123073

AN INTERDISCIPLINARY ANALYSIS OF COLORADO ROCKY MOUNTAIN ENVIRONMENTS USING ADP TECHNIQUES

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January 1974, SIX MONTH PROGRESS REPORT
Type II Report for Period June 30—December 31, 1973

NASA CONTRACT NAS5-21880

Prepared for
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
Type II, No. 3		

4. Title and Subtitle	5. Report Date
An Interdisciplinary Analysis of Colorado Rocky Mountain Environments Using ADP Techniques	December 30, 1973
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Dr. Roger M. Hoffer & Staff	
9. Performing Organization Name and Address	10. Work Unit No.
LARS/Purdue 1220 Potter Drive W. Lafayette, IN 47906	11. Contract or Grant No. NAS5-21880
	13. Type of Report and Period Covered Type II, July 1, 1973 to Dec. 31, 1973
12. Sponsoring Agency Name and Address Goddard Space Flight Center	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in connection with the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Col.

16. Abstract This study involves the use of computer-implemented pattern recognition techniques for analyzing ERTS-1 data for forestry, geology and water resource applications. Results thus far have proven the value of computer-aided analysis techniques. Data handling procedures discussed include (1) a technique to rotate, deskew, and geometrically scale the MSS data, resulting in a 1:24,000 scale printout; (2) use of a digital display to obtain computer enhanced "false color-infrared" composites of MSS data at several scales; and (3) a gridding technique to locate specific areas of interest in the ERTS data. Temporal overlays of six data sets onto a single data tape have allowed qualitative and quantitative analysis of changes in the areal extent of the snow pack. Preliminary results of a study on the interactions between the spectral response measured by ERTS and the forest type, stand density, slope, and aspect of the forest stand are included.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Automatic data processing, computerized mapping, forestry, geomorphology, DCP, hydrology, lake inventory, snow cover mapping, techniques development	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unc.	Unc.	110	

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PURDUE UNIVERSITY
LABORATORY FOR APPLICATIONS OF REMOTE SENSING
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February 1, 1974

Gentlemen:

Attached is a Type II Six Month Progress Report covering the period from July 1, 1973 to December 31, 1973 for NASA contract NAS5-21880. Included in this report as Appendix E, is the paper I presented at the Symposium on Significant Results of the ERTS-1 Satellite.

This report covers activities of Proposal SR030/040 entitled: "An Interdisciplinary Analysis of Colorado Rocky Mountain Environments Using ADP Techniques.

Sincerely yours,

Roger M. Hoffer

Roger M. Hoffer
Principal Investigator
UN103

RMH/dd

TYPE II SIX MONTH PROGRESS REPORT

For the period beginning July 1, 1973 and ending December 31, 1973

A. Title: An Interdisciplinary Analysis of Colorado Rocky Mountain Environments Using ADP Techniques.

ERTS Proposal Number SR 030/040

B. Principal Investigator: Dr. Roger M. Hoffer
LARS/Purdue University

GSFC Identification Number: UN 103

C. There were no noteworthy problems encountered during this reporting period.

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D.1 Ecological Inventory

1.1 ADP Classifications

The classification categories of the various cover types were incorporated into a scheme shown in Table 1 which specifies progressive levels of detail. Table 1 resulted from the examination of the interrelationships among the major factors which caused differences in spectral response in the ERTS data. Results thus far have indicated in addition to cover type per se, spectral response in the ERTS data is strongly related to vegetative density as well as slope and aspect. Consequently, Level 1 in Table 1 indicates the major vegetative categories, i.e. coniferous, deciduous, agricultural, and non-agricultural. Level 2 defines the vegetation types or vegetative communities, while Level 3 is a further breakdown by crown closure densities of the major vegetative units.

A concentrated effort to determine the accuracy of cover type mapping utilized a large number of test sites (approximately 200) in the four quadrangle test area of Ludwig Mountain, Rules Hill, Lemon Reservoir, and Vallecito Reservoir. This area is large enough (14 x 20 miles) to have a variety of slopes, aspects, and crown densities for each vegetation type, and yet small enough to be represented on a 3' x 4' computer printout of the ERTS data at a scale of 1:24,000. The test areas were selected from the aerial photography of the area with comparison with USGS quadrangle maps and the U.S. Forest Service and INSTAAR type maps. The test areas were determined as areas within a uniform vegetation type (based on type map data), with a uniform density (aerial photographs), and with uniform slope and aspect (obtained from the USGS quadrangle maps). Each of the test areas was then ground checked to verify this information.

A total of 183 test areas, ranging from 20 to 120 acres, in the four quadrangle area were defined by the criteria established and all but a few were ground checked.

Each test area was delineated on the computer printed gray scales. Coordinates for the test fields were obtained by laying a geometrically corrected gray scale printout of ERTS over the quad centered photography on a light table. Field boundaries were drawn on the printout within ground checked areas. An effort was made to reduce the number of variables involved by keeping all test fields similar in size (20 acres). A total of 250 such test fields were delineated. A computer card was made for each field and listed the coordinates, vegetation type, slope, direction, and crown closure density.

A procedure using the LARSYS system for analysis of ERTS imagery at Level 1 (Table 1) was developed. The basic general sequence for analysis is to obtain a group of spectral classes (training classes), specify these to the computer which calculates a set of statistical parameters using a statistical algorithm. The statistical parameters are then used to "train" a pattern recognition algorithm which classifies each data point into one of the training classes.

The procedure developed during this reporting period is to choose a number of areas, in this case five (which included 20 percent of the entire quadrangle), each of which are approximately 1500-2000 acres (about 35 lines by 50 columns) and contain four to six cover types for which ground truth information is available (cover type maps and aerial photography from Mission 239). Each area is then clustered into 12 to 15 spectral classes, depending upon the variability of the area. Each spectral class is identified by comparing it to the ground truth. It may be necessary to group two or more similar classes to positively identify the spectral classes. All spectral classes that can be identified as one cover type (or more than one cover type that, when grouped, forms a more general cover type) are statistically compared. If two or more spectral classes have the same mean (or are within one standard deviation) and are identified as the same cover type, they are then combined. If a similar spectral class(es) actually represents two cover types, either a class(es) must be deleted or one spectral class must be accepted as representing two cover types. This spectral class is then identified as a combination of both cover types.

The statistics and separability processors are used to evaluate the separability of the spectral classes. It may be necessary to rearrange the spectral classes if the separability between some of the spectral classes is not satisfactory for the accuracy desired. Care is needed to insure that most of the variation within one cover type is represented in the spectral classes and that the spectral classes represent all of the cover types.

Classification results indicate that in spite of very distinct variations in spectral response due to the effects of slope, aspect, and differences in density of the forest stands, the various Level 1 categories of cover type could be identified to better than 80% accuracy in most cases. The exception to this was the non-agricultural land, which includes meadows and tundra lands. These were classified as forest cover in many cases. Classification results for the test fields defined within the four quadrangle study area are shown in Table 2.

Classification to the Level 2 degree of refinement has shown many variations in spectral response among the coniferous forest cover groups because of the effects of varying slope, aspect and density of the forest stands. There appears to be a high degree of correlation between aspect, slope, and density in spectral response. The interrelationships between these factors are still being studied. It appears that models will have to be developed to take such interrelationships into account before accurate classification can be obtained for the Level 2 categories of coniferous forest cover.

