E7.3 10551
CR-131850

Bi-Monthly Progress Report
For the Period Beginning 1 March 1973 and Ending 30 April 1973

A. Title of Investigation:

An Interdisciplinary Analysis of ERTS Data for Colorado Mountain Environments Using ADP Techniques

ERTS-A Proposal Number: SR030/040

B. GSFC Identification Number: UN103
Principal Investigator: R. M. Hoffer

C. Problem Areas. Receipt of Mission 213 data from JSC in Houston has partially relieved problems encountered because of inadequate underflight data over the San Juan Test Site. Unfortunately, Mission 213 covers only a small portion of the test site. The result continues to be a general lack of comprehensive and detailed photography for use in preparing cover type maps and for analysis of the ERTS imagery. This problem has been partially overcome through cooperation with the U.S. Forest Service, from whom black and white aerial photography for portions of the test site area has been obtained. It should be stressed that good quality, small scale color infrared photography over the entire San Juan Test Site is urgently needed as soon as spring snow melt has occurred.

A number of problems have been encountered in the analysis and interpretation of computer-generated classification results for the test site area, due to geometric distortions in the bulk CCT data. Probable solutions to these problems have been developed and will be tested during the next reporting period.

A previous analysis problem, caused by the lack of availability of CCT data for Scene ID 1047-17200 was alleviated with the receipt of the required data tapes. ERTS data which is both cloud-free and snow-free still does not exist for portions of the test site areas because of the short time period during which ERTS-1 was operating in the late summer and early fall of 1972. Preliminary analysis attempts for both geologic and vegetative cover type mapping with existing data has indicated that even a light snow cover renders the data unuseable for these analysis purposes. It is anticipated that these problems will be overcome with the receipt of ERTS-1 data during the summer of 1973.

D. Progress during the past two month reporting period has been as follows:

1. Ecological inventory. Analysis on the Indian Peaks area has used data collected January 29, 1973 Scene ID 1190-17140. A classification was generated on the basis of training fields selected by a non-supervised clustering algorithm for an area

(E73-10551) AN INTERDISCIPLINARY ANALYSIS OF ERTS DATA FOR COLORADO MOUNTAIN ENVIRONMENTS USING ADP TECHNIQUES Bimonthly Progress Report, 1 Mar. - 30 (Purdue Univ.) 27 p HC $3.50 CSCL 08F
N73-23424
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approximately corresponding to USGS (Mt. Olympus) quad. Relating spectral classes to cover types proved difficult owing to the scarcity of geographic reference points.

On the same data set, gray scale printouts of the Boulder County area (channels 2 and 4) have been sent to INSTAAR. INSTAAR has been requested to specify coordinates of known ground cover types so that a supervised classification can be implemented. However, location of these areas on the gray-scale printouts has proven difficult, so alternate techniques for interfacing with the ERTS data are being developed by LARS analyists.

Analysis in the San Juan Test Site has utilized data collected September 8, 1972 Scene ID 1047-17200. A classification based on training fields of ten clusters generated by a non-supervised clustering algorithm proved to have too few classes--three classes were in clouds and three in shadow, leaving only four spectral classes to relate to vegetative cover. The non-supervised clustering algorithm was then directed to generate sixteen clusters, and the area around the Rio Grande Reservoir was classified on the basis of these sixteen clusters. Classification results were sent to INSTAAR so that they could halp in ascertaining the relationships between spectral classes and actual ground cover.

Vegetation cover type mapping by INSTAAR has been proceding at an accelerated rate. This mapping is being done using a combination of underflight photography (Missions 205, 211, and 213 from NASA; U.S. Forest Service and Mark Hurd photography) and 1:24,000 USGS quadrangle maps. These vegetation cover type maps will be field checked as soon as the snow cover allows the test area to be accessible again. The symbol set used to define the various vegetative cover types is shown in Appendix A. Considerable time has also been spent by INSTAAR on the interpretation and verification of accuracy of the results of computerized classification results produced by LARS. These maps are based upon classification of spectral cluster groups. Preliminary results indicate good correlation between spectral cluster groups and vegetative ground cover for certain categories of vegetative cover types.

Development of techniques for analyzing the ERTS data and interfacing with available surface observation data and vegetative maps is proving challenging. Progress is being made in developing reasonable techniques for these data interfaces, and in advancing these aspects of remote sensing technology.

2. Hydrologic features survey. Five major and two minor efforts have been pursued during the current reporting period. These include (1) the Indian Peaks small lakes inventory; (2) semi-permanent snow body studies; (3) data preprocessing to correct for geometric distortions in the CCT data, and overlaying of multiple

data sets of CCT data; (4) development of a technique for calculating the area of snow coverage within a particular watershed; (5) assessment of the significance of variations in spectral response of snow cover in forested, mountainous areas. Additionally, we are working on the feasibility of spectrally differentiating between shadow areas and water; and also spectrally differentiating between snow and clouds.

The Indian Peaks small lakes inventory project provides a data base which is required for monitoring lake freeze-up and thaw using ERTS-1 sensors. The study area covers the Continental Divide and East Slope of the Colorado Front Range between latitudes 39°52'30" North and 40°30'00" North. Parameters taken from the 1:24,000 quadrangles include: location, elevation, orientation and size of lakes. Detailed work on a sample of lakes will procede using satellite output, ground truth and statistical analyses.

Studies of semi-permanent snow bodies in the Colorado Front Range area were considerably enhanced by a NASA underflight mission in early September which resulted in high quality color and color infrared photography along the continental divide between latitudes 39°52'30"N and 40°30'0"N. This photography has been studied (using standard photointerpretation techniques) to map the many small glaciers and snow patches along the divide. An extension of this study will be the location of "snow-patch scours" which mark the sites of snow patches which survive late into the ablation season, or throughout seasons which do not have a strong negative budget.

