS for DLG Processing

Paneling and Partitioning of Digital Map Data

The DLG is a vector-based, topologically structured file of digital data that encodes cartographic objects (representing political and administrative boundaries, transportation, and hydrography features) and selected spatial and nonspatial attributes and relationships associated with these objects. With few exceptions, DLG's are captured and archived in nominal 7.5-minute quadrangles. Since the quadrangle is an arbitrary unit of spatial coverage, it is not unusual for an object to span multiple quadrangles. Because the quadrangles were produced and digitized independently, the digital representations of the portions of an object residing on different quadrangles are sometimes inconsistent. These inconsistencies include differences in the position (alignment) or attribute codes between the portions of the object encoded in different quadrangles. These differences may accurately reflect the information on the digitized source maps or may be blunders that occurred during the digitizing process. Because there are requirements to archive and distribute DLG data in spatial units different than the quadrangle unit from which they were digitized, it was necessary to develop software to resolve position and attribute code inconsistencies.

The paneling and partitioning software of PROSYS was designed to meet these requirements. Specifically, the paneling software allows:

- Common edges of two adjoining DLG's to be checked for alignment or attribute code inconsistencies (a process called edge checking),

- Common edges of two adjoining DLG's to be checked for inconsistencies and positional (alignment) differences between common edge elements to be resolved (a process called edge aligning), and

- Common edges of two adjoining DLG's to be checked for inconsistencies, the positional differences between common edge elements to be resolved, and the two DLG's to be logically merged (a process called edge joining).

Inconsistencies in DLG's detected by the software are either automatically corrected by the software or inspected and resolved by data collection personnel. Inconsistencies that cannot be resolved are flagged to note their existence to the data user.

The partitioning software clips a simple, four-sided polygon of data out of an existing DLG. The software generates a new neatline around the clipped data, and determines the topological relationships of the elements in the file.

DLG Processors for On-Site Production

Until recently, DLG production was accomplished using the Datapoint 6600 mini-computer and the Amdahl V7 mainframe computer. Programs were used on the Datapoints to create jobstreams which were teleprocessed to the Amdahl to operate the Unified Cartographic Line Graph Encoding System (UCLGES) software. Scitex-scanned DLG data were processed on Perkin-Elmer 3230 minicomputers.

As a result of a 1984 computer telecommunications requirements study, the Division purchased Gould super-minicomputers for local DLG processing at each mapping center. The new minicomputers required the writing of a new front-end program and a conversion of the UCLGES and Perkin-Elmer software to the new PROSYS DLG production software. Implementation of local DLG processors has eliminated the need for telecommunication in a production environment, and the software conversion has allowed the enhancement of existing software and the addition of new processing capabilities.

New processing capabilities of PROSYS include (1) new plotting software, allowing greater flexibility than UCLGES; (2) new structuring software, written as several subroutines of one program, eliminating the manual topology creation of UCLGES; (3) analytically straightened or generated neatlines; (4) paneling and partitioning capabilities, allowing better accuracy along adjoining quadrangle edges; and (5) internal quality control mechanisms, assuring that only DLG's meeting specific standards are entered into the NDCDB.

Local processors also provide the flexibility of adding additional equipment to meet future digital requirements. Presently, the Division is purchasing standalone edit stations to be used as online editing devices, which will change the present configuration of DLG verification and editing procedures.

Verification Plots for DLG Production

In creating DLG's from raw data through PROSYS, verification checks need to be performed. Several plotting programs were developed to facilitate verification. Line, node, and area attributes are checked for accuracy by plotting the features at map scale with the attribute printed alongside. This plot can then be compared to the original graphic. Because various line weights and symbols can be used on the plot, a visual verification against the graphic is possible. The plotting programs can also be used to investigate problem features identified during PROSYS processing. When these problem features are plotted separately, they can be compared with the original graphic to determine the error. Corrections are, therefore, made more rapidly and accurately.

The original plotting program was designed to be used with a Versatec electrostatic raster plotter. This software accesses a digital cartographic file (DCF) to create plots of lines, nodes, and areas. The software also allows a user to select an area-fill option, which places a specific pattern in an area based on the attributes of that area. Because the Versatec is a raster plotter, additional steps to sort the DCF vectors and to convert the data to raster form are required. Three other plotting routines have since been added to accommodate Kongsberg, Calcomp, and Gerber plotters. Because the Kongsberg and Gerber plotters can plot on either film or paper, the plotting program was written for either medium (the Calcomp plots only on paper).

Although the Versatec is the most frequently used plotter because of its speed, each mapping center also has either a Gerber or Kongsberg plotter as backup. Verification through plots is an efficient and accurate method to produce quality DCF's. Problem features can be easily located so that appropriate corrections can be made, and incorrect attribute codes become readily apparent when plotted and matched against the graphic source. The Division is purchasing additional color raster plotters to further enhance the visual verification process.

Development of a DLG Viewing and Editing Capability

Software for Graphics Display and Editing Terminal

The TEKPLOT software recently developed by the Division enables a user to interactively view, identify, query, and manipulate the elements and classification attributes of DLG files using a Tektronix 4100 color graphics terminal. TEKPLOT was designed for use in conjunction with PROSYS and represents an alternate method for the display and editing of DLG files. A large component of DLG production involves analyzing error conditions detected by PROSYS. The software is capable only of directing attention to a suspect feature or area. The time it takes for an operator to understand the cause of an error is directly related to the analytical tools available to look at the digital file in detail. The TEKPLOT editing package greatly facilitates the analytical and editing components of DLG production.

RETSAM--Software for Reviewing and Tagging Digital Data

The Division has developed the Reviewing, Editing, and Tagging Software for Automated Mapping (RETSAM) to perform collection, editing, and review of DLG data using two VAX-based Intergraph interactive graphics systems. RETSAM is based in part on software developed for PDP-based Intergraph systems, but it includes many enhancements that make use of the additional features of the new VAX-based systems.

RETSAM includes software to input DLG-formatted data (from a data collection system, tagging system, or the NDCDB), generate control points for manual digitizing, digitize features, tag attributes, edit attributes, edit linework, symbolize features based on their DLG attributes, and output DLG data to magnetic tape for input to PROSYS. The interactive editing capabilities of the Intergraph system are enhanced by RETSAM menus and user commands.

RETSAM is designed to support all scales of DLG's and a variety of DLG collection activities: manual digitizing, attribute tagging and editing of data collected on other systems, and review of DLG data collected or tagged by other agencies or contractors. To date, RETSAM has primarily been used for the hydrography-tagging and road-review activities associated with the 1:100,000-scale DLG data collection program which is being completed by the Division and the Bureau of the Census. The 1:100,000-scale hydrography files are raster scanned and edited on the Scitex system, structured by software on the Perkin-Elmer computer, and then input to the Intergraph system using RETSAM. RETSAM does some of the attribute code tagging semiautomatically.

Once Intergraph files are created, the RETSAM menus and user commands and standard Intergraph commands are used to (1) interactively tag features with attributes different from those set automatically, (2) place area points inside polygons that have area attributes, (3) digitize any degenerate lines that may exist in the file, and (4) perform any necessary linework edits. In the tagging procedure, the operator enters attributes from the menu (where the most frequently encountered attributes are located) or the keyboard and then uses the cursor to interactively touch each feature. As the attributes are changed, the symbology of the feature is also changed according to a standard symbology scheme in which a feature's color, line weight, and line style are based on its DLG attributes. For example, if a line has the attribute for stream, it will be yellow; if it has the attribute for canal, it will be orange; if the stream or canal is perennial, it will have a solid line style; and if it is intermittent, it will have a dashed line style. The standardized symbology allows the operator doing the tagging and a second person reviewing the file to validate most DLG attributes visually. When tagging, editing, and reviewing are completed, RETSAM generates a magnetic tape that is the input to PROSYS.

The Division's 1:100,000-scale road files are attribute tagged by the Bureau of the Census. As part of the Division's review, the files are input to the Intergraph system using RETSAM for attribute validation. Features with problems are displayed in red, orange, or pink, and a large circle in the same color is placed at their location to facilitate identification. Several checks based on the topology contained in the DLG files are also performed.

RETSAM sets the symbology of features based on their DLG attributes. For roads, line weight and style are based on road class. Color is used to indicate errors and coincidence with other overlays. RETSAM also creates a second symbology, known as level symbology, in which each unique combination of attributes encountered is given a different symbology. This second symbology is especially useful in reviewing highway route numbers that are different for each file and cannot be symbolized by any standardized symbology scheme. The program produces a printout that operators refer to while inspecting the file at the workstation. The printout includes a listing of level symbologies and corresponding attribute combinations and a report on detected potential errors.

Interactive Map Overlay, Digitizing, and Editing System

The Interactive Map Overlay, Digitizing, and Editing System (IMODES) is a geographic data entry system used for DLG production. This system, which evolved from the Cartographic Reproduction and Interactive Graphics System (CRAIGES) developed by the Division in the early 1980's, was designed to improve operating efficiency and flexibility.

IMODES consists of a corporate data base and five subsystems. The corporate data base consists of a design file, the Data Management and Retrieval System (DMRS) data base files, and a registration file. The design file contains the spatial data features, including registration monuments, lines, area labels, nodes, and degenerate line features. The DMRS files contain the attributes and are linked to the design file. The DMRS files can include text, real, and integer data that characterize the spatial data features. The registration file contains pertinent information about the map (for example, latitude and longitude of the southeast corner, etc.). IMODES is designed to run on either the PDP 11/70– or PDP 11/23–based Intergraph systems. The five subsystems are:

1. Project setup, which creates the corporate data base files.

2. Capture and edit, which supports the capture and editing of the spatial and attribute components of the corporate data base. There are separate menus for each overlay containing attributes specific to that overlay. For example, the hydrography menu contains all the necessary user commands for element and attribute manipulation in the corporate data base. The menu also supplies commands for digitizer setup, map registration, attribute definition, and element placement. There are also several cursor menus for specific applications.

3. DLG to IMODES interface, which reads a DLG–format file and loads the information into the corporate data base.

4. IMODES to PROSYS Interface, which extracts information from the corporate data base and builds a reformatted file for input to PROSYS.

5. Quality control, which provides attribute verification utilities to aid in quality control of the final product and to improve efficiency in processing a file for output.

Standalone Edit System

The Division is currently procuring standalone edit systems (SES's) to edit DLG data for inclusion in the NDCDB. The SES's will perform the following functions: (1) review and edit DLG data prior to inclusion in the NDCDB, (2) validate and correct DLG data presently in the NDCDB, and (3) review DLG data prior to sale. System time will also be allocated for research in digital revision and product generation activities.

The SES's will be implemented in the regional mapping centers involved with production and quality control of DLG data. Each SES will consist of a 32–bit microcomputer, 150–mb disk subsystem, video display terminal/operator's console, and a digitizing table. The SES sites will include a magnetic tape subsystem, electrostatic hard–copy device, and a local area network to provide communications between the SES and the DLG processor. Delivery of the first group of systems is expected in December 1987.

DATA BASE COMPONENT

A New Design for the U.S. Geological Survey's National Digital Cartographic Data Base

In analyzing the requirements for the next generation of digital cartographic systems, several enhancements to the NDCDB regarding spatial data structures and data management systems have been identified as key items. The current NDCDB system, which manages an archive of cartographic data files, will have to be enhanced to meet the design goals of the future system. The NDCDB will evolve to become the central focus of most National Mapping Division activities, including maintenance and revision of standard maps and provision of data for geographic information system applications. The major requirements for improvements and changes fall into four areas:

1. Development and implementation of a data management facility within the mapping centers to better support increased data production and product generation requirements.

2. Acquisition and implementation of mass storage systems to support improved data storage and retrieval.

3. Development and implementation of a new data structure and spatial data base management system having enhanced attribute and feature handling characteristics that will support expanded data production, product generation, and analysis requirements.

4. Development and implementation of an NDCDB data distribution subsystem to support the public sale of standard and derivative digital and graphic products.

To meet these requirements, a concept of operations has been developed to define the future data base operations and data structure. The NDCDB is envisioned as functioning in two environments: archival and operational. The archival data base environment will consist of a central data repository, including information and indices about the data (metadata), and will support retrieval by cartographic feature and geographic partitions. The operational environment will provide data staging and tracking facilities for the movement of data between the archival and operational data bases. It will also allow for the manipulation, analysis, and display of the spatial information in a data base context. The queries, retrievals, and uses differ between the archival and the operational environments.

Archival Data Base

The archival data base will consist of spatial data and metadata. The spatial data will be partitioned by series, quadrangles, and categories. These partitions are defined as:

Series: a partition by data content (imagery, elevation matrices, cartographic data) or scale (1:24,000, 1:100,000); interseries topological consistency is not required.

Quadrangles: partitions along latitude, longitude boundaries; matching across boundaries is required.

Categories: a logical subdivision of a series into classes of related data (transportation, hydrography); intercategory topological consistency is required.

Metadata are descriptions of the data content of the NDCDB. These descriptions apply to sets of records, such as a quadrangle of a series, and include information on data source, processing history, and accuracy. The metadata also contain feature keys to quadrangle coverage. For example, a key to all the quadrangles that contain the Potomac River would be maintained in the metadata. Queries are against only the metadata, not the spatial data. The spatial data would be retrieved by quadrangle multiples according to series, category, or feature designations.

Operational Data Base

The operational environment will consist of two subsystems: a data staging and tracking system and a spatial data management system. The data staging and tracking system will provide facilities for the transfer of information between the archival and operational data bases and will manage the local storage of data in work at a production center. The operational data base will be initialized by quadrangle multiples of data from the NDCDB archive. This downloading of data from the archive (where it will reside on a high-density mass storage device such as an optical disk) will probably occur over a wide-area communications network to a remote host computer. Likewise, the downloading of data from the operational data base will probably occur over a local-area communications network to a local host computer or directly to a computer workstation.

The spatial data management system will provide the capabilities to manipulate spatial information with a set of data base tools. The schema used in this system will consist of the various feature, location, and topological components that make up a cartographic data structure. It is postulated that these data elements can be placed in a relational data base and used in the workstation environment. Data retrievals by feature, attribute, topology, or location will be required in the operational environment.

Feature Attribute Coding Standard

A working group was established to evaluate the Defense Mapping Agency's (DMA) Feature Attribute Coding Standard (FACS) and determine its adequacy for supporting the Division's DLG data requirements. FACS is a comprehensive feature-based coding scheme for classifying specific cartographic features. In a feature-based scheme, entities are classified as they occur in reality and not as they are portrayed in graphic representations. The working group identified content inadequacies and the necessarry additions and modifications to FACS to meet present Division requirements.

Data Structures and Data Exchange

Many issues involved in designing the NDCDB deal with the nature of products required by users of the data. In addition to data content, these issues include the form, structure, and organization of the products. Three needs must be considered:

(1) flexibility in answering multipurpose user needs, (2) production of standard products, and (3) compatibility with other Federal agency data. Balancing these needs is an objective of a current Division development effort that is designed to provide a set of standard digital data structures and formats to be used for the exchange of digital cartographic data.

Before these structures can be developed, digital cartographic data, the users and suppliers of the data, and digital cartographic data exchange processes must be understood. Historically, many different application needs have given rise to a wide variety of spatial data models and structures. This variety has led to incompatibilities that make the exchange of data very difficult.

A fundamental step in understanding cartographic data has been an attempt to develop a comprehensive data model that will encompass most existing models. This model is not concerned with organization of data, but rather with defining components and relationships among those components. Different data structures, each of which specifies a logical organization of the components of the data model and the manner in which relationships among components are to be explicitly defined, may then be developed based upon the one comprehensive model.

PRODUCT GENERATION COMPONENT

Digital Elevation Models from Contours

A major goal of the National Mapping Division is the production of Digital Elevation Models (DEM's) from hypsography and hydrography categories of Digital Line Graphs (DLG's). To this end, development of a DEM production system with the capability of generating a DEM from contours, water bodies, and double-line streams is nearing completion. Hypsography data are usually collected by an automated process, such as raster scanning or line following. These data, processed as a DLG file, serve as the hypsography input for the DEM production system. Hydrography data are collected by either an automated or a manual process. These data, also processed as a DLG file, serve as the hydrography input for the system. The DEM production system utilizes specialized contour-to-grid software, which was developed for the Division and designed to operate on a Perkin-Elmer 3230 computer. The gridding algorithm is specifically oriented to accommodate Universal Transverse Mercator coordinates covering a 7.5-minute area with a 30-meter grid spacing. DEM production is completed in five stages. In stage one, the DLG hypsography and hydrography files are converted to an internal file structure conducive to efficient data retrieval. In stage two, significant elements in the hydrography file are identified and are assigned elevations. The elevations assigned in stage two are used in stage three to interpolate elevations along double-line streams, because the gridding algorithm requires that stream coordinates used in the generation of a DEM must contain elevations. In stage four, a DEM is produced using the contour-to-grid software. In the last stage, the DEM is examined for errors and inconsistencies and any anomalies are corrected on a DEM editing system.

Research on the DEM production system is continuing in several areas. These areas include expanding the system to include single-line streams as profile data; investigating system modifications to accommodate variables such as grid spacing, coverage area, and source material scale; utilizing the system to produce DEM's based on geographic coordinates; and modification of the algorithm to accommodate areas in the source graphics where there are no data to support DEM production.

Application of Raster Scanning and Editing Technology to Thematic Map Production

Production of thematic maps by the Survey focuses primarily on meeting the needs of the Geologic and Water Resources Divisions for geologic and hydrologic information and on satisfying the requirements of other Federal agencies for a wide range of special-purpose products. Until recently, thematic maps were produced by traditional scribing, open-window peeling, and type-stickup methods. Using new computer methods developed by the National Mapping Division, thematic compilation manuscripts can be digitized and edited, and screened reproduction negatives can be plotted directly from the digital files. These new techniques also allow additional flexibility for experimenting with colors, symbols, and other design parameters in preparing one-of-a-kind map products.

New techniques for computer-assisted generation of color separates have been developed to support thematic map production. First, color boundary linework is scanned using the Scitex system. The linework is then converted from raster to vector data and processed through PROSYS software. Routines within PROSYS generate a DLG file in which a set of coordinates defines the center of each closed polygon. These coordinates are manually attributed for color separate generation and transformed to a format compatible with the Scitex system. The coordinates and color code are passed back to the Scitex and used with the boundary linework to automatically create raster files. The files can then be manipulated using Scitex software to produce color-separation negatives for printing. This computer-assisted approach also ensures that all polygons within the map have their colors generated automatically, greatly reducing the amount of interactive work required at the Scitex edit station.

Figure 1 is a portion of a thematic map sheet produced using the Scitex. Map colors emphasize the location and areal distribution of hillside material units. Dot patterns differentiate between areas of gentle to deep slope and line patterns indicate faults. Compilation manuscripts were digitized and areal symbolization was produced by interactive editing. Screened reproduction negatives were then plotted directly from the digital files. This new procedure augments other recent developments in raster processing of thematic map products and essentially replaces the tedious and labor-intensive peelcoat technique used in manual cartography.

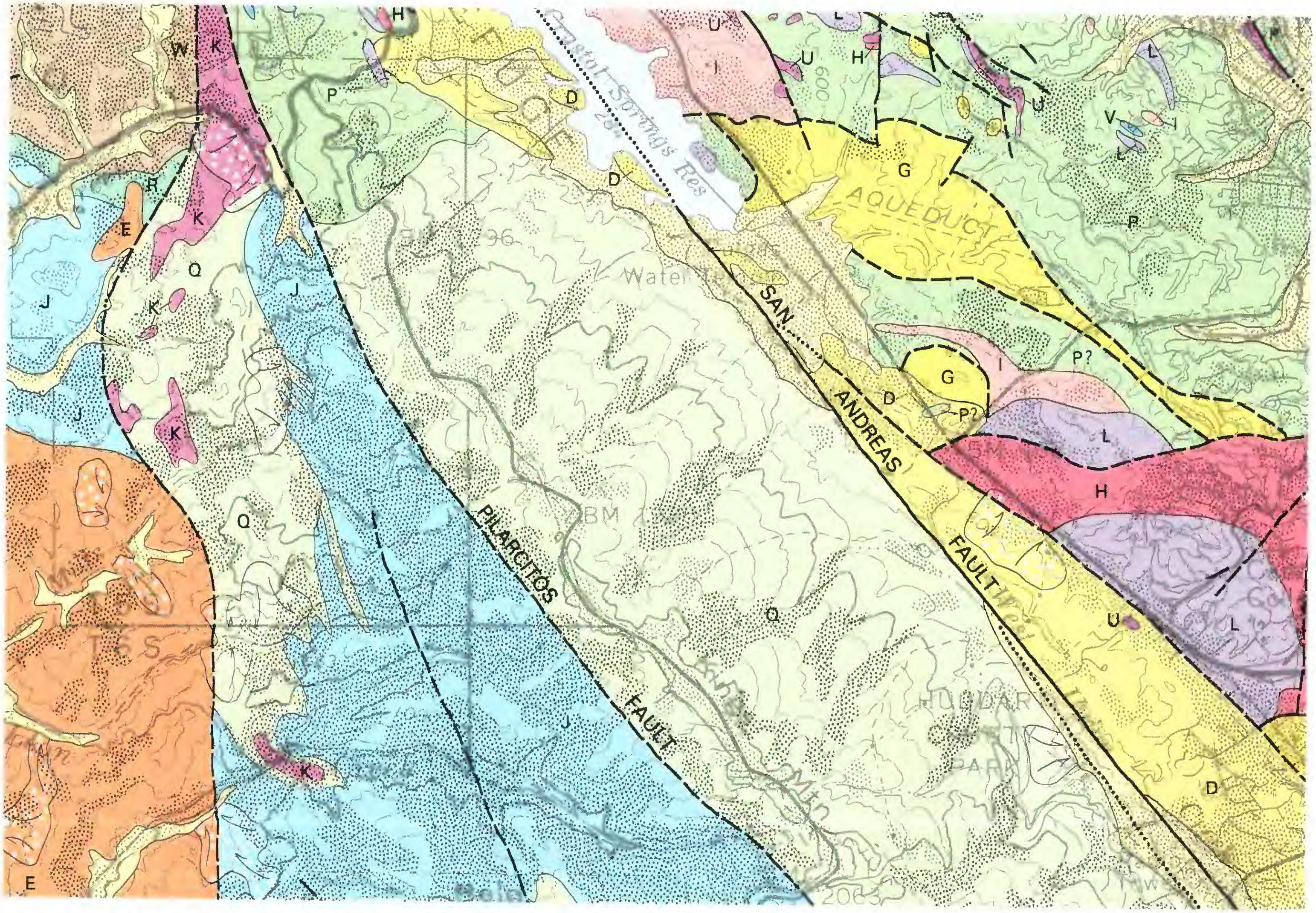

Figure 1.- - Computer–generated thematic map depicting hillside materials and their engineering character, San Mateo County, California. (U.S. Geological Survey Map I–1257D, scale 1:62,500).

MAP PROJECTIONS

Division research has led to publication of formulas for a new low-error map projection for Alaska that is conformal and has less than one-third the range of scale error of standard projections. This projection is based upon a least-squares analysis of points throughout the State and adjacent waters to determine coefficients of a complex-algebra transformation. Related research on another type of low-error projection has led to the ability to construct a corresponding map projection for Alaska or any other region of interest on which all areas are shown correctly and distortion of scale and shape is minimized.

Simpler to derive is a new series of projections for small-scale presentation of information in which the focus is on a limited area, but the relative positions of surrounding regions are desired. The series is called "Magnifying-Glass" map projections (figure 2), a term applied because the central part of the map is enlarged as if being viewed with a magnifying glass, while the surrounding region is shown without loss of any of the surrounding area. The central part may be shown without distorting area (or else distance from the center), and the outer region is shown at either a constant or tapered reduced scale.

The Survey will soon publish a second book-length professional paper on map projections. U.S. Geological Survey Professional Paper 1395, "Map Projections--A Working Manual," is a revision of the Survey's Bulletin 1532, "Map Projections Used by the U.S. Geological Survey," which reached a third printing. The revision includes several other common projections not used by the Survey, as well as newer ones developed by the National Mapping Division.

U.S. Geological Survey Professional Paper 1453, "An Album of Map Projections," presents approximately 90 projections and about 200 computer-generated illustrations to assist the user in selecting and understanding a wide range of projections. The text is presented in concise topical format; formulas are included in the appendix.

A third book-length work, still awaiting publication, is an essentially complete bibliography of map projections. It presents, for the first time, a comprehensive list of pertinent English and foreign literature.

UNIVERSAL PROJECTION PLOTTING SOFTWARE

The Universal Projection Plotting Software (UPPS) is currently being developed as a replacement for several versions of older software that generate publication-quality plots of the neatline, graticule, rectangular coordinate system grids, and labels for various map products. This software was designed with features that will facilitate software maintenance and portability. The software is being written in ANSI standard full-set FORTRAN 77. Therefore, with only minor computer system-dependent modifications, the software will be executable on most computers with a full set FORTRAN 77 compiler and sufficient task memory. Also, the documentation of the application software is a plain language description of each modular task which is cross-referenced to the FORTRAN code and updated as the code evolves. UPPS is divided into 10 major modules, each defining a specific task to minimize software

Figure 2.—A "Magnifying-Glass" Azimuthal Equal-Area projection centered on the Great Lakes region, North America, at lat. 45°N., long. 85°W., with the inner circle of 7° radius bounding a region shown at a constant area scale. The outer circle of 20° radius bounds a region shown at exactly one-fourth of the area scale of the inner circle. This arrangement is one of a series of several new projections relating area or scale of inner and outer regions.

maintenance. One major task is the plotting routines of UPPS. This software is separate and independent of the UPPS application task and communicates with the application task through a standard file format. When a new plotter is added to production, a new driver can be written independently of the UPPS application software. To plot on this new device, the driver is simply directed to read files in the standard file format. Because this software is independent of application task, it can be used by other Division software application tasks. This portable plotting software will be ported to UNIX and VMS operating systems. Investigations are currently being conducted to incorporate the North American Datum of 1983 into this software.

ACCURACY TESTING BY PHOTOGRAMMETRIC METHODS

In the past, to ensure that map products produced by the Division adhere to the National Map Accuracy Standards (NMAS), field surveys were performed to test map accuracy. These surveys determined horizontal and vertical accuracy of planimetric points that appear on the map manuscripts. The field-determined positions and elevations were compared to the manuscript location, and the discrepancies were evaluated against NMAS.

Because of the rising cost of field surveys and the large number of old maps (25 years or older) requiring testing to identify the best method of revision, it is faster and more economical to use photogrammetric accuracy testing procedures. A photogrammetric accuracy test can be performed quickly over a larger area and at a lower cost per quadrangle than with present field survey methods. The photogrammetric positioning of map data is based on the orientation of the stereomodel to positions developed by control extension or aerotriangulation. Vertical positions are determined for well-defined photoidentifiable points and elevations generated through measurements on the photographs or the stereomodels.

With the present density of basic control and availability of quadrangle-centered photography, it is now possible to evenly distribute test points over a large area and develop test point positions that are independent of the original triangulation to ensure that errors in the original procedures are not carried into the test. It is also possible to test all quadrangles on a large project rather than one or two, as is the present practice. Procedures for photogrammetric accuracy testing are currently being documented as part of the Division's Manual of Technical Instructions.

AERIAL PROFILING OF TERRAIN SYSTEM

The Aerial Profiling of Terrain System (APTS), developed by the Survey under contract with the Charles Stark Draper Laboratory of Cambridge, Mass., has completed a series of applications tests. The APTS is an airborne inertial surveying system that uses a laser tracking device to periodically estimate errors in the inertial system. The laser tracker measures precise angles and ranges to retroreflectors installed over known points on the ground. The system also has a separate laser profiler to measure terrain profiles. The APTS has a demonstrated profile accuracy of ±60 centimeters in the horizontal coordinates and ±15 centimeters in the vertical coordinate.

Application testing of the APTS was completed in June 1985, when the APTS was tested in conjunction with an airborne Global Positioning System (GPS) receiver for the U.S. Army Signal Corps. The purpose of this test was to determine the accuracy of velocity and position measurements made by an airborne GPS receiver in real time. The GPS receiver, provided by the Signal Corps, was mounted within the cabin of the APTS aircraft. The test consisted of collecting both APTS and GPS data simultaneously during a flight over a predetermined course on the APTS Calibration Range in Massachusetts. A timing pulse was provided by the GPS receiver to the APTS to time-link the two data sets. The APTS was selected to be the reference for this test because during a tracker lock the position and velocity are measured to an accuracy of 1.0 centimeter and 0.3 millimeters/second one-sigma, respectively. The test was completed satisfactorily and the results provided to the Signal Corps.

The first operational APTS project, conducted in 1985, was to profile the northern half of the Great Salt Lake Desert in Utah. In recent times, the Great Salt Lake water level has been higher than usual, flooding the surrounding roads, railroads, and various industries. In addition the salinity of the lake has dropped significantly, reducing the amount of salt which can be harvested from the lake. To reduce the flooding, the State of Utah established the West Desert Pumping Project. The Utah Department of Natural Resources is building a system of pumps and canals to move the excess water from the Great Salt Lake to the desert basin west of the Newfoundland Mountains. A large shallow lake would be formed in the basin, bounded in some places by dikes to protect highways, railroads, and the Bonneville Speedway. The evaporation of the water from this large lake would help control the level of the Great Salt Lake.

Precise details of the topography of the area were needed to develop engineering plans for this project. The 5-foot interval contours on existing 7.5-minute quadrangles are not sufficiently accurate or detailed to satisfy this purpose. Engineers of the State of Utah and the Geological Survey in Salt Lake City recognized that the capabilities of the APTS meshed well with the preliminary survey requirements of the West Desert Pumping Project. After meeting with State officials, a plan was developed to profile the desert basin using APTS.

The transition from the APTS application testing program to the Salt Lake Desert Profiling Project was significant and offered a considerable challenge. Several factors about the project were new and important:

- The size of the project area, 1,600 square miles, was much larger than any previous APTS project. To fly an area this size would require 30-50 hours of flying time.

- All previous surveys were flown in eastern Massachusetts with cool temperatures, elevations near sea level, moderate topographic relief, many lakes and rivers, and thick stands of timber. The Salt Lake Desert presented extremely different environmental conditions.

The selection of retroreflector sites was influenced by system requirements and the location of existing control. Fortunately, elevations of sufficient accuracy had been surveyed and established at many township corners in the desert during a map control project in 1973. Elevations were also established in remote areas by contractors for the Utah Department of Natural Resources. The spacing of the township corners agreed well with system requirements for retroreflector updates every 3 minutes. The location of the retroreflector sites is shown in figure 3.

The environmental conditions at the project area were vastly different from those encountered in all previous surveys that were flown in eastern Massachusetts. The Salt Lake Desert is at a high elevation, with hot temperatures, little topographic relief, and almost no vegetation.

The project was divided into seven flight areas to stay within maximum aircraft flying time and the limited number of available retroreflectors. Profiles were measured along north-south and diagonal flight lines. The diagonal profiles were flown to satisfy data spacing requirements of 2 miles and to provide a check of profile accuracy at the diagonal intersections. This comparison was significant

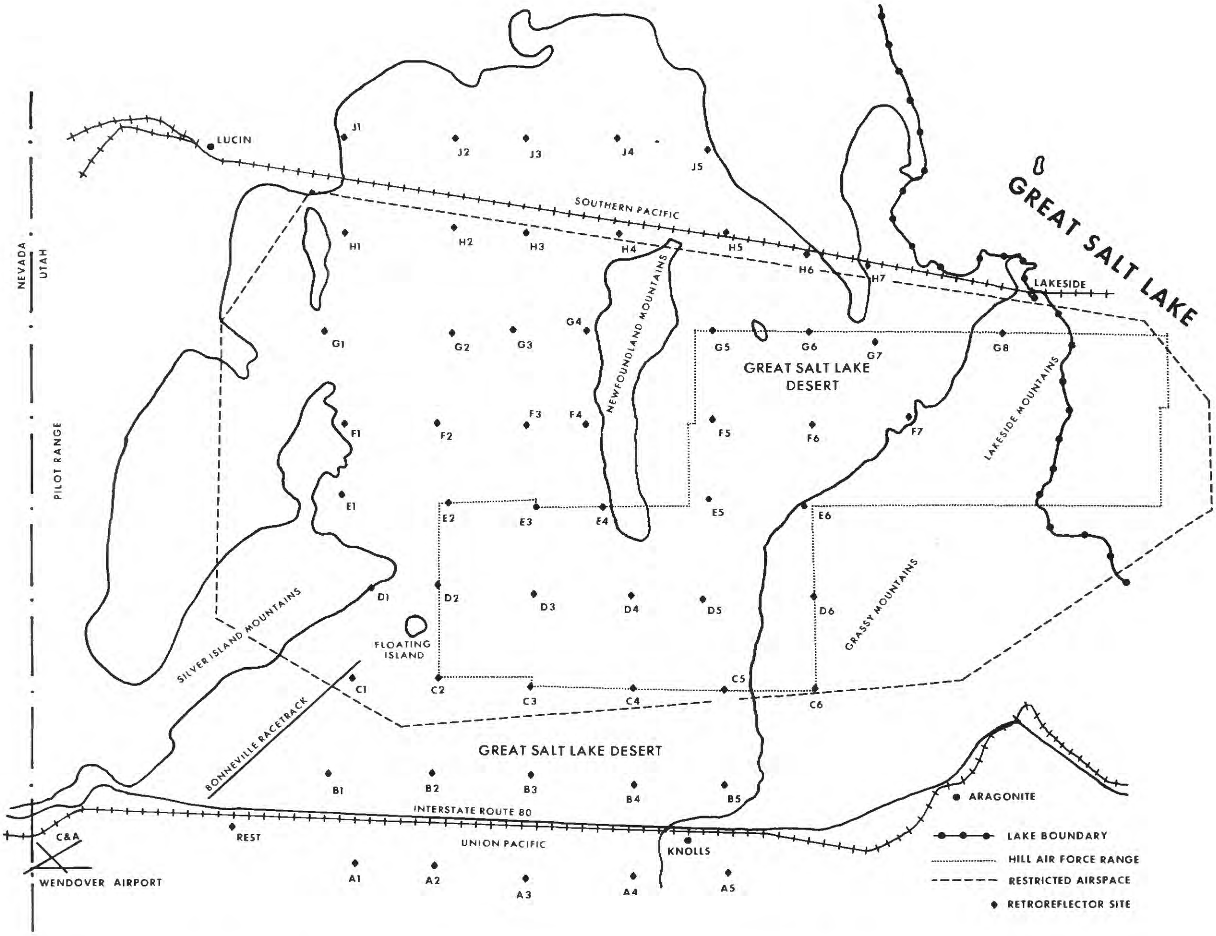

Figure 3.—Retroreflector sites used in the Great Salt Lake Desert, Utah, profiling project. Most sites are at township corners.

because it provided a test of the precision of the profile data. Approximately 1200 miles of profiles were collected by the system. After postprocessing, the resulting data files contained over 900,000 points.

The profile data were used to produce the map of the desert with a 1-foot contour interval. The contours were plotted on a 1:96,000-scale base sheet. Because the data file was very large, automated editing and contour generation programs were used to generate and plot the contours. Although this process established the general location of the contours, it did not produce conventional-looking contours that were visually believable, because of the much greater density of data along the flight line than perpendicular to the flight line. As a result, extensive manual editing of the contours was needed to produce the final sheet. The final version of this map is shown in figure 4.