TABLE 1

COVER TYPE [illegible]

General	Level 1	Level 2	Level 3
FOREST	Conifer	Pinyon-Juniper(PJ)*	Densities
		Ponderosa Pine(P.Pine)	Densities
		Doug & White Fir(DWF)	Densities
		Spruce-Fir(SF)	Densities
		Krummholz(Krum)	Densities
		Col. Blue Spruce(C.B.S.)	Densities
	Deciduous-Conifer(De-Con)	DWF, P.Pine, & Aspen(MIX)	Densities
	Deciduous(Decid)	Cottonwood-willow(Cot-Wil)	Densities
		Alpine Shrub (A-S)	Densities
		Oak-Shrub(O-S)	Densities
		Oak	Densities
		Aspen(A)	Densities
HERBACEOUS	Agricultural(Agrl)	Cultivated Crops(Cul.Crop)	
		Cultivated Pasture(Cult.Past)	
		Pasture(Past)	
	Non-Agricultural(Non-Ag)	Meadow	Densities
		Tundra	Densities
		Wet Meadow(Wet Mead)	Densities
NON-VEGETATED	Rock & Soil(Bare)	Exposed Rock(B. Rock)	
		Exposed Soil(B. Soil)	Wet
			Dry
	Shadow	Ridge shadow(Shadow R)	
		Cloud shadow(Shadow C)	
	Water	Clear	
		Turbid	
	Snow	Snow only	
		Snow-Forest Mix(Snow-For)	
	Cloud		
	Urban		

* in parenthesis, abbreviation for use on computer

Table 2. Test Class Performance for Four Quadrangle Test Site in San Juan Mountains.

Group	No of Samps	Pct. Corct	Number of Samples Classified Into Conifer	Decid	Non-Ag	Agri	Cloud	Shad	Bare	Water
1 Conifer	2031	83.0	1686	180	154	0	0	10	1	0
2 Decid	459	81.7	75	375	6	2	1	0	0	0
3 Non-Ag	276	62.0	60	44	171	0	0	0	1	0
4 Agri	60	86.7	0	8	0	52	0	0	0	0
5 Cloud	123	99.2	0	1	0	0	122	0	0	0
6 Shad	135	96.3	5	0	0	0	0	130	0	0
7 Bare	105	90.5	0	0	2	0	0	0	95	8
8 Water	236	97.9	0	0	0	0	0	0	5	231
TOTAL	3425		1826	608	333	54	123	140	102	239

Overall Performance (2862/3425) = 83.6

Average Performance by Class (697.2/8) = 87.1

168 Test Fields = 3% of Total Area (1554 Hectares or 3836 Acres)

1.2 Photointerpretation of Vegetation Cover Types

Two vegetation mapping symbol systems were generated in September. One represented a simplification of the symbol system previously used for ERTS ground truth mapping (Appendix D). This system is used primarily for detailed vegetation mapping outside of the intensively studied area. The second system takes into account the natural vegetation and the dominant factors determining spectral response (Appendix D). The vegetation is divided into 3 levels corresponding to the levels of detail of interest in the ADP mapping. Minor modifications of each system have occurred as the need arose.

The vegetation mapping of four quads in the San Juan Mountains Test Site (Ludwig Mountain, Vallecito Reservoir, Lemon Reservoir and Rules Hill) began with Ludwig Mountain quad and has been extended into Vallecito Reservoir quad. These were first mapped last spring using the Mark Hurd quad centered photography. The use of this black and white photography limited the detail of mapping. Acquisition of NASA Missions 238, 239 and 248 for this area has greatly increased the ability to distinguish the vegetative detail in mapping. This is due to increased levels of discrimination with use of color film. In most cases, the color infrared film was preferred over the color film (Appendix D). The reason for this was the generally greater difference between the responses of deciduous or herbaceous vegetation and coniferous on color infrared than on color positive film. The distinction between the shades of green on color positive is not as great as between the shades of red on color infrared. There is also a greater distinction between bare soil or bare rock and vegetation on color infrared film than there is on color positive film. These bare areas are often highly reflective and may influence ADP classification. Thus it is important that they be recognized and mapped.

After selection of the film type and coverage best suited for mapping, the ground observations from this summer were consulted. All sites for which forest densities and composition were known were marked on the topographic map to be used as base information. These areas of known composition were then used as photointerpretation standards on the NASA underflight photography. Once confident of color, texture, crown shape, or community characteristics for each cover type and each film, the mapping could begin.

The attempt at use of the Zoom Transfer Scope proved too time-consuming due to the frequent rescaling necessary for accurate alignment. Stereo viewing benefited the analysis in two ways. First, it permitted the photointerpreter to quickly relate the topographic features of the photograph to the USGS topographic map. This allows more rapid placement of communities in the proper locations on the base map. Second, when the scale of the photography is large enough, individual tree crowns may be examined for shape or height. This gives the interpreter one more characteristic for separation of community types. For example, during mid-season the brilliant red signature of willow communities on color infrared is very close to the response of aspen. A stereo mode permits evaluation of crown height and thus separation of these two types. The recent acquisition of a Richards MIM-3 light table with a Bausch and Lomb stereo zoom scope (scope not yet delivered) will increase the photointerpretation capacity.*

Working with the stereoscope on a Hamilton light table, the areas were penciled in on the USGS topographic base map and labeled according to the broader usage and vegetation mapping symbol system (Table 1). Densities and comments, where necessary, were added. The areas were rechecked and then inked in. A mylar overlay was then made of all information contained in the map. The broad range usage symbol system was translated into the ERTS-1 symbol system (Table 2), levels 2 and 3. The entire map was checked several times and then machine copied. After rechecking, LARS was provided with the mylar version and once copy for use in ADP mapping evaluation. The Ludwig Mountain map has been completed according to the above system. Vallecito Reservoir map is nearly completed.

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*Recently acquired on NASA-PY Project Grant Number NGL-06-003-200.

Table 1. Vegetation symbol system for wide range usage with corresponding ERTS categories.

Numerical code	ERTS #	Category	ERTS category
00.	B.1 B.2	Non-vegetated	Exposed Rock Exposed Soil
01.	W	Water	Water
02.	U	Urban	Urban
110	161	Grasslands	Agricultural
121	C.6	Colorado Blue Spruce	Colorado Blue Spruce
122	D.1	Cottonwood-Willow	Cottonwood-Willow
130	N.1	Montane/Subalpine meadow	Meadow
141	N.2I	0-30% vegetative cover tundra	0-30% vegetated tundra
142	N.2II	30-70% vegetative cover tundra	30-70% vegetated tundra
143	N.2III	70-100% vegetative cover tundra	70-100% vegetated tundra
144	N.3	Graminoid wet meadow Usually tundra	Wet meadow
145	D.2	Alpine shrub	Alpine shrub-Willow
151	D.6	Wet shrub	Wet shrub
152	D.3	Dry shrub	Oak-shrub
153	D.4	Oak	Oak
211	D.5	Aspen	Aspen
221	C.1	Piñon Pine/Rocky Mountain Juniper	Piñon Pine/Rocky Mountain Juniper
222	C.2	Ponderosa Pine	Ponderosa Pine
222.1	C.2	Ponderosa Pine with shrub	Ponderosa Pine
223	C.2	Ponderosa Pine/Rocky Mountain Juniper	Ponderosa Pine