The preprocessing technique, developed by LARS Systems Programmers, involves manipulation of the data to eliminate the skew normally found in printouts of the ERTS data, so that the printouts correspond to north-south and east-west coordinates. A system has also been developed whereby the data can be scaled to produce line printer printouts to a scale of 1:24,000. This result is considered to be a significant achievement, in that we will now be able to overlay ERTS data directly onto 1:24,000 scale USGS topographic maps. This will allow more accurate delineation of watershed areas on the ERTS imagery as well as allow a detailed, rapid interpretation of ADP classification results of the ERTS imagery.

Analysis of snow cover has concentrated on the Animas River watershed near Howardsville, Colorado. Overlaying of channels 5 and 7 for four frames of data (1101-17203, 1 November 1972; 1119-17204, 19 November 1972; 1173-17202, 12 January 1973; 1191-17204, 30 January 1973), which are all cloud-free, is currently underway. Maps and tables showing the variation and areal extent of the temporal changes in snow cover will be produced using this overlay data. Non-supervised (clustering) of ERTS MSS data has indicated several different spectral categories are present within the area covered by snow. Interpretation of the factors causing this variation in spectral response has begun. It appears that the RB-57 photography collected in January 1973 over the San Juan Test Site will be of tremendous value for this aspect of the study.

ERTS frame 1029-17195 (21 August 1972) has been analyzed to determine the capability to spectrally separate water bodies from shadow areas. Vallecito Reservoir, located in La Plata County, Colorado, is the primary water body in this region, and was compared to shadow areas caused by clouds and topographic relief. Preliminary results indicate that spectral differentiation of water and shadow areas is feasible, with MSS channel 7 showing the best differentiation possibilities. However, other areas near the Rio Grande Reservoir have not shown as much spectral separability. Therefore, analysis work on this particular problem will continue with various data sets.

Preliminary results indicate that spectral differentiation of clouds and snow is not possible on an reliable, operational basis with the current ERTS-1 MSS data chracteristics. In some cases it does appear possible, but in many other instances the spectral response from both clouds and snow has been so high that the ERTS MSS detectors have been saturated. Detailed analysis on this project has involved frames 1136-17141 and 1101-17203. Additional analysis to more fully document these results will be carried out as suitable data becomes available.

3. Geomorphic analysis. A paper entitled "Recognition of Surface Lithologic and Topographic Patterns in Southwest Colorado with ADP Techniques" was presented at the ERTS-1 Symposium on Significant Results held at GSFC on March 9-11, 1973. A copy of this paper is attached as Appendix B. Further refinement of these results has continued.

Available ground truth data was collected for the Telluride 15' quadrangle, in the northwest part of the San Juan Test Site. This was selected for analysis as being the only area for which detailed geologic mapping is available, and the area contains landslide deposits, rock glaciers, avalanche tracks, and talus cones, features specified for analysis in the basic contract. Pending arrival of ERTS frame 1066-17254 for Telluride, systems familiarization and training has continued by preliminary analysis from digital display output of a series of linear features (gilgai) or "potholes" in Dawson County, Texas, an area being studied by the ERTS Central States Project (Lubbock) at LARS. Using ERTS-1 frame 1078-16254, run number 72036900, analysis indicates that the potholes are quite definitely related to bedrock joint control and are of significance in monitoring the subsurface hydrology of the region.

INSTAAR completed the mapping and duplication of mylar overlays of the geomorphic maps for nine (9) quadrangles in the San Juan test site. One copy of these overlays was sent to LARS to aid in their analysis of ERTS-1 data of these quadrangles.

4. Terrain Modelling. Activities for this reporting period primarily involved the acquisition of basic topographic data from "ground-truthed" areas of the Silverton, Colorado 7-1/2' topographic quadrangle. This work has been completed. A total of 1900 X-Y-Z (location-elevation) observations were obtained at a uniform density of 100/Km^2 for 3 separate areas. These areas include a 9 Km^2 area of north-south facing slopes along the south fork of Mineral Creek; a 2 Km^2 area of distinct steep west facing and less steep east facing slopes along the north fork of Mineral Creek; and an 8 Km^2 area of alpine surface and east-west facing slopes along Cement Creek. The data have been found (by visual comparison) to accurately reproduce the surface configuration of the source map and have been prepared for transmittal to INSTAAR. Current efforts are directed towards inclusion of slope magnitude and slope orientation as additional Z values to complete the topographic data set.

5. Data Collection Platform. The DCP on Niwot ridge is now operational in all eight channels. A fixed 4 volt input was transmitted on all channels and output was satisfactory although further evaluation is needed, as some variation did occur that is, <u>not</u> attributable to the interface or to the 4 volt input. A detailed account in regard to the sensor package operating through each channel and an evaluation of the total system will be included in the next Type II report.

Activities During the Next Reporting Period

1. During the next reporting period, work on the ecological inventory will focus on scene ID 1047-17200. Four separate analysis projects have been defined. The following cover types will be mapped: clouds, shadows, water, exposed rock and soils, grasslands, cropped areas, meadow, deciduous forest, and coniferous forest.

A visitation to Purdue by three INSTAAR researchers during May is planned to further the analysis of existing data and finalize plans for field checking of the results of these primary classification maps. Additional mapping and duplication of vegetation maps will continue.

Analysis of computer maps by INSTAAR personnel will also proceed through this time period. As this is a summer frame, much better success in defining patterns and boundaries should be possible.

2. Hydrologic Features Survey. Work in this area will concentrate on continued assessment of the significance of variations in spectral response of snow cover and further testing of the technique for mapping temporal variations and calculating areas of snow cover within a particular watershed.

Regional snow conditions will be recorded by INSTAAR personnel to coincide with ERTS overpasses. The use of a light aircraft will facilitate a more rapid and complete assessment than is possible with a motor vehicle on the ground.

This period should be critical in intiation and progression of regional snow retreat. Also, lake thaw patterns will be monitored for later reference to ERTS data collected during this time span.

3. Geomorphic. As the initial training site maps for the project have been completed, analysis and comparison of existing data in regard to computer maps from 1047-17200 will be undertaken. Additional ground truth has been collected in the Durango area which will also be considered.

Final plans for the Field season will be compiled after the May meetings at Purdue.