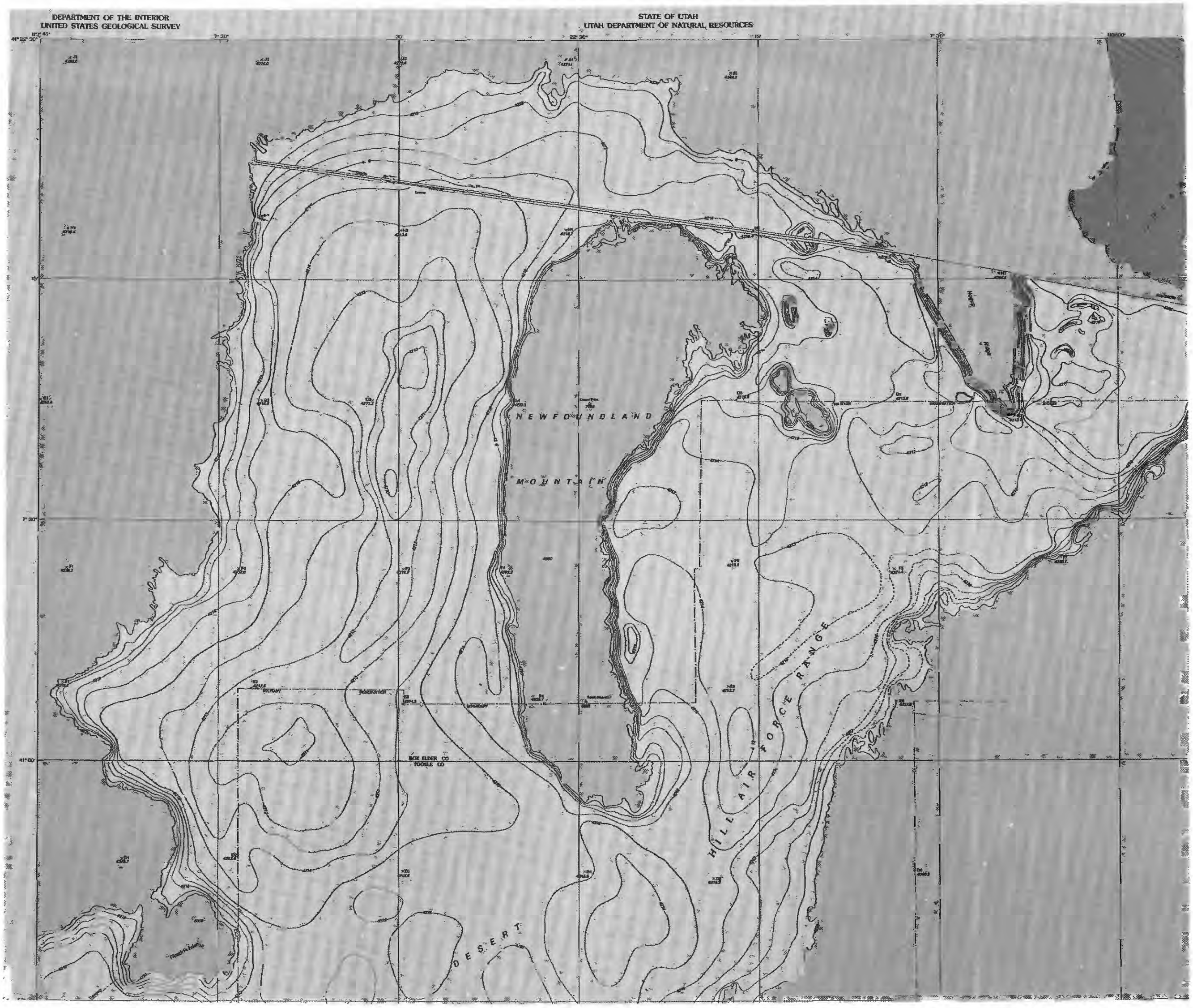

Figure 4.--Basin contours of the northern section, Great Salt Lake Desert, Utah, compiled from Aerial Profiling of Terrain System profile data.

GEODETIC CONTROL COMPUTATION SOFTWARE FOR FIELD DATA COLLECTION AND PROCESSING ON PERSONAL COMPUTERS

The Division recently completed development of a data processing system for the reduction of geodetic and map control data. The Geodetic Computation System (GEOCOMPS) modernizes and consolidates a large number of earlier programs, written in several different languages, into a modular system of FORTRAN-77 programs. The new software is an integrated, menu-driven, disk-based processing system designed to run on a DEC Professional 350 computer. The system features a user friendly interface built with DEC forms management software.

The computational core of the system is a library of FORTRAN-77 subprograms for performing geodetic computations. These subprograms can be ported to other systems supporting FORTRAN-77 with only minor modifications. This high degree of system independence facilitates easy incorporation of the computation subprograms into various target application tasks on other computers.

The system includes programs for computing azimuths, distances, positions, elevations by vertical angles, spheroid parameters, adjustment of elevation networks, and conversions between geodetic and plane coordinates. Related components utilize Hewlett-Packard technology, including the HP-41 and HP-75 programmable calculators, to permit direct entry of field survey data. These data may then be uploaded to more powerful computers for processing.

GEOCOMPS minimizes the manual transcription of data, streamlines geodetic computation operations, and allows electronic storage and transfer of geodetic control data. The system is fully documented so that geodetic equations and algorithms can be easily related to the computer code.

GLOBAL POSITIONING SYSTEM APPLICATIONS

The Global Positioning System (GPS), a satellite-based navigation system under development by the U.S. Department of Defense, has the potential to revolutionize surveying technology. The Survey recognized this potential at an early stage and helped fund the development of the first portable GPS system designed for field survey work, the Texas Instruments TI-4100. The National Mapping Division purchased two of these systems in 1985 and began development of an operational capability in the performance of GPS surveys. Division mapping center personnel received on-the-job training while the system was being tested on a series of pilot mapping projects. Proprietary software was obtained to enable them to process the GPS data on a portable computer in the field.

Surveying progress with the GPS was found to be equal to or better than with conventional methods, even though the present developmental satellite constellation severely limits the daily timeframe for observations. Survey accuracies of one part in 100,000 were consistently obtained from data acquired from 30 minutes of observations. A controlled test in the Adirondack Mountains, N.Y., showed that GPS ellipsoidal heights could be combined with gravimetric geoid separation data to produce elevations for mapping control. The system was used to establish a 50-station subsidence monitoring network in the Sacramento Valley, Calif., for the Survey's Water Resources Division, and more work is anticipated.

The National Mapping Division also participated in several interagency experiments designed to test the GPS system for use on crustal motion surveys and for decimeter-level navigation of ships and aircraft.

Because of the favorable results obtained with the GPS, the Division plans to purchase three additional survey systems in 1987. Research efforts will focus on maximizing the efficiency of the system for mapping control surveys, refining the methods used for subsidence surveys and for determining elevations from the system, and establishing an in-house capability for precise dynamic (navigation) positioning. Applications testing on Survey interdivisional projects will continue.

IMPLEMENTATION OF NORTH AMERICAN DATUM OF 1983

The Geological Survey is in the process of developing a plan for implementing the new North American Datum of 1983 (NAD 83) for the National Mapping Program. The Survey started providing information to map users on the NAD 83 as early as 1979 by indicating the components of the datum shift in map credit notes and showing the datum shift graphically by dashed crosses in the four corners of the map. However, this information was based on predicted datum differences furnished by the National Geodetic Survey and applied only to the geographic graticule and not to the rectangular grids that are dependent on the ellipsoid. The readjustment of the horizontal control net has now been completed, creating the NAD 83. The present North American Datum of 1927 (NAD 27) is based on the Clarke 1866 ellipsoid, but NAD 83 is an Earth-centered datum based on the newly adopted Geodetic Reference System 1980 (GRS 80) ellipsoid. The State Plane Coordinate Systems are being redefined in conjunction with the establishment of NAD 83. Also, the Universal Transverse Mercator (UTM) grid is affected by the change to a new ellipsoid, independent of the readjustment of the control. Therefore, the location of both the State Plane and the UTM grids will be changed with respect to the geographic coordinates and with respect to each other.

Conversion to NAD 83 will be of increasing importance as use is made of the Global Positioning System and other satellite-derived data, which basically are referenced to the center of mass of the Earth. Conversion to NAD 83 will also remove known existing anomalies in the horizonal network.

The differences between the old datum and NAD 83 range from 0 to 110 meters in the conterminous 48 States, 80 to 200 meters in Alaska, and over 400 meters in Hawaii. These differences indicate the necessity of an adjustment to the geodetic coordinates (latitude and longitude) of features shown on Division map products. The primary map series is nearing completion and will provide once-over coverage on NAD 27. The Division will soon be faced with the problem of accommodating the map users who need to reference the mapped detail, shown on nearly 60,000 quadrangle maps, in coordinate systems based on NAD 83.

The goal of the Division is to develop a conversion plan that can be completed within an acceptable timeframe and cost, with minimal impact on other Federal agencies and the map user community.

A number of alternatives for resolving this anticipated problem were discussed, resulting in the following four options:

1. Continue producing maps on the 1927 datum and show the NAD 83 corners together with a description of the components of the projection shift between the two datums in the map margin (current practice); or conversely,

2. Cartographically adjust map features to the NAD 83 position and show the four corners based on the 1927 datum in the margin; or

3. Recompile maps to a photogrammetric control solution based on NAD 83; or

4. Recast only the map projection and grids to NAD 83 and fit to the existing compilation of the mapped area .

Each option was evaluated considering user requirements, capacity, cost, and time-frame required to complete the transition to NAD 83. Based on this evaluation, it was determined that option 4 was the most effective and economical approach; however, it will result in map corners not being even multiples of degrees and minutes.

Option 4 will be implemented by generating a new graticule, State Plane Coordinate System, and full-line Universal Transverse Mercator grid separations based on NAD 83. These new separations will be fitted to the existing map detail and limits. To the extent practicable, existing maps will be converted to NAD 83 in blocks, preferably by State, to maintain continuity in the map coverage.

A pilot project consisting of thirty-six 7.5-minute quadrangle maps covering the State of Rhode Island has been authorized to develop technical applications and to obtain user response. The difference in the geodetic position between NAD 27 and NAD 83 in this area is about 40 meters or 0.07-inches at 1:24,000 scale. NAD 83 values for each of the 7.5-minute intersections have been obtained from the National Geodetic Survey and will be used in the conversion process. Work is underway to develop the software to generate the new graticule and grid separations to fit the present map limits considering that scale distortions exist in the materials. Modifications to the map collar content and format are also being considered to facilitate the conversion program.

THE PROPOSED NATIONAL VERTICAL DATUM

The National Mapping Program includes more than 60,000 different map products, of which over 7 million copies are distributed annually. Of the 60,000 maps, about 55,000 are in the 7.5-minute, 1:24,000-scale, primary quadrangle map series. Complete coverage of the lower 49 States in this series is expected by 1991. Since the 7.5-minute series maps are the largest scale produced by the Survey and contain the greatest detail and elevation accuracy, they are affected most by datum changes. Accordingly, the following discussion will be limited to this series.

Most 7.5-minute maps have been produced since the end of World War II, when photogrammetric methods became common practice. The procedures used today for producing a map were established in the early 1950's and, with the exception of some evolutionary changes in instruments and technology, have remained essentially the same. The elevation information on 7.5-minute maps is based on the North American Vertical Datum of 1929. This datum was established by the U.S. Coast and Geodetic Survey by adjusting the existing 75,159 kilometers of level lines (Canada providing an additional 31,565 kilometers) and forcing agreement to mean sea level measured at 21 tide stations located along the Atlantic, Pacific, and Gulf coastlines.

Contours are the major source of vertical information on a 7.5-minute map. The contour intervals are selected from the standard values (5, 10, 20, 40, and 80 feet) to best express the topography of the area. The distribution of the various contour intervals in the country is depicted in figure 5. A small percentage of the 7.5-minute map series contains metric contours. These were converted and rounded to the nearest foot interval for inclusion in the following statistics.

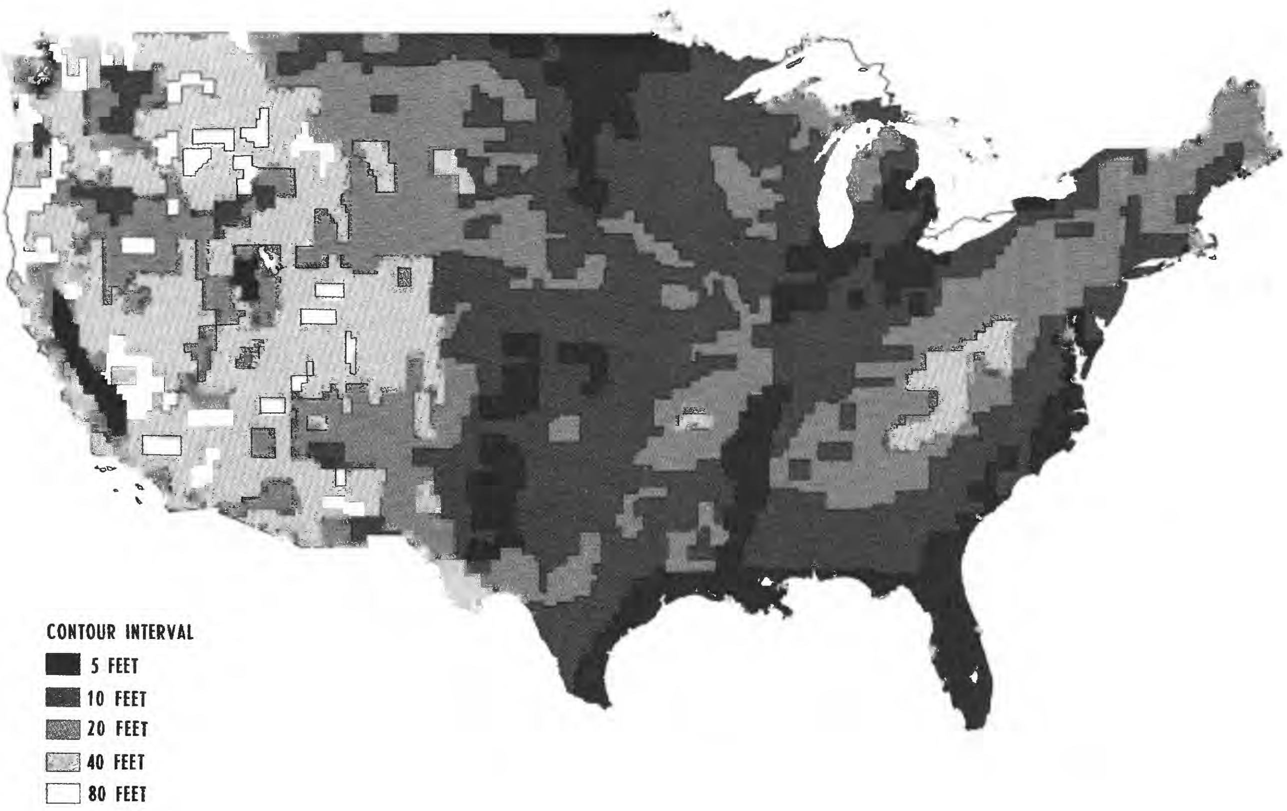

Figure 5.--Distribution of topographic maps by contour interval.

In the lower 48 States, 14 percent of the 7.5-minute maps contain 5-foot contours, 34 percent contain 10-foot, 29 percent contain 20-foot, 18 percent contain 40-foot, and 5 percent contain 80-foot. The contours meet National Map Accuracy Standards, which require that the error in at least 90 percent of the points tested be less than one-half the contour interval. Other sources of vertical information available on the 7.5-minute maps are labeled elevations for bench marks and spot elevations. Spot elevations are given to the nearest foot and are usually spaced at two points per square mile or about 100 per 7.5-minute map. The bench mark elevations are accurate to one-half foot and the spot elevations are accurate to about one-third of the contour interval.

The impact of the North American Vertical Datum of 1988 on the National Mapping Program is not known at this time because "datum definition" is one of the last tasks to be performed. However, a discussion of the possibilities is appropriate. A dramatic change in datum definition would significantly impact the National Mapping Program. The expense of recontouring all of the 7.5-minute maps would be prohibitive because the cost of contouring a single map can range from $3,000 to $5,000. A more reasonable change can be expected that will probably be based on the following deficiencies in the present datum:

- An east–west slope of 0.7 meters due to constraining tide gauge heights.

- A north–south slope of unknown origin along the west coast of about 1 meter.

- Irregularities of about 0.3 meters due to accumulative errors in the original data.

- Local errors due to subsidence, crustal motion, post–glacial uplift, and bench mark frost heave.

- Other errors such as ignoring refraction corrections and the use of nominal gravity rather than true gravity.

Considering only the first three deficiencies, which are regional, and ignoring local effects that will have to be dealt with in any case, the changes can be controlled to a reasonable level by careful definition of the datum parameters. At the time of reprinting of almost all maps, a datum shift statement will have to be added, similar to that used on the Durango, Colo., (1908), 15–minute map (fig. 6), to provide information to update labeled bench mark and spot elevations.

MULTIPURPOSE CADASTRE ACTIVITIES

The multipurpose cadastre is a land–parcel–based land information system that integrates spatial and record data. Essential elements of a multipurpose cadastre are a network of geodetic control points tied to the the national network, a set of accurate large–scale base maps, a map layer delineating cadastral parcels, and land data records linked to the parcels. In a functioning multipurpose cadastre, single sets of data would be used by individuals and organizations for varied purposes; redundant data storage and handling would be reduced through shared use of common data files and maps. While the multipurpose cadastre is a local government system, it will allow data transfer between local, State, and national levels.

The need for Federal participation in multipurpose cadastre development has been recognized in publications by the National Research Council. The Council identified several areas for Federal participation that directly relate to Survey programs including assistance in the development of standards in areas in which the agencies have expertise, and technical studies to identify land information and display standards. Current Survey multipurpose cadastre initiatives fall in three areas:

1. Membership in the Multipurpose Cadastre Task Force of the Federal Geodetic Control Committee. The task force is monitoring and co–ordinating Federal multipurpose cadastre activities. The task force is also considering developing a guidebook on how to design and build a multipurpose cadastre and conducting a study of existing exemplary systems.

2. Development of digital and graphic cartographic standards that apply to multipurpose cadastre activities.

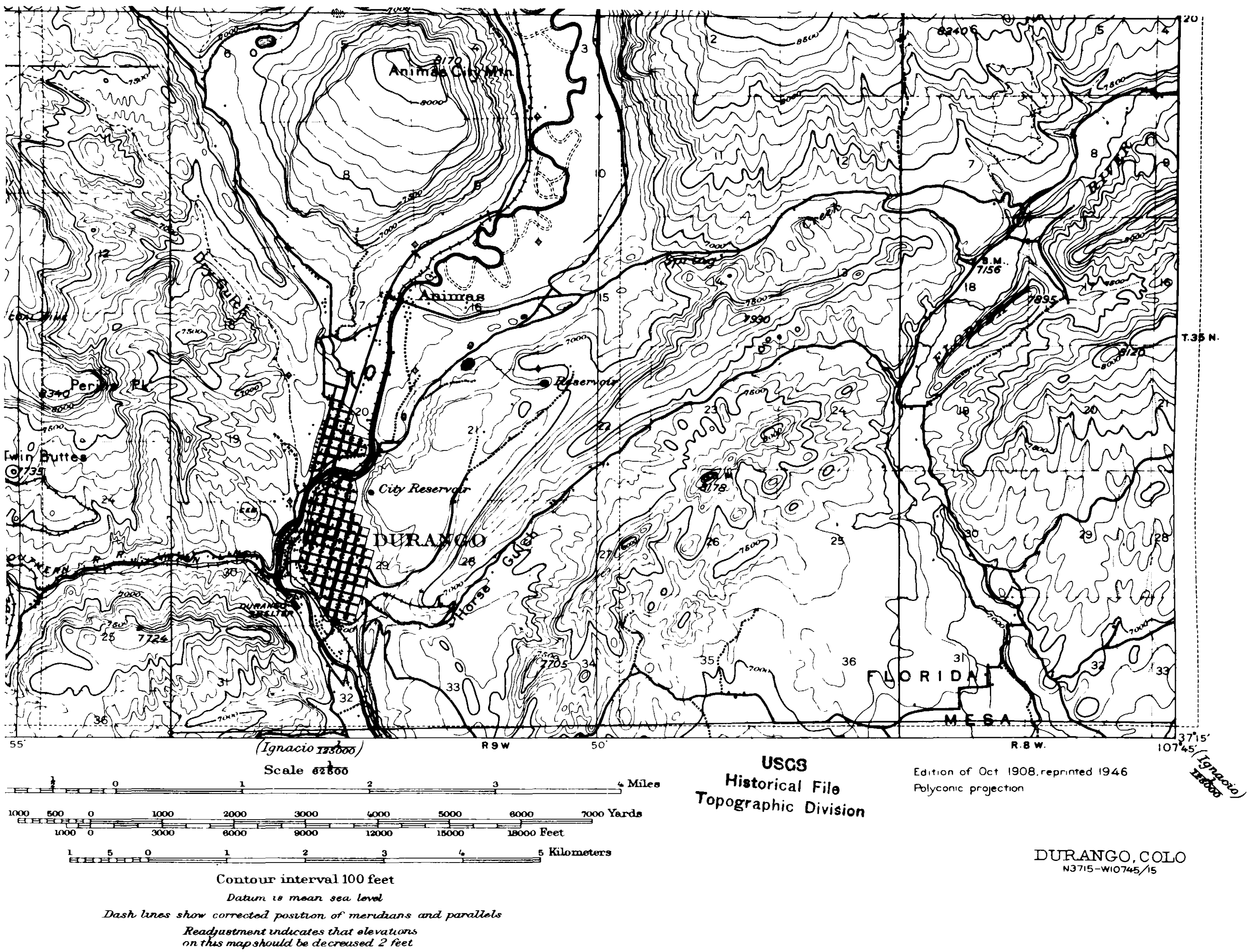

Figure 6.- -Part of Durango, Colo., 15-minute map (example of datum change statement).

3. Pilot projects and other multipurpose cadastre support. Pilot projects will be conducted in different areas of the country to determine how cartographic data can be used in a local government multipurpose cadastre, and how data generated in a multipurpose cadastre can be used to revise and augment digital data and quadrangles. The Survey has also agreed to support local multipurpose cadastre efforts by providing technical assistance and products such as base maps and overlays, larger scale orthophotographs, and base category data from the NDCDB.

DIGITAL ORTHOPHOTOGRAPHS

A method has been developed to rectify an aerial photograph using digital techniques. A digital image created by scanning an aerial photograph using a film scanner and a DEM of the same area are used as input to the process that rectifies the image in two major steps, one operating on 30-meter DEM cells and one operating on individual image pixels.

The software, DPSOR (Digital Photogrammetric System Ortho Photo), is installed on a Gould 32/9780 computer. It can produce digital orthophotographs in a prototype mode from quadrangle-centered, high-altitude aerial photographs scanned at 25 micrometers. After processing, the digital orthophotograph is written to film, then enlarged on a copy camera to 1:24,000 scale. Each pixel is 75 micrometers, representing approximately 2 meters on the ground.

Research continues into the use of image processing techniques to sharpen image quality, perform digital mosaicking, create color digital orthophotographs, and determine optimal use of film scanners and writers. Improvements in processing efficiency are also being investigated. A version of DPSOR has been installed on the Cray X-MP supercomputer at NASA Ames Research Center to determine optimal memory size and the effect of parallel processing-machine architecture.

SHADED RELIEF MAPS FROM DEM DATA

Shaded relief maps are traditionally produced by interpolating the terrain from a contour plate using an airbrush. Experimental work has been done to produce shaded relief maps using DEM data. The DEM data are transformed into a shaded relief product using specialized computer software. Two projects, completed for the National Ocean Service, involved preparation of digital shaded relief separates as a replacement for hand-drawn shaded relief separates in the preparation of the 1:500,000-scale Anchorage Sectional Aeronautical Chart and the 1:250,000-scale Los Angeles Terminal Air Chart. Another project involved production of a shaded relief image of the Rocky Mountain National Park area to be used as a reference image printed on the reverse side of the revised topographic map. Each of these projects involved the mosaicking of 1:250,000-scale DEM cells and reformatting of the data to the appropriate map projection at an output ground resolution of 100-meter pixels. The artificial shadowing was created using a program called SUNSHADE on an HP 3000 computer system. A considerable amount of time was spent determining program parameters that would provide products similar to the hand-drawn shaded relief separates. The three parameters of importance are Sun elevation, which controls the length of the shadows; Sun direction, normally set from the northwest at 315°; and ambience, which controls the light intensity within the shadow areas.

A new shaded relief map of the region surrounding Kilauea Crater in Hawaii Volcanoes National Park was created using a digital approach. Contours were scanned and edited on the Scitex, then converted into vector form and tagged interactively with contour values. Gridding software was used to form a non-standard DEM with a grid spacing of 50 meters. From the DEM, a shaded relief image was generated on the Interactive Digital Image Manipulation System using software that computes surface brightness based on a variety of parameters, including Sun elevation above the horizon, Sun azimuth, degree of surface roughness, and available ambient light. To minimize the amount of photographic enlargement necessary to produce a shaded relief plate, the relatively small image was digitally enlarged 13 times, then smoothed using a convolution filter before being written out to film. The resulting negative was photographically enlarged to fit the 1:24,000-scale scribed map base and manually edited to remove edge effects.

PRODUCTION OF A VOLCANO-EARTHQUAKE WORLD MAP

In a cooperative project between the Survey and the Smithsonian Institution, a new world map showing the epicenters of over 150,000 earthquakes and locations of 1,459 volcanoes is being developed and will be overprinted on a computer-generated NOAA physiographic base that illustrates the Earth's major geophysical features. The map scale will be 1:30,000,000 at the equator and will measure 1.12 by 1.50 meters in size. It will show seismic zones, volcano belts, and physiography when viewed from a distance; greater detail will be visible on close examination.

After experimenting with several different classifications, the current proposal is to subdivide the presentation of the earthquakes into four classes. "Small" earthquakes (magnitude 4-8) are to be shown in solid black circles of two sizes, with the larger of the two representing earthquakes occurring at depths greater than 60 kilometers. The localities of "large" earthquakes (magnitude greater than 8) are to be indicated by open black circles, with the larger of the symbols again representing depths greater than 60 kilometers. All of the earthquakes represented have occurred since 1 A.D.

The volcanoes, symbolized by red triangles, are to be subdivided according to the time of their eruption: (1) this century (1900 to the present); (2) the previous 2,000 years; and (3) Holocene (20,000-2,000 years before present). The proposed symbolization is of decreasing intensity, designed to represent the progression of time: solid triangles for the first class, open triangles for the second, and open triangles of a lighter lineweight for the third. A fourth class of volcanoes, symbolized by small open triangles, is included. These will represent localities where volcanoes are assumed to have occurred but are not verified.

In a subdued manner, the physiography will be depicted both by shaded relief and by color. Variation in ocean depth will be indicated by deepening shades of blue corresponding to the areas of greatest depth and by dark gray shading to emphasize sharper features. On land, the flatter lowlands will be shown by various greens, while the uplands and mountainous areas generally will be tones of light red with yellow highlighting the western slopes in contrast to grayed eastern slopes.

The map is intended as a research and teaching aid for classrooms in all parts of the world; map captions will be available in several languages. An example of a portion of the map is shown in figure 7.

SATELLITE IMAGE MAP PRODUCTION

During 1985 and 1986, the Division continued to refine procedures to produce and enhance satellite image map products. Accomplishments include improvements in procedures to convert digitally mosaicked image data to hard copy (color

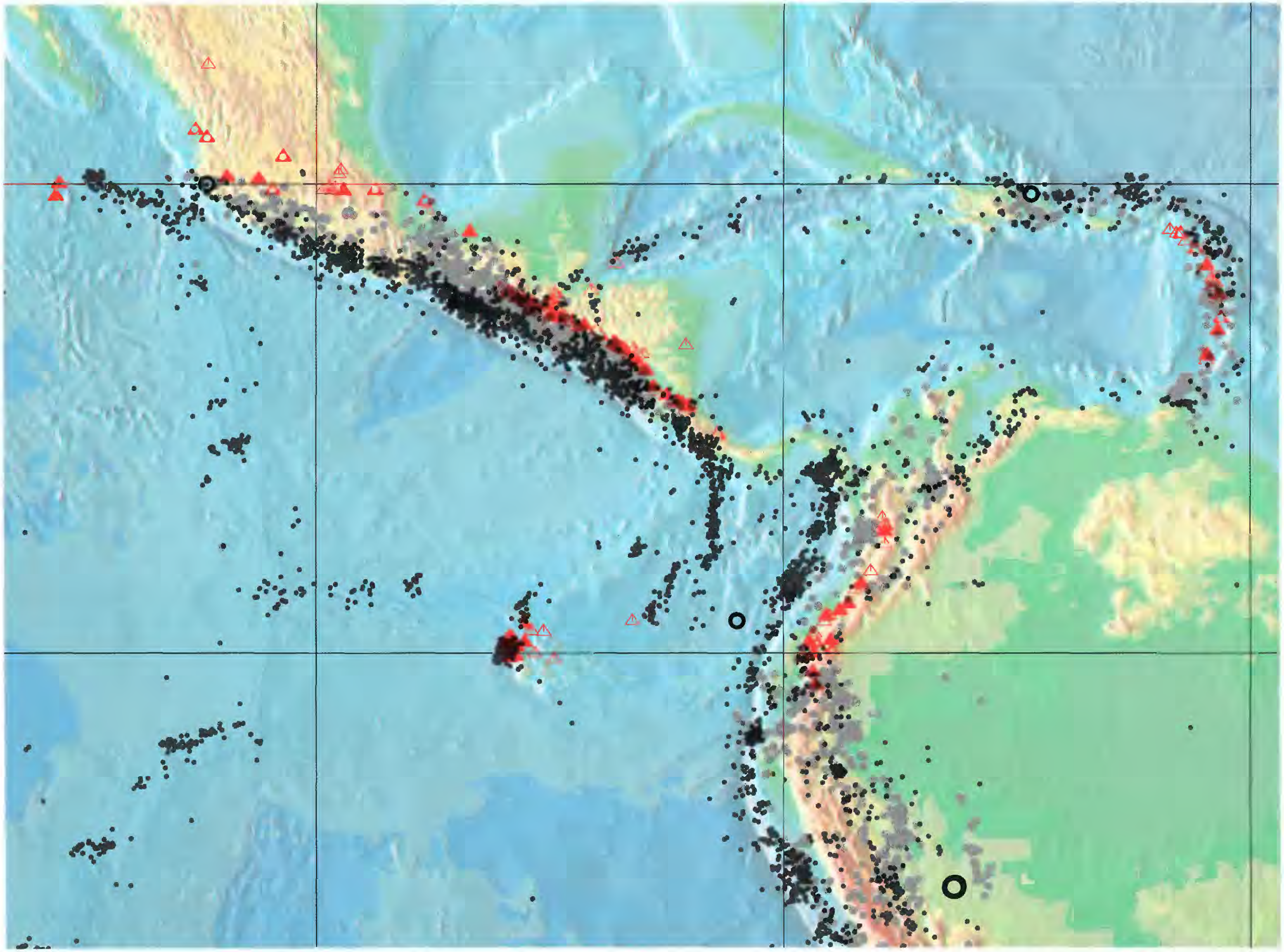

Figure 7.—Portion of proof of Volcano–Earthquake World Map showing location of earthquakes and volcanoes, overprinted on the National Oceanic and Atmospheric Administration's shaded-relief physiographic base.

transparency film) that is more suitable for processing on the graphic arts scanner that produces the halftone separates for lithographic printing. Other refinements include the implementation of spatial filtering software for image enhancement and deconvolution (restoration) software to improve image resampling during geometric transformation.

Image map generation focused on products from Landsat Thematic Mapper (TM) and multispectral scanner (MSS) data. Research dealing with both Advanced Very High Resolution Radiometer (AVHRR) data and Systemé Probatoire d'Observation de la Terre (SPOT) data has also begun. Satellite image maps are currently being produced at scales ranging from 1:100,000 to 1:4,000,000. The Denali National Park, Alaska; Anchorage, Alaska; Mariposa, Calif.; and Richmond, Va., quadrangles were printed at 1:250,000 scale from MSS data. Digital image processing has been completed for the TM 1:100,000-scale image map of Pahute Mesa and Cactus Flats, Nev., and Kansas City and Olathe, Kans.. These four image maps and 1:250,000-scale MSS image maps for Goldfield and Tonopah, Nev., Needles, Calif.; and Roanoke, Va. are expected to be printed during 1987. Image processing for 10 additional 1:250,000-scale MSS image maps has been completed for quadrangles in Alaska, Colorado, and Pennsylvania. The processed images are currently being scanned to produce publication-scale halftone separates for printing.

An experimental image mosaic of the western United States was prepared at 1:4,000,000 scale by digitally mosaicking five AVHRR scenes. AVHRR data collection for Alaska has been initiated to produce a similar mosaic for that State. Research is being conducted to determine the largest scale at which AVHRR data can be used to provide base map coverage for unmapped areas of the world.

Four quadrangle-formatted image mosaics of the Norfolk, Va., area were produced for the Defense Mapping Agency, using both leaf-on season and leaf-off season images from 1:250,000-scale MSS data and 1:100,000-scale TM data. Both photographic products and digital tapes of the mosaics were supplied.

A project with the Mid-America Regional Council was completed to produce a 1:100,000-scale, two-scene TM digital mosaic of the Kansas City area using the Large Area Mosaicking Software system. The Kansas City area was digitally extracted from a larger data set to prepare the image map using TM bands 1, 3, and 5.

Two Florida State base image maps are being prepared from MSS data. The maps will be printed at two scales: 1:500,000, with a north half and a south half, and 1:750,000, showing the entire State. The water areas in the Atlantic Ocean and the Gulf of Mexico will be shown using AVHRR data where available.

AVHRR MOSAIC OF THE WESTERN UNITED STATES

The National Mapping Division has investigated the feasibility of using digital processing techniques to develop an Advanced Very High Resolution Radiometer (AVHRR) mosaic of the western United States and is assessing the utility of these data for preparing continentwide image maps.

A digital mosaic was created using five scenes of AVHRR data acquired on consecutive dates (May 27-31, 1984) over the western United States. For each of the 5 images, 200 ground control points were generated automatically using software obtained from the Institute of Oceanography. The ground control points were used with Large Area Mosaicking Software to register and digitally mosaic the five

Figure 8.—AVHRR mosaic of the western United States with State boundaries embedded in the image.

images to a 1,500–meter Albers Equal Area Grid. To provide State boundaries, a mask of the western United States was created using 1:2,000,000–scale DLG data and was applied to the registered image. The coastal boundary was extended into the ocean approximately 25 kilometers so that the water/land boundary could be visualized. The image was smoothed so that when the final image was recorded on film, it would be difficult to see individual pixels. After the image was smoothed, it was enhanced using a 151– by 151–filter with an 80–percent addback of color. The final image was then merged with a rasterized map collar that had been prepared using a vector processing system. The final image (figure 8) was recorded on film using a color film recorder and a 20–micrometer spot size, resulting in a film scale of 1:16,640,000.

The preparation of the western United States AVHRR mosaic demonstrated that these data could be useful for developing countrywide and continentwide image maps at a scale of 1:2,000,000 or smaller. The only other satellite image mapping data available globally at this time are from Landsat, which has higher spatial resolution than is needed for producing continentwide image maps. For example, it would take over 300 Landsat images to create a mosaic of the western United States similar to one created using 5 AVHRR scenes.