Numerical code	ERTS #	Category	ERTS category
224	C.2.3	Ponderosa Pine/Douglasfir	Ponderosa Pine/Douglasfir
225	C.4	Engelmann Spruce-Subalpine Fir	Spruce/Fir
Zipatone	C.5	Krummholz	Krummholz
225.1	C.4	Engelmann Spruce/Douglasfir	Spruce/Fir
226	C.7	Lodge Pole Pine	Lodge Pole Pine
227		Limber Pine/Bristlecone Pine	Not extensive
228	C.3	Douglasfir/White Fir	Douglasfir/White Fir
229		Mixed Coniferous (DF/WF/ESP/PP)	Special analysis required
231	M.1	Douglasfir/Ponderosa Pine/Aspen	DWF, P. Pine, other conifer
232	M.1	Douglasfir/White Fir/Aspen	DWF, Aspen/Oak
233	M.1	Lodge Pole/Aspen	DWF
234	M.1	Mixed Coniferous-Deciduous	DWF
161	A.3	Pasture	Pasture
162	A.1	Cultivated crop	Cultivated crop
163	A.2	Cultivated pasture	Cultivated pasture

Table 2. ERTS-1 Vegetation map categories and cover type breakdown

General	Level 1		Level 2		Level 3	
Forest	C	Conifer (Con)	.1	Pinon-Juniper (PJ)	I	0-30%
			.2	Ponderosa Pine (P. Pine)	II	30-70%
			.2.3	Ponderosa Pine/Douglasfir	III	70-100%
			.4	Spruce - Fir (SF)		
			.5	Krummholz (Krum)		
			.6	Col. Blue Spruce (CBS)		as above
			.7	Lodge Pole Pine		
	M	Deciduous-Coniferous (De-Con)	.1	Coniferous species and Aspen		as above
	D	Deciduous (Decid)	.1	Cottonwood-Willow		
			.2	Alpine Shrub (AS)		
			.3	Oak Shrub (OS)		
			.4	Oak (O)		
			.5	Aspen (A)		
			.6	Wet Shrub (WS)		
Herbaceous	A	Agricultural (Agrl)	.1	Cultivated Crops (Cul. Crop)		
			.2	Cultivated Pasture (Cul. Past)		
			.3	Pasture (Past)		
	N	Non-Agricultural (Non-Ag)	.1	Meadow (M)		
			.2	Tundra (T)	I	0-30%
					II	30-70%
					III	70-100%
			.3	Wet Meadow (Wet Mead)		
Non-Vegetated	B	Rock-Soil (Bare)	.1	Exposed Rock (B. Rock)		
			.2	Exposed Soil (B. Soil)		Wet
						Dry
		Shadow		Ridge Shadow (Shadow R)		
				Cloud Shadow (Shadow C)		
	W	Water		Clear		
				Turbid		
	S	Snow		Snow only		
				Snow-Forest Mix (Snow-For)		
	C	Cloud				
	U	Urban				

D. 2 Hydrological Features Survey

2.1 Snow Cover Mapping

Climate and subsurface geology combine to make water a scarce and valuable commodity in the western United States, and most of the water supply comes from the spring and summer runoff of winter snow accumulations in the Rocky Mountains. A network of reservoirs has been constructed to conserve this resource and both satisfy the needs of communities and provide water for irrigation. In addition, this water is used for generating hydroelectric power and for providing recreational facilities. The network is operated by various government agencies such as the U.S. Army Corps of Engineers, the Bureau of Reclamation and state power commissions. To regulate these reservoirs properly the dam operator must have an estimate of both discharge required downstream and the concomitant recharge needed from the reservoir's source, which in most cases is a mountain stream. The objective of this research is to investigate methods by which ERTS-1 MSS data can be applied to the process of mapping snow cover thereby enabling prediction of runoff from mountain streams. Since the methods to be studied may vary in time, cost, and practicality of application, parameters must be established to insure the techniques involved are economically advantageous, i.e., that similar information is provided at less cost than conventional methods or that increased costs is accompanied by increased information.

To meet these objectives this analysis has purposely been kept simple in an effort to implement an operational system at a cost that would be acceptable to a user agency. Other, more complicated methods are being investigated at a basic research level.

One of the tools being used in this investigation is automatic data processing (ADP). It provides the researcher with a rapid quantitative analysis of data from geographic areas such as that acquired by ERTS. In addition, it allows for objective analysis between different dates of the same area.

Two dates, May 18, 1973 (scene ID 1299-17204) and June 5, 1973 (scene ID 1317-17204) have been added to the four original overlayed frames, 1101-17203 (Nov. 1, 1973), 1119-17204 (Nov. 19, 1973), 1173-17202 (Jan. 12, 1973) and 1191-17204 (Jan. 30, 1973).

Classification of these frames into snow and non-snow classes has been performed as they have been received. Consequently each classification is independent of the others. Several methods for performing independent and dependent classifications are currently under investigation. Results of these investigations as well as a comprehensive summary of this study to date will be included in the final report.

A program was then developed to allow the snow cover changes from one date to the next to be mapped. The output was in the form of color coded images, indicating areas in which snow is present in both data sets, areas in which snow is not present on either data set, and areas of change from non-snow to snow and from snow to non-snow.

2.2 Clouds - Snow Separability

Spectral differentiation of snow and clouds has been a major objective of the hydrological features survey. This differentiation is mandatory for the accurate classification in acreage estimates of snow fields in a mountainous region. Detailed analysis has been completed on ERTS frames 1101-17203, 1136-17141 and 1299-17205.

To quantitatively illustrate the inability to separate clouds from snow, several areas of cloud cover and snow cover were defined on a small portion of these data sets, and the spectral characteristics of these areas were summarized using the statistics processor of the LARSYS programs. Table 1 indicates the mean, plus or minus one standard deviation, for several areas which are identified as cloud cover and several areas which are identified as snow cover on each of the three different dates. A relative response level of 128 indicates saturation for channels 4, 5 and 6 of ERTS data. A relative response level of 64 indicates saturation in channel 7. As can be seen from Figure 1 both snow and clouds saturate all four detectors on the first two dates examined and approach saturation for the third date.

Thus, the areal extent of snow cover cannot be reliably determined with ERTS-1 data sets in which moderate amounts of cloud cover are present. In many cases clouds can be identified by shadow effects but this does not appear to be a reliable technique. Preliminary work with SKYLAB data does indicate however that these materials can be differentiated in the middle infrared wavelengths, including a 1.55-1.75 micrometer band. It should be noted here that this differentiation was not included in the Earth Observation Satellite Panel discussion report of the Water Resources Committee. If this differentiation can successfully be accomplished by using the 1.55-1.75 micrometer band these bands should certainly be included in the Earth Observation Satellite.