The LARS team will concentrate on analysis of the Telluride quadrangle. The objectives of this analysis are:

a) To extend the classification statistics for lithologic types; i.e. to add training fields obtained from ERTS data of the Telluride area, for sandstone, shale, and recent alluvium to those obtained near Durango.

b) To automatically classify surface landforms present in the Telluride region (e.s. talus, slopes, rock glaciers, landslide deposits, glacial moraines, colluvium, alluvial cones).

c) To extend mapping eastward across the San Juan mountains, subsequent to technique development in Telluride.

4. Terrain Modelling. For the next reporting period, efforts will focus on delimitation of minimum recognizable geographic areas from the September 8, 1972 imagery and transferal of these areas to 7-1/2' topoquads for encoding of topographic data. Each delimited area will be examined for cover type homogeneity by comparison with existing ground truth maps of field reconnaisance and grouped accordingly. Mean reflectance values from the four channels will be obtained for each area and employed in preliminary analysis of topographic effect, provided a sufficient number of areas of homogeneous cover type can be defined. Continued effort will also be directed toward refinement of topographic data gathering procedures to reduce both cost and time expenditures.

Shadow, slope, and aspects maps will be produced by INSTAAR for the areas where LARS has provided the X-Y-Z coordinate cards to INSTAAR.

F. A paper entitled: "Recognition of Surface Lithologic and Topographic Patterns in Southwest Colorado with ADP Techniques" is attached. This paper was presented at the recent ERTS Symposium held at Goddard March 9-11, 1973.

G. Acknowledgement of retrospective data orders by the Data User Service at Goddard would be appreciated. Currently, we have no way of knowing if retrospective tape orders have been received and if they are being processed. Recently, analysis of data for Scene ID 1047-17200 was delayed two months because we were not aware that the order had never been received by Data User Services, and therefore a long, possibly avoidable delay was encountered.

H. No further additions or changes are contemplated for the ERTS standing orders.

The following list represents 14 scene ID's for which we have received computer compatible tapes. We have determined that these data do not 1) contain a sufficient portion of the test sites or 2) the sites are excessively cloud covered so as to be unusable. The Scene ID's for which the CCT data will be returned to NDPF are:

1083-17201	1154-17150	1172-17261	1192-17260
1118-17150	1155-17201	1173-17200	1192-17263
1119-17202		1190-17145	
1137-17205		1183-17193	

I. Appropriate ERTS Image Description Forms are included as Attachment 1, to this report.

J. A copy of an ERTS Data Request Form for CCT data from Scene ID 1066-17254 is included as Attachment 2 to this report.

K. Originally aircraft underflights were scheduled for April, 1973. No notification was received concerning the status of the April flight. We would recommend written notification from the mission managers concerning flight status. This would aid any additional planning required on our part.

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

NDPF USE ONLY
D
N
ID

DATE May 15, 1973

PRINCIPAL INVESTIGATOR Dr. R. M. Hoffer

GSFC UN-103

ORGANIZATION LARS/Purdue University

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	hydrol	geomorp.	vegetation	
1047-17200 M,D	x			water; clouds, shadows mountains, streams
1047-17200 M,D		x		cirque, divide, moraine, valley
1047-17200 M,D			x	forest; conifer, deciduous, tundra, meadow, grassland, timberline
1191-17204 M,D	x			mountains, snowpack frozen lakes, streams
1119-17204 M,D		x		mountains, annular drainage, dendritic drainage, hogbacks, fault, dike, floodplain, alluvial, terrace, gretslope, strath, superimposed stream, strike valley, gravel deposit

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

NDPF USE ONLY

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ERTS DATA REQUEST FORM
560-213 (7/72)

1. DATE 20 MARCH 1973

2. USER ID UN 103

4. SHIP TO:

ADDRESS R.M. HOFFER ☐ NEW

LARS | PURDUE UNIVERSITY

1220 POTTER DRIVE

WEST LAFAYETTE, IN. 47906

5. TELEPHONE NO. (317) 749-2052 ☐ NEW

6. CATALOGUES DESIRED

STANDARD ☐ U.S. ☐ NON-U.S.

DCS ☐

MICROFILM ☐ U.S. ☐ NON-U.S.

ADDDHHMMS OBSERVATION IDENTIFIER	C CENTER POINT COORDINATES	B SENSOR BAND	P PRODUCT TYPE	F PRODUCT FORMAT	T TICK MARKS	NN NUMBER OF COPIES	A AREA
1066-17254	37.472N 108.786W	M	D	9		1	U
1066-17254	37.472N 108.786W	7	B	P		1	U
1066-17254	37-472N 108-786W	7	B	T		1	U

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Data Release Report

3I and J Geomorphic and Landform Surveys. Lithologic Surveys.

"Recognition of Surface Lithologic and Topographic Patterns in Southwest Colorado with ADP Techniques"

This research was supported by NASA Contract NAS5-21880 GSFC Identification number UN103; Roger M. Hoffer Principal Investigator. Research was performed by Wilton N. Melhorn and Scott Sinnock of the Laboratory for Applications of Remote Sensing - Purdue University.

Analysis was performed on ERTS-1 Scene ID 1119-17204, channels 4-7, (LARS tape library run number 72048000) obtained over the San Juan Mountain Test Site in southwest Colorado on November 19, 1972. The objectives of the analysis were: 1) to map surface lithologic and geomorphic patterns from ERTS-1 imagery at a scale of approximately 1:24,000 and 2) to determine the feasibility of machine mapping of small areas (150 square miles) from ERTS-1 imagery.

Analysis of ERTS multispectral data by LARSYS automatic pattern recognition procedures promises application toward grappling with current and future resource stresses by providing a means for refining existing geologic maps. The degree of refinement is dependent upon: 1) the character of the terrain, 2) the areal distribution of lithologic surface exposure, and 3) the objective purpose of the desired maps.

The LARSYS procedures used in the current analysis already yield encouraging results toward the eventual machine recognition of surface lithologic and topographic patterns. The ongoing analysis has been limited to an approximate 100 square mile area centered near Durango, Colorado.