DENALI NATIONAL PARK MAP

During July 1986, the Survey published the Denali National Park and Preserve, Alaska, 1:250,000-scale satellite image map. The map is significant in that Mount McKinley (Denali) has perhaps the greatest relief of any land mountain in the world in that it rises over 5,000 meters (approximately 17,000 feet) above its base. In addition, the area presents a stark contrast between the snow and ice and summer vegetation. Because summer seasons are short and cloud prone, it was necessary to select and match images from 5 years of Landsat multispectral scanner (MSS) coverage. Relief displacement was not removed and yet the map was produced with good geometric accuracy through careful selection of the nearly orthographic space imagery.

Nine MSS images were geometrically corrected, digitally mosaicked, and enhanced using the Large Area Mosaicking Software. This process involved ground control and digital resampling to the Universal Transverse Mercator projection. After a digital-to-analog film conversion was performed on a MacDonald Dettwiler Color Fire 240 Recorder, the resulting color transparency was rescanned, digitally enlarged, and output at final scale in halftone format using a Hell CP-340 graphic arts scanner/ plotter. A grid was cast to a Universal Transverse Mercator projection and registered to the image data. An updated line map of the Denali National Park was prepared and printed on the reverse side of the image map. The final map sheets were printed on a plastic-coated map stock for durability.

ILLINOIS STATE MAP--ECONOMIC ALTERNATIVE FOR TM IMAGE MAP PRODUCTION

The photomechanical mosaic of 12 Landsat Thematic Mapper (TM) scenes provided the base for a satellite image map of Illinois at a map scale of 1:500,000. The TM scenes used were acquired from September 30, 1982, to October 25, 1982, and provided a high-contrast, uniform, scene-to-scene match. An image map produced by digital mosaicking was beyond the resources available to the Northern Illinois University (NIU), who produced the map for the Illinois State Geological Survey. NIU requested assistance in producing the map through more economical photomechanical mosaicking procedures. The 12 individual scenes were ordered from the EROS Data Center as contrast balanced negatives. They were reproduced from master film positives sent to the Data Center from NASA Goddard Space Flight Center. The scenes were positioned to the drainage pattern on the State base map reduced to 1:1,000,000 scale. A mosaicking specialist from the Division demonstrated the film mosaicking technology to NIU and provided advice on halftone film parameters for a graphic arts electronic color scanner to produce the final halftone separations at 1:500,000 scale. Details on the production of the map are published in the paper "A Satellite Image Mosaic of Illinois" by Richard E. Dahlberg and others, NIU, 1986.

One year was required between the availability of the TM data and the first edition of 5,000. The actual production work was compressed into an 8-month period. Two additional image maps were also reproduced on the graphic arts scanner from the same TM mosaic--"Landscapes of Northern Illinois at 1:375,000 Scale" and "Satellite Image Map of Northeastern Illinois at 1:200,000 Scale."

PRODUCTION OF EEZ ATLAS

The "Atlas of the Exclusive Economic Zone, Western Conterminous United States" (U.S. Geological Survey Miscellaneous Investigations Series Maps I-1792), contains 1:500,000-scale sonar image mosaics of the ocean floor along with bathymetry, geologic interpretations, seismic reflection data, and magnetic anomaly data. The imagery was acquired using a side-scan system known as GLORIA (Geological Long-Range Inclined ASDIC), which records acoustic energy reflected by the ocean floor as digital data. Special software was developed to handle the processing of the sonar image data. The software package is part of the Geological Survey's Mini Image Processing System (MIPS). The GLORIA data were geometrically and radiometrically corrected prior to being written to film at 1:750,000 scale with a 25-micrometer pixel size.

More than 2,000 film negatives were required for the mosaicking process. As many as 70 pieces of film were used for each 2° x 2° map sheet. To keep the original quality and tone throughout, each reproduction was carefully controlled for density. The mosaic masks of each sheet were generated from a control template. The exact position of each image was outlined on scribecoat and scribed. Four or five sensitized peelcoats were made, depending on the number of masks required. Unique windows were opened for each image piece within a set of masks. The film was then carefully positioned and taped onto the open window. Each window was exposed individually on a variable intensity printer (VIP) to obtain the proper density. The VIP allows for controlled localized dodging throughout the film area. Once the film mosaic was completed, positives were produced and sent to the marine geologists for interpretation. Their interpretations were manually scribed and registered to the mosaic for final printing. The atlas is the first publicly available document to illustrate a sizable area of sea floor. A portion of one of the atlas sheets is shown in figure 9.

FOUR-COLOR PROCESS PRINTING OF SATELLITE IMAGE MAPS

The National Mapping Division now uses a color film transparency for scanning and plotting of halftone separates for lithographic printing of satellite image maps. Previously, the yellow, magenta, and cyan halftone image separates were generated by scanning three black-and-white Laser Beam Recorder (LBR) transparencies. The use of a color film transparency on the scanner allows for the generation of a black halftone separate in addition to the yellow, magenta, and cyan separates. The black halftone increases image density and contrast in the final image map.

A MacDonald Dettwiler Color Fire 240 film recorder is used to image a continuous-tone 9.5- by 9.5-inch color film transparency directly from digitally mosaicked Landsat data. The Color Fire 240 transparency, with a density range of 1.40, is then duplicated on Ektachrome film to a density range of 2.30 to provide improved processing control on the Hell CP-340 graphic arts color scanner/plotter used

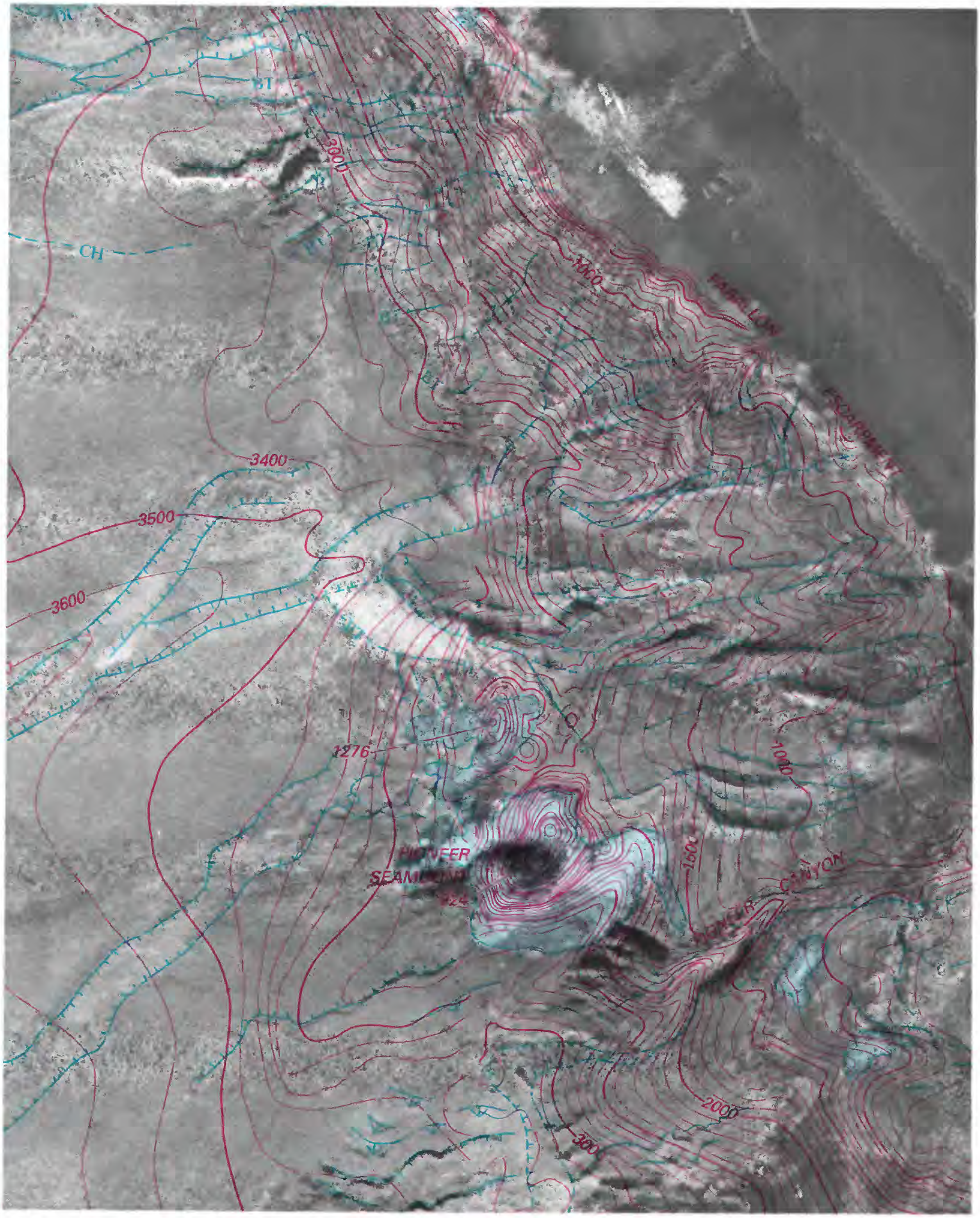

Figure 9.—Portion of Exclusive Economic Zone atlas sheet showing sonar imagery overprinted with bathymetric contours (blue) and geologic interpretation (red).

to produce halftone separates. Duplication of the Color Fire transparency to achieve a higher density range is necessary because its compressed density range of 1.40 is too low for the scanner to accurately reproduce acceptable imagery. In addition, there are color-processing inconsistencies between Color Fire 240 transparencies of different images that prevent a standard scanner setup, such as a blue cast in highlight areas and the dot structure caused by the 60-micron aperture through which the Color Fire image data are recorded. The Ektachrome duplication transparency has helped to minimize these problems. The same 16-step density scale previously used for the three LBR image separates is used for tone curve control. Additionally, six 16-step density scales are imaged on the Ektachrome transparency for color control in process colors yellow, magenta, and cyan and their combinations green, red, and blue to remove color contamination.

The resulting image map product is superior to that produced from LBR black-and-white separates in terms of resolution, band-to-band registration, geometry, color contrast, and saturation. Processing time and costs are also reduced, as the LBR procedure requires four runs to produce film test images and an additional photographic laboratory step to produce a final-scale color proof for evaluation. The color proof time has been reduced from 1-2 weeks to 2-3 days. LBR film transparencies continue to be used for preparation of photomechanical film mosaics of Landsat image products.

TAPE-TO-FILM PROCESSING FOR IMAGE MAPPING

In 1985, the Scitex electronic laser plotter was upgraded to provide the capability to produce publication-scale, continuous-tone and halftone film transparencies of remotely sensed imagery. The plotter system permits direct input of Landsat and other digital data. Its maximum output format is 40- by 72-inches. An example of image output is shown in figure 10.

Using a 16-bit central processing unit, the Scitex can process and generate 256 levels of either continuous-tone density or halftone percent dot. The system differentiates between continuous-tone files, which have yellow, magenta, cyan, and black separation value assignments for each pixel, and linework files, which have separation values for each run length of data. Continuous-tone files can be plotted as either continuous-tone or halftone at up to 15 times the resolution of the file. The maximum possible resolution is 44 lines/millimeter for continuous tone and 99 lines/millimeter for halftone. Although Scitex only guarantees a maximum of 72 lines/millimeter for halftones, excellent results have been achieved at 96 lines/millimeter (about 200 lines/inch.)

The sharpness of continuous-tone plots can be controlled by varying the dot overlap. At an overlap of 1.5 (each dot overlaps neighboring dots by half its diameter), the edges of each square pixel are fairly well defined and produce a blocky image that most closely represents the nature of the data. By increasing the overlap to 5.5 the image appears much smoother, but the definition between different data areas is compromised.

Exposure tables are used to further manipulate the appearance of data. Curve modification and manipulation tables can be constructed to alter the expression of highlight, shadow, or midtone characteristics, to expand or limit the effective range of data, or to invert data from positive to negative or vice versa. Exposure tables affect only the appearance of the image on film and do not alter the original data.

Figure 10.--Portion of a halftone image of the National Oceanic and Atmospheric Administration's "Relief Map of the Surface of the Earth" produced on the Scitex Response-280 Laser Plotter.

Current developmental work with the newly upgraded Scitex laser plotter is focusing on optimum procedures to: (1) generate a black separation from the three process color separations for the purpose of increasing the contrast of halftone images; (2) perform edge enhancements of images prior to plotting film separations; (3) refine continuous-tone film plotting techniques for use with a microlenticular screen; and (4) utilize the plotter for halftone output of GLORIA sonar image products and Landsat image map products.

ALGORITHMS FOR IMAGE PROCESSING

Digital Image Restoration

The National Mapping Division has developed a digital image restoration capability for processing data acquired by the Landsat MSS and TM sensors. Research for this capability was performed primarily at the University of Arizona by Dr. Robert Schowengerdt during 1986. Software developed by Dr. Schowengerdt, which models the degradations of the data and generates deconvolution kernels to remove these degradations, was implemented in June 1986. Joint investigations between the Division and the University of Arizona for developing restoration techniques for AVHRR and SPOT images were initiated late in late 1986.

The digital image restoration capability developed was based on results of studies of the restoration process used by the Environmental Research Institute of Michigan (ERIM). Like the ERIM process, the Division restoration procedure is used in place of image resampling during geometric correction. Because restoration-based resampling removes existing degradations rather than introducing new ones (as do interpolation-based resamplers such as cubic convolution), it is possible to generate geometrically corrected images that are sharper than their uncorrected counterparts (figure 11). In addition, the procedure produces restoration kernels thatare optimal for a particular image and can enhance the image's high frequencies during resampling, thus eliminating the need to perform edge enhancement as an additional processing step.

Two TM images were processed in 1986 to compare the restoration process with cubic convolution. A scene acquired over the San Francisco Bay, Calif., area was corrected and restored at a scale of 1:100,000, and a scene of the Wadi-as-Suqah region in Saudi Arabia was restored at a scale of 1:50,000. MSS data restorations at 1:250,000 scale of the New Orleans, La., area and the Namoi/Gwydir Valley in Australia are scheduled for completion in early 1987.

Digital to Lithographic Process

Research is being conducted to produce halftone image separates for satellite image maps directly from digital data using the Scitex system. To improve lithographic products generated directly from digital data, an investigation has been initiated to develop digital processing methods for undercolor removal from color digital imagery to allow production of a black halftone separate from digital Landsat data. The process is accomplished by removing an equal amount of cyan, magenta, and yellow ink at each pixel location and replacing it with a corresponding amount of black ink. Thus, a digital tape containing a three-band, red-green-blue image can be used directly on the Scitex to produce four halftone separates (cyan, magenta, yellow, and black) for printing. A black separate increases the quality of printed images by increasing the contrast.

Sensor and Spacecraft Platform Modeling

An investigation of sensor and spacecraft platform modeling for image rectification has been initiated for two reasons: (1) raw data can be preprocessed to remove noise patterns, which are difficult to remove after the data are resampled; and

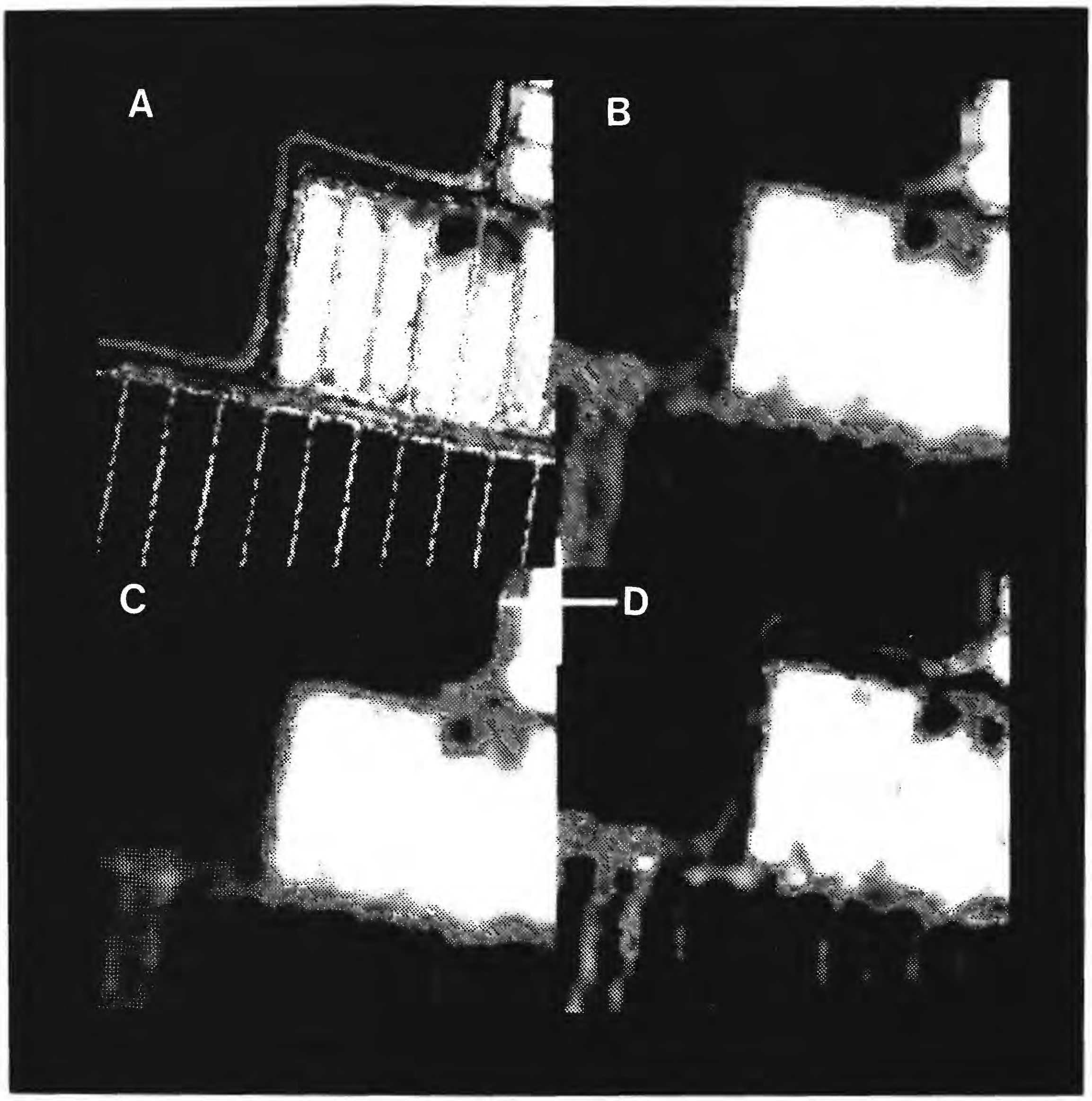

Figure 11.--Resampling techniques for image magnification: (a) 7-meter airborne Daedalus data (simulating SPOT) of the San Jose sewage treatment plant; the 7-meter image was degraded to 28-meter resolution using the TM degradation model, then reconstructed at 7-meter resolution using (b) bilinear interpolation; (c) cubic convolution, and (d) restoration.

(2) with the increased resolution and off-nadir pointing capabilities of new satellite remote sensing systems such as SPOT, it is imperative to take relief displacement into account. Relief displacement removal is best performed with the raw, un-resampled data since the relief effect is along the original scan line of the sensor. To date, image rectification is performed on imagery that has already been re-sampled to remove systematic geometric distortions. Because the initial systematic rectification and resampling correct for the high-frequency geometric distortions in

the imagery, a finite element or polynomial interpolation of control points is sufficient to accurately rectify the imagery except in areas where relief displacement must be accounted for.

Several different platform modeling software systems are being evaluated. System Model for Image Registration (SMIR) is a software package that was originally designed by DBA Systems, Inc., for the National Aeronautics and Space Administration's (NASA) Multi-Linear Array (MLA) Shuttle mission. Because SPOT uses an MLA sensor similar to the proposed NASA MLA, the SMIR software is being modified to process SPOT data. The major drawback of the SMIR software is that it lacks the capability to correct for relief displacement. The other software system being investigated was designed by STSystems Corporation to geometrically rectify and remove relief displacement from the SPOT and Landsat sensors.

Digital Image Mosaicking

Digital image mosaicking requires registration of data at adjacent image boundaries as well as rectification of inherent geometric distortions. Dr. Albert Zobrist, Jet Propulsion Laboratory, developed a surface interpolation technique referred to as a finite element model for digital image mosaicking. This technique was implemented by the National Mapping Division in 1983 and has been used in image map production, but was not well-documented. An analysis of the finite element technique has provided additional documentation of the procedure, identified its strengths and weaknesses, and compared it to a second-order polynomial surface interpolation. Results indicate that the finite element surface interpolation provides increased registration accuracy of the data in the overlap regions of adjacent images. New procedures for collecting tiepoints in the image overlap region were identified. Extensive graphics and editing software was developed to provide a method of identifying and documenting the sources of registration problems.

Digital Data Merging

Increased spatial resolution in multispectral images, without sacrificing spectral information, can be obtained by merging data from different sensor systems. Often, data of high spatial resolution are available in panchromatic form that can complement lower resolution multispectral data. The standard method of integrating these two forms of data modulates the intensity of the multispectral data with the panchromatic data. An alternative and less subjective approach has been implemented that uses an algorithm to describe color in terms of intensity (I), hue (H), and satura- tion (S). This IHS technique was used to combine 10-meter-resolution panchromatic SPOT data with 28.5-meter-resolution multispectral TM data and 20-meter- resolution multispectral SPOT data. The data are registered to each other and the multispectral data are converted to IHS color space. The panchromatic data are mapped to the intensity of the multispectral data and then substituted for the multispectral intensity. The merged IHS data are transformed back into red, green, and blue color space, resulting in a product that combines the high resolution of the panchromatic data with the color of the multispectral data, thus producing a high-resolution multispectral image.

USE OF LANDSAT TM BANDS 5 AND 7 FOR CLOUD AND SNOW SEPARATION

The Landsat Thematic Mapper (TM) system made available to users a new data set that has better spatial and spectral resolution than the widely used Landsat MSS data. The 30-meter resolution allows better feature recognition of spatial information. The new spectral bands (TM bands 1, 5, 6, and 7) allow a user to analyze an area of interest to an increased level of classification as compared to satellite data previously available. Band 1 increases the amount of information that can be seen in water bodies, and band 6 records thermal information (at a spatial resolution of 120 meters). Bands 5 and 7 have been useful not only for geologic mapping, but also for mapping vegetation types and information related to moisture content.

One of the major problems with using Landsat MSS or SPOT data in Antarctica is that of cloud and snow separation, as well as saturation due to the high albedo. The spectral bands used by these two imaging systems make it very difficult, and often impossible, to separate clouds from snow in Antarctica. Bands 1, 2, 3, and 4 on the Landsat TM imaging system have the same problem because the spectral bands are very similar to those on the MSS and SPOT systems. However, TM bands 5 and 7, which are influenced much more by moisture content than bands 1, 2, 3, and 4, do an excellent job of separating clouds and snow and do not have the saturation problem. In fact, snow often has a lower reflectance response in these bands than soils and rocks.

Figure 12 shows a black-and-white print of Landsat TM band 2, approximately equal to the old MSS band 4 and SPOT XS band 1, of one quadrant of an image just east of the Dry Valley area in Antarctica. Notice the information in the mountain shadowed areas and that some cloud shadows can be seen. However, it is difficult to separate or identify the clouds from the snow-covered areas. Figure 13 shows an image of TM band 4, approximately equal to the old MSS band 6 and SPOT XS band 3 (near-IR band) of the same area. This image has slightly more detail but is not significantly better for cloud and snow separation. It does have less of a problem with saturation than do TM bands 1, 2, and 3. Figure 14 shows an image of TM band 5 of the same area. Notice the excellent separation of clouds from snow in the top right and bottom center of the image, where the clouds are still white but the snow has brightness values that are less than or equal to the soils and rocks in the area. The rocks in the lower right quadrant of the image are dark basalts. In this image there are also some locations that are covered by blue-ice.

The separation between clouds and snow is even better when the data are color composited. From both statistical and visual analyses, one of the better color composite combinations is the one made from TM bands 3, 4, and 5 or 7; if maximum cloud and snow separation (moisture-related information) is wanted, a composite using TM bands 4, 5, and 7 should be used (this combination also has the minimum amount of saturation problems).

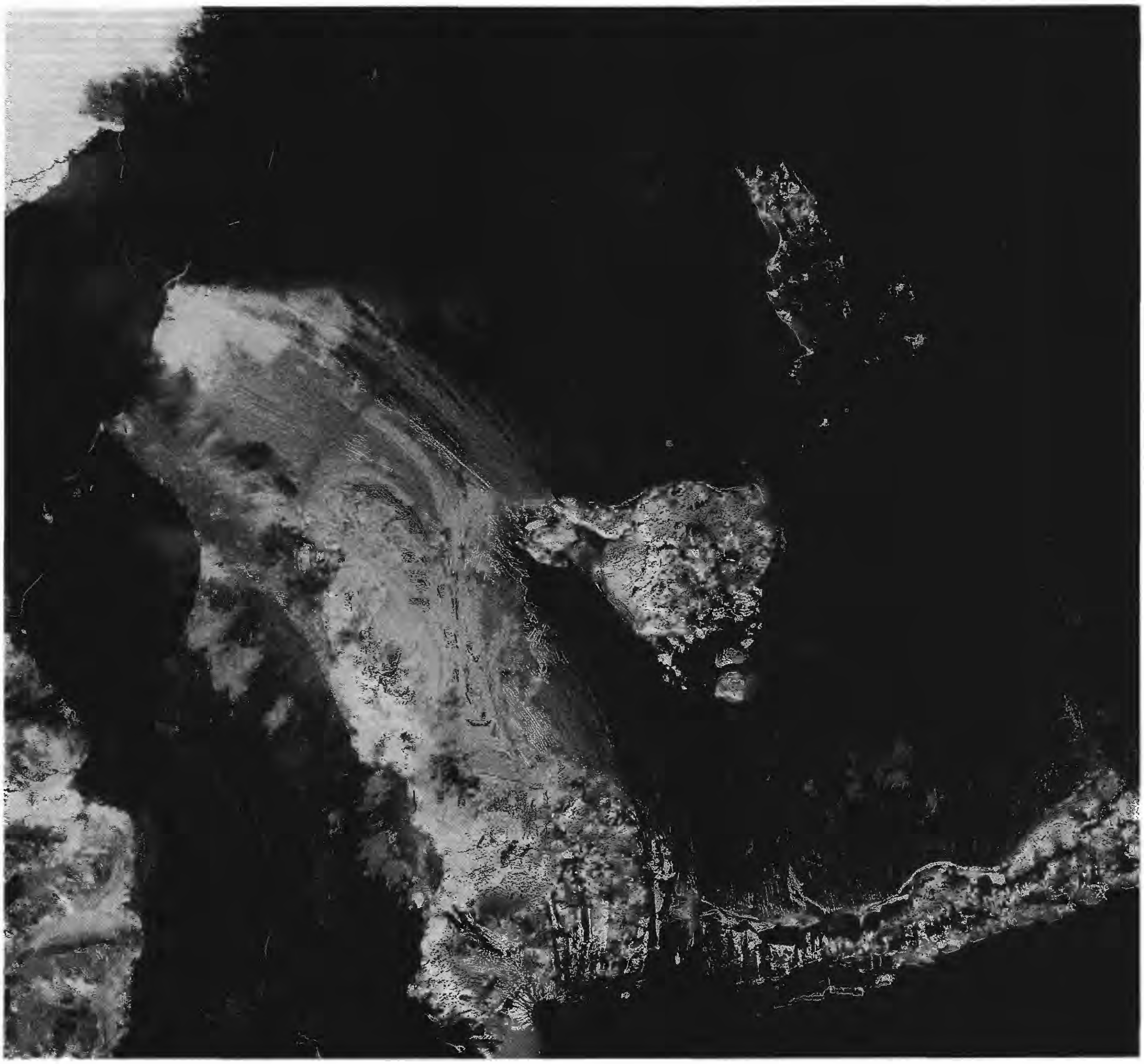

Figure 12.--Landsat TM band 2 image quadrant of an area east of the Dry Valley area in Antarctica. There is information in mountain shadowed areas, and some cloud shadows can be seen. There is difficulty in identifying clouds from snow-covered areas. Shown here at approximately 1:500,000-scale.

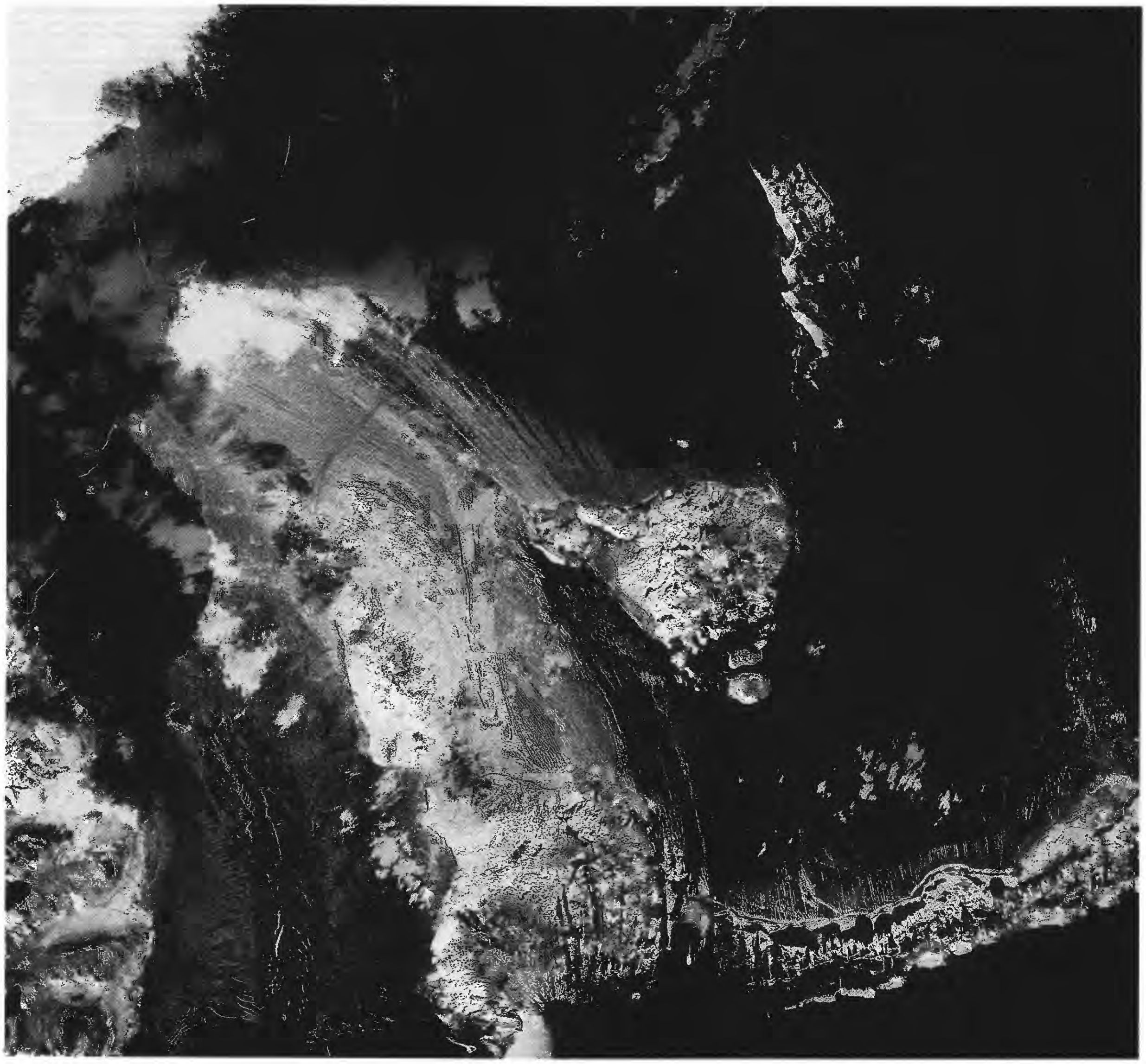

Figure 13.—Landsat TM band 4 image of same area as figure 12, showing slightly more detail but not significantly better for cloud and snow separation. Shown here at approximately 1:500,000-scale.

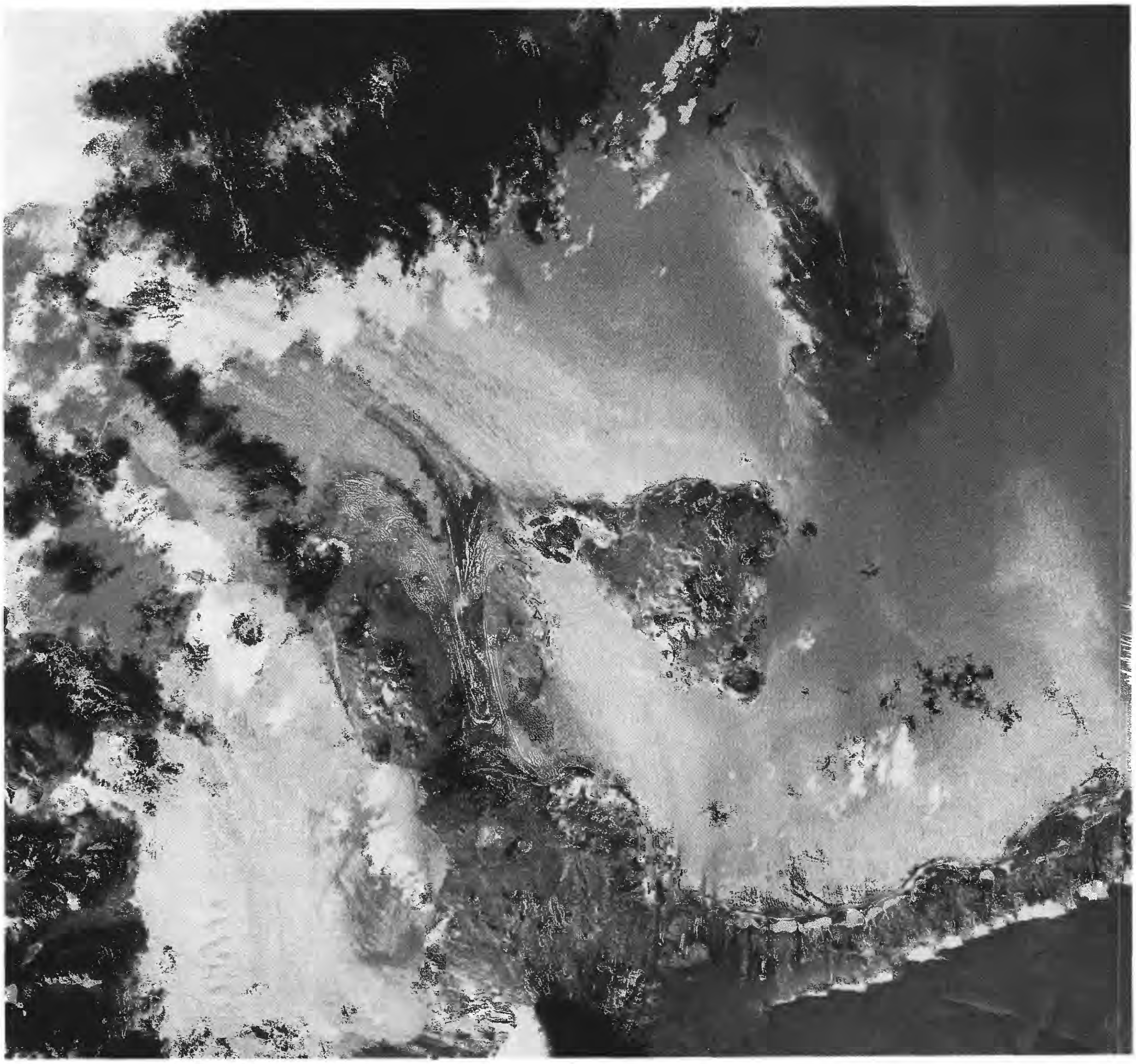

Figure 14.--Landsat TM band 5 image of area shown in figures 12 and 13. Note the excellent separation of clouds from snow in top left and bottom center of image. Shown here at approximately 1:500,000-scale.