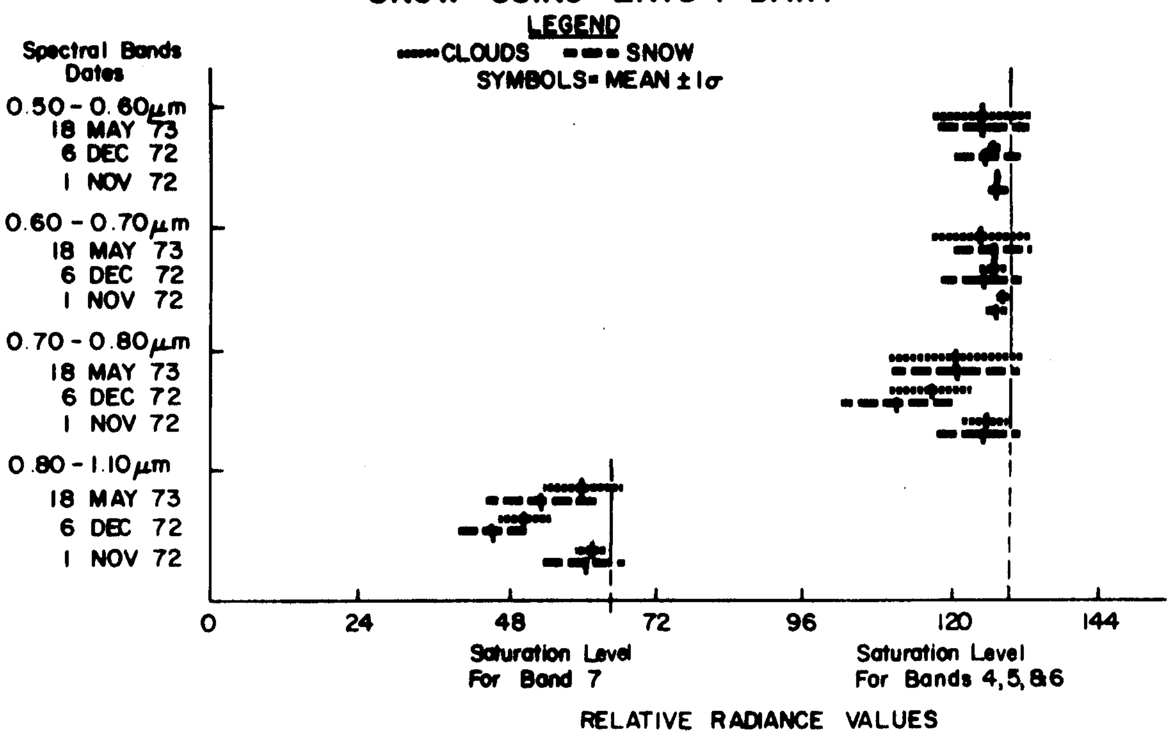
Table 1 Comparison of Spectral Response of Clouds and Snow Using ERTS-1 Data

	Channel			
	4	5	6	7
	(0.5-0.6μm)	(0.6-0.7μm)	(0.7-0.8μm)	(0.8-1.1μm)
Clouds	126.6 ± 2.3[1]	126.2 ± 2.8	118.2 ± 6.8	55.6 ± 6.7
Snow	125.4 ± 5.2	125.0 ± 5.6	116.2 ± 10.2	51.2 ± 9.0

[1] Numbers indicate mean relative response = 1 standard deviation using a combination of approximately 3000 data resolution elements, representing several areas of clouds and snow on each of these dates (1 Nov. 1972, 6 Dec. 1972, 18 May 1973). The saturation level for channels 4, 5 and 6 is 128 and for channel 7 is 64.

Fig. 1

SPECTRAL COMPARISON OF CLOUDS AND SNOW USING ERTS-I DATA



2.3 Field Observations

The purpose of this field study was to monitor the diminution of the winter snow pack along the Eastern Slope of the Front Range of the Rocky Mountains in Colorado between Rollins Pass and Estes Park.

The area under observation was approximately 350 square miles and exhibited an elevational range of 5,000 feet. A variety of topographic and vegetational conditions were represented including glacial bowls, stream drainages, tundra and coniferous forest. All observations were made on the eastern side of the mountains; consequently, slopes having exposure to the west were not observed.

The entire area was surveyed by car once every 7-10 days, and viewed from a panoramic observation point on days coinciding with ERTS-1 overpasses. Ground photographs of individual snow collection areas as well as of the entire study area were taken periodically. Observations of snow diminution made on a weekly basis describe areas as seen from vantage points located along a north-south transect from Estes Park to Rollins Pass. Quantitative information is in the form of percent snow cover of a given slope, percent snow cover of a particular collection area, and elevation of the lower snow line. A technical index consisting of the field notes taken from June through August, 1973 will be included in the final report. The study area can be divided into four general areas: Rollins Pass/Tolland, Indian Peaks/Sawtooth Mountain, Longs Peak, and Estes Park. As the winter snow pack broke up, necessitating observation of more specific sites, each of the four areas was further divided into a number of specific bowls and patches. In order to make volumetric estimates of snow collection areas, preliminary study of the geometry of snow bowls and subsequent use of elementary surveying methods of measurement would be necessary. Field reports through June 27, 1973 consist of observations of each of the four general areas. After 27 June each bowl or patch is described and discussed separately.

One conclusion drawn from observations made during this field study is that the snow melt was characterized by three phases. The first lasted from the time of the last snow on June 4 until the end of June. During this period the melt proceeded uniformly along the entire transect as was shown by the recession of a continuous snow line which extended the length of the transect. There was differential elevation of this line depending on aspect of the slope. On N-facing slopes, the lower snow line was approximately 100-200 feet lower than on S-facing slopes, but even this difference was consistent within the entire study area. Presumably the melt rate during this period was governed primarily by factors capable of having general influence over an area of 350 square miles, such as climate, or by factors such as elevation whose influence would be consistent regardless of other local conditions. During this period quantitative observations were made in terms of elevation of lower snow line.

The advent of the second phase of the snow melt pattern was characterized by the disappearance of the continuous lower snow line in late June. By June 27, this line was no longer visible from the ground, and snow cover appeared to be limited to discontinuous areas on a given slope or collection of slope. During this period it seemed that the melt rate was controlled less by such general factors as weather and elevation than by factors causing differential melt within a particular local area, such as slope exposure, percent grade of slope, topography, substrate and vegetation cover type. Quantitative observations during this period were made relative to percent snow cover on a tend to underestimate size of snow patches which linger on the upwind side of surface irregularities.

As the summer progressed the melt pattern changed again, although at a point in time which was different for each area. During this third phase the snow was entirely restricted to nearby areas having the same aspect, elevation and exposure to weather were snow free. Presumably substrate, local relief, and microclimate were now primary among the factors limiting diminution of snow cover. During this phase quantitative information was recorded in terms of percent cover of the original collection area.

The field data has shown that there is a temporal factor in the diminution of snow cover which should be considered in making areal and volumetric estimates of the winter snow pack, and indicates further that there may be a pattern to the temporal diminution in which the value of a particular factor influencing melt varies in time with its degree of local influence.

There remains another set of conclusions concerning the methods employed in conducting the study itself. The subject of observation, i.e. diminution of winter snow pack in the Front Range of the Colorado Rockies is characterized by its occurrence over a very large physical area as well as by its transient internal conditions. Such a subject does not lend itself easily to quantitative observations. The size of the area, 350 square miles, made it difficult to become familiar with the entire study site in a short time as well as to cover the entire area comprehensively.

A skyline profile of the major peaks in the study area was invaluable in enabling the observer to locate himself in reference to observation sites often removed by a distance of several miles. Another problem caused by the large study area was that of the impracticability of making on-site observation and measurement, and thus, only estimates could be made.

In addition to the problems of size of the study area, other difficulties arose from the transient nature of snow conditions. The purpose of the study was that of monitoring snow changes and presumably the rate of change is not constant. Consequently, more frequent observations might be required at one time than another.