Late Mesozoic and early Cenozoic shales and sandstones extend as a series of hogbacks and strike valleys along the northwest flank of the San Juan Basin, and have been tentatively mapped as surface features by machine analysis. Minimal man-machine interaction can be used to interpolate the surface location of Cretaceous coal-bearing strata within the lithologies of the area.

Pleistocene and recent alluvial deposits, including sand and gravel aggregate materials, are clearly separable by the use of LARSYS data analysis in the Durango area. Possibly owing to a higher infiltration rate, and consequent lower moisture content of the surface layer, the alluvium has much higher relative reflectance characteristics than all other surface material types in all four ERTS spectral bands. The determination of causes for separable spectral signatures is dependent upon extensive correlation of micro and macro field-based ground truth observations with the satellite data.

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VEGETATION MAPPING

SYMBOL SYSTEM

0.0 Non-Vegetated

Vegetated

100. Non-Forested
    - 110. Grassland
    - 120. Flood plain
    - 130. Meadow (Subalpine/Montane)
    - 140. Tundra
    - 150. Shrub
        - 151. Sagebruah/Rabbitbrush/Potentilla
        - 152. Mt. Mahogany/Rose/Ninebark/Snowberry/Thimbleberry
        - 153. Willow/Alder/Birch
        - 154. Rocky Mt. Maple/Ribes (Gooseberry)
        - 155. Oak

200. Forested
    - 210. Deciduous
        - 211. Aspen
        - 212. Narrowleaf Cottonwood
    - 220. Coniferous
        - 221. Pinon Pine - Rocky Mt. Juniper
        - 222. Ponderosa Pine (with shrub)
            - 222.1. with oak
            - 222.2. with other shrub
        - 223. Ponderosa Pine - Rocky Mt. Juniper
        - 224. Ponderosa Pine - Douglasfir
        - 225. Engelmann Spruce - Subalpine Fir
        - 226. Lodgepole Pine
        - 227. Limber Pine/Bristlecone Pine
        - 228. Colorado Blue Spruce
        - 229. Mixed Coniferous (3 or more species)
            - 229.1. Ponderosa Pine - Rocky Mt. Juniper - Douglasfir
            - 229.2. Douglasfir - Ponderosa Pine with Engelmann Spruce/Colorado Blue Spruce
            - 229.3. Douglasfir - Engelmann Spruce - White Fir
            - 229.4. Lodgepole Pine with Ponderosa Pine - Rocky Mt. Juniper/ Ponderosa Pine - Douglasfir
            - 229.5. Lodgepole Pine - Douglasfir - Engelmann Spruce
    - 230. Coniferous - Deciduous
        - 231. Ponderosa Pine/Douglasfir - Aspen
        - 232. Douglasfir/White Fir - Aspen
        - 233. Douglasfir/Engelmann Spruce - Aspen
        - 234. Engelmann Spruce - Subalpine Fir - Aspen
        - 235. Engelmann Spruce/Colorado Blue Spruce - Narrowleaf Cottonwood

VEGETATION MAPPING--TUNDRA

SYMBOL SYSTEM

142.0 Willow-shrub

144.0 Wet meadow

145.0 basically non-vegetated rocky (<80%) tundra

146.0 Vegetated meadow

- 146.1 thickly vegetated (>80%)
- 146.2 moderately vegetated (50-80%)
- 146.3 sparcely vegetated (21-50%)

225.0 Forest

- 225.1 krummholz sparce forest
  - 225.12 sparce with willow
- 225.2 dense forest

W Lakes (water)

SPECIAL NOTATIONS

/1	Krummholz	(Stipple)
/2	Burn	(Horizontal lines)
/3	Logging	(Diagonal lines)
/4	Agricultural	
	Crop	(Wavy lines)
	"Hay"	(Clumps)
/5	Ski Site	(Vertical lines)
/6	Housing	(Town or subdivision) (Cross-hatch)

LARS Information Note 030273

Recognition of Surface Lithologic and Topographic Patterns in Southwest Colorado with ADP Techniques

by
W.N. Melhorn and
S. Sinnock

This paper was presented at the "Symposium on Significant Results Obtained from ERTS-1 Data," Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973.

The Laboratory for Applications of Remote Sensing

Purdue University, West Lafayette, Indiana

1973

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RECOGNITION OF SURFACE LITHOLOGIC AND TOPOGRAPHIC PATTERNS IN SOUTHWEST COLORADO WITH ADP TECHNIQUES

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ABSTRACT

Analysis of ERTS-1 multispectral data by automatic pattern recognition procedures is applicable toward grappling with current and future resource stresses by providing a means for refining existing geologic maps. The procedures used in the current analysis already yield encouraging results toward the eventual machine recognition of extensive surface lithologic and topographic patterns. Automatic mapping of a series of hogbacks, strike valleys, and alluvial surfaces along the northwest flank of the San Juan Basin in Colorado can be obtained by minimal man-machine interaction. The determination of causes for separable spectral signatures is dependent upon extensive correlation of micro- and macro field based ground truth observations and aircraft underflight data with the satellite data.

1. *INTRODUCTION*

The results described in this paper pertain to automatic data processing of ERTS-1 MSS data (Scene I.D. 1119-17204, November 19, 1972) for mapping physiography and geology of an area in southwestern Colorado. A block of approximately 200 mi^2 located peripherally to the San Juan Mountain Test Site, an area defined by LARS for conducting ERTS research, was chosen for computer analysis. This area, centered around Durango, Colorado was originally chosen because it appeared as a large, cloud-free block on otherwise cloud-covered data (Scene I.D. 1029-17195, August 21, 1972). Subsequent analysis was performed on the cloud-free November data set. No correlation with aircraft underflight photography or MSS imagery has been performed for this area.

The work described in this report was sponsored by the National Aeronautics and Space Administration (NASA) under Grant No. NAS 5-21880.