DIGITAL MERGING OF LANDSAT TM AND DIGITIZED NHAP DATA FOR 1:24,000-SCALE IMAGE MAPPING

In recent years, users of remotely sensed data have been exposed to a "data explosion." This is particularly true for data that are recorded in, or can be converted into, digital format for computer processing and analysis. Examples of digital data that are available include Landsat MSS and TM images; Seasat and Shuttle Imaging Radar (SIR-A and -B) images; AVHRR and other low-resolution images; and SPOT images.

Integrating or merging data sets collected by different remote sensors to fully utilize complementary information is becoming an important component of digital image processing. By digitally merging different data types, the user can take advantage of the unique characteristics of each particular data set.

A project was initiated to extract the spectral information from Landsat TM data and combine it with the spatial information from a data set having much higher spatial resolution. The project was also designed to ascertain the maximum scale at which such results could be printed for image mapping purposes. The Landsat TM data were selected for their spectral content. TM bands 5 and 7 provide unique data not available in either the Landsat MSS or SPOT simulator data. The data set used for spatial information was a digitized panchromatic aerial photograph acquired as part of the Survey's National High-Altitude Photography (NHAP) Program.

The area covered by the two data sets is approximately 30 kilometers west of Washington, D.C.; Dulles International Airport is shown near the center of the images (figs. 15a-15c). About 8 kilometers to the east of Dulles is Reston, Va., where the Survey has its national headquarters (figs. 16a-16c). The area is mostly rural and highly vegetated, with isolated pockets of small urban communities. There is some agricultural land (cropland and pasture), and the forest type is mixed deciduous.

The TM data were collected by Landsat 4 on November 2, 1982. The data were resampled to a pixel size of approximately 28.5 meters, and there are seven spectral bands. In this study, the thermal infrared data, which have 120-meter spatial resolution, were not used. The panchromatic NHAP photograph was acquired in April 1980 at a scale of 1:80,000. The panchromatic image was recorded using a 153.8-millimeter nominal (6-inch) focal-length camera with Kodak 2405 film from an altitude of approximately 12.3 kilometers, and was digitized using an Optronics C100 scanner. A spot size of 50 micrometers was used to digitize the NHAP photograph, which generated a pixel size of approximately 4 meters on the ground. Figures 15a, 16a and 15b, 16b show the TM data and the digitized NHAP image.

The actual combination of data from different sensors, or sources, involves two distinct steps. The first step deals with the geometric registration of the data. The second step involves the merging of the data for digital or visual analysis.

Several methods can be used to geometrically register different data sets. The method used in this project differs slightly from most others in the way the two sets of data, with the extreme difference in spatial resolution (28 meters versus 4

Figure 15a.—Landsat TM false-color composite of bands 2, 3, and 4 of the Dulles International Airport, Va., area after digital enlargement and smoothing. Shown here at approximately 1:66,000-scale.

Figure 15b.—Digitized NHAP photograph of Dulles area. Shown here at approximately 1:66,000-scale.

Figure 15c.--False-color composite of Dulles area with the NHAP photograph added pixel by pixel, to TM data of bands 2, 3, and 4. Shown here at approximately 1:66,000-scale.

meters), are processed. It involves formatting the two data sets to approximately the same pixel size[1] before registration is performed. This was accomplished by digitally expanding the TM image data and creating pixels of 4-meter size.

The Landsat TM data set was digitally expanded in both the x and y directions by a factor of seven using pixel duplication. Because digital enlargement by pixel duplication produces a blocky image, the results are smoothed using a low-pass filter having dimensions equal to the digital enlargement. This eliminates blocky patterns and allows images of different spatial resolutions to be digitally merged in a minimum amount of computer time. Figures 15a and 16a show the results when applied to the TM data.

Once the data sets have been registered, the second step involves the actual merging or combining of the data for digital or visual analysis. The method used can influence the type of information seen in the resultant product. For example, some digital combination techniques will enhance the high frequencies or the fine detail within the image, while others will enhance the brightness/color of various cover types. Methods that can be used to combine the information from two registered data sets include adding, subtracting, or ratioing, pixel by pixel, the two data sets.

[1]The term "pixel size" is used rather than "pixel resolution" because it is not being implied that the digitally expanded TM data have 4-meter resolution.

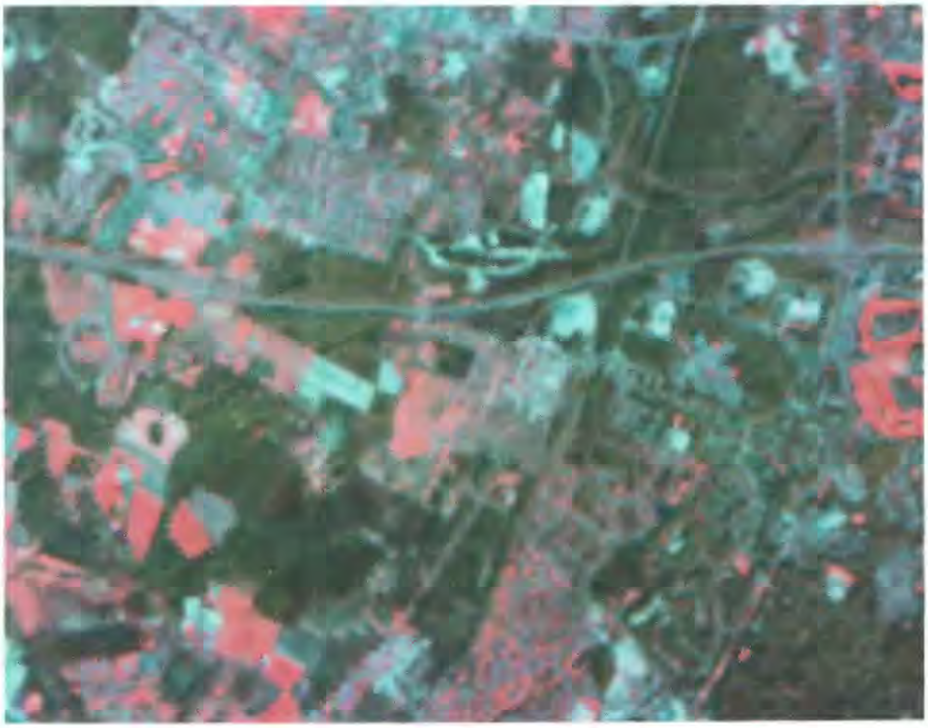

Figure 16a.--Landsat TM false-color composite (bands 2, 3, 4) of Reston, Va., (approximately 8 kilometers east of Dulles International Airport area). Shown here at approximately 1:66,000-scale.

Figure 16b.--Digitized NHAP photographs of Reston, Va., area. Shown here at approximately 1:66,000-scale.

Figure 16c.--Landsat TM bands 2, 3, 4 of Reston, Va., area with NHAP photograph added, pixel by pixel. Shown here at approximately 1:66,000-scale.

The results generated from the geometrically registered and digitally combined TM and NHAP data are shown in figures 15c and 16c. A color-composite image of TM bands 2, 3, and 4 after digital enlargement and smoothing is shown. Figures 15c and 16c show the results of combining the TM data with the NHAP data by adding the two data sets on a pixel-by-pixel basis. The ground area is shown in these two figures at an approximate scale of 1:33,000. The results in Figures 15c and 16c should be compared with the individual TM and NHAP images shown in figures 15a, 15b, 16a, and 16b. Notice that the color or spectral information from the TM data is present, as is the spatial information from the NHAP photograph. By comparing these products, it is evident that the primary objective of the project--the merging of two different data sets to obtain the best of both the spectral and spatial information--was accomplished. Once the data sets have been geometrically registered to each other, different types of composite images can be generated either by using a different method to merge them digitally (for example, subtracting) or by merging the NHAP data with different TM band combinations, such as TM bands 3, 4, and 5.

AN IMPROVED DARK-OBJECT SUBTRACTION TECHNIQUE FOR ATMOSPHERIC SCATTERING CORRECTION OF MULTISPECTRAL DATA

Digital analysis of remotely sensed data has become an important component of many earth-science studies. These data are often processed through a set of preprocessing or cleanup routines that includes a correction for atmospheric scattering, often called haze. The atmosphere influences the amount of electromagnetic energy that is sensed by the detectors of an imaging system, and these effects are wavelength dependent. The atmosphere affects images by scattering, absorbing, and refracting light. The most dominant of these effects is usually light scattering. Various methods to correct or remove the additive haze component have been developed, including the widely used dark-object subtraction technique. A problem with most of these methods is that the haze values for each spectral band are selected independent of the others. This independent selection can create problems because atmospheric scattering is highly wavelength-dependent in the visible part of the electromagnetic spectrum and these values are correlated with each other. Therefore, multispectral data such as from the Landsat TM and MSS must be corrected with haze values that are dependent on their particular spectral wavelengths.

The effects of atmospheric scattering on remotely sensed multispectral digital image data have been extensively studied and documented during the past 15 years. Ideally, a method that uses ground-truth information is the most accurate in terms of correcting for atmospheric haze effects. However, most users must work with remotely sensed data that have already been collected. It is under this condition that the simple dark-object subtraction technique can be used because it requires only information contained in the digital image data. This type of correction involves subtracting a constant digital number (DN) value from the entire digital image (a DN value is the value of reflectance recorded for each pixel in the digital image). This assumes a constant haze value throughout the entire image, which often is not the case. However, it does accomplish a first-order correction which is better than no correction at all. A different constant is used for each spectral band, and a different set of constants is used from image to image.

A modified dark-object subtraction technique has been developed that allows the user to select a relative atmospheric scattering model to predict the haze values for all the spectral bands from a selected starting band haze value. This technique normalizes the predicted haze values for the different gain and offset parameters used by the imaging system. This modification is an improvement to existing dark-object subtraction techniques that derive the correction DN values solely from the digital data with no outside information. Examples of haze value differences between the old and improved methods for TM bands 1, 2, 3, 4, 5, and 7 are 40.0, 13.0, 12.0, 8.0, 5.0, and 2.0 versus 40.0, 13.2, 8.9, 4.9, 16.7, and 3.3, respectively, using a relative scattering model of a clear atmosphere. In one Landsat MSS image the haze value differences for bands 4, 5, 6, and 7 were 30.0, 50.0, 50.0, and 40.0 for the old method versus 30.0, 34.4, 43.6, and 6.4 for the new method using a relative scattering model of a hazy atmosphere.

If digital multispectral image data are haze corrected using the standard dark-object subtraction technique, problems may be encountered in the analysis stage because the DN values selected for haze removal may not conform to a realistic relative atmospheric scattering model. This lack of conformity may cause the data to be overcorrected in some or all of the spectral bands, and the spectral relationship between the bands will not be correct.

In the improved method, the user selects a starting band dark-object subtraction haze value using the histogram of one of the spectral bands. The user then selects a relative scattering model that best represents the atmospheric conditions at the time of data collection. The amplitude of the starting haze value can be used as a guide to identify the type of atmospheric conditions that existed during data collection (that is, very clear, clear, moderate, hazy, or very hazy). The selected relative scattering model is then used to predict the haze values for the other spectral bands from the starting haze value.

The critical aspect of this method is that haze-correction DN values used in dark-object subtraction techniques must be computed using a relative scattering model to ensure that the haze values do represent, or better approximate, true atmospheric scattering possibilities. Using published information and extrapolating to very clear and very hazy atmospheres, one possible set of relative scattering models are:

Atmospheric conditions	Relative scattering model
Very clear	λ^{-4}
Clear	λ^{-2}
Moderate	λ^{-1}
Hazy	$\lambda^{-0.7}$
Very hazy	$\lambda^{-0.5}$

Using the relative scattering model of λ^{-4} for a very clear atmosphere, TM band 1 accounts for slightly over 50 percent of the total scattering and TM band 5 for only 0.4 percent (sum of six nonthermal TM bands). This model shows that the great majority of atmospheric scattering, which is an additive component, occurs in the visible part of the spectrum for a very clear atmosphere.

The relative scattering models presented here have generated good visual results. The computed haze values have been used to create TM calibrated natural-color composites using TM bands 1, 2, and 3; some results are shown in figure 17.

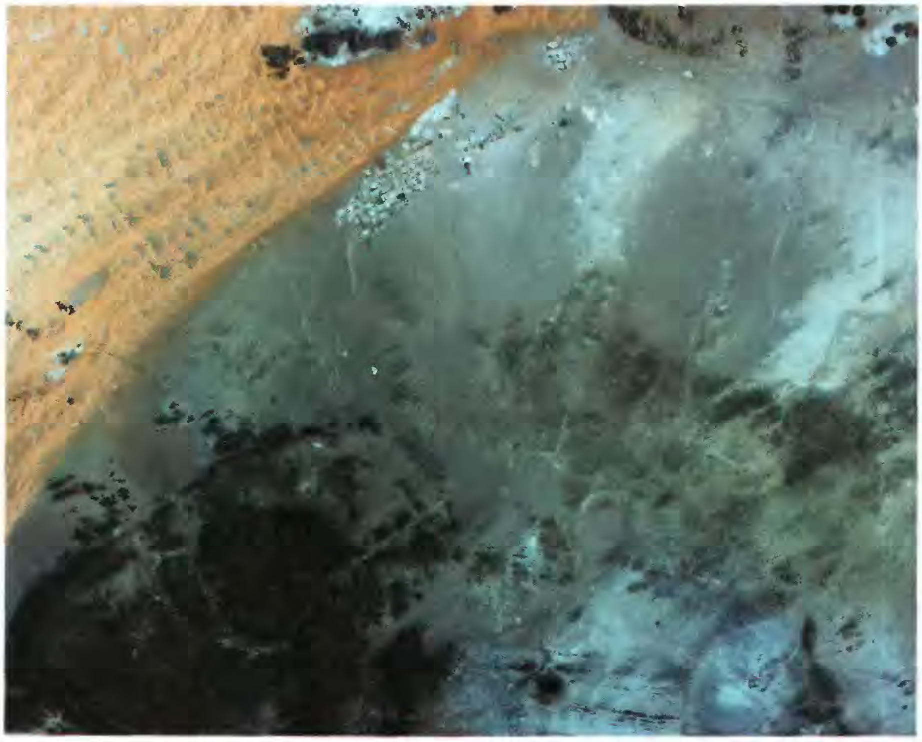

Figure 17a.--Landsat TM image (bands 1, 2, 3) of Hā'il, Saudi Arabia, produced with standard linear stretch. Shown here at approximately 1:600,000-scale.

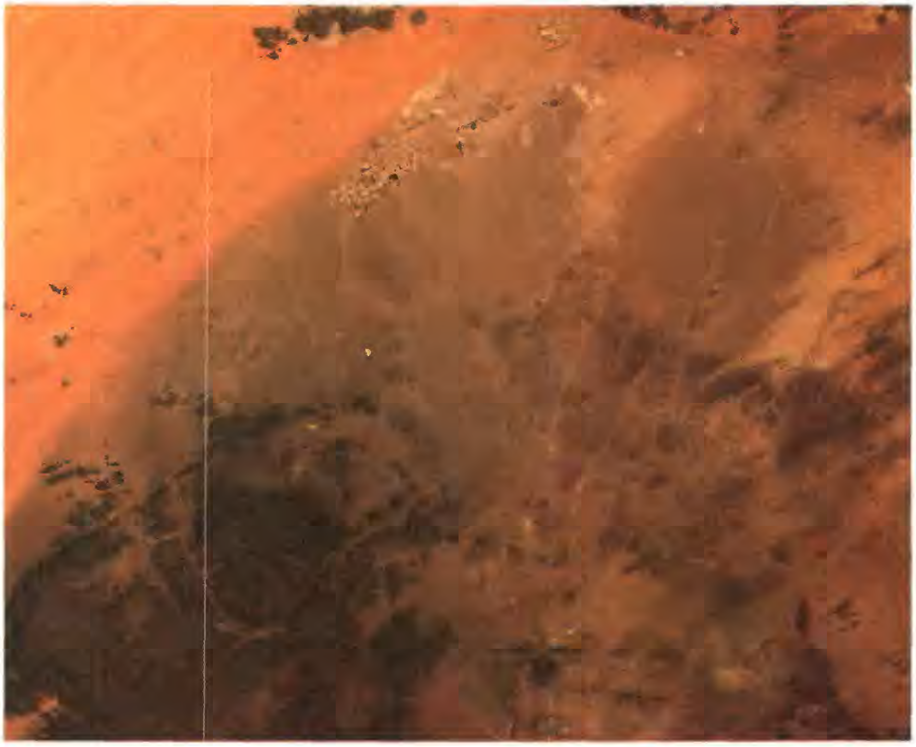

Figure 17b.--Landsat TM image (bands 1, 2, 3) of Hā'il, Saudi Arabia, with calibrated natural color using new haze correction techniques. Shown here at approximately 1:600,000-scale.

Figure 17 is a composite made from TM bands 1, 2, and 3 with standard linear stretches (1a) and after the data have been haze corrected and calibrated (17b). Field investigations have confirmed the visual results seen on the final products. Table 1 shows the corresponding haze values to be used for Landsat 4 TM bands 1, 2, 3, and 4 data using TM band 1 as the starting haze value. The table was generated using the five relative scattering models shown above, and a similar table can be generated using other models and for other Landsat or non-Landsat multispectral imaging systems. Table 1 is set up to use the appropriate relative scattering model based on the amplitude of the starting haze value of TM band 1 (that is, use the veryclear relative scattering model for small starting haze values up to the very hazy relative scattering model for very large starting haze values). A table could be generated where the power used in the relative scattering model is continually variable rather than just five discrete values, as in this particular case. This variable power would allow the relative scattering function to change continuously and eliminate abrupt boundary changes.

This type of correction or calibration is important if remotely sensed data are to be exploited to their maximum potential. Studies dealing with analyses of the spectral response of cover types, temporal studies, and signature extension (temporally and spatially) must include the capability to correct or remove variable factors, such as atmospheric scattering, that have nothing to do with the information of interest. Research is underway to establish a better relationship between the starting haze value and the type of atmospheric conditions present during data collection.

Table 1.--Predicted haze values for TM bands 2, 3, and 4 using relative atmospheric scattering model

	TM1*	TM2	TM3	TM4
	30.0	11.1	7.4	4.3
	35.0	12.5	8.4	4.7
Very Clear	40.0	13.9	9.4	5.1
(≤55)	45.0	15.4	10.4	5.5
	50.0	16.8	11.4	5.9
	55.0	18.2	12.3	6.4
Clear	60.0	25.4	23.3	16.1
(56-75)	65.0	27.3	25.1	17.2
	70.0	29.2	26.9	18.4
	75.0	31.1	28.7	19.6
Moderate	80.0	37.8	41.0	34.1
(76-95)	85.0	40.0	43.4	36.2
	90.0	42.2	45.9	38.2
	95.0	44.4	48.4	40.2
Hazy	100.0	48.6	55.6	49.3
(96-115)	105.0	50.9	58.4	51.7
	110.0	53.2	61.1	54.1
	115.0	55.5	63.8	56.4
Very hazy	120.0	59.4	70.5	65.3
(>115)	125.0	61.7	73.4	67.9
	130.0	64.1	76.2	70.5
	135.0	66.5	79.1	73.2

*TM band 1 was used as the starting haze value band. Notice the jump that occurs between the functions used. This could be eliminated by using a continually variable power model rather than just five discrete values. The amplitude of the starting haze value is used to determine the type of atmospheric conditions that existed during data collection. The relationship used in this table was derived from analysis of over 25 TM scenes.

RESTORATION TECHNIQUES FOR SIR-B DIGITAL RADAR IMAGES

Digital, synthetic-aperture radar images were acquired over Saudi Arabia as part of the second Space Shuttle Imaging Radar (SIR-B) mission in October 1984. These images contain both radiometric- and speckle-noise patterns that bear no relationship to the microwave reflectance properties of terrain features. Radiometric noise, a low spatial-frequency pattern, manifests itself as a scene brightening at near- and far-range image areas and as a scene darkening at mid-range image areas. Its across-track or range profile resembles a one-cycle sinusoidal curve. This noise pattern was introduced by a correction applied to the raw data at the Jet Propulsion Laboratory to compensate for the range antenna signal pattern modulation. Speckle, a high spatial-frequency noise pattern, occurs in random fashion and is caused by the interference of dephased but coherent microwave energy. It is observed as a granular appearance on an image with spatial dimensions of up to several pixels (picture elements) and is an inherent characteristic of all synthetic-aperture radar systems.

For SIR-B applications research, it is desirable to suppress both of the noise components for three important reasons:

1. Digital enhancements, such as contrast stretching, can accentuate the noise at the expense of terrain detail.

2. The noise may contribute to false signatures when digitally merged with other image data sets.

3. Radiometric noise hinders backscatter comparisons for similar terrain targets that are located in different across-track positions.

SIR-B radiometric noise is responsible for producing DN's (digital numbers or bright- ness values) with two components, or DN's that incorporate some combination of valid and invalid data. The goal in the first phase of this research project was to remove or suppress the invalid component. In the spatial domain, the noise pattern extends in nonlinear fashion from near to far range, with its magnitude varying as a function of across-track position. Its visual impact is most pronounced at near- and far-range image areas where there is a dramatic increase in overall scene brightening.

The algorithm to suppress the radiometric-noise component has a similar design to the algorithms that were developed to correct shading problems associated with airborne radar and sonar digital images. The method relies solely on the digital image data to compute multiplicative correction coefficients. To determine SIR-B correction coefficients, an entire across-track subscene image was digitally isolated as a separate file. The subscene was a good approximation of a flat-field background because it was dominated by radiometric and speckle noise and essentially void of terrain backscatter responses. The subscene measured 2,600 pixels along track by 7,000 pixels across track; the latter dimension covered the entire range swath of the original image.

Three mathematical procedures were then applied to the subscene digital data to compute the correction coefficients:

1. A low-frequency digital image, containing only the radiometric-noise component, was generated by spatially filtering the original subscene DN's with a mean-value, smoothing filter measuring 125 by 125 pixels. This function essentially removed the high-frequency speckle-noise component and any other nonradiometric DN variations that might have existed in the image data. A DN profile plot in the across-track direction for the low-frequency digital image clearly shows the characteristics of the range-related, radiometric-noise component.

2. A mean-valued digital image was generated by stretching or mapping all DN's of the low-frequency digital image to its average value.

3. Multiplicative correction coefficients, which vary as a function of range position, were then produced by dividing the low-frequency digital image into the mean-valued digital image.

Because the low-frequency radiometric-noise pattern changes so gradually, correction coefficients for only nine equally spaced across-track points were used with linear interpolation applied between coefficient pairs. The nine correction coefficients had the following values:

FAR RANGE				MID RANGE				NEAR RANGE
0.85	0.91	0.98	1.03	1.06	1.05	1.03	0.99	0.93

Their values indicate that there is a substantial across-track, radiometric-noise component. Note that the coefficients vary up to 13 percent from mid range to near range and 21 percent from mid to far range. Once applied to an original digital image, the magnitude and range location of the multiplicative coefficients reveal the following: (1) DN diminutions would take place in far- and near-range areas, with a greater reduction in the far-range zone, and (2) DN levels would be increased in the mid-range zone.

The second phase of this research project was to evaluate the performance of five different spatial filters for their ability to suppress the randomly occurring, speckle- noise component that still resided in the radiometrically corrected SIR-B images. For visual and statistical assessments, the following filter operations were imple- mented on a 3,500- by 4,800-pixel subscene: (1) median filter, 3- by 3-pixel kernel size; (2) mode filter, 3- by 3-pixel kernel size; (3) mean filter, 2- by 2-pixel kernel size; (4) mean filter, 3- by 3-pixel kernel size; and (5) mean filter, 3- by 3-pixel kernel size on threshold DN limits established from a 5- by 5-pixel, high-pass filter operation (selective mean filter).

Visual comparisons between the original and five filtered images of the subscene indicate that each filter operation appeared to diminish the visual impact of speckle noise. However, examination of local image areas under magnification indicated that the most favorable results were obtained with the 3- by 3-pixel median and 2- by 2-pixel mean filters. These two filtering operations suppressed speckle noise and affected the original resolution integrity by the smallest amount. Examination of various statistical measures of each image shows that the 3- by 3-pixel median and 2- by 2-pixel mean filters affected the digital data in the same manner and almost by the same amount.

UNDERWATER MAPPING USING GLORIA SONAR DATA AND MIPS PROCESSING TECHNIQUES

The mapping of large areas of the ocean floor, even at relatively small scales such as 1:500,000, has been prohibitively expensive and technically impractical until recently. Advances in image processing of Geological Long-Range Inclined ASDIC (GLORIA) sidescan sonar image data collected over selected areas of the U.S. Exclusive Economic Zone have made it possible to map large areas of the ocean floor. The GLORIA system, designed and built by the Institute of Oceanographic Sciences (IOS) in England, is an active sonar system that uses acoustical waves to produce images called sonographs. The sonographs are a measure of the reflectance properties of the sea floor's geomorphic features. The GLORIA system currently has the capability to record acoustical digital data with a 20–, 30–, or 40–second pulse–repetition rate, which produces a swath width on both port and starboard of approximately 15, 22, and 30 kilometers, respectively, for water depths approaching 4,000 meters.

The Geological Survey and IOS have conducted several joint sonar image collection surveys in the water bodies bordering the United States. The first joint survey took place in 1979 along a portion of the eastern coastline of the United States. The acoustical data were recorded only in analog form. The second joint survey occurred in early 1982 for a small area in the Gulf of Mexico, where, for the first time, the data were collected in digital form. Many of the Survey's computer processing techniques to handle digital sonographs were developed during this stage of the project. However, it was not until the third survey in 1984 that the software was improved and expanded to create an operational sonar image processing system. The third survey collected data in digital form along the western United States coastline from Mexico to Canada and to approximately 320 kilometers offshore.

The computer software developed for GLORIA processing is part of the Geological Survey's Mini Image Processing System (MIPS) and forms the framework for an operational sonar processing system within the Survey. Software has been developed to correct for both geometric and radiometric distortions that exist in the original "raw" sonar data. Preprocessing algorithms that are GLORIA–specific include corrections for slant–range geometry, water column offset, aspect ratio distortion, changes in the ship's velocity, speckle–noise, and shading problems caused by the power drop–off which occurs as a function of range. The cleaned–up data base generated by the preprocessing stage can be used as input into several information extraction and analysis routines. Spatial filters and first difference techniques are used to enhance linear–type features. Pseudo sea–floor elevation data, generated entirely from the sonar image data, are used to create stereopairs and new perspective views using a portion of a sonar image. Smoothing filters combined with color–coding techniques are used to identify areas with similar backscatter characteristics.

Until recently, the digitally processed strips of GLORIA images in track–line format have been photographically mosaicked in 2° x 2° quadrangles. While useful for visual analysis, mosaicked sonar data in analog form cannot be merged and processed with related digital data sets for further analysis or information extraction. To overcome this problem, MIPS software was developed to geometrically correct and digitally mosaic the individual track–line image strips to produce the 2° x 2° quadrangles.

The procedures for digital mosaicking of GLORIA sonar image data are more difficult than those required for other types of remotely sensed data, such as Landsat data, because geometric control is available only at nadir locations. Currently, no information exists about the pointing characteristics of the imaging system; that is, pitch, roll, and yaw. As with other data sets, the geometric corrections for digital mosaicking involve the following major steps: (1) the identification of control points and the generation of the transformation file using these control points; and (2) the actual resampling of the image file using the transformation. Because control points are available only at nadir locations, the first step becomes much more involved. The second step is straightforward and very similar, or identical, to that used on other remotely sensed data. Also, because of the radiometric quality of the sonar image data, especially at far–range locations, additional work is required to get an acceptable tone match between the various track lines. An interactive digital stenciling or feathering capability was developed to optimize this stage of the process. Figure 18 shows the results of a 2° x 2° mosaic covering an area due west of Washington State.

One of the major advantages of digital mosaicking over film mosaicking is that it allows the data, in quadrangle format, to be merged digitally with other image and nonimage data sets for analysis. In this project, the magnetic and bathymetric data, which were collected every 2 minutes at nadir locations during the GLORIA cruise, were merged with the sonar image data. The magnetic and bathymetric data first had to be converted from vector to raster format with the same pixel size and geometric projection as the sonar image data (figs. 19a and 19b). A spatial filtering technique was used to interpolate a surface through these data points. Special attention was given to the density and distribution of the data points (high density in the along-track direction and low density in the across-track direction). The resultant image products were then used individually and with the sonar image data for digital and visual analysis (figs. 20a and 20b).

The Survey's first sonar image atlas, Atlas of the Exclusive Economic Zone, Western Conterminous United States, published in 1986, was produced using photographically mosaicked GLORIA data. A second atlas containing sonar images of the Gulf of Mexico and eastern Caribbean, planned for publication in 1987, will be produced from digitally mosaicked GLORIA data. In digital form, these data can also be merged with magnetic, gravimetric, and bathymetric digital data for computer analysis to further enhance marine geologic interpretation. The various products being generated show, often for the first time, detailed information that will be used to map the ocean floor. These maps, in turn, will provide a large overview picture of the ocean floor, similar to regional views of land areas provided by Landsat MSS images, and will help to identify areas of interest for further detailed studies for exploration and (or) potential hazard areas.

STANDARDIZATION OF THE MINI IMAGE PROCESSING SYSTEM

The U.S. Geological Survey's MIPS (Mini Image Processing System) was designed and developed as an office minicomputer digital image processing system and as a potential field environment system. MIPS generically is an outgrowth of the Flagstaff Image Processing System developed by the Survey in the late 1970's, but with major additions made to make the system more user friendly. The main objective of the original design was to assemble an office system for research and development that would be relatively inexpensive, but powerful enough to be a standalone system. The software package was designed to allow optimization of the processing speed on DEC PDP-11 hardware with a minimum use of assembler code. MIPS has proven to be both an excellent office environment research system and a good operational production system for individual projects.

Standardizations, for both the user and programmer interface with the system, are critical elements in any software package. They make the software package more useful and easier to modify, expand, and transport. The user prompting, screen formatting, and error checking for all MIPS programs have been standardized with the common use of a group of FORTRAN subroutines. The programmer interface in MIPS has been standardized, in most cases, with the use of one subroutine and several utility routines. Also, a standard front-end program documentation is used

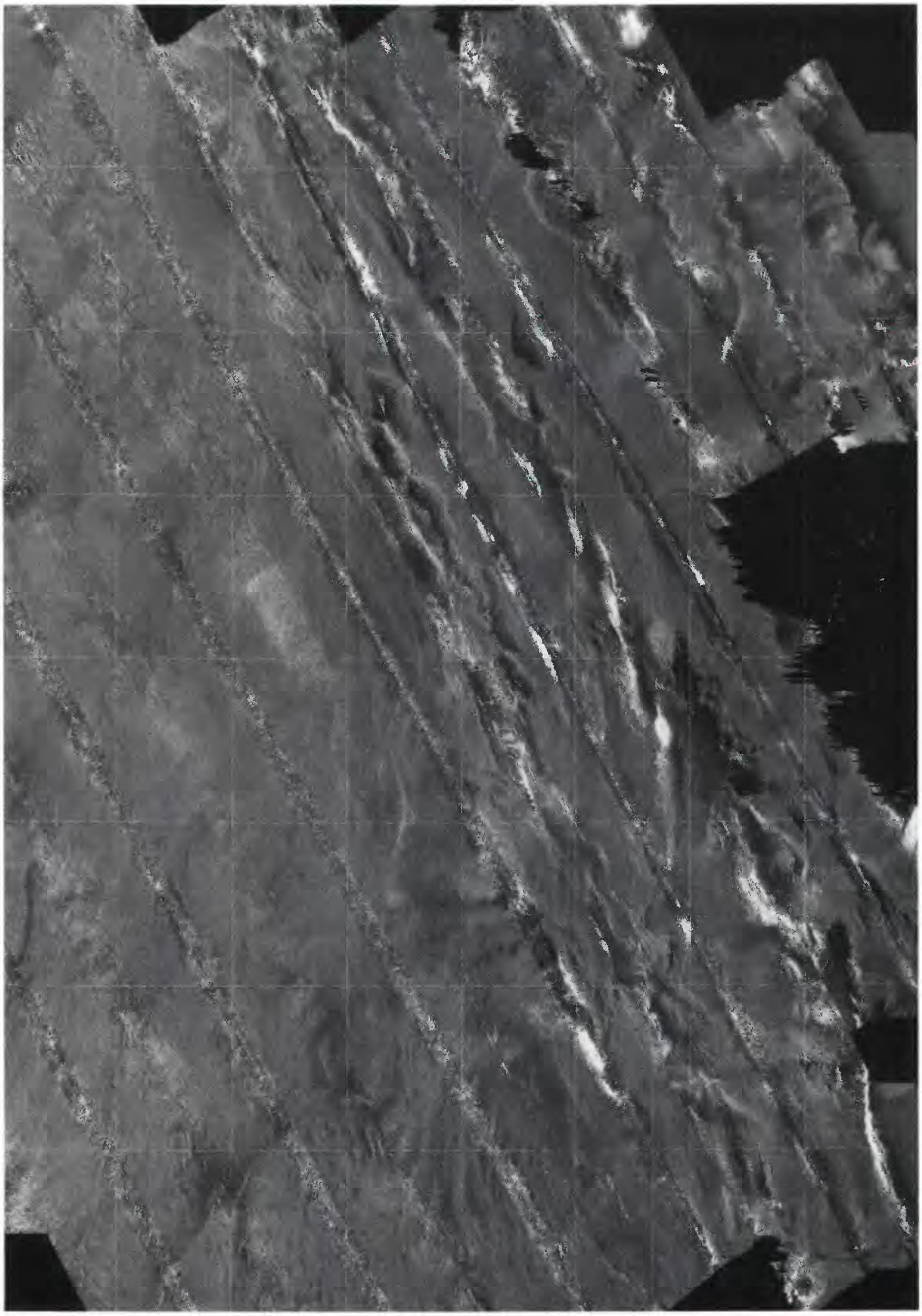

Figure 18.--GLORIA sonar image mosaic of a 2° x 2° area west of the State of Washington. Shown here at approximately 1,100,000-scale.