A further problem developed from the unquantifiable nature of observations of snow changes. This difficulty is due in part to lack of on-site observations and the consequent use of estimates and subjective judgements. However, the greater part of the problem is due to the fact that the nature of the process being observed changed completely over the period of observation such that the parameters described at the beginning of the field season were not those described at the end. For example, initial observations were descriptions of the elevation of the lower snow line and by making some general observations regarding the rate of ascent of this line. When the winter pack broke up into patches during the last week in June, this type of observation was no longer useful. The descriptive method became the percent of snow cover of various characteristic slopes. However, a "slope" is in most cases an arbitrarily defined entity. Except for aspect and elevation there was rarely an objective standard by which one slope could be differentiated from the next. Also, at some point which differed for each site, the winter snow pack was reducted entirely to separate and distinct collection areas, all other surfaces being bare. This change of conditions once again rendered previous types of description inapplicable. Where the snow cover was described in terms of percent cover of an entire slope, the descriptions were then in terms of percent cover of the particular collection area.

Lack of data from previous years was a limitation. With the exception of some obvious glacial bowls, the collection areas which were to hold snow all summer could not, in July, be distinguished in any way from those which were to melt off in several weeks time. The consequence was that observations were being made on several scales simultaneously: elevation of lower snow line, percent cover of total slope and percent cover of each particular collection area.

D.3 Geomorphological Features Survey

Geomorphological analysis in western Colorado has been directed toward collecting ground based data and determining factors influencing spectral response. Appendix A details results of field work of August, 1973, and subsequent indexing of the collected ground based photography. The field work plus the indexing required approximately 1.5 man-months. Appendices B and C present the research results now in press. The preparation of these technical reports required about 4.5 man-months.

Vegetation is the primary reflectance element in most areas of the earth's surface. Therefore, to better understand our task of surface spectral classification, we decided to automatically map the vegetational assemblages of a broad area centered upon the Uncompahgre Plateau. This area offered the opportunity to correlate the vegetational sequences, as developed in response to altitude, with landforms and soils, function of the underlying lithologies. In areas of well developed vegetational zonation, as the chosen study area, this method of analysis provides a means to construct a qualitative topographic map. Certain species dominate the uplands, and others, the lowlands. By approximately grouping the classified vegetation zones for display, on the alphanumeric coded printer image or color coded digital display image, a map can be obtained showing highlands, lowlands, and intervening slopes. Correlation between altitude and vegetation zone can be used to estimate altitudes within the classified area. The results of this project were presented at the Fourth Annual Conference on Remote Sensing of Arid Lands in Tucson, Arizona, November, 1973 (Appendix B).

Manual interpretation of landforms represented on ERTS-1 imagery also provides clues that aid in development of an automatic landform classification scheme. We spent much effort during the past six months on such interpretation. The history of the Colorado River in western Colorado was the subject of our investigation. Certain anomolous patterns of surface drainage led us to recognition of an ancient drainage network no longer operative. Development of an historial hypothesis concerning this ancient network followed. As the vegetational zonation study, the results of this project were presented at the Tucson Conference on Remote Sensing. (Appendix C).

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D. 4 Interpretation Techniques Development

4.1 Topographic Modeling of Forested Areas

Study of the ERTS data has indicated a great deal of variability within areas being identified as forested. In some cases this variability is related to species composition, but it has also been observed that a great amount of variation in spectral response exists within each of the species present in the ERTS study areas. It had previously been anticipated that spectral response would be strongly influenced by topographic variables such as slope and aspect, as well as by vegetative variables such as species and density. Therefore this study was undertaken to meet the following objectives: 1) To determine the impact of density, slope, and aspect on the spectral response of each of four forest types, including ponderosa pine, douglas fir, spruce fir, and aspen. 2) Develop statistical models through regression analysis for determining possible relationships between spectral response in each of the four ERTS wavelength bands and the topographic - vegetative variables. 3) Determine the general relationships between spectral response as a function of wavelength region and the characteristics of the forest types involved, in order to determine the ability to generalize these findings to other situations.

As part of the ecological inventory research, 168 test areas were designated in the area around Vallecito and Lemon Reservoirs within the San Juan test site. Each of these areas is from 5 to 20 hectares (10 to 40 acres) in size. Density estimates were made using aerial photos, while the slope and aspect were derived from USGS topographic maps of the area. The species and characteristics of each sample site were field checked in July and August 1973 by personnel from LARS and INSTAAR. Of the 168 test areas so designated, 101 involved the four forest types designated for use in this study. Table 1 indicates the number of samples (each sample being one of the test areas), the total number of ERTS data points, and the total land area in both hectares and acres for each of the forest types.

TABLE 1. Areal extent of sample data.

Species	Number of Samples	Number of ERTS Data Points	Acres	Hectares
Ponderosa pine	41	869	955.9	387.1
Douglas fir	26	380	418.0	169.3
Spruce-fir	12	269	295.9	119.8
Aspen	22	341	375.1	151.9

The samples were chosen so that the slope, aspect, and cover density would be homogeneous within each sample. The spectral response of a sample was determined by averaging the spectral response of all ERTS data points in the sample for each of the four wavelength bands using ERTS data collected on September 8, 1972 (scene ID 1047-17200). At the time the data was taken, the sun azimuth was 136°.

The density of each forest type cover was obtained through photointerpretation of aerial photography in conjunction with the ground observations. Density was measured as percentage of area covered by the tree crowns, to the nearest 10%, using a crown density scale comparator. The densities ranged from 20% to 100%, as shown in Table 2.

The slope of each sample site was also measured as a percentage.

TABLE 2. Range of Independent Variables

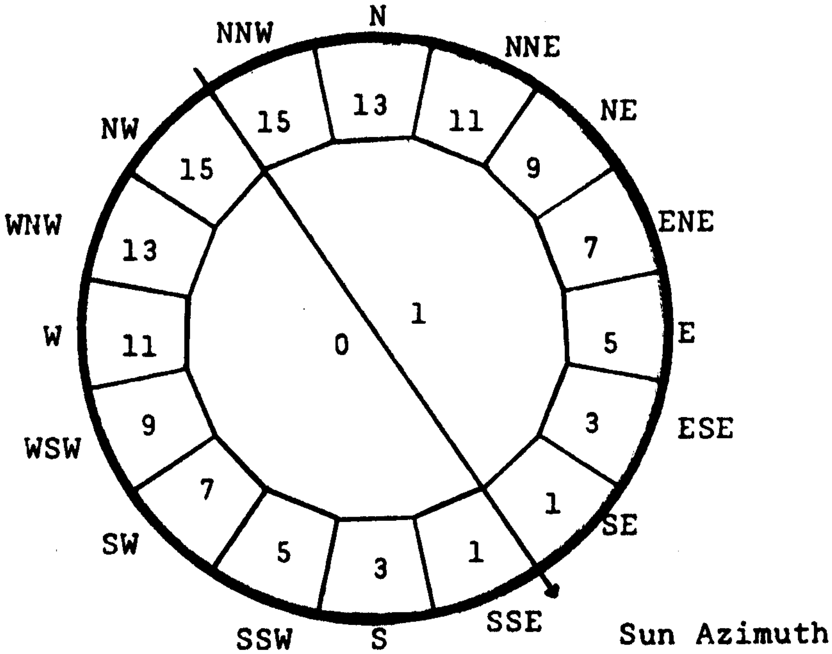
Species	Density (%)	Slope (%)	Angle from Sun Azimuth
Ponderosa pine	20-100	0-60	0-15
Douglas fir	20-100	15-70	1-15
Spruce-fir	50-100	10-60	1-15
Aspen	80-100	15-50	1-15

This percentage is equal to the change in vertical distance per 100 units of horizontal distance. A flat site has a slope of 0%, and a 45° slope would have a percentage slope of 100%. The slopes of the data shown in Table 2 are given to the nearest 5% and range from 0% to 70%.