2. *PHYSICAL SETTING OF AREA*

The area studied near Durango ranges in altitude from 6,500 feet to about 9,000 feet above MSL. Climate is relatively moderate. Mean annual precipitation at Durango is 19.54 inches but diminishes with a decrease in elevation. Winter snow accumulation of 10 to 40 feet is not uncommon, depending on altitude. Grassland or bare soil dominates below 6,000 feet, scattered pinon and juniper occur from 6,000 to 7,000 feet, and ponderosa pine and aspen become increasingly abundant above 7,000 feet. Orchards and row crops grow in the Animas River valley. Florida Mesa southeast of Durango has been irrigated for pasture and crops since about 1900.

Geology. The San Juan Mountains are essentially an eroded, domal uplift covering about 10,000 mi^2 in southwestern Colorado. They are composed principally of volcanic rocks of Tertiary age, but older bodies of Precambrian, Paleozoic, and Mesozoic rocks are locally exposed in the mountainous core. At many places around the margin of the San Juan Mountains, Mesozoic rocks occur as a series of tilted strata that dip towards adjacent basins, and form a series of linear topographic highs and lows, or "hogback" ridges and strike valleys. The volcanic episode was succeeded during the Pleistocene by climatic conditions suitable for generation and vigorous activity of numerous, large valley glaciers that have recurred during at least 3 irregularly-spaced intervals of relatively short duration. Consequently, the geomorphic history of this rugged mountain and basin area is exceedingly but not abnormally complex. The regional erosion surface (late Tertiary) is in many places overlain by varying thicknesses of glacial till and outwash gravels. The area has been reportedly, gently upwarped in recent geologic time, so that many of the glacial deposits and associated rocks are unstable under present slope conditions. Major landslides, mudflows, and rock avalanches are not uncommon anywhere in the San Juan region. The best general accounts of the topography and geology of the region are contained in Atwood and Mather (1) and Mather (2).

Immediately east of Durango the hogbacks and strike valleys, developed respectively on hard, durable sandstones and weakly resistant shales, are particularly prominent. The slopes developed on sandstone dip southeast at about 20°. Some of the best examples of glacially alluviated benches, cut terraces, and floodplains of the entire region exist on Florida Mesa and along the valleys of the Animas and Florida rivers. Such deposits are generally highly reflective to any sensor system.

Sandstones of the hogbacks near Durango are of terrestrial origin and contain coal beds of fairly high quality and good calorific value (14,000 BTU). Mining has been sporadic, but

Zapp (3) estimated measured reserves of 42 million short tons of bituminous coal, and total recoverable reserves of 1,853 million short tons (estimating 65% recovery) within 3,000 feet of the present surface.

General stratigraphy and topographic relations of rock units in the study area are shown in Table 1.

3. *ANALYTIC PROCEDURE*

As already stated the objectives of the continuing research are to utilize LARSYS automatic pattern recognition to obtain geologic maps which refine existing maps and to produce landform simulation maps. To map geologic materials by any remote sensing technique it is necessary to assume:

1) That subsurface materials will manifest themselves as spectrally separable classes at the earth's surface. Lithologic types, sandstone, shale, etc., are often obscured with a veneer of soil, vegetation, water, and man-made features which reflect incident sunlight to the remote sensor. If the subsurface lithologies are to be mapped based on spectral information received by the sensor, it must be assumed that many spectrally separable surface features indicate subsurface lithologic variations.

2) That lithologic types are naturally segregated into a limited number of discrete compositional and textural categories which can be recognized and classified by pattern recognition procedures, either machine or human. This assumption is false, but it facilitates clustering of similar lithologies into discrete classes. Transitional features which spectrally fall between two arbitrarily chosen training classes will be classified as one of the two chosen classes. The relative spatial distribution of these "misclassified" features will reflect the natural lithologic composition (e.g., an area of sandy shale may be classified as a random distribution of feature elements of the two discrete classes, sandstone and shale).

Classes Considered: Based on the information provided by Zapp (1949), we divided the lithologies of the Durango area into three discrete types for analysis -- sandstone, shale, and alluvium. Sandstone is the subsurface rock type on the dip slopes of the hogback ridges; shale on the cret slopes and along the strike valleys; alluvium on the terraces and floodplains. These three material types are sufficient

GEOLOGIC AGE	FORMATION (MAP SYMBOL)	THICKNESS IN FEET	LITHOLOGIC AND TYPOGRAPHIC CHARACTERISTICS (TOPOGRAPHY UNDERLINED)
Quaternary	----- (Qal)	------	Low-level terrace deposits, glacial till, and outwash along Animas and Florida rivers.
	----- (Qg)	------	High-level terrace and pediment gravels, particularly on Florida Mesa.
	Unconformity		
Upper Cretaceous	Animas formation (Ka) McDermott formation (Kmd)	250-300	Interbedded andesite breccia, volcanic conglomerates, sandy tuffs, and reddish-brown to purple clay shale. McDermott is ridge-former.
	Kirtland shale (Kk)	1200±	Interbedded greenish shale, sandy shale, sandstone; thin carbonaceous shales and coals, mostly in Farmington Sandstone member in middle of unit.
	Fruitland formation (Kf)	300-500	Non-marine, chloritic sandstone, shale, and coal beds up to 40 ft. thick.
	Pictured Cliffs sandstone (Kpc)	200-300	Light gray, marine sandstone, cliff-former, interbedded dark gray shale.
	Lewis shale (Kl)	1400-1800	Dark gray to black, calcareous, bentonitic marine shale. Wide valley-former.
	Mesa Verde Group: Cliff House sandstone (Kch)	300-350	Gray, marine sandstone, forms both scarp and dip slopes, interbedded calcareous mudstone and silty shale.
	Mesa Verde Group: Menefee formation (Kmf)	100-350	Cross-bedded gray and brown sandstone, forms ridges and scarps, with brown-black shales and bituminous coal units 4-9 feet thick.
	Mesa Verde Group: Point Lookout sandstone (Kpl)	400±	Massive, buff sandstone, cliff-former, lower part interbedded sandstone and shale.
	Mancos shale (Km)	1900-2200	Dark gray to black marine shale, valley former, sandy shale and limestone lenses (Greenhorn and Niobrara equivalents?)
	Dakota sandstone (Kd)	200±	Hard, brown sandstone, major cliff-former near Durango, interbedded carbonaceous black shale, coal lenses, and conglomeratic sandstone at base.
	Unconformity		
Upper Jurassic	Morrison formation (Jm)	1000±	Variegated colored, bentonitic shale, mudstone, and sandstone, forms both slopes and cliffs in Durango area.