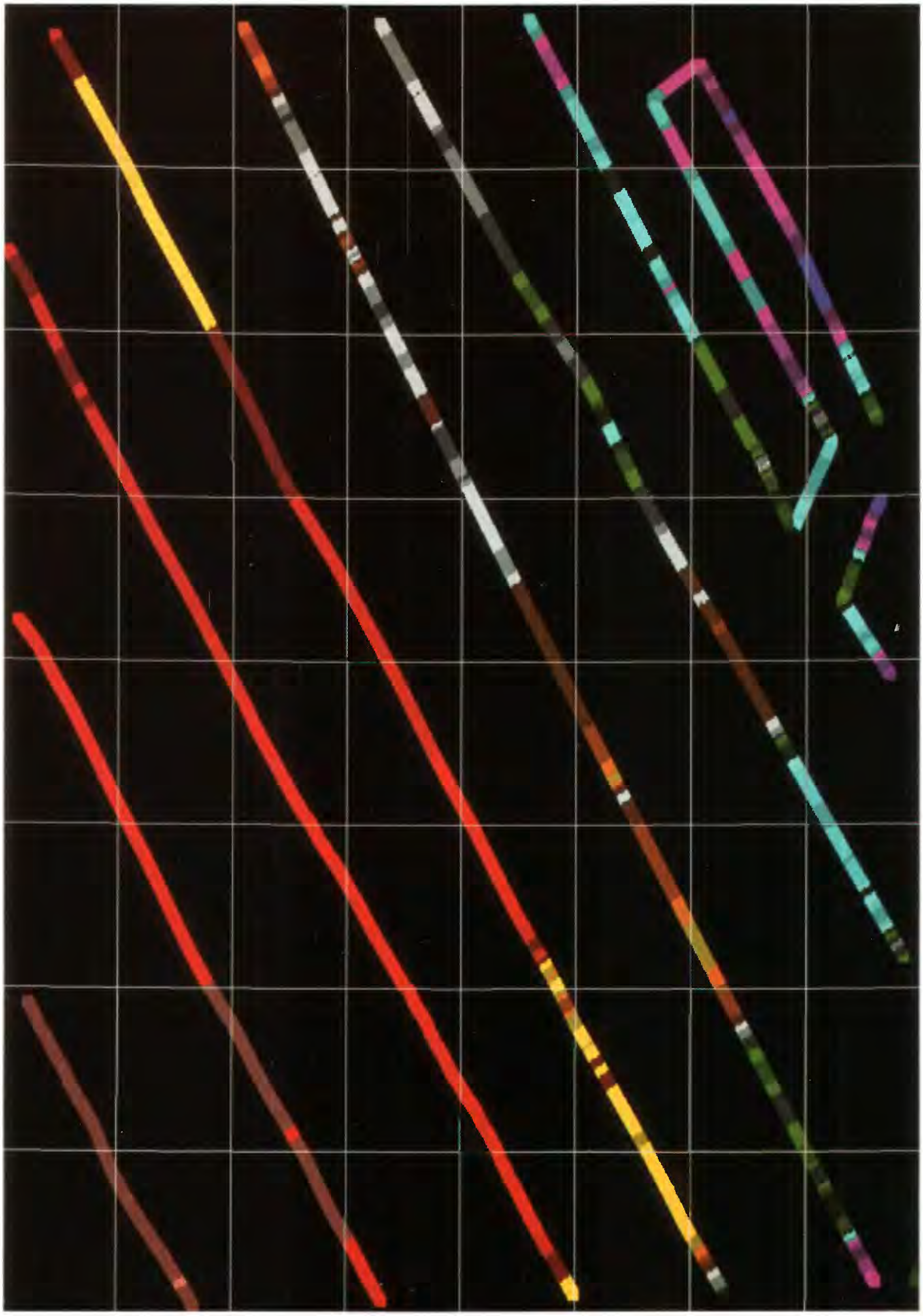

Figure 19a.—Bathymetric data from GLORIA cruise converted to raster format, starting at 400 meters in 100-meter contours.

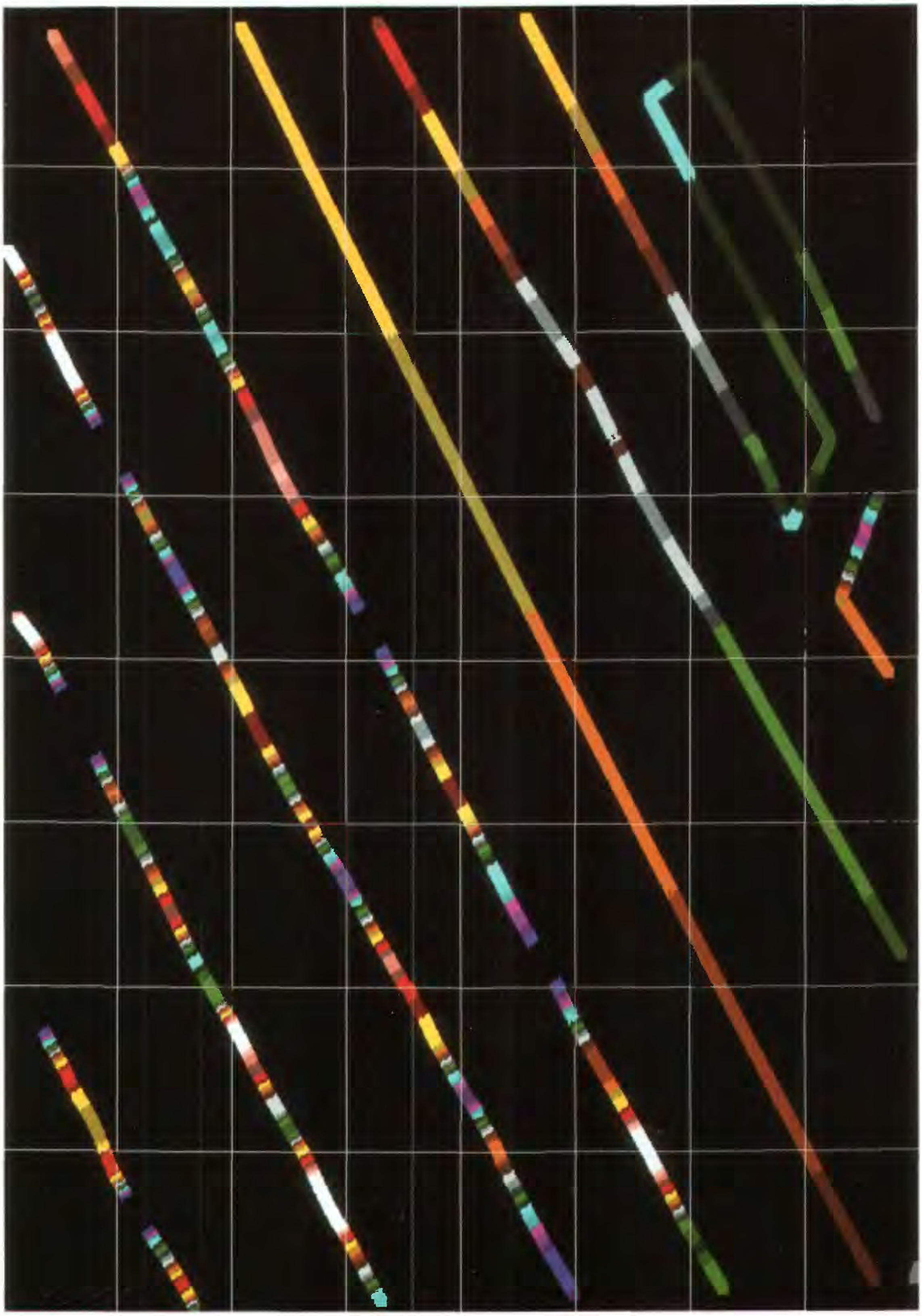

Figure 19b.--Magnetic data from GLORIA cruise converted to raster format, starting at -100 gammas in 15-gamma contours.

Figure 20a.--Bathymetric data from GLORIA cruise after applying spatial filtering techniques.

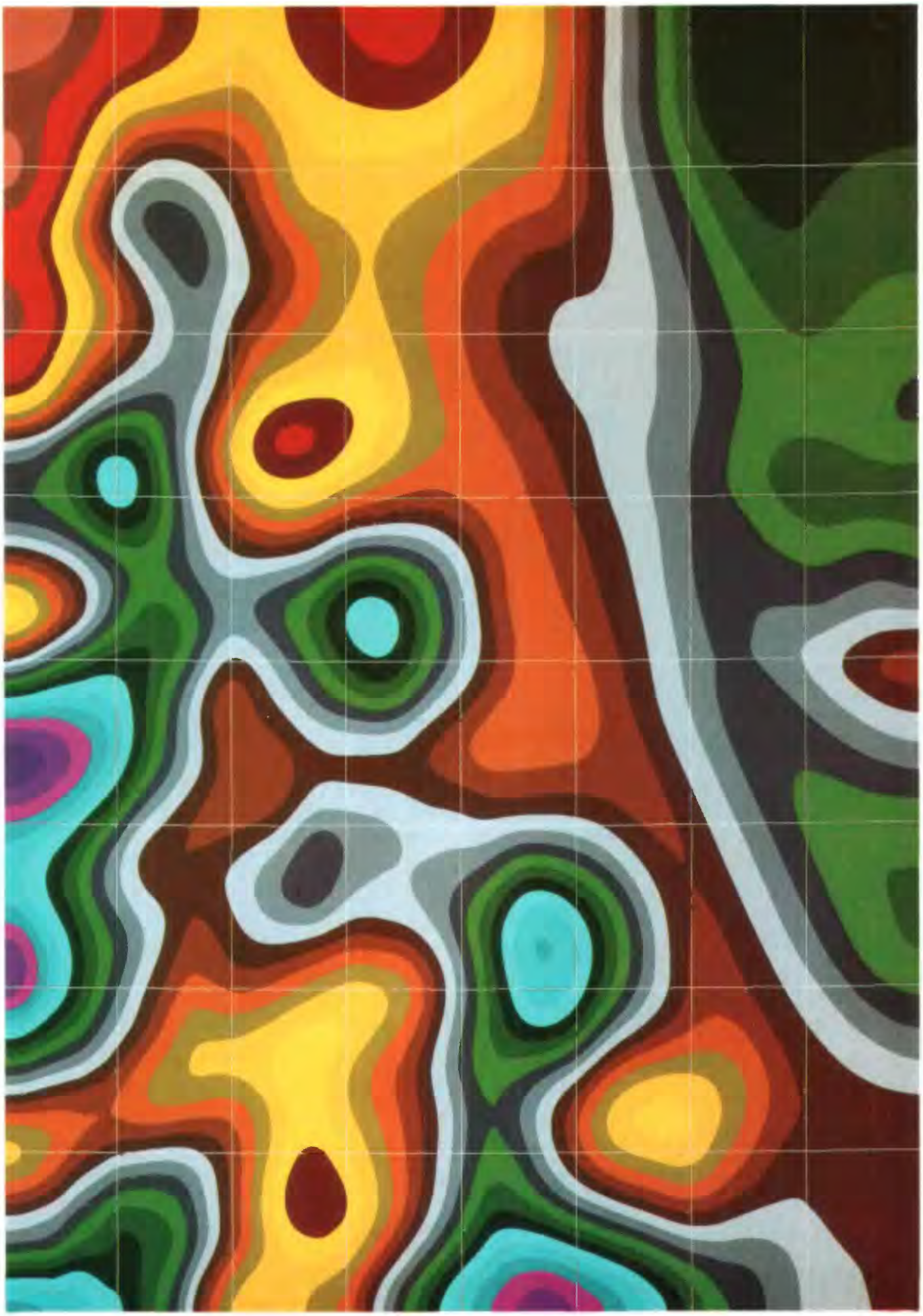

Figure 20b.—Magnetic data from GLORIA cruise after applying spatial filtering techniques.

on every routine no matter how minor a function it performs. New routines can easily be documented in the required format by using a fill-in-the-blank type of program.

The user-system interface in MIPS is handled by several subroutines used by all the programs to keep the prompting, screen formatting, and error messages consistent within the system. The prompting and screen formatting are handled by a FORTRAN subroutine that creates a standard format. This subroutine is called by the image processing formatter subroutine, which is generated as a separate task by the application program. This formatter task executes in its own memory partition, handles all of the user prompting, and is then removed from memory (that is, it exits and the application program continues). This design is different from other user-system interfaces, which have a resident executive in memory at all times controlling every application software request. MIPS loads user-prompting routines only when required, and the application program is the one that is always in control. This design allows MIPS prompting to execute on both 32- and 16-bit systems with low overhead in terms of memory and central processing unit time.

There are two major types of user prompts that are incorporated in MIPS programs. They correspond to requests for information from the user about (1) the image files that contain, or will contain, the image data, and (2) keywords identifying particular parameters needed by the application program being used. MIPS prompting has been standardized so that user prompting occurs in the upper two-thirds of the terminal screen.

The software package is programmer-friendly because of subroutines used to standardize the programmer-system interface. The programmer has available an extensive set of subroutines that are stored in one of three different libraries: utility data handling, image display, and terminal display. The routines in the utility data handling library manipulate or handle data that are in memory of the host computer, on disk, or on tape (for example, does table look-ups, moves data from buffer-to-buffer, or reads/writes data from/to disk). Routines that are in the image display library perform general utility functions for the image display system (for example, loads data from disk or the host computer into refresh memory, does table look-ups for the image display, or reads the cursor position on the CRT screen). The third library handles various functions on the user's terminal.

Many of the MIPS programs have been written using a concept in which all nonalgorithm-dependent operations, such as input/output and other bookkeeping-type requirements, are isolated from the application routines, making it easy to add new programs to the software package. This concept was developed by the Survey in Flagstaff in 1974 and has evolved into a powerful procedure. In addition, several subroutines have been written for use with all the programs to standardize the error checking within the entire software package. There are routines that check for image file and parameters response errors, as well as routines that check for possible image file errors. These are all available to the programmer for use on any new programs that are developed.

The MIPS software package was converted to the Micro VAX-II environment during the summer of 1986 to utilize the higher speed and increased addressing capabilities. The conversion was made so that the user and programmer interfaces are identical to those used on the PDP-11 hardware, thereby maintaining the standardization of MIPS.

IMAGE PROCESSING LAND ANALYSIS SYSTEM

In June 1984, a Memorandum of Understanding was signed between the Division and the NASA Goddard Space Flight Center (GSFC) for the development, implementation, and maintenance of the Land Analysis System (LAS). Initially released to users in the fall of 1985, LAS provides a broad range of functional capabilities in image processing and analysis, tabular data processing and analysis, geographic data input and manipulation, and custom product generation. LAS provides a comprehensive user-friendly interface and an array of executive services supporting over 250 applications programs in earth science data processing, analysis, display, and product generation.

The Division is continuing to enhance LAS through the development of new applications programs and system utilities, and is also pursuing the implementation of LAS on microprocessor-based workstations to increase its utility. Functional subsets of LAS are being implemented on MicroVAX II hardware under the VMS operating system, as well as SUN microprocessors under the UNIX operating system. The conversion of LAS to the UNIX domain is continuing in an effort to enhance its portability to other systems and thereby expand its capability for a larger number of potential applications.

AVHRR RECEPTION AND PROCESSING SYSTEM

The Survey, in cooperation with the National Oceanic and Atmospheric Administration (NOAA), is developing a reception and processing system at the EROS Data Center for NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data. The system will routinely provide, within 24 hours of overpass, limited quantities of geographically referenced AVHRR data over the conterminous United States to support Federal earth science research and land management programs. The AVHRR Data Acquisition and Processing System is planned to be operational in May 1987. When completed, the system will receive and process data acquired during three daytime passes per satellite and predawn passes on request. Data from all passes will be indexed and archived for 90 days after receipt, and then screened for quality and cloud cover. The data from passes with low cloud cover will be permanently stored in the land remote sensing archive on computer-compatible magnetic tapes. Researchers will be able to obtain digital data that have been geographically referenced to one of several map projections and, optionally, merged with line data obtained from other map sources. Digital data will be available initially on standard 1/2-inch magnetic tape and, subsequently, on magnetic diskettes. Additional processing may be requested to produce black-and-white or color prints of the digital data.

The Survey, in cooperation with the Bureau of Land Management (BLM), has found AVHRR data useful for mapping fire fuels in support of BLM's wildfire Initial Attack Management System. Also, the Bureau of Indian Affairs has found these data useful for monitoring rangeland conditions (fig. 21). After the system becomes operational, other Department of the Interior bureaus will have better access to AVHRR data to investigate the utility of these data for monitoring the growth of ephemeral vegetation, mapping snow cover, producing enhanced image maps, and conducting time-series analyses to support a wide variety of geologic, hydrologic, and land management applications.

SPATIAL VARIABILITY OF AVHRR DATA IN A HIERARCHICAL SOIL DATA BASE

The objective of this study was to use AVHRR data with a soil-derived data base to evaluate the spectral variability of land areas within a hierarchical framework of polygons defined by various soil characteristics. Soil taxonomic data plus ancillary information were used to construct the data base.

The spectral variability of land area within each polygon was measured by computing the standard deviation of a vegetation greenness index calculated from the AVHRR data. The standard deviation is important for implementing statistical tests to determine if the polygons have similar or different mean values. The mean values of the vegetation greenness index were then used to assess and model land surface variations.

Polygons as defined by soil associations have the least spectral variance of nearly all the data base factors tested. Even though the soil-association data base layer has the largest number of polygons and the least spectral variance, it has the advantage of consisting of groupings of several soil series that are taxonomic units with described characteristics. These descriptions include soil characterization data such

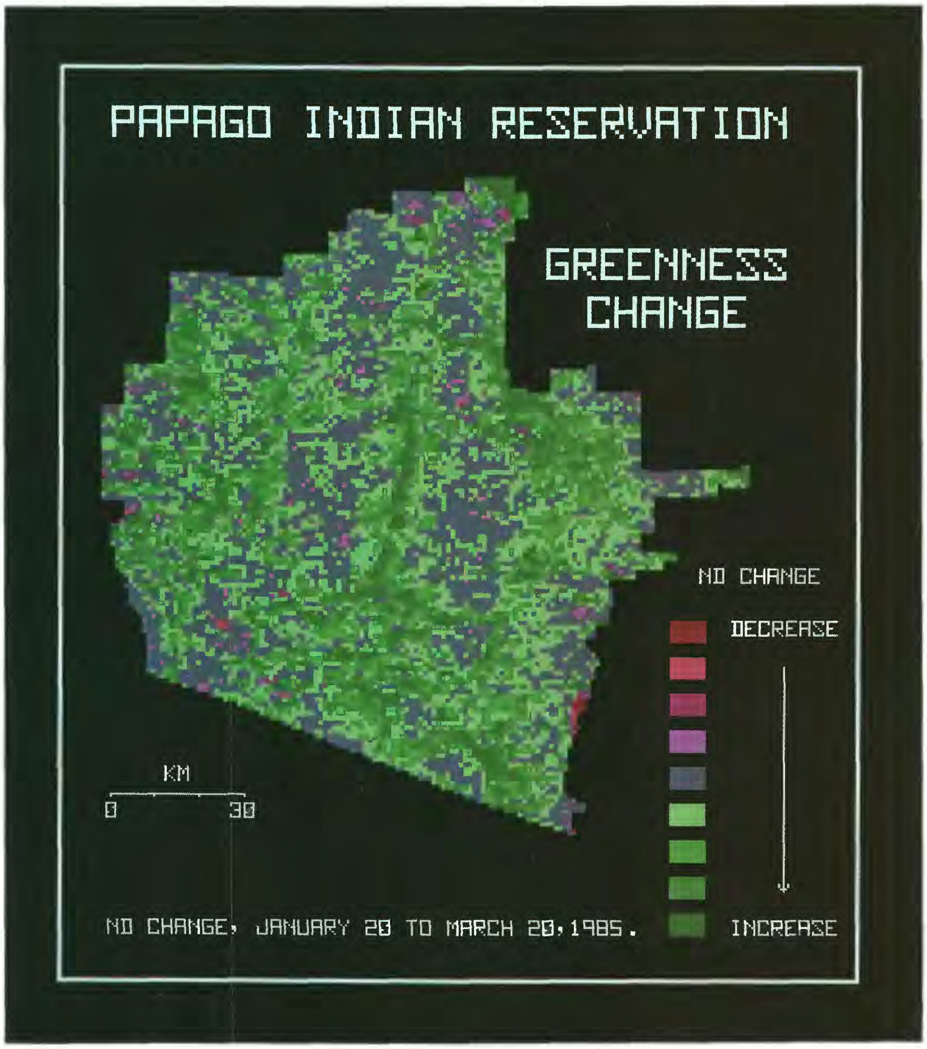

Figure 21.—The change in greenness from January 20 to March 20, 1985, as derived from AVHRR data for the Papago Indian Reservation in southern Arizona.

as texture, permeability, depth to bedrock, potential for flooding, and high water table. Descriptions also include range site and soil capability class and subclass. These characteristics affect land productivity. Thus, each soil association polygon can be characterized and classified more completely than most other data base layers for monitoring the current land production by satellite.

FIRE DANGER WARNINGS USING AVHRR DATA

Rangeland fires that occur during periods of high fire hazard in central and western Nebraska pose a serious threat to property and livestock forage. To monitor the degree of fire hazard, the Nebraska Forest Service computes a daily fire-danger rating that is based on the contributory influences of forecasted weather factors and the observed rangeland fuel condition. Historically, information on rangeland fuel condition has been acquired from ground estimates of percent green biomass at three sites considered to be representative of major climatic regions within the State.

A cooperative project between the National Mapping Division and the Nebraska Forest Service evaluated the use of AVHRR data for monitoring rangeland fuel conditions on a statewide basis. Rangeland greenness values, computed from multitemporal AVHRR data by means of the normalized difference transformation, were analyzed for nine dates acquired over two growing seasons. A registered digital data base was used to exclude non-range areas and center-pivot irrigation fields from each scene. Rangeland greenness values averaged across climatic regions within AVHRR data were well correlated with the historical ground observations of percent green biomass. Computations of fire-danger ratings that included AVHRR greenness compared favorably with fire-danger ratings using percent green biomass when both were analyzed relative to historic records of fire occurrence.

This project demonstrated that rangeland greenness conditions could be readily monitored at the county or fire-district level using AVHRR data (fig. 22). If provided in a timely fashion, such information would be useful for computing fire-danger ratings that would aid fire preparedness and prevention at these local levels of jurisdiction (fig. 23).

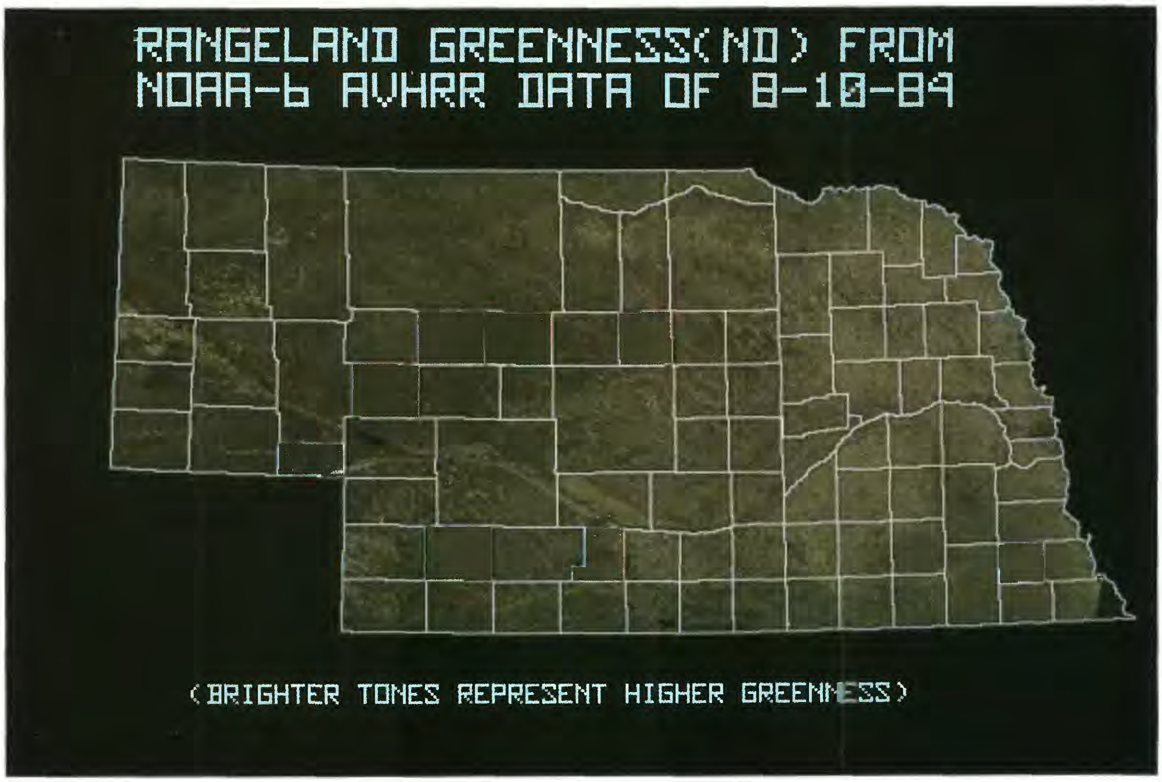

Figure 22.—AVHRR greenness conditions for the State of Nebraska on August 10, 1984. The varying levels of brightness serve to differentiate areas of actively growing green vegetation (brighter tones represent higher greenness). The brightest tones correspond to the very green agricultural regions. Note the relatively low greenness of the rangelands in central and western Nebraska at this time of year.

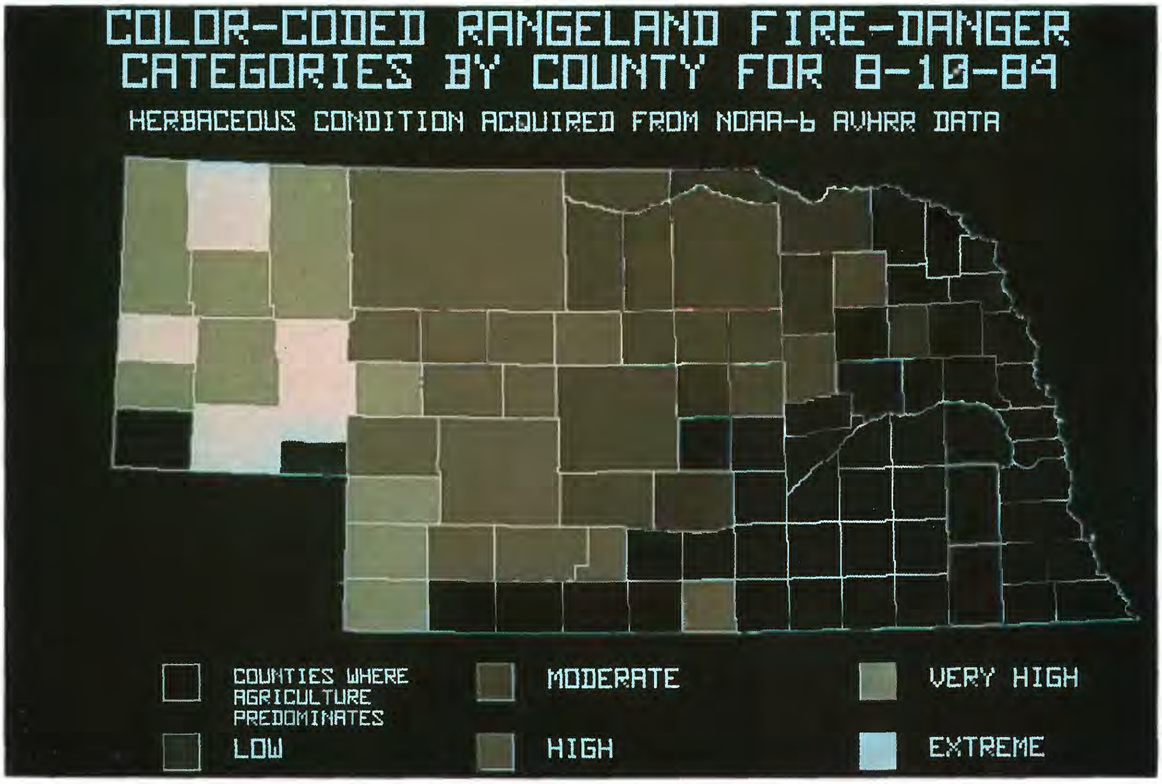

Figure 23.—Example of fire-danger categories computed at the county level from rangeland greenness conditions that existed on August 10, 1984.

AVHRR USED TO MAP IRRIGATED CROPLAND IN OREGON

Current statewide acreage estimates of land cover, especially irrigated cropland, are costly to obtain and are infrequently available in digital form for geographic information systems applications. To determine the amount and distribution of generalized land cover classes for the State of Oregon, AVHRR data were obtained and processed. Data collected on July 30, 1984, were registered to an Albers Equal Area projection and then clustered and classified. Cluster analysis produced 26 unique spectral classes which were used to classify the approximately 400,000 1-kilometer cells covering parts of Washington, Idaho, and all of the State of Oregon.

The classification was interpreted to produce land cover information for herbaceous rangeland, shrub rangeland, forest land, irrigated cropland, nonirrigated cropland, and water. Each of the 26 spectral classes was then grouped into one of these 6 land cover classes and converted to a file consisting of 550 rows by 750 samples. Each of the six land cover classes was converted to a polygon format using ARC/INFO. The land cover layer was then merged with other layers in a geographic information system to model water quality for the entire State.

INTERNATIONAL LAND SURFACE CLIMATOLOGY PROJECT

The National Mapping Division is participating in the International Satellite Land Surface Climatology Program (ISLSCP). The overall ISLSCP objective is to develop methodologies for deriving quantitative estimates of land surface climatological variables from satellite observations of reflected and emitted Earth radiation. The Retrospective Analysis Program (IRAP) is a component of the ISLSCP and is under the direction of Dr. Robert Murphy, Chief of the Land Processes Branch within the Earth Science and Applications Division, NASA. The goal of the IRAP component is to evaluate retrospective satellite data to assess the utility of satellites to measure land surface parameters that affect climate consistently and quantitatively over long periods of time (years). The Division was selected for the IRAP investigation through a proposal to study spectral changes associated with increases in land area under center-pivot irrigation in western Nebraska during 1972 to 1985.

This project is designed to examine spectral change and the possible effects on climate resulting from irrigation development in western Nebraska. Retrospective Landsat MSS data from 1972 to the present are being used to characterize spectral change in three counties. The three counties include one that has undergone a major transition from rangeland to irrigated agriculture, one that has remained rangeland, and one that has been generally stable irrigated agriculture for 30 to 40 years.

AVHRR data from 1979 to the present are being evaluated for representation of spectral change as determined by MSS data and for applicability to regional or global analysis of land cover change. Several climatological parameters are being examined for trends that might be related to spectral changes shown by AVHRR over the region.

Spectral change is determined using selected data transformations of greenness and albedo, which can be readily computed using both MSS and AVHRR data. These spectral transforms are currently being computed and will be compared for various image dates to quantify differences in mean values of county areas and in the proportions of land area that correspond to various levels of transform values. Spectral change will be assessed relative to actual changes in land cover.

In 1987, weather data will be examined for temporal trends at various locations throughout the study area. Trends prior to and during irrigation development within the study areas and at adjacent locations will be examined. Methods of using recorded climate data to estimate evapotranspiration demand will be explored. Weather trends will be compared to spectral changes to determine if correlations exist between the two phenomena.

GREAT PLAINS MONITORING PROJECT

In the fall of 1986, a cooperative project between NOAA/National Environmental Satellite, Data, and Information Services and the National Mapping Division was implemented to evaluate the utility of AVHRR data for observing and monitoring land surface and climatic conditions in the Great Plains area, shown in figure 24.

AVHRR data, surface weather observations, and weekly climatic indices are being acquired and compiled into weekly raster composites. A geographic information

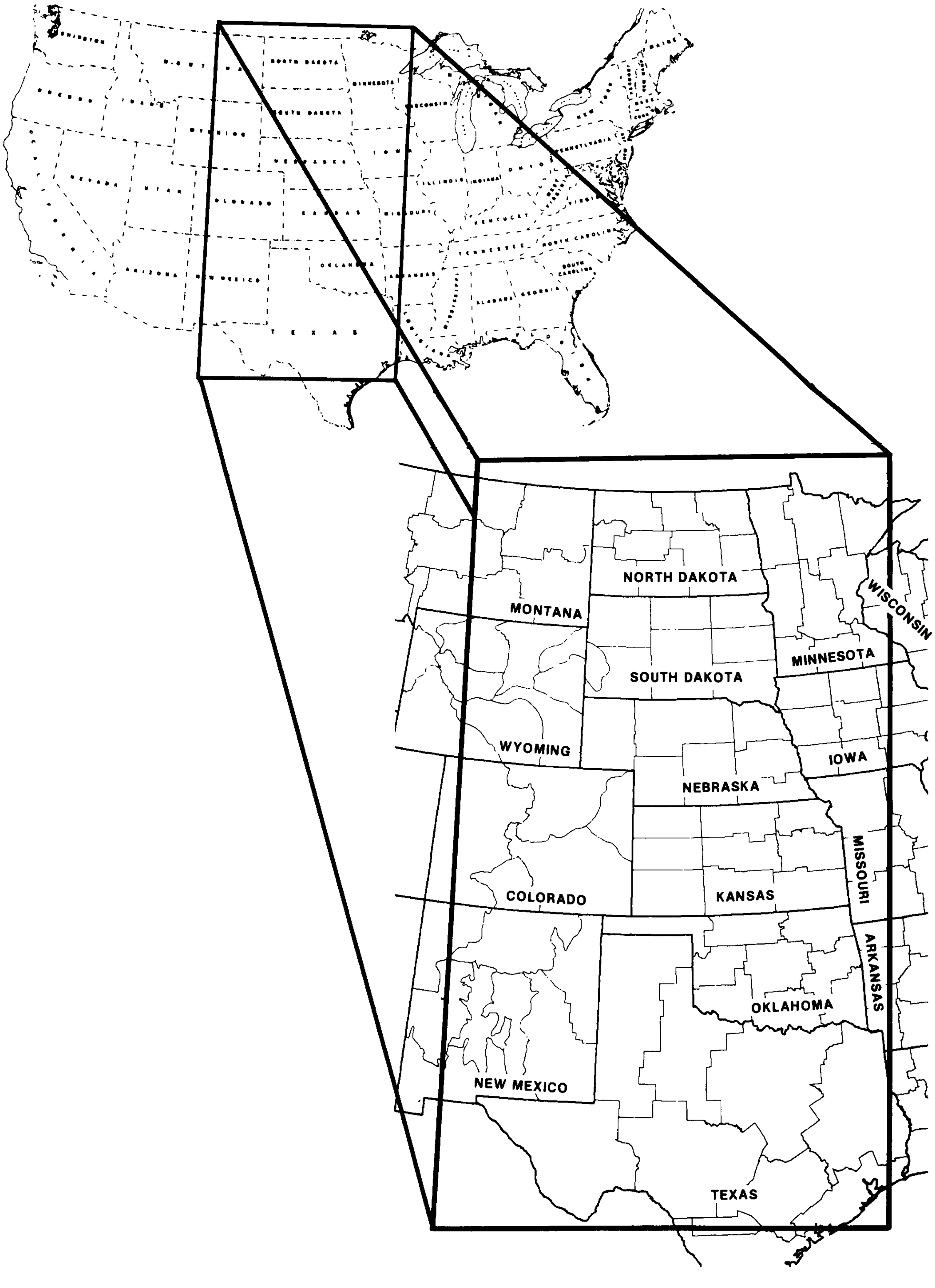

Figure 24.--Area of Great Plains study and State climatic districts.

system (GIS) is being used to merge these data with other data sets that characterize the land surface. The land surface data include NOAA climatic district boundaries, Soil Conservation Service land resource areas, State and county boundaries from Digital Line Graph files, and U.S. Department of Agriculture crop statistics.