The aspect, or direction of slope, of each sample was originally coded as one of 16 compass points; for example, WSW or SSE. These must be changed to a numeric code to be used in the regression analysis. The traditional coding--N as 0°, NNE as 22.5°, . . ., NNW as 337.5°--has some inherent difficulties. NNW and N are physically close but numerically farthest apart when this scheme is used.

Thus, a procedure had to be developed so that aspects which are close together physically are also numerically close, and where each aspect has a unique representation. The choice used in this study is not the only choice which could be made but offers some advantages in the later interpretation of the models containing this representation of aspect. Aspect is represented by two variables which are defined by dividing the circle representing the compass into two semicircles as shown in Figure 1. One variable takes on the value 0 or 1,

Figure 1. Representation of Aspect



depending on which semicircle the aspect of the sample is in; the second variable represents the angle from the dividing line. The line was arbitrarily set between SSE and SE because the sun azimuth lies approximately there. This gives a physical meaning to the second variable -- it is related to the angle from the sun azimuth.

The value of the second variable at any compass point is defined as the angle between the compass point heading and the arbitrary sun azimuth line divided by 11.25° (1/32 of a circle). Notice that the angle between S and the dividing line is 3/32 of a circle while the angle between SSE and the dividing line is only 1/32 of a circle. Since the angle between adjacent compass headings is 2/32 of a circle and the dividing line is offset 1/32 of a circle (11.25°) from a compass heading, only odd numbers appear as values of the second variable. If a sample has 0% slope, both of the aspect variables are set equal to 0.

The first variable now only represents whether a sample faces generally southwest (0) or generally northeast (1). This variable was not expected to have a significant influence on the spectral response while the second variable (angle from sun azimuth), was expected to be much more influential.

Results

The spectral response in each wavelength band for ponderosa pine was graphed separately against density, slope, and angle from sun azimuth. Examination of these plots did not suggest that a model other than a polynomial approximation should be considered. Polynomial regression analysis of spectral response in each of the four wavelength bands, considering density and slope separately suggested that the second-order terms could add significantly to the regression. An analysis of variance was not run due to the unequal number of observations and null observations at several levels of the independent variables. Instead, a program which investigates all possible regressions (RSQ) was used to continue the analysis. The variables listed in Table 3 were input to RSQ as independent variables. For each species, RSQ was run four times, once for each channel, with spectral response the dependent variable.

The variation explained by the regression was evaluated by using the R^2 value (the square of the multiple correlation coefficient) obtained from the RSQ program. Table 4 was obtained from the RSQ output. The variable listed for each channel and each species is the variable which, by itself, gave the highest R^2 value of any of the thirteen variables. Notice that, for individual species, the visible wavelength bands (channels 4 and 1) have the same variables, except for two instances.

TABLE 3. Variables Input to RSQ

Variable Number	Variable	Description
1	D	% density of cover type
2	S	% slope of site
3	U	(0,1) variable representing SW or NE semicircle
4	A	Angle from sun azimuth
5	D^2	Density squared
6	S^2	Slope squared
7	A^2	Angle from sun azimuth squared
8	DS	Density-slope interaction
9	DA	Density-angle from sun azimuth interaction
10	SA	Slope-angle from sun azimuth interaction
11	UD	Semicircle-density interaction
12	US	Semicircle-slope interaction
13	UA	Semicircle-angle from sun azimuth interaction

Again for individual species the infrared wavelength bands (channels 6 and 7) have the same variables, except for one instance. These instances are not serious exceptions when additional information is considered. In channel 7, Ponderosa pine, DA was the variable with the second highest R^2 value: R^2=0.170; in channel 4, Spruce-fir, D was second with R^2=0.238; in channel 5, Aspen, A was second with R^2=0.118.

TABLE 4. Single Variable with Highest R^2 Value.

	Ponderosa pine Variable	R^2	Spruce-fir Variable	R^2	Douglas fir Variable	R^2	Aspen Variable	R^2
Channel 4	D	.497	A^2	.242	A^2	.254	A	.111
Channel 5	D	.567	D	.220	A^2	.281	A^2	.119
Channel 6	DA	.216	A^2	.332	DA	.647	A	.371
Channel 7	S	.174	A^2	.350	DA	.700	A	.390

From these results, it appears that the density of the cover and the angle from the sun azimuth are generally the most influential variables. The results are not the same from species to species, but may be generalized over classes of wavelengths (visible and infrared).

The output from RSQ also indicated that density, slope, and the two aspect variables in a second-order linear model, in some cases, would adequately explain the variation in the data available. However, as Table 5 shows, it would not be possible, in any case, to construct a model which could adequately treat the variation in an entirely new data set.

This insufficiency generated a question: what other variables influence spectral response? Elevation, or distance above sea level, of a site is a factor affecting the growth pattern of a species and so affecting the spectral response of the sample. Therefore the average

TABLE 5. R^2 Values for 13-variable Regression.

Species	Channel 4	Channel 5	Channel 6	Channel 7
Ponderosa pine	.792	.794	.665	.639
Douglas fir	.555	.515	.802	.863
Spruce-fir	1.000*	1.000*	1.000*	1.000*
Aspen	.595	.580	.770	.779

*There are only 12 Spruce-fir samples and 13 variables in the regression. This forces R^2 to equal 1.

elevation of a site is recommended for inclusion in further analysis.

While it was recognized that the models containing just density, slope, and aspect cannot totally explain the variation in spectral response, it was decided that the models suggested by the RSQ program should be examined to see if the regressions were significant and if the coefficients of both wavelength bands in a pair (visible and infrared) were of the same order of magnitude.

The simplest models are those consisting of two variables. The two-variable models were inspected to determine which ones had an R^2 value greater than 0.65. Table 6 shows the models which met this criterion. Since the models for ponderosa pine in the infrared channels, douglas fir in the visible channels, and aspen in all four channels did not have an R^2 value greater than 0.65, they were not considered in the remaining steps of the analysis.

TABLE 6. Two variable Regression Models of Spectral Response ($R^2 \geq .65$)

Species	Visible	Infrared
Ponderosa Pine	$Y = B_o+B_1D+B_5D^2+E$	
Douglas Fir		$Y = B_o+B_4A+B_5D^2+E$
Spruce-fir	$Y = B_o+B_2S+B_6S^2+E$	$Y = B_o+B_{11}UD+B_{12}US+E$

In order to investigate the magnitudes of the coefficients and to statistically test the significance of the regression, the models in Table 6 were put through a general-purpose regression program, SPSS-15. In this study, the program was used to obtain the coefficients, R^2 values, and computed F-values shown in Table 7.

The results show that the regressions for these models are statistically significant. The regression equations in both visible wavelength bands and both infrared bands do have coefficients of the same order of magnitude.