Table 1. Generalized Lithologic and Typographic Section of the Durango, Colorado Area.

to describe the geologic materials of all erosional and depositional surfaces in the study area. Since ERTS-1 passes over the Durango area at about 10:30 hours, the west-facing cret slopes and other west-facing declivities are in shadow on the ERTS-1 data sets. Shadow areas have significantly different spectral signatures than sunlit areas and have been considered as a fourth major class.

To obtain training field coordinate numbers for the classes of interest, it was necessary to generate a coordinated graphical display of portions of the study area. Four areas within the study region were chosen for non-supervised classification (NSCLAS) and display. The coordinates of these areas were procurred from television gray scale imagery (EDIT) of the entire August 21, 1972 ERTS frame. The four areas contained representatives of all the rock types and topographic forms in the study area. The resultant NSCLAS display provided reliable visual separability of shadow patterns and alluvial areas. Geomorphic interpretation of shadow patterns yielded locations for the sandstone dip slopes and shale valleys. Field coordinates were then obtained for the sandstone, shale, alluvial, and shadow areas. Training fields on each sanstone dip slope and shale valley were separated into discrete training subclasses within the major lithologic classes. Nine groups of training fields -- four sandstone, three shale, one alluvium, and one shadow -- were then exposed to the LARSYS supervised clustering algorithm (CLASS) and the entire study area classified. The display map showed much greater visual separability of the sandstone and shale areas than the NSCLAS display from which the training fields were selected. Training class performance of the features within the training fields was 63.7%. With refinement of the coordinates of the training fields, the addition of two alluvial subclasses, one shale subclass, and two shadow subclasses, visual correlation with Zapp's geologic map improved greatly as did the training class performance (89.8%). This classification scheme of fourteen subclasses in the present degree of refinement defines the state of the art of the continuing analysis at this time.

4. *RESULTS*

The LARSYS routines available for visual display of classified areas are: 1) PHOTO, a color or gray scale coded television image, and 2) DISPLAY, an alphanumeric coded printer image. Both modes of classification display were chosen for visual presentation of the results derived from the Durango area experiment. PHOTO images of the study region are shown in Figures 1 and 2.

Figure 1 is a physiographic simulation map displaying the four major classes. From darkest to lightest the classes are: shadow, alluvium, shale, and sandstone. The three lightest classes represent areas in sunlight and are displayed with low contrasting gray scales. The darkest class, shadow, is represented as a highly contrasting black area. This four-class display produces the illusion of the third dimension in the perception of an observer familiar with vertical or low oblique remote sensing imagery. This effect consequently gives a "feel" for the physiography of the study area by forcing perception to selectively focus on contrasting gray scale patterns which represent topographic variations. A color-coded PHOTO display which simulates the USGS "shaded" topographic maps is also available.

Figure 2 is a machine generated geologic map of the Durango area. The four major classes have been displayed as three classes which represent the geologic materials only. Based on geomorphic knowledge of the usual relationship between bedrock types and their topographic expression, it was assumed that the areas in shadow are underlain by shale. The shadow areas are on cret slopes that stratigraphically fall immediately below the sandstone caprock of the ridges. In a region of hogbacks and strike valleys developed on sandstones and shales, it may be inferred with a high degree of confidence that the surface area stratigraphically below the caprock is underlain by shale. With this assumption, we combined the shale and shadow classes as one displayable unit. The resultant gray scale coded map (Figure 2A) visually correlates in general form with Zapp's map of the same area. In detail (Figure 2B) the two maps are somewhat contradictory. Based on very scanty ground truth information other than Zapp's map, the authors have confidence that the machine produced map is more reliable than the existing geologic map.