The goals of the project are (1) to develop procedures to efficiently integrate and analyze disparate data sets, including time-series data; and (2) to evaluate the utility of regional remotely sensed data for monitoring land surface and climatic variables. Specific objectives include the following:

- Determine an appropriate data structure for efficient analysis
- Evaluate various stratification schemes to develop meaningful monitoring units
- Develop automated procedures to display a time series of vegetation indices
- Monitor seasonal changes of vegetation indices
- Evaluate relationships between modeled indicators of plant stress and vegetation indices
- Evaluate relationships between diurnal temperature changes and vegetation indices
- Evaluate the effects of viewing/illumination geometry on vegetation indices

DETERMINATION OF IRRIGATED AREAS AND CROP TYPES ON THE COLUMBIA PLATEAU

A joint project between National Mapping Division and the Water Resources Division (WRD) has been completed to provide a summary, by crop type, of ground-water irrigated crops on the Columbia Plateau in eastern Washington. The acreage summaries were used to calculate water use as an input to a ground-water use model being developed for the Plateau by WRD.

Landsat MSS data, acquired on May 21 and August 25, 1985, were used in an unsupervised clustering and maximum likelihood classification procedure to identify crop types. Classified images were converted to ARC/INFO format to compute classification accuracies, determine acreages by crop type, and create summary files. Individual crop classification accuracy was 72 percent and accuracy by water-use category was 70 percent.

Landsat TM data (bands 3, 4, and 5), acquired on June 22, 1985, were used in an unsupervised clustering and maximum likelihood classification procedure to identify crop types as a comparison to the MSS results. Initial results on a test area were determined to be promising enough to proceed with a classification for most of the study area covered by the TM image. Individual crop classification accuracy was 71 percent; however, accuracy by water-use category was 84 percent. In addition, the TM data made it possible to identify seven individual crops, separate irrigated and nonirrigated wheat as well as fallow land, and maintain field boundaries of nearly all categories identified. WRD personnel are planning to incorporate TM crop classification procedures into the ground-water use monitoring program on the Columbia Plateau.

EVALUATION OF THEMATIC MAPPER DATA IN NATURAL LANDSCAPES

Previous National Mapping Division studies have shown that Landsat TM images, reproduced at 1:100,000 scale, are useful for mapping grassland resource types and for monitoring the degree of utilization and patterns within management units. Evaluation of 1:100,000-scale TM images of the Warm Springs and Yakima Indian Reservations in Oregon and Washington confirms the practical utility of TM images for mapping natural resource types and evaluating the ecological status of range and forest sites. On rangelands, it is possible to identify annual grass types within sagebrush/grass communities. Major forest types, including open stand ponderosa pine, closed canopy ponderosa pine, lodgepole pine, Douglas fir, and alpine fir, are clearly distinguishable on TM bands 3, 4, 5 color-composite images. Past management practices can be easily assessed and the regrowth status of clear cut openings as small as 20–25 acres can be evaluated. In the forest, ecosystems, roads, trails, and some other features can be more easily identified on TM bands 2, 3, 4 images, but the plant community types are best differentiated on TM bands 3,4,5 images.

The Bureau of Indian Affairs used the 1:100,000-scale TM color-composite images to map land use and land cover types in preparation for a detailed rangeland survey at the San Carlos Reservation. A field evaluation indicated that land use was properly identified and mapped accurately on both TM band 2,3,4 and 3, 4, 5 images. Some of the arid land plant-community types were best differentiated on the 3, 4, 5 images. These cover type boundaries are being digitized as a data layer in the reservation's geographic digital data base and will be used in developing sampling strategies for the comprehensive range survey to be conducted at San Carlos.

CHERNOBYL (U.S.S.R.) IMAGE ANALYSIS

A nuclear accident occurred the nights of April 25–26, 1986, at Chernobyl, U.S.S.R., and both the Landsat and SPOT satellites were able to record the scene within the next few days. Landsat had also recorded the scene several times prior to the accident. These data were carefully analyzed on a priority basis because of the intense global interest in the accident. From the standpoint of mapping from space, the following applications were well demonstrated in the Chernobyl case and are considered significant:

- Capability to detect temperature anomalies. The near- and thermal-infrared wavebands of the Landsat TM clearly demonstrated the power of multispectral sensing from space. The thermal band 6 (10.4 to 12.5 micrometers) mapped the small temperature differences in the cooling pond of the nuclear powerplant and thus indicated when the plant was in operation (fig. 25). However, this band does not have the dynamic range to respond to the several hundred degrees of temperature differences that were created by the nuclear accident. On the other hand, the two near-infrared bands 5 and 7 (1.55 to 1.75 micrometers and 2.08 to 2.35 micrometers) did record the temperature anomaly associated with the

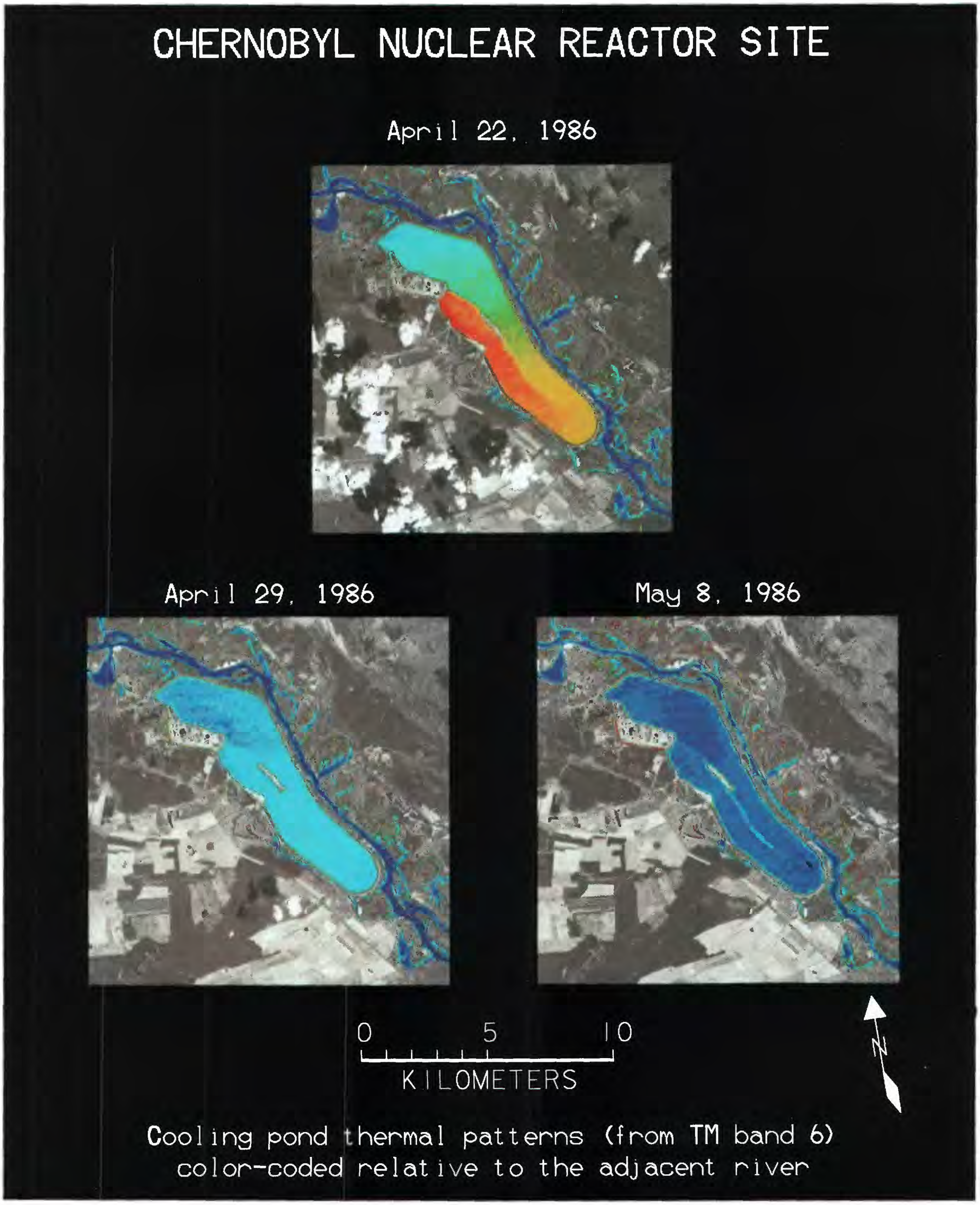

Figure 25.—Images of Thematic Mapper band 6 (thermal band) for each of three dates.

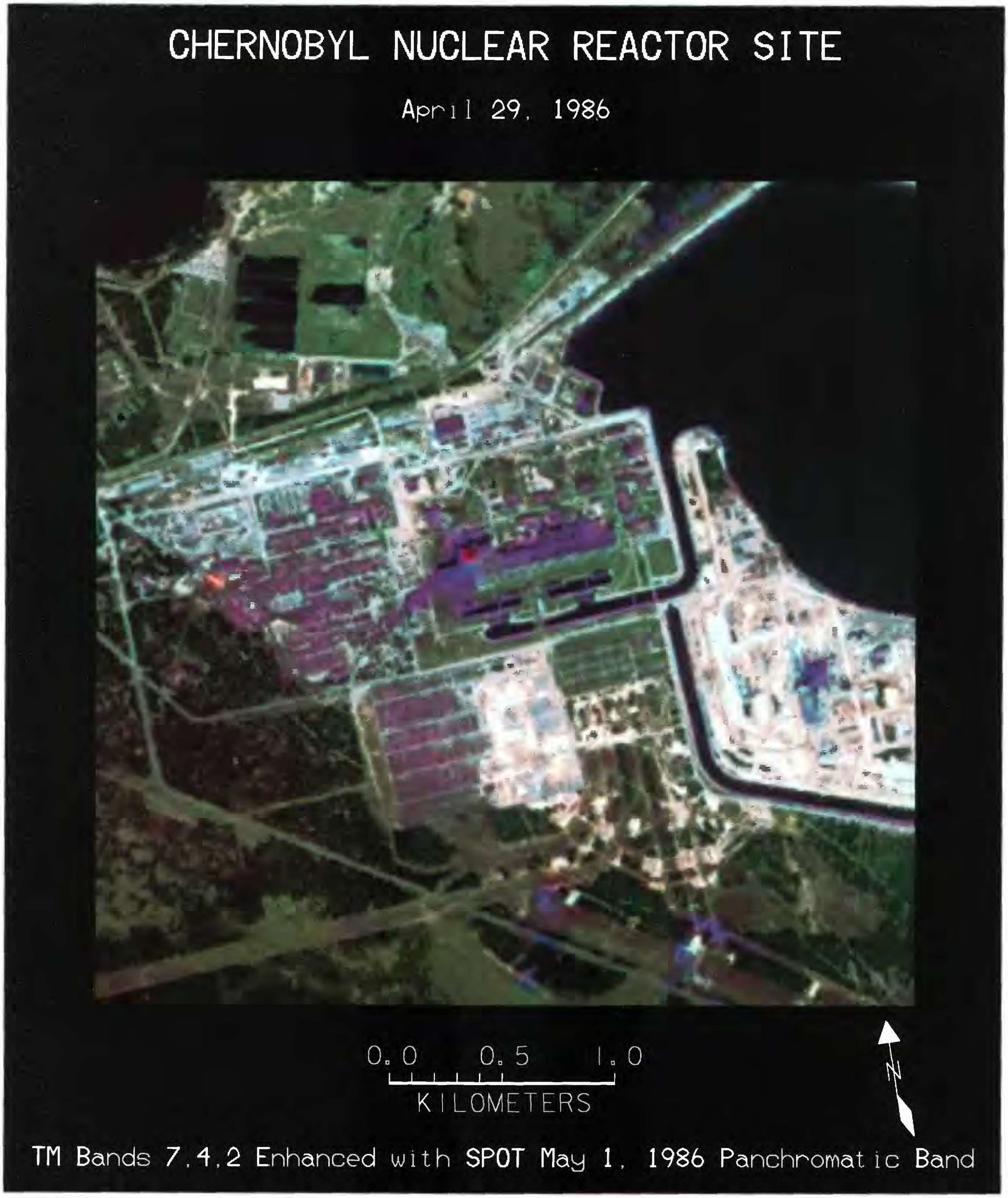

Figure 26.--Color-composite image of Thematic Mapper spectral bands 2, 4, 7, with the spatial enhancement of the SPOT high-resolution visible panchromatic band. (SPOT Data ©1986 CNES).

accident (fig. 26). Since there are many natural heat sources, such as forest fires and molten lava which create comparable temperatures on the order of 1,000 to 1,500 degrees Kelvin (727 to 1,227 degrees Centigrade), the ability to record such hot areas is of general interest and importance.

- <u>Geometric registration of two unlike space data systems</u>. Landsat TM data of April 29, 1986, and SPOT panchromatic data of May 1, 1986, provided excellent dual coverage of the Chernobyl area. The multi-spectral TM data were of 30-meter resolution and near vertical, whereas the SPOT data were of 10-meter resolution and taken at 8.4 degrees off the vertical. Registering such data sets was of obvious importance but also presented a real challenge to the image data processor. Division scientists, using a manual approach for selecting commonly identifiable control points and then fitting one set to the other (SPOT to Landsat), achieved such registration throughout a limited (3.5 by 3.5 kilometer) area within a 12-hour period. To register unlike data sets over sizable areas by such a manual method would, of course, be very expensive and time consuming. However, the automated correlation of unlike data sets has been demonstrated, and it may be assumed that SPOT and Landsat data sets can be correlated (registered) by automated means when so justified.

- <u>Cloud attenuation in correlated data sets</u>. In the Chernobyl area a few small clouds occurred in the TM imagery whereas the SPOT data were cloud free. The two sets were combined with an I.H.S. (<u>i</u>ntensity, <u>h</u>ue, <u>s</u>aturation) transform, largely eliminating the effects of both the clouds and cloud shadows. Although color (hue and saturation) was not restored in these areas, the intensity derived from the SPOT data provided excellent image detail in the areas of cloud and cloud shadows on the TM imagery (figs. 27a and 27b).

- <u>Height measurements from shadow measurements on SPOT data</u>. A large hyperbolic cooling tower is recorded on the SPOT data about 2 kilometers east-southeast of the nuclear plant. The shadow of this tower is well defined and falls on a reasonably flat area surrounding the tower. Technical data provided by SPOT indicate the following:

  -- attitude of image (angle off the vertical)--8.4 degrees
  -- Sun zenith angle--38.5 degrees

  With such data the height of the tower can be estimated from the shadow length. In this case, the tower height was estimated to be 100 meters. In addition to large manmade objects, natural features such as icebergs, cliffs, mountains, and clouds cast shadows from which height estimates can be made from the satellite data.

Analysis and display of the Chernobyl image data is of particular importance in that it represented an actual case of mapping a transitory phenomenon in a matter of a few days' time. This near-real-time mapping, performed by Division scientists, was so effective that it was carried on national television. The television program was well received and, probably for the first time, provided the public with a graphic display of a manmade disaster as seen from space and shown shortly after it occurred. By the close of 1986, a formal report covering the space data analysis of the Chernobyl accident had been approved for publication as a Survey bulletin.

Figure 27a.--TM image of Chernobyl, U.S.S.R., area showing clouds and cloud shadows (near bottom center of image). Shown here at approximately 1:41,500-scale.

Figure 27b.--Combined TM and SPOT image, processed using an I.H.S. (intensity, hue, saturation) transform to bring out image detail in areas of cloud and cloud shadows appearing on the TM imagery. Shown here at approximately 1:41,500-scale. (SPOT Data © 1986 CNES).

SPACE MAPPING OF HYDRILLA--POTOMAC RIVER BELOW WASHINGTON, D.C.

On September 15, 1985, Landsat TM imagery was acquired of the upper tidal Potomac River below Washington, D.C. (fig. 28). This imagery clearly recorded the extent of the submersed aquatic vegetation that includes hydrilla, a native plant of southeast Asia. To many, such as shore-front-property owners, hydrilla and other aquatic vegetation are considered a nuisance, but the vegetation has played a key role in bringing new aquatic life to this previously barren stretch of tidal water. The Landsat imagery compares favorably with aerial photographs taken 3 days earlier of the same area. Both the space and aerial images appear in the September 1986 issue of Photogrammetric Engineering and Remote Sensing. Landsat imagery of this area was again acquired on August 1, 1986, and analyzed along with aerial photography of the area taken in late summer of 1986. These new data indicate a generally stabilized condition of the submersed aquatic vegetation.

The controversy over this lush growth of underwater plants continues, but there is evidence that this reach of the Potomac River is now much closer to the natural condition that existed before it was polluted by man beginning some 60 years ago.

This research project has been conducted in cooperation with the Water Resources Division which has basic responsibility for the research.

LAND USE AND LAND COVER MAPPING

Land Cover Mapping of National Wildlife Refuges and Other Federal Lands in Alaska

During the past 5 years, the Division's Field Office in Anchorage, Alaska, has worked cooperatively with Federal and State resource management agencies to produce land cover and terrain maps for 245 million acres of Alaska (fig. 29).

The need for current land cover information in Alaska comes principally from the Alaska National Interest Lands Conservation Act, which requires major land management agencies to prepare comprehensive management plans.

The land cover mapping projects integrate digital Landsat data, terrain data, aerial photographs, and field data, utilizing a Hewlett Packard computer system and IDIMS software. The resultant land cover and terrain maps and associated data bases are used for resource assessment, management, and planning by many Alaska agencies including the U.S. Fish and Wildlife Service (USFWS), the U.S. Forest Service (USFS), the Bureau of Land Management (BLM), and the Alaska Department of Natural Resources (ADNR). Applications addressed through use of the digital land cover and terrain data bases range from comprehensive refuge planning to multiphased sampling procedures designed to inventory vegetation statewide.

In 1986, data bases and land cover map products for over 30 million acres in Alaska were produced and delivered to cooperating agencies as part of the Field Office's cooperative mapping program. Completion of land cover and terrain maps and digital products for the Yukon Delta and the Selawik National Wildlife Refuges brings the Field Office to within one refuge of completing a cooperative program for the USFWS, which has provided data bases for over 120 million acres.

Figure 28.--Landsat TM image (September 15, 1985) showing submersed vegetation (black) in upper tidal Potomac River below Washington, D.C. The Woodrow Wilson Bridge is in upper right where Route 95 crosses the Potomac. Fort Belvoir is at the lower left. Shown here at approximately 1:62,500-scale.

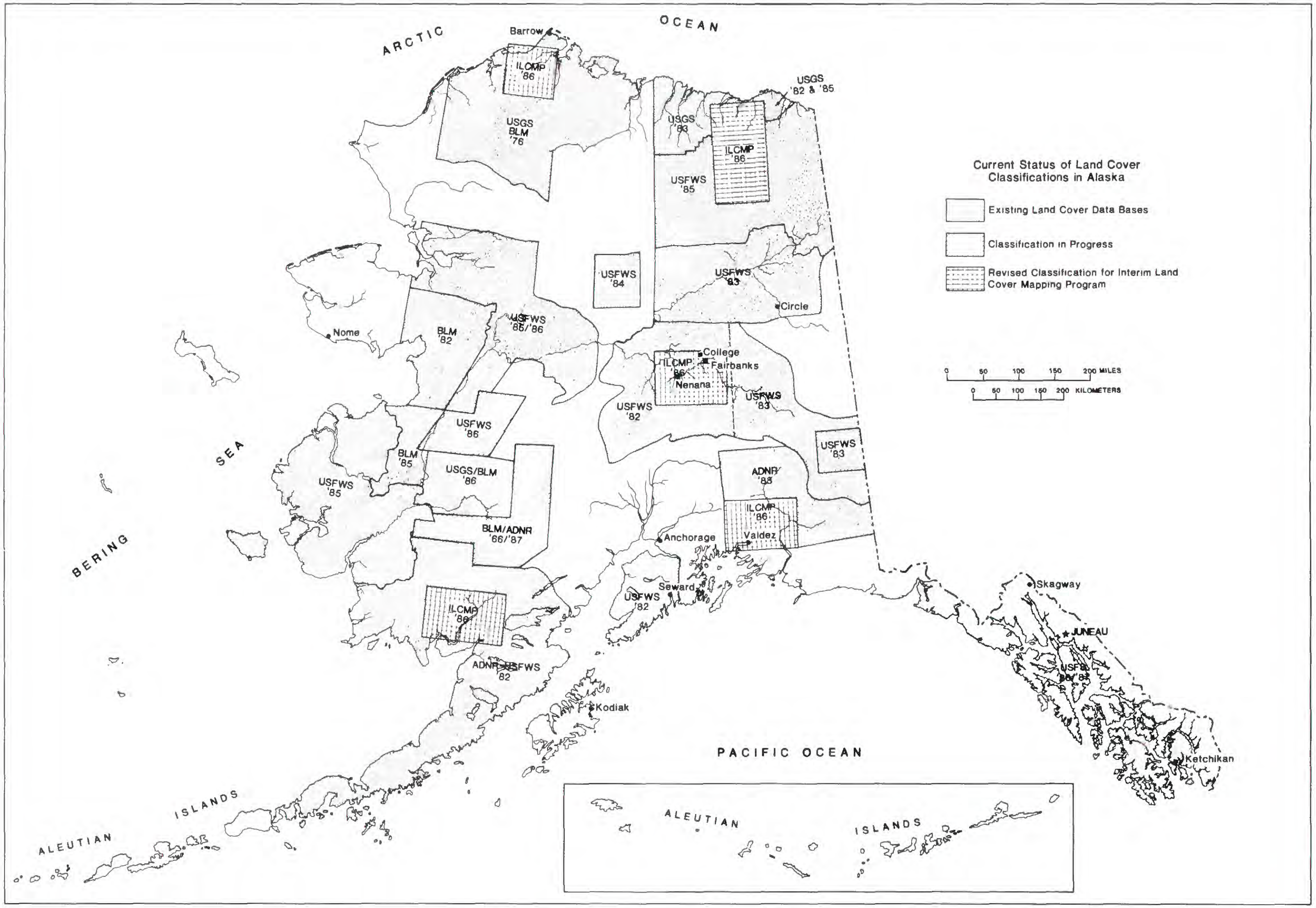

Figure 29.– Current status of land cover classifications in Alaska. Classification mapping was done cooperatively among the U.S. Geological Survey, the U.S. Fish and Wildlife Service, the U.S. Forest Service, the Bureau of Land Management, and the Alaska Department of Natural Resources.

Work on the 4-million acre Innoko National Wildlife Refuge will be completed in early 1987 and will complete land cover mapping for 14 of 16 national wildlife refuges. Follow-on work with data bases created for the USFWS in previous years resulted in derivative habitat maps and data products for an additional 40 million acres of national wildlife refuge lands.

In other cooperative mapping programs, land cover classifications were produced for the BLM for the 8-million acre Iditarod-George Resource Management Area, and the 12-million acre Kuskokwim River Resource Management Area. USFS personnel made significant progress towards completion of a 21-million acre mapping effort in Southeast Alaska.

The cooperative land cover mapping projects in Alaska have demonstrated the operational utility of digital Landsat data. As a result, the Division has proposed an interim land cover mapping program to compile a standard 1:250,000-scale series of digitally produced land cover maps in Alaska using a uniform statewide land cover classification system.

Land Use and Land Cover Mapping--Alaska Interim Mapping Program

The National Mapping Division is investigating the use of Landsat-derived land cover classifications as an interim solution to producing land cover maps for Alaska. A research project was begun in 1985 to convert land cover classifications produced under cooperative agreement with or for Government agencies to standard digital and graphic products at a scale of 1:250,000. This original digital land cover classification was reformatted to a standard statewide land cover legend for the products, developed by the Committee on Natural Resource Information Management (CONRIM). Land cover maps corresponding to six 1:250,000-scale quadrangle areas are being produced: Valdez, Arctic, Dillingham, Fairbanks, Meade River, and Mount Michelson.

The method for producing land cover classifications in Alaska involves digital Landsat MSS data and terrain data in a digital data base approach. The terrain data are 1:250,000-scale (arc-second) DEM's. Other source materials, such as maps showing administrative boundaries or interpretations made from aerial photographs (for example, urban, built-up, or settled areas), are usually in map or map-like form and are converted to digital form for entry into the data base. Multiple data sets are easily integrated and analyzed in a raster-based image processing system.

The postclassification procedures use a variety of techniques to improve the separation of land cover classes. For example, digitized physiographic information are used to segregate specific areas, and cluster statistics are derived within these areas. Furthermore, Landsat winter scenes registered to the data base are used to separate land cover classes that have similar spectral signatures on a spring or summer scene. DEM data are used in a similar way to separate areas based on combinations of elevation, slope, and aspect. The accuracy of the Landsat classification is improved when other types of digital data are used in the postclassification process.

The focus of research for producing the 1:250,000-scale maps has been on digitally reprocessing the existing classification data to a uniform classification and color scheme, registering the DEM and Landsat MSS data to the Universal Transverse

Mercator map projection, and preparing registered color separates directly from the digital data using the Scitex laser plotter. Area statistics on land cover types will be printed on the reverse side of the map. The acreage data are summarized on a computer printout that is photographically reduced to layout size, eliminating the need for costly and time-consuming typesetting.

L–series land cover maps at 1:250,000 scale will be available to the public and disseminated by the National Cartographic Information Center. The land cover classifications in digital tape format will be maintained as part of the NDCDB.

GIS RESEARCH AND APPLICATIONS OVERVIEW

A review of the list of Survey research and applications projects leads to the conclusion that the past 2 years have been extremely busy in the area of geographic information systems (GIS's). Tremendous progress has been made in basic spatial data base research in terms of the accuracy, content, and structuring of cartographic and geographic data. The results of recent efforts to improve and exchange various spatial data bases should make GIS applications more efficient and cost effective.

Recent and ongoing cooperative GIS applications projects have demonstrated the use of GIS technologies for improving the capability of the Survey to perform its traditional missions of earth science data collection, research, and information delivery. GIS technology allows users to collect, manipulate, analyze, create, and display many data sets simultaneously.

The Survey has established a GIS Policy Task Force and Technical Advisory Committee. A GIS fund has been established to continue support for ongoing projects and to provide full funding for new projects. These projects stress the applications of GIS technology to address major earth science problems, to facilitate data base exchange, and to expand interdisciplinary research among Survey divisions and State and other Federal agencies.

Much effort has also been devoted to the consolidation of Survey resources into cooperative, interdivisional laboratories in Reston, Va., and at field locations in Denver, Colorado, Menlo Park, Calif., as well as a research facility located at Sioux Falls, S. Dak. These facilities provide a unique multidisciplinary environment for cooperative GIS research and problem solving.

U.S. GEOLOGICAL SURVEY GIS RESEARCH LABORATORY

In 1986, a consolidated, multidivisional GIS research and applications laboratory was established at the Survey's National Headquarters in Reston, Va. (fig. 30). By consolidating development activities at one physical site, participants have access to a greater range of resources (hardware and software) than would be possible in separate project-level sites. The consolidated facility also offers an interdisciplinary environment where day-to-day contact, observation, informal discussion, and technical consultation provide continual upgrading of skills and encourage cooperative problem-solving.

Equipment installed, or being procured, for the laboratory includes high-resolution color display systems; minicomputers; large-format color plotters; image processing systems; artificial intelligence workstations and engines; manual digitizing tables; scanning digitizers; optical disk system;, and a variety of low-end, personal computer-based systems. A growing library of commercial and public domain software is available for digitizing, editing, analyzing, and displaying base category mapping and multilayered thematic data.

Demonstrations of GIS technology and cooperative applications development, both interdivisional and interagency, are underway, including joint efforts with the

Figure 30.--Users area in U.S. Geological Survey GIS Research Laboratory, Reston, Va..

Environmental Protection Agency and the States of Virginia and Maryland, the Bureau of Land Management, the Forest Service, the Soil Conservation Service, the Nature Conservancy International, and others.

GEOGRAPHIC INFORMATION SYSTEMS DEVELOPMENT

Spatial Data Processor Research

Research on the development of a spatial data processor has focused on using relational data base concepts to describe spatial data handling. To understand the conceptual design being proposed for the spatial data processor, it is helpful to see how digital cartographic data serve as a model of spatial reality. The key is to define and develop abstract global descriptions for digital cartographic and geographic data. This issue of data abstraction arises with respect to the identification of spatial entities.

To a user whose applications are to be supported by spatial analysis operations, individual points, lines, and polygons are but abstractions of the user's view of spatial reality. It would benefit the user if spatial entities and respective operators were defined at a user-logic level. Spatial reality from a user's view probably comprises visually or logically discernible geographic point, linear, and areal features (such as landmarks, roads, and counties), each with their respective descriptive attributes. These spatial entities will be termed cartographic features.

More precisely, a cartographic feature is the set of points, lines, and (or) areas that meet some specified attribute or spatial criteria. Features may be simple (composed of a single point, line, or area; for example, Plymouth Rock) or complex. Examples of complex features include highways, by route number or by name; named complexes, such as Dulles Airport; unnamed complexes, such as a drive-in theater; and named natural features such as the Potomac River, including its shorelines, islands, falls, rocks, and mudflats. A spatial data base management system would allow the user not only to pose questions, but also to receive responses expressed in the user-logic level of abstraction, that is, in terms of cartographic features. The actual manipulations would occur at a lower level of abstraction, one that contains the geometric information about the spatial entity.

In addition to modeling the geometry of cartographic features, the relationships of these features to each other need to be described in the model. One set of these relations describes the topology of the features (that is, relationships such as adjacent to, connected to, contained in, and bounded by). A second set of relations describes the class of objects that comprise a given cartographic feature. In summary, the cartographic data model consists of spatial entities and their associated objects, descriptive attributes for the objects, geometric descriptions of those objects, and the relationships among the objects.

As described, the cartographic data model consists of the basic components (entities, designations, and properties) used in the extended relational data model. This then, allows relational data manipulations to be performed using the set of relational operators (select, project, product, union, intersection, difference, join, and divide). Thus, the spatial data base management system has full manipulative power of the relational model available to process the descriptive attributes and the other nonspatial components of the cartographic data model. For the spatial (geometric) components of the model, it is proposed to use a set of spatial operators. The commonly referenced spatial operators are listed in table 2.

Spatial operators represent the basic and fundamental manipulations of spatial entities. The purpose of both the relational and spatial operators is to allow for the writing of expressions, which themselves serve many purposes, including data retrieval. The spatial operators are the analogs for spatial data to the set of relational operators used with nonspatial data. As such, spatial operators would be applied to various geometric components of the cartographic data model and relational operators to the remaining elements of the model.

Taken in concert, the relational and spatial operators provide full manipulative capabilities over all elements of the cartographic data model. They are the building blocks that may be aggregated in various ways to support the increasingly complex forms of geoprocessing. Included are both the data structure and the data manipula- tion components that are necessary for a spatial processor.

Vector Data Interchange

The exchange of data from one vector format to another is essential because of the recent proliferation of GIS's and of methods of representing coordinate information. The Division has completed the design and development of a coherent vector data interchange concept, and operational procedures have been implemented.

Table 2.—Commonly referenced spatial operators

OPERATOR	CLASS	OPERAND	RESULT	COMMENTS
LENGTH	Mon	1–cell	Nu	
AREA	Mon	2–cell	Nu	
BOUNDARY	Mon	2–cell	1–cell	Set of points that comprise limit of α.
COMPLEMENT	Mon	n–cell	n–cell	Set of points that are not members of α.
EXTEND	Mon	n–cell	2–cell	Set of points within a distance 'd' of α.
SEPARATION	Dya,sym	n–cell	Nu	Minimum of distances between points of α and points of β.
OVERLAP	Dya,sym	n–cell	B	True if α and β have at least one point in common.
EQUALS	Dya,sym	n–cell	B	True if all points are members of both α and β.
CONTAINS	Dya,asy	n–cell	B	True if all points of β are members of α.
INTERSECTION	Dya,sym	n–cell	n–cell	Set of points that are members of α AND members of β.
UNION	Dya,sym	n–cell	n–cell	Set of points that are members of α OR members of β.
DIFFERENCE	Dya,asy	n–cell	n–cell	Set of points that are members of α and not members of β.

Mon : Monadic
Dya : Dyadic
Sym : Symmetric
Asy : Asymmetric
Nu : Numeric
B : Boolean
n–cell : 0–cell, 1–cell, 2–cell or combination
α, β : Operands

The vector data interchange concept revolves around a relational data base hub. Interfaces to various vector analysis systems or transport data structures are arranged as spokes about the hub. Vector data from a given system may be introduced into the hub and transformed into the interchange structure using relational operators and software data manipulation tools. Similarly, data in the interchange structure can be transformed into any well-defined vector structure for use by another vector analysis system.

Each interface is approached in four steps. First, the vector data structure is analyzed and rigorously defined. Second, a test data set is converted. Third, when an effective transformation process is established, the procedure is implemented in a command language and made available for further testing. Finally, an interchange procedure is optimized and placed in operation. The following procedures are now operational:

- To and from Digital Line Graphs
- To and from ARC/INFO
- To and from Intergraph
- To and from raster-formatted data
- From Automated Mapping System
- From Geographic Entry System
- To Map Overlay and Statistical System

Error Structure in Multilayered Spatial Data Bases

Error structure in a complex, multilayered data base is being investigated as part of the Division's GIS research and development program. A portion of one particular data base developed jointly by the U.S. Forest Service (Flathead National Forest, Mont.) and the National Park Service (Glacier National Park, Mont.) is being used in the study. The relevant data layers are slope, aspect, elevation, species composition, moisture class, tree density class, and tree size class for two adjacent 7.5-minute quadrangle maps, Mount Grant and Pinnacle, Mont.

Information about the error structure of multilayered spatial data bases is important for several reasons. The accuracy or reliability of products derived from the data base cannot be determined without knowledge of the error structure, and the confidence in decisions based on these products cannot be known without accuracy estimates. A priori information about error structure of a data base is also important, particularly if various ancillary data sources are used to produce a particular data layer. An example might be using slope and aspect data to refine clusters developed from remotely sensed data. This same information may also aid in choosing optimum layers for the development of output products through overlay analyses.

Studying the relationships of errors between layers of a spatial data base is essential for determining whether errors in different layers are independent of each other or whether errors in one or more layers influence the presence of errors in derived layers. Determining whether errors in different layers are independent is quite straightforward, involving formulas for finding the probabilities of intersections of events. An event is the occurrence of an error in classification in a particular layer. The probabilistic structure of the various intersections of events determines whether the events are independent or not. As an example, consider the elevation, aspect, slope, and species composition layers. The four events of interest are the occurrence of error in each layer. The intersection of interest is the occurrence of error in four layers simultaneously. Preliminary work conducted in 1986 on the probability structure of that intersection indicates the errors in elevation do not influence errors in slope or aspect, so errors in those layers are independent. However, errors in slope and errors in aspect tend to increase the presence of errors in species composition.

Another aspect of this study project is to investigate the spatial autocorrelation structure of errors within each layer. This portion of the project has proven to be very difficult. The field data collected are binary. A sampled pixel is given a value of one if the classification is correct, zero otherwise. Most spatial autocorrelation measures found in the literature do not apply to qualitative data. Those spatial autocorrelation measures that do apply to qualitative data require sampling methods not used in this project. Attempts were made to derive spatial autocorrelation measures using the same assumptions and sampling methods of this study project, but those spatial autocorrelation measures proved to be very poor. The biggest problem with these measures is the correlations are not constrained to be between plus and minus one.