TABLE 7. Coefficients, R^2 values, and computed F-values for each forest type and wavelength band with $R^2 > 0.65$

Ponderosa pine

Channel 4 0.5 to 0.6 micrometers

$Y_1 = 30.53263 - 0.26099D + 0.00171D^2$

$R^2 = 0.660$

$F_{2,38} = 37.04280$** $\quad F_{2,30,0.95} = 3.32$

$F_{2,30,0.99} = 5.39$

Channel 5 0.6 to 0.7 micrometers

$Y_2 = 30.97367 - 0.40580D + 0.00260D^2$

$R^2 = 0.72512$

$F_{2,38} = 50.12079$**

Douglas fir

Channel 6 0.7 to 0.8 micrometers

$Y_3 = 39.07317 - 0.96745A - 0.00045D^2$

$R^2 = 0.67634$

$F_{2,23} = 24.03066$** $\quad F_{2,20,0.95} = 3.49$

$F_{2,20,0.99} = 5.85$

Channel 7 0.8 to 1.1 micrometers

$Y_4 = 23.69073 - 0.65502A - 0.00037D^2$

$R^2 = 0.72888$

$F_{2,23} = 30.91707$**

Spruce-fir

Channel 4 0.5 to 0.6 micrometers

$Y_1 = 25.01723 - 0.46488S + 0.00650S^2$

$R^2 = 0.72377$

$F_{2,9} = 11.79076$** $\quad F_{2,9,0.95} = 4.26$

$F_{2,9,0.99} = 8.02$

Spruce-fir (continued)

Channel 5 0.6 to 0.7 micrometers

$Y_2 = 21.41394 - 0.56830S + 0.00767S^2$

$R^2 = 0.73609$

$F_{2,9} = 12.55100^{**}$

Channel 6 0.7 to 0.8 micrometers

$Y_3 = 23.87903 - 0.36237UD + 0.59708US$

$R^2 = 0.65089$

$F_{2,9} = 8.38988^{**}$

Channel 7 0.8 to 1.1 micrometers

$Y_4 = 13.31213 - 0.23927UD + 0.39489US$

$R^2 = 0.65888$

$F_{2,9} = 8.69168^{**}$

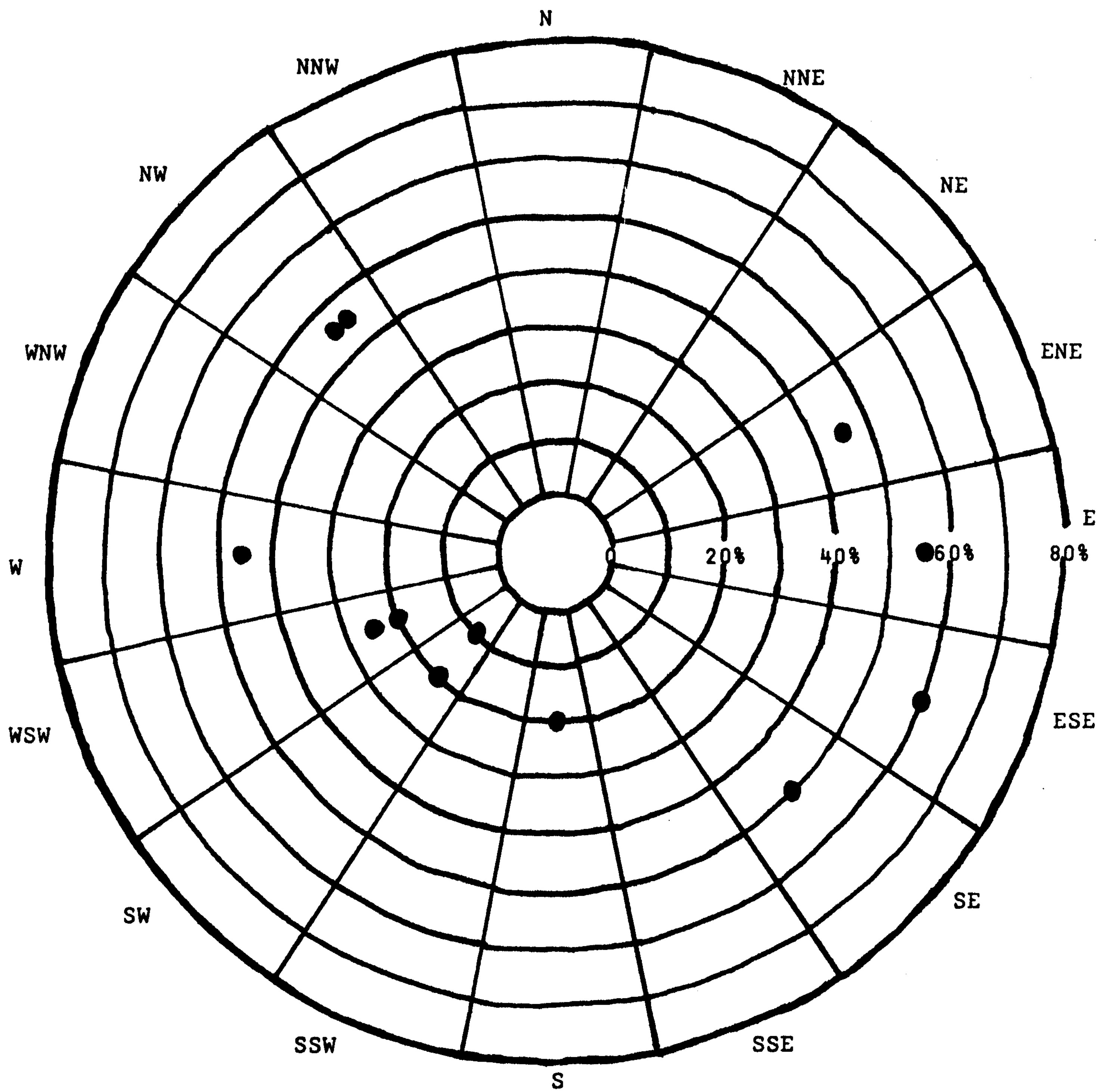
* - significant at d = 0.05

** - significant at d = 0.01

The infrared Spruce-fir model shown in Table 6 was unexpected. It was previously hypothesized that the semicircle variable (U) should not have any significant effect on spectral response, and also should not significantly interact with the other variables. So the US and UD interactions for Spruce-fir were investigated further. Figure 2 shows the distribution of the Spruce-fir samples with regard to aspect and slope. Notice that the samples with slopes in the range 10% to 40% are all in the SW semicircle; all the samples with slopes between 50% and 60% are in the NW semicircle. The graphs in Figures 3 through 7 which plot the spectral response of Spruce-fir in channels 6 and 7 versus the semicircle variable, the slope, and the density show that there is a difference in spectral response between the two semicircles in the data available for spruce-fir. The interaction can be seen in the data available for this study, but it is not certain whether this effect would continue to appear if more data on Spruce-fir were available.

The results of this investigation can be stated in terms of the objectives: (1) angle from sun azimuth is the variable having the greatest impact, density next, and slope has least influence on the spectral response of the

Figure 2. Graph of spruce-fir distribution by aspect and percent slope.



communities studied in a majority of wavelength bands; (2) two-variable statistical models with an $R^2 \geq .65$ can be constructed for ponderosa pine in channels 4 and 5, for douglas fir in channels 6 and 7, and for spruce-fir in all four channels; (3) the results can be generalized over classes of wavelength bands (visible and infrared), but not over species.

Results also indicated that density, slope, and the two aspect variables do not totally explain the variation present in the data. Elevation has been suggested as a variable which should be considered in future studies.