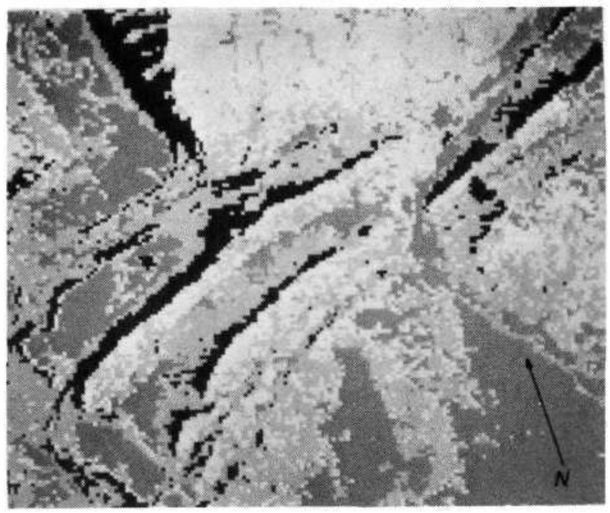
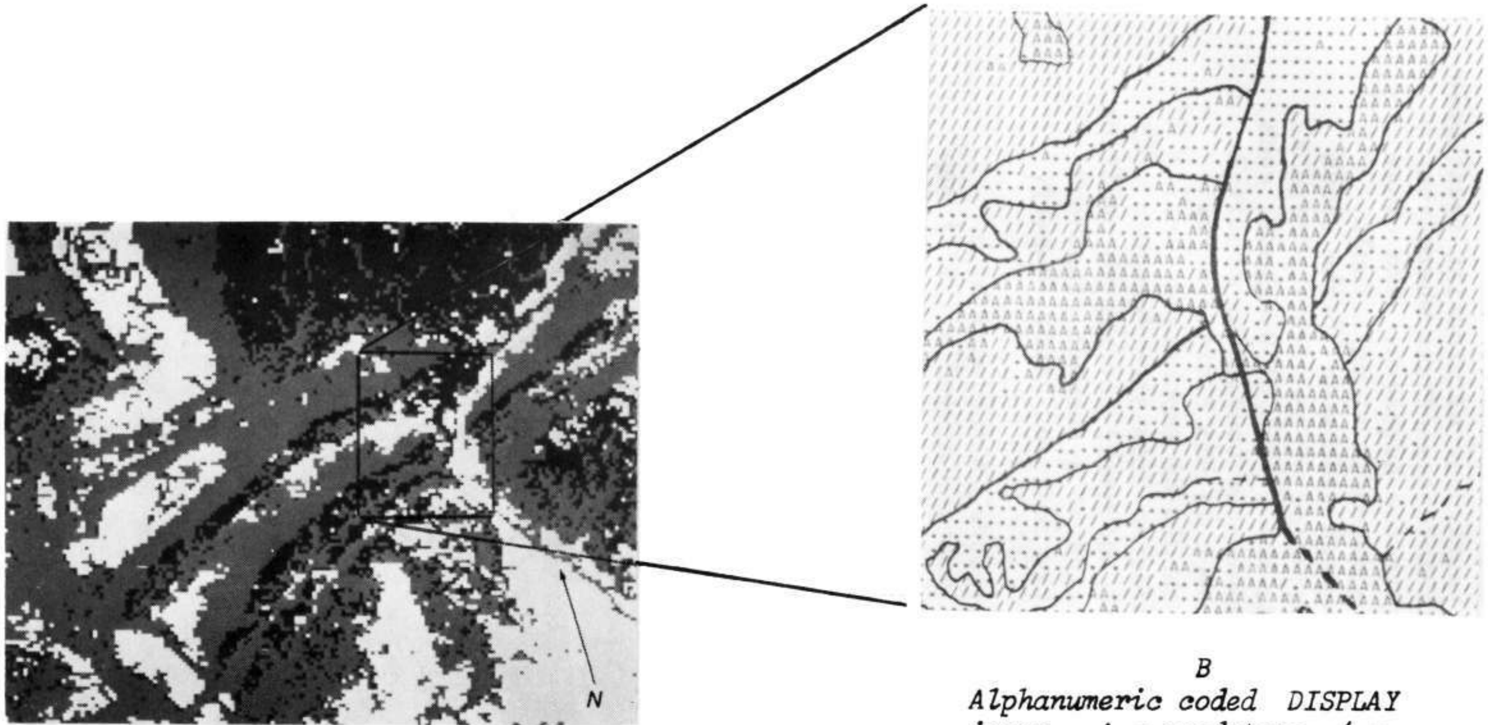


Figure 1. Computer generated physiography of the Durango, Colorado area. Approximate scale 1:150,000.



A
Gray scale coded PHOTO image. White = alluvium, gray = shale, black = sandstone. Approximate scale 1:150,000.

B
Alphanumeric coded DISPLAY image. A = sandstone, / = shale, . = sandstone. Photographically reduced from original scale of approximately 1:24,000.

Figure 2. Computer-Generated Geologic Map of the Durango Area. Black, heavy lines representing the surface locations of lithologic contacts have been manually superimposed on the photograph (B).

There are two reasons for this confidence. First, on the automatically produced map the pattern of alternating sandstones and shales striking northeast is abruptly offset where the Florida River is superposed across the hogbacks. The cause of this offset is inferred to be movement along a fault. The rocks on the east side have been displaced to the south relative to the rocks on the west side of the fault. Zapp's map shows no fault in this area, but a zone of weakness, such as a fault, is necessary to produce the conditions required for superposition of a stream, such as the Florida River, across resistant hogbacks. It should be emphasized that the presence of the fault is inferred from stratigraphic patterns as recognized by LARSYS automatic pattern recognition rather than from visual recognition of a surface lineament represented on non-classified gray scale or color imagery.

The second reason for confidence is the very high correlation between the machine map and Atwood's (1932) map of relict erosion surfaces. Atwood shows a remnant of the Tertiary erosion surface on the dip slope of the Pictured Cliff Sandstone just east of Durango. The boundaries of this "ancient peneplain" remnant are surprisingly similar to the boundaries of the Pictured Cliff dip slope as outlined by the computer. These two reasons, the first based on geologic inference, the second on correlation with previously mapped ground truth, indicate a high degree of accuracy and applicability of the experimental map for geologic purposes.

Figure 3. Physiography of the Second Test Area, Located 30 Miles East of Durango Training Area. Approximate Scale 1:150,000.

Figure 4. Geologic Map of the Second Test Area.

To test the applicability of the classification scheme to regional areas, an approximate 200 mi^2 area centered 35 miles northeast of Durango was classified by using the same statistics calculated on the experimental training fields located two to five miles east of Durango. This new test area was chosen because: 1) the lithologies were similar to those of the first study area, 2) the elevations and presumably the altitude dependent vegetative cover types were different, and, 3) the reflective sun angle on the hogbacks was different. The display images of this area are presented in Figures 3 and 4. The physiographic and geologic maps of the test region "make sense" geologically, but no ground truth is available to test our results. It is apparent that extensive field based micro- and macro-ground truth observations and aircraft underflight data of this second area are needed before any definitive statement concerning the reliability and accuracy of the machine produced maps can be demonstrated.

5. *APPLICATION CONSIDERATIONS*

In our opinion, the experimental method outlined has several applications for improving geologic mapping capabilities. The degree of improvement depends on: 1) the character of the terrain, 2) the areal distribution of surface features, and 3) the purpose of the maps required for a particular project. Additionally:

1) Multiple use of the same classification statistics can be employed for producing alternate map types (e.g., physiographic and geologic maps).
2) Multiple map scales, ranging from 1:24,000 to 1:1,000,000, are available to users of unaltered LARSYS displays.
3) A high degree of accuracy is obtained.
4) Statistics calculated from a "type section" of limited areal extent can be applied regionally to obtain classification maps of broad areas.
5) Compact storage in magnetic data tape libraries is possible. (The Durango study area statistics necessary for display of the maps presented in this report are stored on about 30 feet of magnetic tape.)