In 1987 the analysis portion of this study project will continue. The relationship of errors between layers will be further investigated. A new approach for studying within-layer spatial autocorrelation will also be tried.

GEOGRAPHIC INFORMATION SYSTEMS APPLICATIONS

Wasatch Front Earthquake Hazard Reduction Project, Utah

The Sugar House 7.5-minute quadrangle in east-central Utah served as a test site for investigating applications of digital map data bases and GIS technology to the mitigation of earthquake hazards. The research was conducted in cooperation with the Survey's Geologic Division in support of their National Earthquake Hazards Reduction Program. Other principal cooperating agencies were the Federal Emergency Management Agency (FEMA), the Utah Geological and Mineral Survey, the Utah State Division of Comprehensive Emergency Management, and the Utah Office of Automated Geographic Referencing.

More than two dozen cartographic data themes were entered into the project data base using the ARC/INFO software. The map themes were selected based on their relevance to description of earthquake hazard conditions and their effects. Included were standard DLG data categories of roads, boundaries, Public Land Survey System, and hydrography, as well as other data from a variety of sources, which were manually digitized by the project team. Among the other data were surficial geology, Wasatch Fault zone, potential liquefaction zones, predicted land stability during earthquakes, FEMA flood zones, landslide and mudflow zones, land use, gas and water mains, and critical and response facilities including schools, hospitals and other medical facilities, police stations, and fire stations.

Several analysis capabilities were demonstrated, including automated measuring and mapping of schools and residential areas that coincide with high potential earthquake hazard zones (fig. 31), lifelines crossing potential fault rupture zones, and undeveloped land that lies outside identified multihazard zones. Many other kinds of analyses can be performed on these and similar data sets, such as pre-earthquake

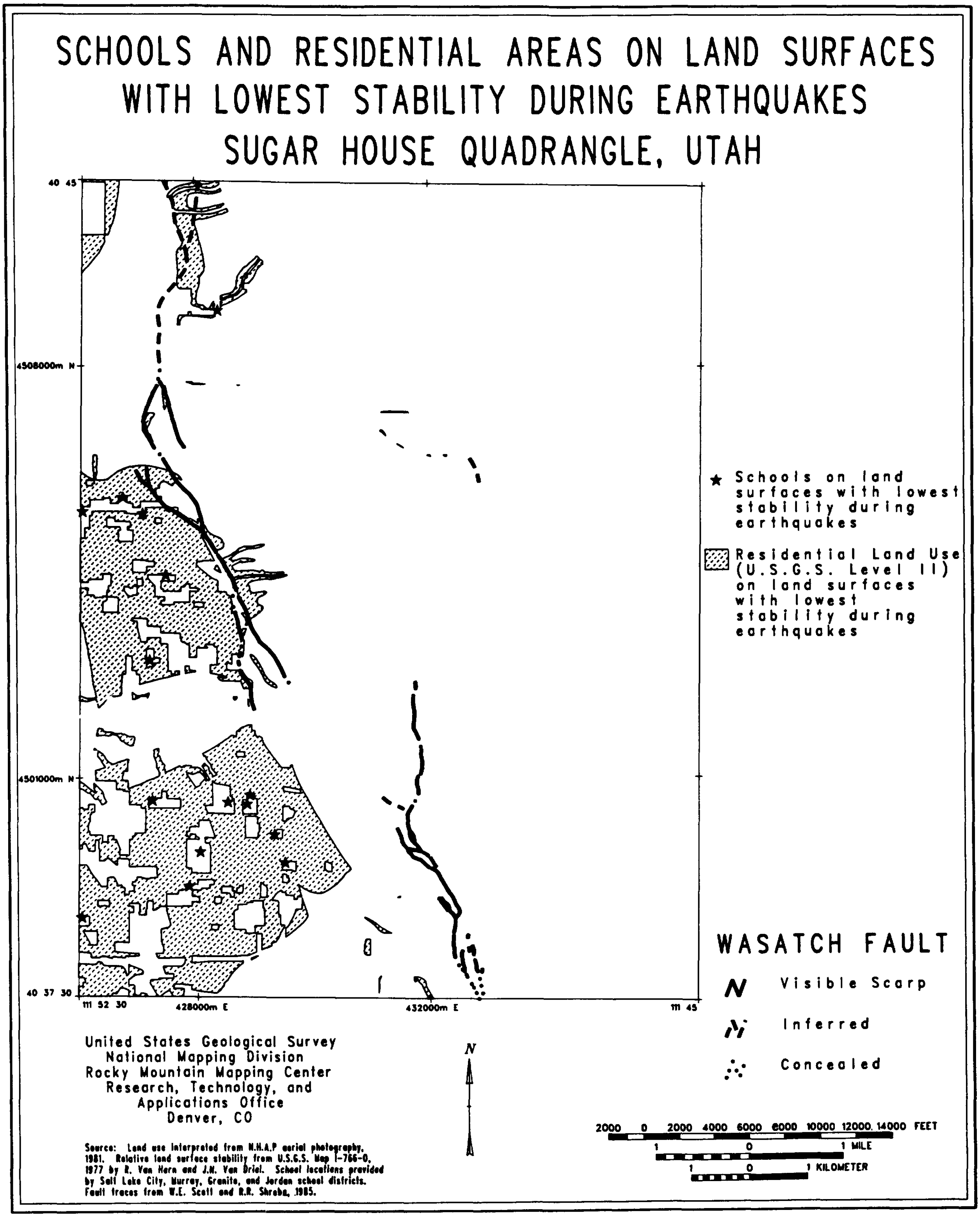

Figure 31.--The Sugar House quadrangle, Utah, showing digital data sets merged in a GIS to depict locations of schools and residential areas that coincide with high potential earthquake hazard zones.

planning for response and recovery, loss estimation prior to earthquake occurrence, and hazard mitigation via land use planning where opportunities still exist for guiding new development away from the areas of greatest potential hazard.

Exhibits of the various data sets were combined into a 30-plate atlas and presented for review at meetings and workshops in Utah, Colorado, and Washington, D.C. User feedback identified several potential applications of the digital technology to the interdisciplinary fields of earthquake hazards assessment and reduction (for example, geological/geophysical research, land use planning, disaster response and recovery, future earthquake loss estimation). Strongly expressed needs of State and local government agencies include moving the results of the research and technology demonstrations toward implementation of loss-reduction measures. It was recommended that cooperative development and sharing of digital data bases and use of the GIS technology be part of the implementation efforts. Feasibility demonstration of data sharing took place at a workshop in 1986, where Survey data produced in this project were successfully transferred to the Utah Office of Automated Geographic Referencing, the Utah State agency responsible for coordinating digital mapping and geographic referencing of data for State and local user groups.

Earthquake loss estimation was identified as a major challenge and potential future application of digital data bases and GIS technology. Loss estimation is an interdisciplinary technique in which geologic and geophysical processes are linked to data on the human uses of earthquake-prone regions to calculate expected economic losses and human casualties from typical earthquakes likely to occur in the future. Since losses vary greatly with site conditions, loss estimations can be used by government agencies and others in detailed planning for the reduction of such losses.

Further research is planned to model various earthquake scenarios in computer systems compatible with formats of standard data bases, to integrate data bases compiled from maps at various scales, and to link local government land parcel data bases with those adhering to Survey standards. Also recommended are adaptations of census data to models that will update and supplement decennial files to current year, to seasonal population estimates, and to estimates of day and night populations.

San Juan GIS Project--Automated Data Compilation, Data Analysis, and Map Production for Geologic and Hydrologic Resource Studies

Many geologic and hydrologic resource studies entail the compilation, manipulation, and analysis of large spatial data bases. It is not unusual for such studies to employ similar techniques, types and sources of data, and to present the results in some cartographic form. The National Mapping Division is working with Water Resources and Geologic Divisions to develop mutually beneficial techniques for using a GIS to automate tasks that are common to geologic and hydrologic resource studies. For its contribution, the Division is developing automated mapping procedures that will support (1) the compilation of digital base maps prepared to National Mapping Division standards, and (2) the direct generation of publication-quality cartographic products. The establishment of these general-purpose capabilities will greatly enhance the ability of the National Mapping Division to respond to the thematic mapping requirements of other divisions.

The San Juan Basin, a structural depression encompassing 20,000 square miles in the Four Corners region of Colorado, Utah, Arizona, and New Mexico, serves as the geographic focus of this investigation. Twenty-three DLG data sets at a scale of 1:100,000 provide coverage of the study area. More than 500 of the component 7.5-minute DLG digital data subsets have been paneled together to build a digital base map for the study area. Feature categories include selected transportation and hydrographic features supplemented by boundary and names information. The cartographic design capabilities of the GIS will be used to create a refined base map suitable for the superposition of geohydrologic data. The development of program interfaces to the Division's Gerber 4477 and Kongsberg GC300 high-accuracy automated cartographic drafting systems will provide for the direct generation of publication-quality products.

Elizabeth River GIS Research Project

The Survey entered into a Memorandum of Understanding (MOU) with the U.S. Environmental Protection Agency (EPA) in November 1984 to "assure that the mandate of each agency is applied most effectively to achieve the water quality and natural resource goals of the Chesapeake Bay."

The Chesapeake Bay, the Nation's largest estuary, drains approximately 65,000 square miles from six States and the District of Columbia. It has shown significant decline in water quality over the last two decades. The EPA's Chesapeake Bay Program, in keeping with the spirit of the MOU, has requested that the Survey develop a pilot GIS for the Elizabeth River drainage basin, one of several sub-basins responsible for a large flow of pollutants to the Bay. The Elizabeth River basin, in southeastern Virginia, drains approximately 205 square miles of some of the most heavily industrialized and developed area on the Bay watershed.

To assess the potential for contamination in the Elizabeth River basin, a series of data layers covering location, movement, and impact areas is needed. Using a multidivisional approach for acquiring the necessary data layers, a project proposal was submitted to the Survey's GIS Policy Task Force outlining these tasks and responsibilities. The project was subsequently funded with work beginning in July 1986. In keeping with the project timeframe, the following tasks have been accomplished:

1. Land use and land cover data were converted from GIRAS to ARC/INFO format.

2. Hydrography for the nine 7.5-minute quadrangles containing the drainage basin was digitized using ARC/INFO and converted to DLG format.

3. Current land use data provided by the Environmental Photo Interpretation Center (EPIC) were scan-digitized and converted to ARC/INFO format.

4. Nonpoint source data from EPIC were digitized and converted to ARC/INFO format.

5. Data files from Virginia Institute of Marine Science, Virginia Water Control Board, and EPA Region III was converted to ARC/INFO coverages.

6. MOSS–formatted data from the Fish and Wildlife Service were converted to ARC/INFO format.

The Elizabeth River data base will be housed in the Water Resources Division's Mid–Atlantic District office in Richmond, Va., where it will assist various State, local, and Federal agencies in making more prudent environmental management decisions within the basin and ultimately the Bay watershed.

James River Basin Refinement Study

In cooperation with the Bureau of Reclamation, the National Mapping Division and the Water Resources Division collaborated on a project to assess the hydrology of the James River basin, North Dakota, upstream of the Jamestown Dam and Reservoir. The Bureau of Reclamation is responsible for evaluating the Jamestown Dam and Reservoir, which requires estimating the volume of the probable maximum flood (PMF), the largest possible flood that reasonably could be expected to occur. The Survey assisted in obtaining the hydrologic characteristics necessary for the evaluation. Five test sites considered representative of the glaciated pothole terrain comprising the upper James River Basin were selected for detailed study. Potholes formed by Wisconsin glaciation made it difficult to manually derive the hydrologic information needed to estimate PMF. The use of DEM data was thought to be a means of acquiring this information.

DEM's of three levels of accuracy were used in the analysis to provide a basis for the level of accuracy and, respectively, the approximate cost of a DEM that can be used to produce acceptable hydrologic characteristics. DEM's were produced by gridding algorithms that operate on digitized contour data. The lowest level of accuracy was obtained by digitizing contours from the published 7.5–minute topographic maps. A higher level of accuracy was obtained by collecting the digital contour data from stereomodels using aerial photography flown at 9,600 feet above mean ground level. DEM's with the highest level of accuracy, and the most expensive to derive, were obtained by stereomodel digitizing of 4–foot contours from 4,800–foot photography. Additional accuracy is inherent in the stereomodel technique because intermediate contours at any elevation can be added to better define the topography.

Programs were developed to derive the initial hydrologic characteristics from the high–accuracy DEM's such as pothole volumes and basin areas. The IDIMS was used to manage and display the gridded data. Figure 32 shows a shaded–relief image generated from DEM data for one of the test sites. The ARC/INFO GIS was used extensively for data management, graphic display, and data tabulation. Maps were prepared of surface depressions, drainage area boundaries, and pour point locations (fig. 33).

Hydrologists applied the hydrologic characteristics that were produced from the DEM's to compute runoff for the test sites. A solution for the entire basin was extrapolated from the results of the processing of the selected test sites. A rainfall–runoff model was applied to compute the PMF from the sub–basins and to route and combine all hydrographs into the Jamestown Reservoir.

Spatial processing and hydrologic modeling techniques developed in this study offer a highly useful method for assessing hydrology in areas similar to the James River basin. Hydrologists preferred the DEM with the highest level of accuracy, due to

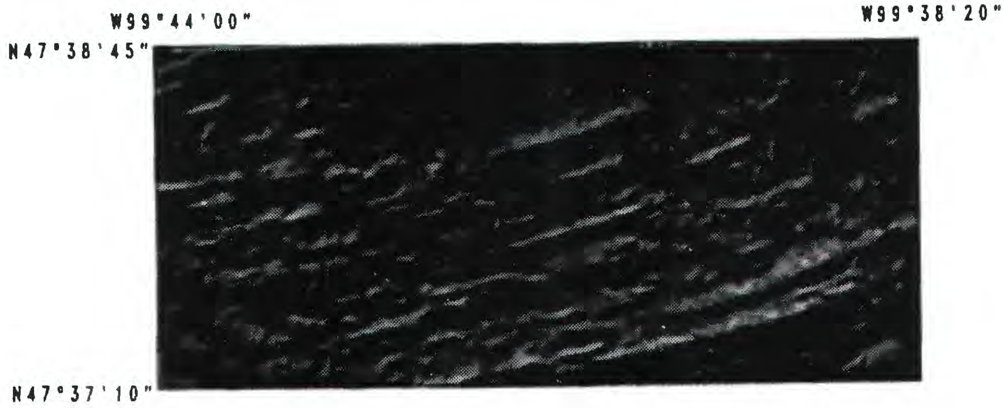

Figure 32.--Shaded-relief representation of DEM data for one of the James River basin, N. Dak., test sites.

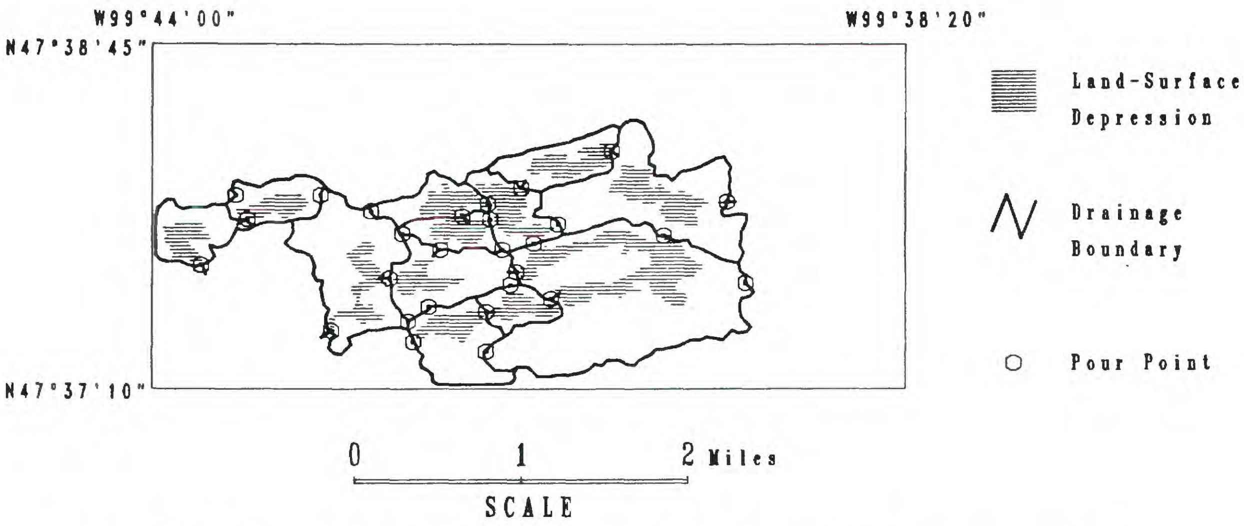

Figure 33.--Selected potholes, watersheds, and pour points for the test site.

the modeling procedure used and the impact that the outcome of the study may have on life and property. A recommendation regarding changes in the structure of the Jamestown Dam is pending the modeling results of routing of all hydrographs into the Jamestown Reservoir.

Landslide Prediction for San Mateo County, California

Debris flows are geologic events that often cause significant damage to life and property. A GIS is being used to help predict the occurrence of these rapidly moving landslides in San Mateo County, Calif. It is obvious that landslides are correlated with soil type, topographic slope, and rainfall intensity. It has also been shown that underlying geology, physiography, vegetation, and other factors are important variables. What is not known is the total effect and importance of each of these factors. To learn more about the effects and to create a predictive model, data for all these factors were assembled in digital form. They were used, along with Landsat TM data and a digitized map of known debris flows compiled by Survey geologists, in a logistic regression analysis (LOGIT).

LOGIT was used to determine the characteristics of the variables for a random sampling of both debris sites and nondebris sites. These training data, based upon both continuous (such as TM) and discrete (such as geologic units) data, were used to estimate the coefficients for the logistic regression. The coefficients were used to classify the entire matrix of grid cells. Each was assigned a value based on the probability of that grid cell belonging to the known class of debris sites. Correlation between areas of the resulting map showing high probability and actual past occurrence of slides was very high (fig. 34). Additional, more refined digital factor maps will help in developing a general methodology for application in other areas.

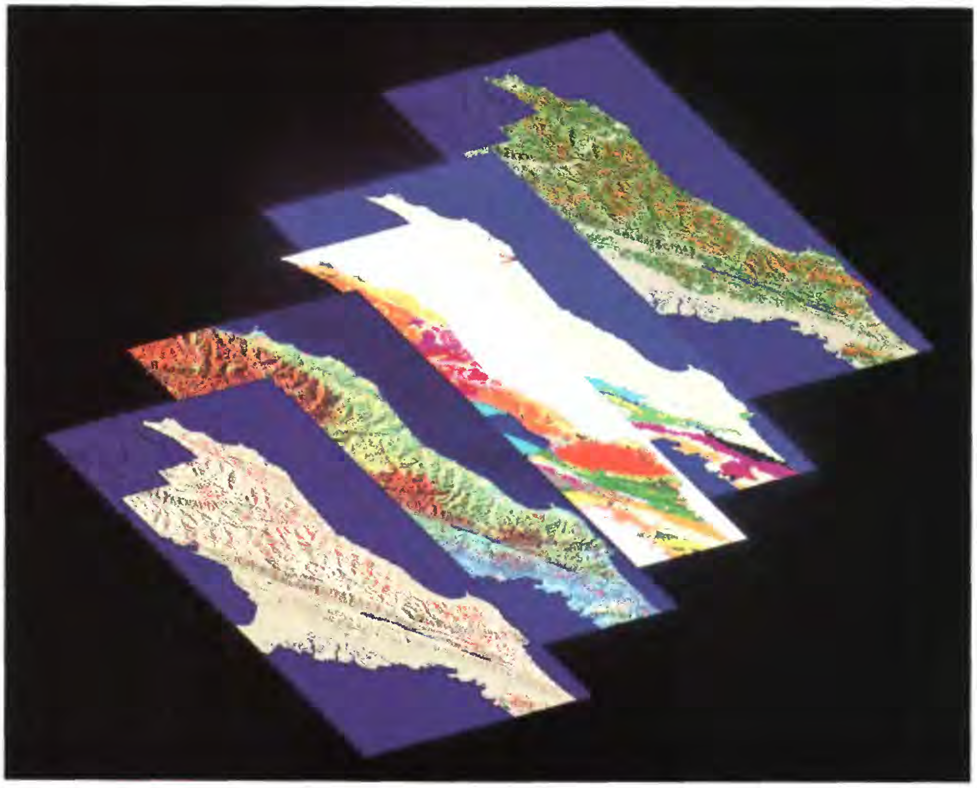

Figure 34.--Information on recent landslide locations, and Landsat TM, geologic, and soils data were used in a model to determine the probability of debris slides for San Mateo County, Calif. Areas of highest probability are indicated in red and orange on the bottom image.

Analysis of the Black Hills, South Dakota, Region using a Knowledge-Based Geographic Information System

A demonstration of artificial intelligence techniques applied to natural resources analysis was conducted using a knowledge-based geographic information system (KBGIS) codeveloped by the University of California at Santa Barbara and the

Survey. Three test scenarios were studied: (1) identification of surface water/ground water interchange areas, (2) characterization of known mineral deposits and identification of additional sites of similar mineralization, and (3) description and identification of potential landslide sites. The results of these tests were presented to the Survey in 1986.

The data for the KBGIS demonstration were originally collected for a study of the relationship of drainage basin characteristics to stream flow for the Black Hills of South Dakota and Wyoming. The original data base included the entire Black Hills uplift and a portion of the surrounding plains. However, for this demonstration, a subscene was chosen for an area of the northern hills near the town of Lead, S. Dak. This subscene was chosen to include a diversity of geologic and topographic environments with which to train the KBGIS to recognize various terrain and relational features.

The following is a brief description of the data layers that were included in the KBGIS data base:

Elevation-- Elevation data were derived from National Mapping Division 7.5-minute DEM's, which are recorded at 30-meter intervals. The original data were resampled to 50-meter spacing for entry into the KBGIS data base. Portions of nine 7.5-minute quadrangles are found within the demonstration subscene.

Slope-- Slope data were derived from the DEM layer using an algorithm maintained on the IDIMS. Each cell is coded for the average slope within a 3- by 3-cell window.

Aspect-- Aspect data were also derived from the DEM layer using another IDIMS algorithm. Each cell is coded for the average slope aspect, or compass direction of slope. Actual reported values are grouped into 2° classes so that the values fit into one-byte words (0 - 180).

Roads-- Highways and major roads mapped on the 7.5-minute quadrangles were digitized for inclusion into the data base. Cells are numerically coded with a one where roads are present and a zero elsewhere.

Geology-- The geologic data layer was digitized from Darton and Paige's Black Hills folio of 1925. Each cell is coded for the major geologic unit found within its representative area. Approximately 30 different lithologic units occur in the demonstration subscene.

Federal Land Information System

The Survey's Federal Land Information System (FLIS), formerly the Federal Mineral Land Information System was established in 1983. The objectives of FLIS are (1) to develop the proper procedures and guidelines for selection and retrieval of data sets from existing external data bases for inclusion in the FLIS network of data layers, (2) to demonstrate the development and use of networked spatial data with GIS capabilities for large-area spatial analysis applications, and (3) to convert and reformat data sets for use within a variety of spatial analysis systems in order to address questions and issues concerning Federal lands. Selected data layers and data attributes are extracted from data bases for periodic use. FLIS was not designed to be a data collection or a data base system. Direct involvement with cooperators to develop capabilities that serve their needs is integral to all of these objectives.

The initial FLIS data sets were mineral potential and occurrence, land and mineral status, and base cartographic data. The framework for the system was broadened in 1986 to include surface resources base information, such as land use and land cover, soils, and terrain data.

Two demonstration pilot projects were conducted. The first was the Medford, Oreg., 1:250,000-scale quadrangle raster-data network demonstration (1983) and the second was the Silver City, Ariz.-N. Mex. 1:250,000-scale quadrangle vector-data network demonstration (1985 to present). The Silver City area continues to be used for testing and demonstrating new FLIS applications.

Alaska was the first large-area, statewide FLIS project. The availability of general- ized mineral potential, land and mineral status, and base cartographic data state- wide permitted the demonstration of handling large volumes of data over a large area using available GIS technologies. Data sources were the Geologic Division's Regional Alaska Mineral Resource Assessment Program (RAMRAP) maps for mineral
assessment, the Bureau of Land Management's Alaska Automated Land and Minerals Record System (ALMRS)--a computerized, tabular data base for land and mineral status--and the National Mapping Division's 1:2,000,000-scale digital cartographic data base for base cartographic data. Data base development, analysis, and output were accomplished and successfully demonstrated (fig. 35) during 1985. In addition, the Geologic Division's more detailed mineral potential data from the Alaska Mineral Resource Assessment Program and mineral occurrence data from the revised Mineral Resource Data System, both available for only scattered 1:250,000-scale quadrangles in Alaska, have been brought into the network. Mineral occurrence data from the Bureau of Mines Mineral Industry Locational Subsystem were also added to the system.

Research activities in Alaska during 1986 were focused on (1) enhancing the existing data sets, (2) investigating the suitability of additional surface resource data sets, and (3) raster-to-vector conversion of the data in use in the FLIS data network. Alaska interim land cover raster data were successfully generalized and converted to vector data and brought into a vector system (fig. 36). Progress was made toward meeting the goal of converting ALMRS computerized, tabular data by linking the data to section-level geographic coordinates. This generalized ALMRS data will be created initially for the Silver City demonstration area.

Spatial Data Processing in Support of Geochemical Studies

As an extension to previous Conterminous United States Mineral Appraisal Program (CUSMAP) studies for the Tonopah, Nev., quadrangle, research is being conducted by the Division on digital spatial analysis techniques to enhance regional geochemical interpretations. The objective of the study is to merge geochemical data with the areal proportions of geologic units within selected drainage areas specific to geochemical sample sites by using spatial overlay and relational data base techniques.

Figure 35.--The two data base layers brought into FLIS for this analysis--RAMRAP mineral potential and Alaska ALMRS surface land ownership--were converted to a spatial data format. Overlay analysis was performed on a raster system to generate information showing zinc favorability on Federal (red areas) and non-Federal (orange areas) lands in Alaska. Light-gray areas show other Federal lands and dark gray areas other non-Federal lands.

The resultant data set can be used for investigating the spatial distribution and concentration of geochemical elements and for examining the relationships between geology and stream sediment geochemistry. The principal emphasis of this research is to explore various methods for determining geochemical thresholds that define single element anomalies and multielement associations, and which may serve as potential indicators of mineralization within drainage areas.

Multivariate techniques, such as regression and factor analysis, were used to adjust the estimates of background geochemical values based on the areal distribution of rock types within the drainage areas. These adjusted estimates resulted in improved definition of geochemical anomalies. Drainage areas were characterized on the basis of geochemistry and geology, and then were combined with other data sets for thematic display. The results of this work demonstrate advanced digital spatial data analysis techniques that can be applied to enhance regional geochemical interpretations, as well as illustrate procedures and capabilities requisite for the exchange of digital earth science data sets.

In addition to the work done on the Tonopah quadrangle, a cooperative project is being conducted with the Geologic Division to apply GIS techniques for analyzing the distribution of selenium and other geochemical trace elements in the San Joaquin Valley, Calif. The project has three goals: (1) to identify models for geochemical trace element transport, particularly for selenium and mercury; (2) to

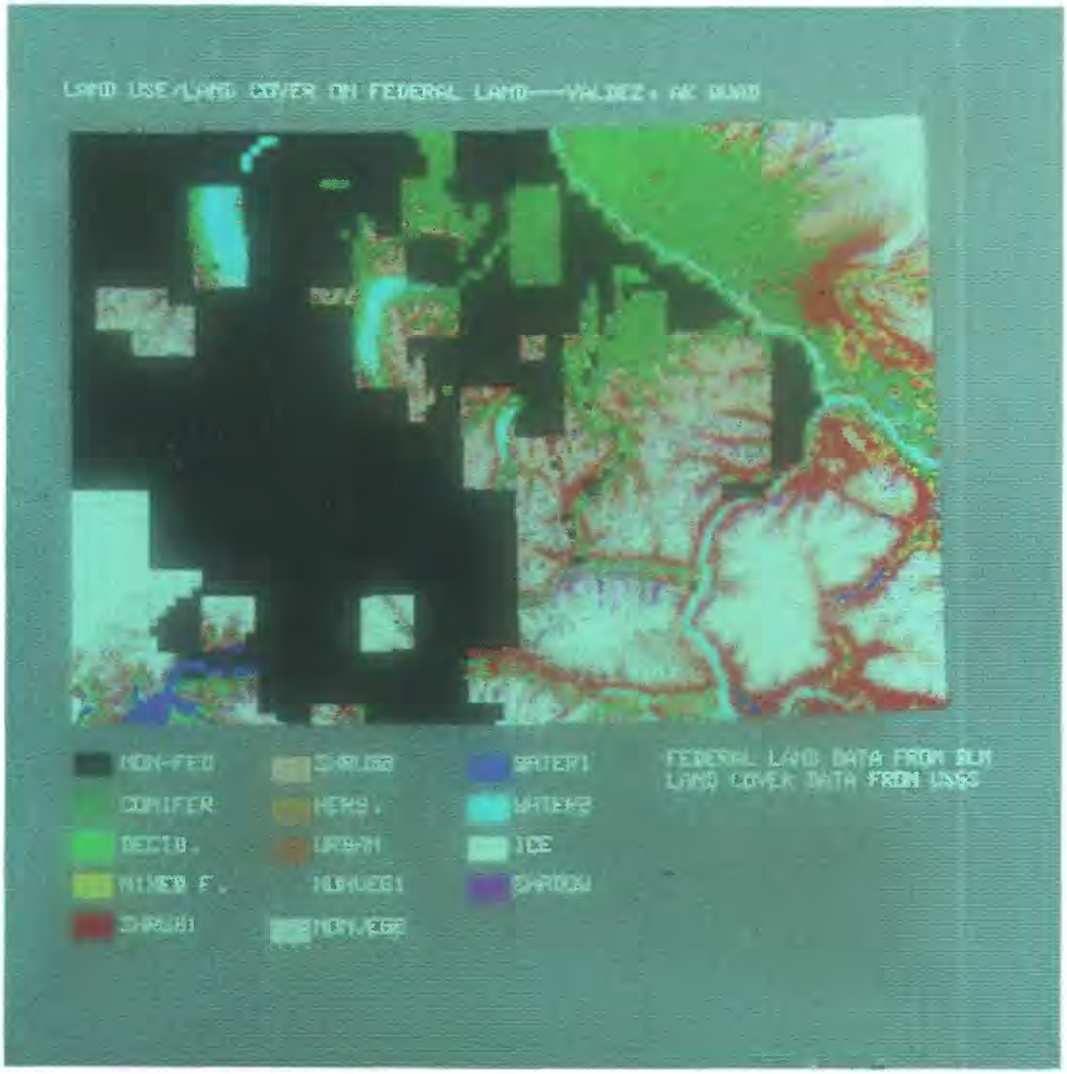

Figure 36.--A land cover classification of Federal lands for the Valdez, Alaska, 1:250,000-scale quadrangle. The raster Alaska Interim Land Cover data were generalized from nearly 100,000 land cover polygon areas to about 10 percent of that number. The generalized land cover data and the Alaska ALMRS surface land ownership data were then used on a raster system to generate this product.

identify the geologic host rocks of the selenium; and (3) to determine the ultimate source of the selenium. The National Mapping Division's role in this joint effort is to help formulate the models for trace element transport using GIS techniques.

A comprehensive digital data base has been constructed for the portion of the San Joaquin Valley from Stockton to Fresno, Calif. Six arc-second DEM's covering the Monterey, San Jose, Fresno (western half), and Mariposa 1:250,000-scale quadrangles have been mosaicked together. Two Landsat MSS scenes covering most of the area have also been mosaicked. The 1:250,000-scale geologic maps showing geologic units and faults and more detailed geologic maps at 1:24,000 scale were digitized and entered into the data base. A soils map was digitized by a contractor and included in the data base. Geochemical data collected at point locations throughout the entire study area and for the Panoche Fan intensive study area were supplied by the Geologic Division. From these point data, interpolated surfaces were generated. The DEM and Landsat mosaics, the geologic and soils maps, and the geochemical surfaces are all in raster format and are being analyzed using IDIMS. In addition, geochemical points are stored in vector and tabular formats in the ARC/INFO system.

Preliminary overlay analysis of geology and the interpolated geochemical surfaces, particularly in the Panoche Fan intensive-study area, have shown obvious relationships between certain geochemical trace elements and rock types. It is possible that the soils and structure data layers may aid in identifying modes of trace element transport. Factor analysis has helped to identify relationships between trace elements and simplifies using the geochemical data in modeling. Spatial analyses applied to the data base will be completed in 1987, and results of the study will be jointly published by the National Mapping Division and the Geologic Division.

Data Base and Information Processing in Support of Conterminous United States Mineral Appraisal Program (CUSMAP)/Alaska Mineral Resource Appraisal Program (AMRAP)

Cooperative research is being conducted with the Geologic Division in the application of an advanced GIS to mineral resource assessment. This joint effort has resulted in the development of extensive geological, geophysical, and geochemical digital data bases and resource-specific data processing tech- niques. Selected 1° x 2° quadrangles are currently being evaluated as part of the Survey's CUSMAP and AMRAP activities.

Multivariate models based on known mineral occurrences and spatial analyses of variables incorporated within the data bases were used to identify and quantify vein-, porphyry-, skarn-, and placer-type base- and precious-metal mineral potential in the Dillon, Idaho-Mont., and Butte, Mont., 1° x 2° quadrangles. Of particular importance in this effort was the development of interfaces between vector, raster, and tabular data processing subsystems of the GIS. The interfaces facilitated the reformatting and transfer of data to appropriate hardware and analytical tools within the system.

Cartographic products from these studies are currently being prepared for publication in the Survey's Miscellaneous Field Investigations Map Series (figs. 37 and 38). When this phase of research is completed, the technology will be transferred to the Survey's regional centers for operational testing and application.

Slope and Aspect from Digital Elevation Models for Soil Classification

For the past 5 years, the Division has assisted the Soil Conservation Service (SCS) in using DEM's to derive slope and aspect maps and statistical summaries for the production of soil premaps. Procedures jointly developed under the Soil Landscape Analysis Project have progressed through research and development to operational implementation by the Bureau of Land Management and SCS. In 1986, investigations

Figure 37.—-Map showing the results of modeling geological, geophysical, geochemical, and mineral resource data within a GIS to describe favorable environments for vein-type base- and precious-metal mineralization in the Dillon, Idaho-Mont., 1° x 2° quadrangle. Color codes describe model intervals ranging from 0 to 18 points (18 points equals most favorable).

