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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.

2. PHYSICAL SETTING OF AREA

The area studied near Durango ranges from 6,500 feet to about 9,000 feet MSL. Climate is relatively moderate. Mean annual precipitation at Durango is 19.54 inches but diminishes with decrease in elevation.

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Winter snow accumulation of 10 to 40 feet is not uncommon, depending on altitude. Grassland or bare soil dominates below 6,000 feet, scattered piñon 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, and 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, 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 repeatedly, gently upwarped in recent geologic time, so that many of the glacial deposits and associated rocks are unstable under present slope conditions, and 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°; thus, some strike valleys on the northwest side of hogback ridges are always in shadow at the sun-time of ERTS-1 overpass. 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.

GEOLOGIC AGE	FORMATION (MAP SYMBOL)		THICKNESS IN FEET	LITHOLOGIC AND TOPOGRAPHIC 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.
		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.
		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 topographic section of the Durango, Colorado area.

3. ANALYTIC PROCEDURE

As stated above, the objectives of the continuing research are to utilize the LARSYS automatic pattern recognition procedures 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).

<u>Classes Considered</u>: Based on the information provided by Zapp (1949), it was decided to divide lithologies of the Durango area into three discrete types for analytic purposes--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. Considered as a unit, these three material types are sufficient 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. The only ERTS-1 data set available for study of the San Juan test site was an August 21 frame. 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 ERTS frame. The four chosen areas contained representatives of all the rock types and topographic forms present in the study area. The resultant NSCLAS display provided reliable visual separability of shadow patterns and alluvial areas. Application of geomorphic interpretation to the shadow patterns yielded highly probable 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 sandstone 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 resultant display map showed a much higher 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%. However, the results were still insufficient to meet our personal satisfaction criteria. 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 the time of writing.

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.

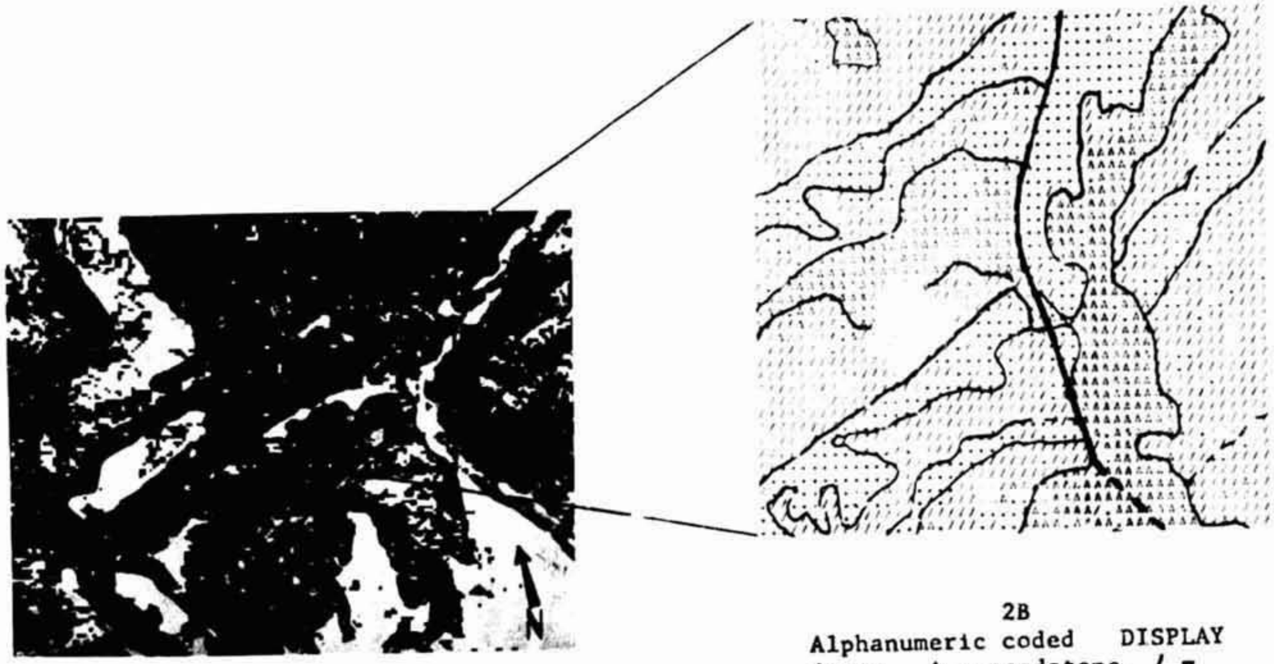
Figure 1 is a physiographic simulation map displaying the four major classes. From darkest to lightest the classes are: shadow, alluvium, shale, and sandstone. The three lightest classes represent areas in sunlight and are displayed with low contrasting gray scales. The darkest class, shadow, is represented 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 images. This effect consequently gives one a "feel" for the physiography of the study area by forcing perception to selectively focus on contrasting gray scale patterns, representing topographic variations which are surface manifestations of subsurface lithologic variations. A color coded PHOTO display which simulates the USGS "shaded" topographic maps is also available.

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

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 cap rocks 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 cap rock is underlain by shale. Proceeding on this assumption, we combined the shale and shadow classes as one displayable unit. The resultant gray scale coded map (Fig. 2A) visually correlates in general form with Zapp's map of the same area. In detail (Fig. 2B) the two maps become somewhat contradictory to one another. Based on the very scanty ground truth information other than Zapp's map, we have confidence that the automatically produced map is more reliable than the existing geologic map.

There are two reasons for this confidence. First, on the automatically produced map the pattern of alternating sandstones and shales striking northeast is seen to be abruptly offset where the Florida River is superposed across the hogbacks. The cause of this offset is inferred to be movement of the rocks along a fault in the earth's crust. 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 a fault is inferred from the stratigraphic patterns as recognized by LARSYS automatic pattern recognition rather than from the 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 [illegible] relict erosion surfaces



2A
Gray scale coded PHOTO image. White = alluvium, gray = shale, black = sandstone. Approximate scale 1:150,000.

2B
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 photographs.

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.

Atwood shows a remnant of a Tertiary erosion surface as it exists today 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.

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 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 verify 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 above has several unique 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 technique for producing alternate map types (e.g., physiographic and geologic maps) can be obtained from the same statistics.
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.) There is a regional applicability of statistics obtained from a "type section" of limited areal extent.
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 15 feet of magnetic tape.)

6. REFERENCES CITED

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