6. *NON-CLASSIFIED FEATURES*

Visual recognition of relative amounts of stream flow in the Animas River on temperally different ERTS-1 data sets is possible by using gray scale television imagery (EDIT). Figure 5A shows the August 21, 1972 Animas as it meanders across its broad floodplain just north of Durango. Figure 5B is the same area as seen by ERTS-1 on November 19, 1972. The areal extent of the surface waters of the river is greater on the November imagery as a consequence of the addition of flow to the Animas system of meltwater from an early November snowstorm in the San Juan Mountains. The increase in surface area of the Animas River at high flow is due to bank overflow and ponding of floodwaters in old meander scars and other floodplain depressions. Quantitative analysis of the extent of the snowpack in the mountains, the discharge rates of the river system as measured at local USGS gaging stations, and the areal extent of the Animas floodwater as determined from ERTS-1 imagery might prove useful as a means of flood prediction in the Durango area.

Another non-classified feature of cursory interest is the series of lineaments streaming outward from the San Juan Mountains (Figure 6). These lineaments are inferred to be a dike swarm which is localized along a zone of structural weakness extending southward from the San Juan center of vulcanism. To establish any relationship between the volcanics and the dikes, laboratory and field analysis of the rocks comprising the mountains and dike ridges is necessary.

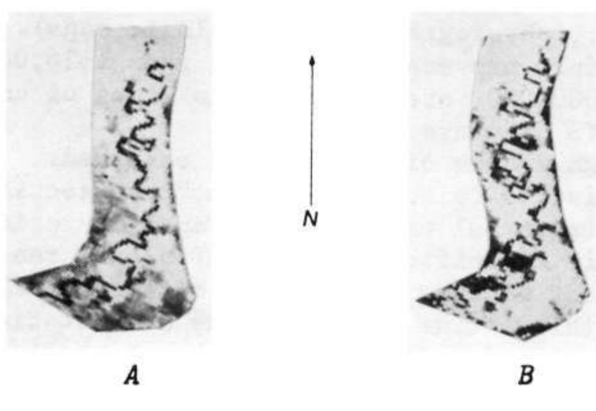


Figure 5. Animas River and Floodplain as Seen by ERTS-1 on August 21,1972 (A) and November 19, 1972 (B).

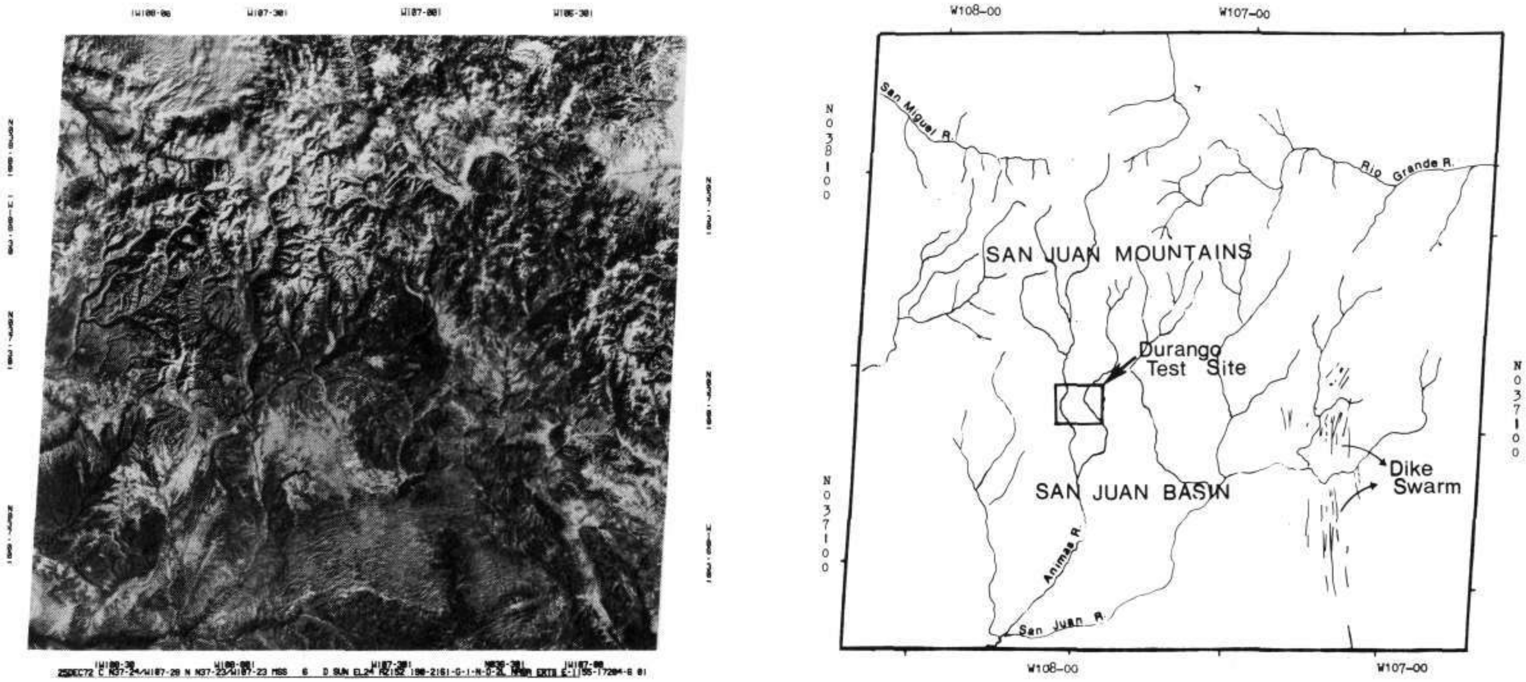


Figure 6. 185 x 185-kilometer ERTS-1 Frame (Scene ID - E 1155-17204, Christmas Day, 1972, Channel 5) Showing the Locations of the Durango Study Area, the Major Drainage Systems Radiating from the San Juan Mountains, and a Dike Swarm Streaming from the Mountains into the San Juan Basin.

7. *REFERENCES CITED*

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