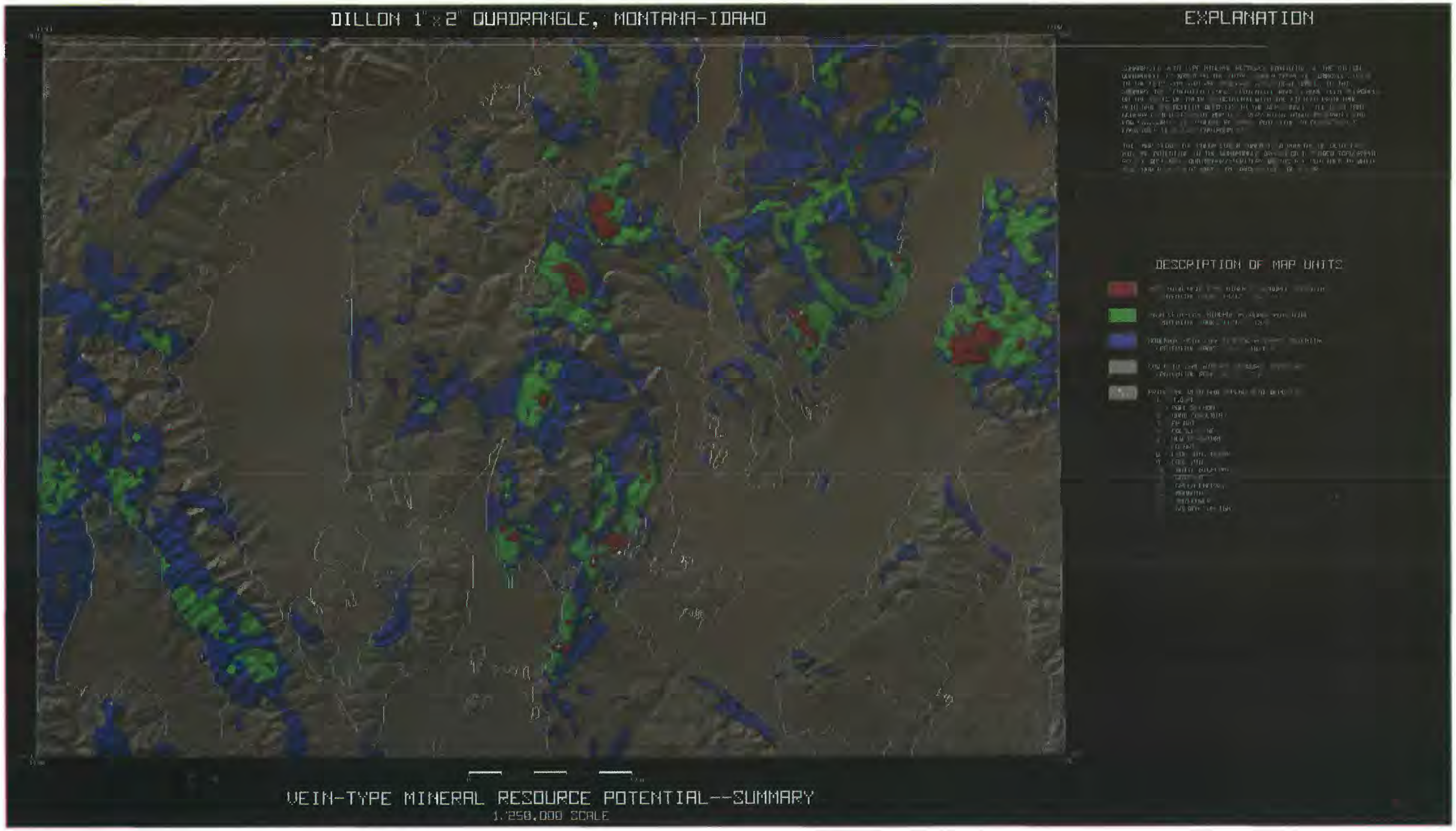

Figure 38.--Map showing the summary of vein-type base- and precious-metal potential in the Dillon 1° x 2° quadrangle. The summary is derived from an aggregation of model intervals shown in figure 37. The summary classifies areas as having very high, high, moderate, and low potential for undiscovered vein-type mineral deposits.

were continued with the SCS in which a set of standardized aspect and slope map products have been defined and developed that can be provided wherever 7.5-minute DEM data are available.

One of the goals of the continuing investigation is to move from specialized analysis techniques into a more generic set of analysis functions. Thus, for the production of standardized aspect and slope map products, the Division will be using a restricted set of well-defined grid cell functions, a standard relational data base management system, and a commercially available statistical package. With minimal effort, any of these systems can be replaced by comparable systems. The processing sequence will be finalized in 1987 and transferred from a research and development environment to a production operation, whereby Federal agencies can order customized slope and aspect maps and statistical summaries derived from DEM's.

Structuring Attribute Files for Interpreting Soils Data

In a cooperative project with the SCS the Division is incorporating the State General Soil Geographic Data Base (STATSGO) into a GIS. As part of this process, the soils attributes have been reformatted into a relational data structure.

The characteristics, properties, and interpretations of soils are maintained by the SCS as part of its national soil data bases. The Soil Interpretation Record data base contains 150 attributes for each of the 25,000 soil series used in the United States. The records are referenced to a mapping unit by the Map Unit Use File data base, which describes the 300,000 map units used in the United States. A mapping unit may be made up of several soil phases. For each phase, a single phase record can be formed that contains the soil interpretations for that phase.

The single-phase records have been restructured into a normalized form for use in a relational data base. Separate relational tables have been created for each level of the hierarchy of soil attributes with key fields to link them together. In relational form, the data are suitable for query and analysis in a GIS in order to produce interpretive maps and tables.

Interpretation of Soils and Land Use and Land Cover for the Chesapeake Bay Watershed

As part of the STATSGO cooperative project with the SCS, the Division has produced interpretive maps of soil properties from digital soil association maps. Data currently are being acquired for the project in the Chesapeake Bay watershed study area. A GIS is used to produce interpretive maps from the soil association data. The data are overlayed with land use and land cover data, and summarized by hydrologic unit or political unit. A visual representation of topographic background is provided by a shaded-relief image generated from a DEM, and geographic reference is provided by DLG data for transportation and hydrography.

The STATSGO project will provide the first nationally available computerized soil association maps, which are expected to have substantial applications for water resource planning and management. The maps will be available by mid-1988.

Annual Educational Weather Balloon Launch Graphic

In 1985 the Triangle Coalition for Scientific Education (TCSE), in conjunction with the American Geological Institute, sponsored a simultaneous launch of approximately 5,000 helium-filled balloons by public school students across the country. The launching was to become an annual event for the encouragement of scientific interest and inquiry among students nationwide. By identifying the landing site of recovered balloons, wind patterns in effect over the Nation at the time of the launch could be ascertained. The 1986 launch of approximately 200,000 balloons marked the involvement of the Survey in an effort to develop an automated means of visually portraying the results of the experiment. Software was developed to convert the geographic coordinates taken from the Geographic Names Information System data base into decimal degrees for each of the launch and retrieval sites. The point data were then passed through additional software to create line segments for processing using ARC/INFO software. The Versatec plotter was then used to produce a hard-copy graphic of the launch and retrieval sites of the balloons (fig. 39).

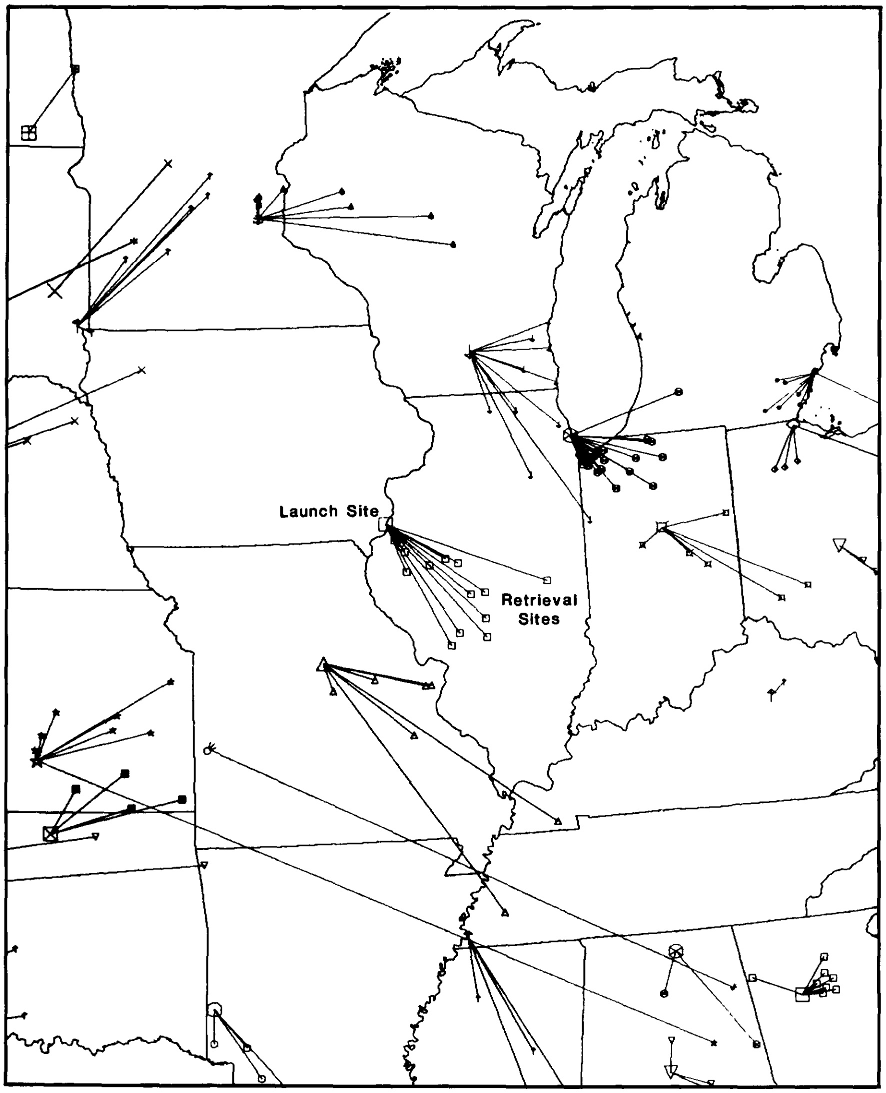

Figure 39.--Reduced (1:4,000,000-scale) portion of 1986 balloon launch graphic. The Great Lakes region is in the upper right corner.

TECHNICAL INSTRUCTIONS FOR THE NATIONAL MAPPING PROGRAM

Technical documentation of products and services of the National Mapping Program is being prepared to update and expand the Manual of Technical Instructions, which sets forth policies, standards, and procedures. The Manual includes:

- Standards - Documents which are used as the basis for establishing and judging the quality of the National Mapping Division products and services. The core standards for cartographic products are the map symbol specifications and the National Map Accuracy Standards. In general, standards do not incorporate instructions as to how the standards are to be met. Such descriptions are left to procedure manuals. Portions of the following standards have been drafted or completed:

  - Preparation of Technical Instructions
  - 1:24,000- and 1:25,000-Scale Quadrangle Maps
  - 1:50,000- and 1:100,000-Scale County Formatted Maps
  - 1:100,000-Scale Quadrangle Maps
  - 1:100,000- and 1:250,000-Scale Land Use and Land Cover and Associated Maps and Digital Data
  - Digital Line Graphs
  - Digital Elevation Models

- Procedure Manuals - Procedure manuals provide guidelines for the production processes necessary to create products to meet the standards. Procedure manuals drafted or completed include:

  - Configuration Management
  - Management of Scientific Computer Software
  - Calibration of Comparators
  - Calibration of Photogrammetric Cameras
  - Preparation of Satellite Image Maps
  - Off-line Orthophoto Printing System
  - Off-line Orthophoto Printing System Data Preparation
  - Map Accuracy Testing
  - Digital Elevation Model Editing System
  - RETSAM, Review, Editing, and Tagging Software for Automated Mapping: Manual for Systems Managers

- Software Documentation - Software documentation provides the maintenance programmer with the information needed to understand a program, its operating environment, and required maintenance procedures. Existing divisionwide scientific software that has never been documented is now being documented with emphasis on programs that are used as subroutines in other programs or that interface with other programs. New software is documented by the programmer who develops it.

- Users Manuals - Users manuals provide information in nontechnical terms on how to use a program correctly, including how to prepare the input data, execute the program, and interpret the results.

- Data Users Guides - Data users guides present information about National Mapping Division digital data and are specifically written for the public user. The purpose of the guides is to allow the potential user to determine if and how the data can be used. The guides provide an overview of data structures, data formats, and coding schemes. They are published in the U.S. Geological Survey Data Users Guide Series and are replacing Circular 895, which addressed the Survey's digital cartographic data standards. The data users guides may be obtained through the National Cartographic Information Center. Data users guides currently available are:

  - Digital Line Graphs from 1:24,000-Scale Maps
  - Digital Line Graphs from 1:100,000-Scale Maps
  - Digital Line Graphs from 1:2,000,000-Scale Maps
  - Land Use and Land Cover Digital Data from 1:250,000- and 1:100,000-Scale maps
  - Digital Elevation Models
  - Geographic Names Information System
  - Alaska Interim Land Cover Mapping Program

STANDARDS FOR GEOGRAPHIC NAMES

The U.S. Board on Geographic Names, conjointly with the Secretary of the Interior, is responsible by law for providing uniform geographic name usage throughout the Federal government in cooperation with State and local governments and the public. The Survey provides staff research and administrative support for the domestic names activities of the Board. These efforts include the preparation and publication of decision lists and other documents needed for support of national standardization and gazetteer programs. Recent publications include:

- The Board on Geographic Names' Principles, Policies, and Procedures - Domestic Geographic Names, 1987. This document represents the first time since 1933 that the Board's guidelines for national standardization have been made available in one publication.

- The National Geographic Names Data Base - Phase II Instructions, 1987. Phase II Instructions provide, for the National Gazetteer Program, standards and procedures for collecting names data from published sources other than large-scale Survey maps. Instructions are necessary because most of the work is done by cooperating State agencies and universities. Phase I, the collection of names data from Survey maps, was completed in 1981.

- Function and Organization of a National Geographical Names Program. This publication, prepared by National Mapping Division staff and to be published by the United Nations, outlines the organization and basic procedures for establishing a national geographic names authority and carrying out a standardization program. The document was prepared at the request of the United Nations Group of Experts on Geographical Names to assist its program of international standardization, which is essentially based on national standardization.

DEVELOPMENT OF FEDERAL GEOGRAPHIC DATA EXCHANGE STANDARDS

Information required for the solution of many national problems is contained in various digital map-based and earth-science related data bases. Unfortunately, these data bases, maintained by separate Federal agencies, have different, mostly incompatible data structures and formats. These different structures and formats have made the exchange and integration of Federal geographic and cartographic data very difficult.

In part to address this problem, the Office of Management and Budget (OMB) created in 1983 the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC), consisting of 27 Federal agencies and chaired by the Chief, National Mapping Division. FICCDC was charged with the critical task of "developing and adopting, for use by all Federal agencies, common standards of content, format, and accuracy for digital cartographic data to increase its interchangeability and enhance its potential for multiple use." A first step towards these standards is delineating the data structures and formats needed to facilitate interagency exchanges of digital cartographic and geographic data. The prototype Federal Geographic Exchange Format (FGEF) developed by the Standards Working Group of FICCDC is such a step.

In developing the format, some major concerns were immediately apparent to the FICCDC Standards Working Group. First, the format would have to accommodate existing spatial and earth science data bases as much as possible. Second, the format would have to be flexible enough to handle future spatial data base developments. Finally, the format had to be prevented from becoming unwieldy both in terms of complexity and in terms of implementation costs. Simplicity and flexibility became the primary design goals.

Testing of the prototype FGEF is being conducted within and between many Federal agencies in many parts of the country. Hydrographic, topographic, hydrologic, demographic, geologic, administrative, navigation, transportation, land survey, ownership, soils, natural resource, and other types of data are all being used to test the capabilities of FGEF. Once this prototype testing is completed in 1987, the National Mapping Division will be responsible for finalizing an operational version of the exchange format, the ultimate goal being to make the format a Federal Information Processing Standard for the exchange of digital geographic and cartographic data.

TRAINING AND TECHNICAL ASSISTANCE IN REMOTE SENSING AND GIS TECHNOLOGY

The Division administers an extensive program of training courses in remote sensing and GIS applications to resource management problems. Primary attention in the training program has been to prepare Department of the Interior agencies in techniques related to remotely sensed data analysis. Technological developments in data processing and analysis systems have, however, led to a shifting emphasis in the workshop program. In addition to training in traditional remote sensing data sets (aircraft and satellite sensor systems), an increasing training emphasis has been on the integration of data sets (for example, topographic and geochemical) into a GIS.

In the past 2 years, fifteen 1-week workshops related to remote sensing and the development of GIS's have been offered. A typical workshop will include sessions on the characteristics of remotely sensed data, the integration of such data in information systems, and the utility of such systems in solving resource inventory problems.

In addition to the 1-week workshops, a more extensive 5-week workshop is offered annually for the international community. A series of 25 International Remote Sensing Workshops has been given, and over 500 scientists, representing 92 countries and a full range of earth science disciplines, have attended. Emphasis in the international workshops has been on the manual analysis of Landsat data and application of that analysis to resource management needs. Recent workshops have included sessions on supplemental data sources and introduction to digital data processing and analysis systems.

TECHNICAL EXCHANGE WITH THE PEOPLE'S REPUBLIC OF CHINA

Through an agreement between the United States and the People's Republic of China (PRC), the Survey and the PRC National Bureau of Surveying and Mapping (NBSM) have agreed to a protocol of scientific and technical cooperation in two areas: (1) the development of geographic information systems; and (2) the application of remote sensing techniques. This protocol was initiated during 1986 and several visits were made by scientists of both countries. Continuing work plans for 1987 have been developed that also include activities by NOAA on geodetic data bases and by DMA on geographic names data bases.

The cooperative studies on remote sensing are directed at jointly developing capabilities to make image maps, thematic maps, and map revisions at scales of 1:50,000, 1:100,000, and 1:250,000. The NBSM chose the Ningxiang area in Hunan Province and the Survey chose the Black Hills area in South Dakota for conducting the studies. In 1986, Chinese and American scientists digitally processed Landsat Thematic Mapper data acquired over the Black Hills area. They used the digital image processing facilities at the Survey's EROS Data Center and jointly performed radiometric calibrations, destriping, control point selection, geometric registration, resampling, mosaicking, contrast stretching, spatial filtering, training site selection, classification, and product generation. Results of this work were evaluated in the field in September 1986. Work will continue in 1987 using both Landsat and SPOT data acquired over the Ningxiang area.

WRD/WYOMING STATE ENGINEERS OFFICE GIS TECHNICAL ASSISTANCE PROJECT

The Division has entered into a cooperative project with the Water Resources Division (WRD) Wyoming District Office and the Wyoming State Engineers Office to produce 52 DLG data sets covering the Wind River Indian Reservation. These data served used as a base for the compilation of water rights information in an ARC/INFO GIS for use in a water judication action. The Division provided technical assistance in the conversion of the DLG files to WRD's PRIME-based GIS, and assisted in training the Wyoming WRD District Office and State personnel in the use of ARC/INFO software. Additional assistance to the Wyoming State Engineers Office has included the transfer of several modified ARC/INFO programs that enable a more efficient use of ARC/INFO capabilities. The National Mapping Division will continue to assist Wyoming WRD and State personnel as they acquire more experience with DLG data sets and ARC/INFO.

GEOGRAPHIC NAMES INFORMATION SYSTEM

Data Base Management

The Survey, in cooperation with the U.S. Board on Geographic Names, has established an automated names data base as a national names depository. This data base, called the Geographic Names Information System (GNIS), has been designated the official source in the Federal Government for publication of features with proper names. Many State and local governments, as well as business and the general public, rely on the integrity of GNIS data. Management of the data base requires attention to maintenance, training, user services, and product development. Recent data base improvements include a more efficient backup procedure, streamlined data input procedures, and simplified procedures for user access. GNIS products such as interim gazetteers and other listings are produced more efficiently using laser printers. Both standard and nonstandard GNIS tape products are now available to users through the National Mapping Division's National Cartographic Information Center. The Division is currently evaluating possible reconfiguration of the data base to allow more efficient access by the growing community of GNIS users. In addition, guidelines for expanding interactive access to GNIS by other Federal agencies are being developed.

Software Development and Maintenance

A replacement for the Datapoint version of the GNIS Data Input Program was developed for use in an IBM-PC compatible environment. The program prompts the user for data through a series of approximately 20 input screens. Auxilliary attribute generation, data checking, and error-handling routines are incorporated in the procedure. Function keys are used for various operations including viewing of user help screens and error correction. A somewhat more extensive data checking routine for geographic coordinates has been developed and will be available with the next version of the software. The coordinates entered will be validated against the name of the map entered. An offshoot of the development of this routine will be a geographic coordinate/map name query system. Software documentation manuals and a users guide are being prepared.

Topographic Map Names Data Base

The Topographic Map Names Data Base is the repository of official names and other associated information about the topographic map series published by the Survey. The data base is maintained from the information provided by the Division's regional mapping centers and other sources for special map series. The primary activity has focused on the input of data regarding approved names for previously unmapped areas. Routine maintenance includes alterations relating to changes of names previously assigned during standard topographic mapping and bathymetric mapping, or as a result of actions taken by the U.S. Board on Geographic Names.

Special Projects

The Concise file of GNIS is designed to be an abridged version of the entire National Geographic Names Data Base. It consists of domestic names contained in the index of the Survey's National Atlas of the United States of America with the addition of other prominent cultural and physical features. To assure that the coordinates of a feature in the Concise file agree with the coordinates of that feature in the individual State files, software was developed to match the names from both files. The coordinates were then compared to determine if they fell within a 30-second tolerance. If they were within tolerance, the coordinates from the Concise file were replaced by the more accurate coordinates from the GNIS State file. Those features with matching names but whose coordinates fell outside the tolerance were written to a separate file and manually checked. Software was written to interactively add elevations to populated place records. The name, State, and coordinates of the populated place appear on the computer terminal and prompt the researcher for the elevation. Then using the Dictionary of Altitudes in the United States, the alphabetical State listings, and other pertinent sources, the elevation is determined and entered into an update file that is then processed into the Concise file.

The Micronesia GNIS file consists of entries for the Marshall, Caroline, and Mariana Islands, the former Trust Territory of the Pacific Islands. A contractor compiled information on the Carolines and Marianas from Survey maps, DMA charts, and U.S. Board on Geographic Names' Foreign Names Committee cards. Compilation of the Marshalls has not yet been done because of a lack of large-scale map coverage. After completion of the contract, the name cards for the Marshalls were obtained for edit and addition to the Micronesia file.

GAZETTEER PROGRAM

The National Gazetteer Program is a concerted research effort to publish The National Gazetteer of the United States of America as U.S. Geological Survey Professional Paper 1200. The National Gazetteer is being published in separate volumes for each State and territory or outlying area. The research prior to publication is completed in two phases. Phase I has been completed for all States, territories and outlying areas and includes recording most of the geographic names from large-scale topographic maps. The second phase, Phase II, is research on a State-by- State basis and includes recording names from most Federal and State sources as well as historical and other pertinent materials. After the second phase is complete, a new State gazetteer is published.

Gazetteer volumes for New Jersey, Delaware and Kansas have been published, and the Arizona volume will be published in 1987. The Oregon volume is being edited and is scheduled to be printed in 1987. Contracts for research and compilation of names data are in process for South Dakota, North Dakota, Florida, Alabama, Mississippi, and Utah, and these volumes will be processed in that order.

DIRECT DERIVATION OF 1:250,000–SCALE CONTOURS FROM 1:24,000– and 1:100,000–SCALE SOURCE MATERIALS

In planning for the production of geologic maps based on the 1:250,000–scale Harrison, Ark.–Mo., quadrangle, the Arkansas Geology Commission found the horizontal and vertical accuracy of the existing 1958 map to be unsatisfactory. They expressed the need for a more accurate map and requested the contours be in customary units. Currently, metric unit contours are a requirement of the 1:250,000–scale series.

The 1958 map has a 100–foot contour interval, an extremely tight interval for the type of topography found in this part of the Ozarks. An estimated 400 hours would be required to scribe the customary unit contours requested by the Commission. Because there was no other requirement for customary unit contours at the 1:250,000 scale, finding a less costly method of contour generation was important in planning the project. A plan was devised to produce topographic 1:100,000–scale quadrangles from 1:24,000–scale quadrangles using conventional procedures. The 1:100,000–scale topographic editions would then be used as the source material to revise the Harrison 1:250,000–scale quadrangle.

The 1:24,000–scale quadrangles were reduced to 1:100,000 scale and paneled. Contours were interpolated to metric units during the scribing process. Contours were first scribed on the 1:100,000–scale boards at a 40–meter interval. After a film was made, contours were added to create the desired 1:100,000–scale contour interval of 20 meters. Metric unit contours for the 1:250,000–scale quadrangle were derived by reducing the 1:100,000–scale, 40–meter contour films to the smaller scale and paneling them together.

Contours for the customary unit version were produced by reducing the four 1:100,000–scale panels (composed of reduced 7.5–minute contour panels) to 1:250,000 scale and paneling. Because of the reduction from 1:24,000 scale to 1:250,000 scale, the intermediate contours dropped out, leaving only the heavier index contours which, as a result of the reduction, were approximately equal to the intermediate lineweight. The 7.5–minute contour interval is 20 feet; therefore, the derived interval is 100 feet, the same interval that is on the 1:250,000–scale map of 1958.

Contour lineweights on individual 7.5–minute panels can be photographically controlled when the contours are reduced to 1:100,000 scale, or, if the reduction has already taken place, masks can be cut to allow photographic manipulation of individual panels. The latter method was used on the Harrison map. Limited touchup work was done to the resulting negative. Index contours for the 1:250,000–scale quadrangle were scribed on a separate guide and combined with the photographically derived contour plate into a reproduction negative––the heavier scribed index contours covering the corresponding lighter contour line. Separate contour number and spot elevation plates were produced for each version.

This method of contour production for derivative mapping requires significantly fewer man–hours than would normally be required to scribe a map of this contour density, and very little additional photographic processing time is required (about 20 hours for Harrison). When Practical the 100,000–scale contour interval could be reproduced at the smaller scale, providing a tighter than usual contour interval at no additional cost.

PROTOTYPE TECHNIQUES FOR THE DIGITAL REVISION OF HYDROGRAPHY IN ALASKA

Research was conducted during 1986 to investigate techniques for producing Digital Line Graph-3 (DLG-3) hydrographic overlays from revised Alaskan map quadrangles. Strong interest in obtaining current digital data for Alaska as expressed by several Federal and State agencies was a significant requirement behind this investigation. Compatibility with NDCDB data was a key requirement from the National Mapping Division perspective.

The primary objective was to examine and compare manual and semiautomated digitizing procedures for their capability, accuracy, and cost. A secondary objective was to determine the suitability of digitizing the hydrographic data category from othophotoquads using color-infrared (CIR) photography to interpret the land/water interface.

The Cordova (B-4), Alaska, 1:63,360-scale quadrangle was selected jointly by the Alaska Department of Natural Resources and the Survey as the pilot test site. This quadrangle is approximately 160 miles southeast of Anchorage and covers a portion of the Copper River delta. The original map, published in 1951, was in need of revision from an uplift of the delta area following the 1964 Anchorage earthquake.

In the first compilation method investigated, a scale-stable film positive orthophoto was used as the source material, with the exposure exaggerated to provide the greatest amount of contrast between land and water. In comparing the orthophoto with the CIR photographs, it was found that most of the lakes and streams visible on the photographs were not readily visible on the orthophoto. The land/water interfaces were outlined on a clear, scale-stable, punch-registered overlay using a stereo-
scope to observe the stereoimage formed by the orthophoto and CIR photograph. Standard manual digitizing procedures were then applied when capturing DLG-3 format topologically structured data.

The second method of data compilation examined consisted of three main phases: analog data collection through stereocompilation, followed by raster scanning of the compilation manuscript and subsequent data editing. The third method of obtaining DLG-3 data involved manual digitizing using the Environmental Systems Research Institute's ARC/INFO GIS software package. Semiautomatic tagging techniques were utilized to attribute the appropriate nodes, lines, and areas.

Based on the findings of this project, the use of orthophoto quadrangles as source materials for manually digitizing hydrographic data in Alaska is inadvisable. Although orthophotos may be suitable source materials for digitizing certain data categories such as roads or vegetation in areas of low relief, their use for manual digitizing of all data categories, and especially Alaska hydrography, is limited by their resolution, the potential for incomplete content and compilation, tedious manual compilation methods, and overlay misregistration.

The use of manual digitizing systems, including advanced systems such as ARC/INFO, also may not be a feasible means for collecting DLG-3 Alaska hydrographic overlays. Known deficiencies in manual digitizing, including high processing costs, the requirements for quality source materials, and the complex nature of hydrographic detail existing on many Alaska quadrangles, supported the search for alternative data collection technology and methods.

Stereocompilation and semiautomatic tagging techniques were found to be a superior method of collecting DLG-3 Alaska hydrographic data. A refinement of techniques is necessary before full cost savings can be achieved. Nevertheless, the National Mapping Division has developed new DLG-3 processing software and enhancements to existing Scitex and DLG-3 processing software that will further streamline the time and procedures used for the second method of this investigation.

DEVELOPMENT OF DIGITIZED FONTS FOR INTERACTIVE TYPE PLACEMENT UTILIZING SCITEX TECHNOLOGY

Current type fonts in use on the Intergraph Interactive Graphic Design System were developed mainly by manual digitizing. After characters were digitized into a design file, the individual characters were incorporated into a cell library for update into the font library. The plotting of fonts generated by this method tends to be time consuming due to the excessive number of coordinate pairs in each character. Text created in this manner usually has an excessive number of lines in each character as well. Excess lines were required to ensure that no holes were visible in the plotted cjaracter. By using the Scitex to scan the text, to create the outline of the text, and to vectorize lines within text, the following improvements are achieved:

1. The shape of the text exactly matches the original text shape created by the typesetter.

2. The Scitex frame commands produce uniform offset lines within letters, totally filling the character.

3. A minimum number of coordinates are produced due to vectorization performed by the Scitex.

4. Scitex scanning is a more cost-effective solution for digitizing font libraries than manual digitizing.

The results of using text generated by the Scitex are that both the updating of the Intergraph display screens and plotting by the Gerber plotter are significantly faster. The resultant output from the Gerber plotter has been visually compared to the original text from the typesetters and found to match exactly.

ENHANCEMENT OF THE DEM EDITING SYSTEM

In 1986, several important upgrades to the DEM Editing System were implemented in production and quality control operations. The DEM Editing System provides for visual inspection and verification by computer processing of the DEM data to create color image displays of color-banded elevation, shaded relief and slope, and anaglyphic stereographic displays. Image enhancement techniques, such as pseudocolor and histogram equalization, can be applied as well as interactive editing techniques, including single-point editing, based on either simple point replacement or sophisticated neighborhood averaging and area editing of either previously stored data or of data being collected during online map digitizing.

The DEM Editing System was upgraded to improve effectiveness of production, compatibility with the NDCDB data structure, capability to display data from a 7.5-minute quadrangle in standard format, and capability to interactively edit individual points and collections of points. Tradeoffs among cost, user training, speed, and memory requirements led to a system based on the Digital Equipment Corporation LSI 11/23 microcomputer system and a Comtal display, which brings the functional power of the PDP 11/34 class of minicomputer to the microcomputer level. This powerful image processing system, coupled with interactive software, provides significant error detection and correction capability. The original system has been upgraded with the addition of a digitizing table and programs to calculate the root-mean-square error of the DEM. The wide color range displayed affords a significant ability to visually detect slope irregularities. The anaglyphic stereographic and shaded-relief displays are comparable in quality to those generated on more high-powered and expensive minicomputers. Four systems are now used in National Mapping Division production. A typical DEM Editing System is shown in figure 40.

Figure 40.--DEM Editing System.

SCIENTIFIC AND TECHNICAL REFERENCE COLLECTION

Since the scientific and technical reference collection was established in the Division in 1982, the number of staff members served has steadily increased. This library collection contains over 5,000 books and periodicals in the fields of automated cartography, geography and geographic information systems, photogrammetry and remote sensing, and computer sciences (fig. 41). Because this is a supplementary collection, a majority of these publications are not available in the main Survey library. During 1985–86, a total of 539 new books and periodicals were added to the collection.

The development of dBase II records and programs for automation of the author/title/subject catalog was completed in 1986 and a report with documentation was published as U.S. Geological Survey Open-File Report 86-003, "A Computer-Based Library Reference System." In late 1986 the library received a new microcomputer with expanded memory capacity and dBase III+ software to enhance the catalog record. To date all catalog and program files have been successfully transferred to the new system.

Figure 41.--National Mapping Division employees using the scientific and technical reference collection.

Several years ago the library established an archival collection of published and internal reports and papers published by Division staff members. Currently (1986), there are 1,258 reports, papers, or published abstracts in this collection.

HISTORICAL MAP ARCHIVES

The National Mapping Division historical map archives contains over 200,000 maps dating from the 1870's to the present (1986). During the past 2 years, over 9,000 maps were added to the archives, and a map library technician was hired to manage the growing collection. The maps are catalogued in three time periods, 1870/80's to 1933, 1934–1984, and 1985–2035. Methods are being investigated, such as the preparation of color microfiche records, to preserve the early historical maps from the 1870/80's-to-1933 segment. At present, only a black-and-white microfilm record exists of these maps. In the meantime, the more fragile maps are being enclosed in acid-free folders and tears are being repaired with special archival tape.

CONFIGURATION MANAGEMENT

Configuration management is a process designed to promote positive control over a complex system during its life cycle. It consists of a rigorous accounting procedure to control, record, and report changes and to monitor implementations of and modifications to systems.

One of the goals of the National Mapping Division is to promote and establish procedures for the standardization and change control of selected advanced cartographic systems and processes. In most cases, these selected systems will be computers, computer-controlled equipment, computer software, or a combination of these items. Research and development processes also require formal change control. In this way, the design and subsequent changes to the design are properly reviewed and documented. This standardization and change control will be accomplished through a formal configuration management process. Further, the Geological Survey and the Defense Mapping Agency have signed a Memorandum of Understanding to establish a uniform method of defining and controlling changes to selected hardware, software, and processes common to both agencies.

The key features of configuration management are the following:

- Improved quality control and minimization of the impact of change
- Systems changes based on full coordination and concurrence of all affected parties and implemented only upon proper approvals
- Full capability of all levels of the organization to initiate corrections and to propose enhancements
- Complete documentation of all proposed changes, whether implemented or not
- Full audits to ensure the integrity of the controlled systems with regard to specifications, documentation, and requirements

The Chief, National Mapping Division, has established a Configuration Control Board (CCB). A memorandum, signed by the Division Chief, designates a system to be placed under configuration control and specifies an Office of Primary Responsibility (OPR) for the maintenance of the system. The OPR develops the baseline documentation for the system. The baseline documentation, when approved by the CCB, becomes a reference point against which changes can be proposed, evaluated, and incorporated.

Anyone may initiate a change. A change can be the correction of a problem or the addition of a new capability. The change is initiated by preparing a Discrepancy Report, which is then evaluated by the OPR. If the Discrepancy Report is found to be valid, a Request for Change is written and distributed to the CCB members for evaluation. If approved, the changes are made to the affected system. The CCB monitors the implementation of changes and, when necessary, calls for audits of a system to verify that the current baseline documentation matches the actual status of a system.

AERIAL CAMERA CALIBRATION ACTIVITIES

The Division's Optical Science Laboratory continues to provide scientific-quality camera calibration services for Federal and State agencies and for commercial clients. During the 2 two years, calibrations have been performed on 176 aerial mapping cameras submitted by the Survey, Tennessee Valley Authority, U.S. Forest Service, U.S. Army Corps of Engineers, DMA Inter-American Geodetic Survey, several State highway departments, private mapping contractors, and camera manufacturers. Two Hasselblad cameras were calibrated for the U.S. Navy, David Taylor Model Basin of the U.S. Navy. The "Procedure Manual for Calibration of Photogrammetric Cameras" has been published as a volume of the Division's Technical Instructions.

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