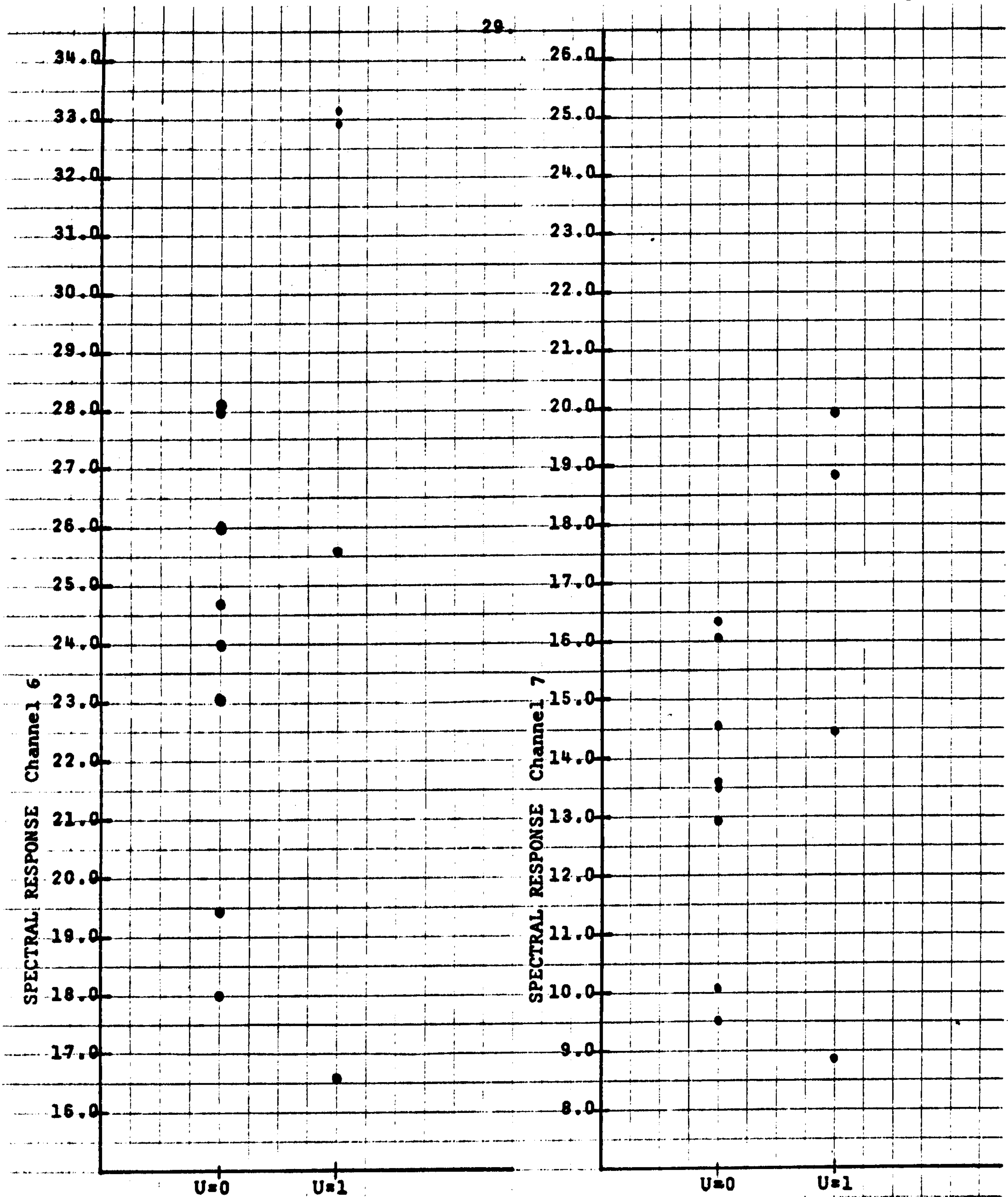


Figure 3. spectral response versus semicircle variable for spruce-fir data.

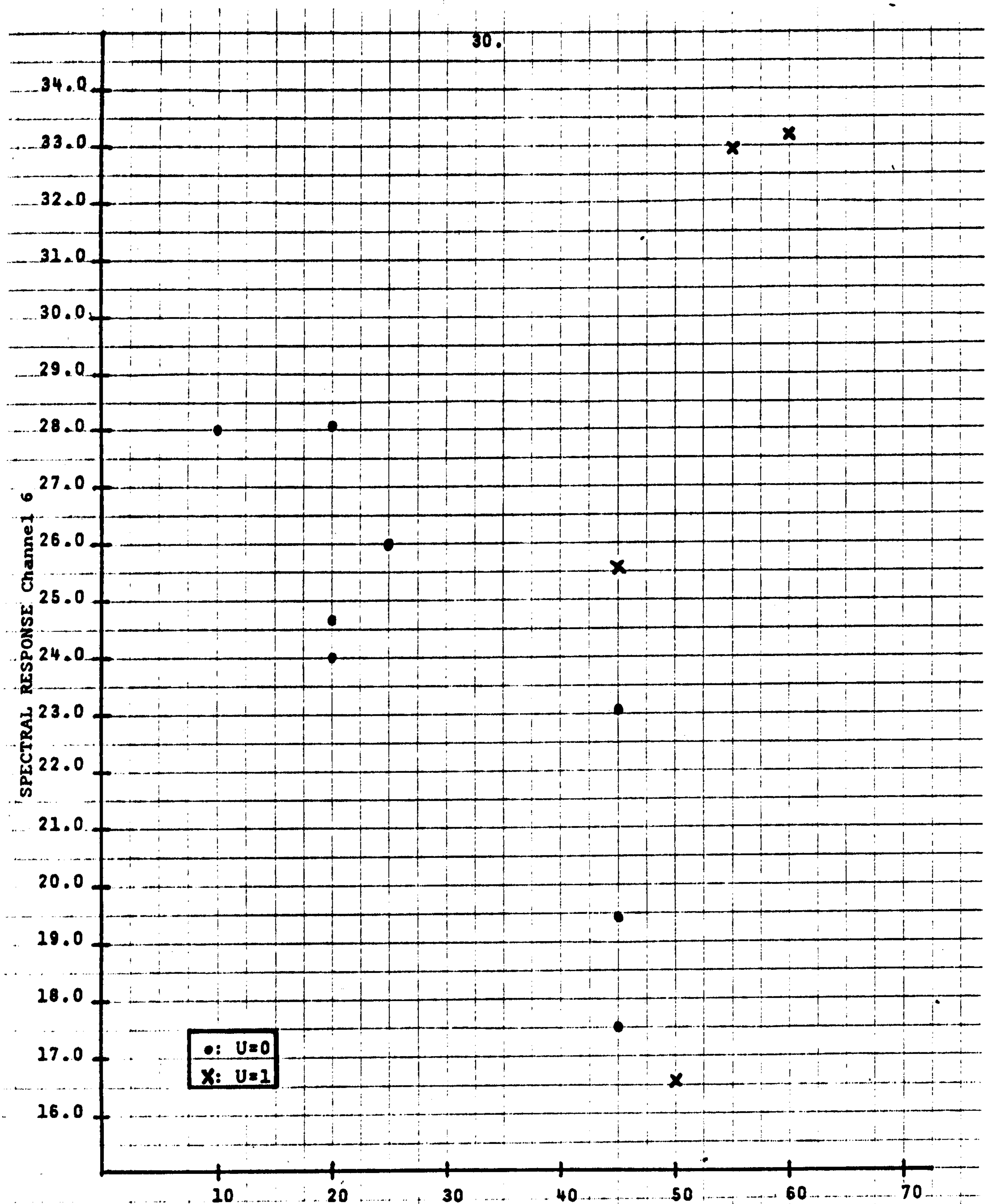


Figure 4. spectral response versus percent slope for spruce-fir data

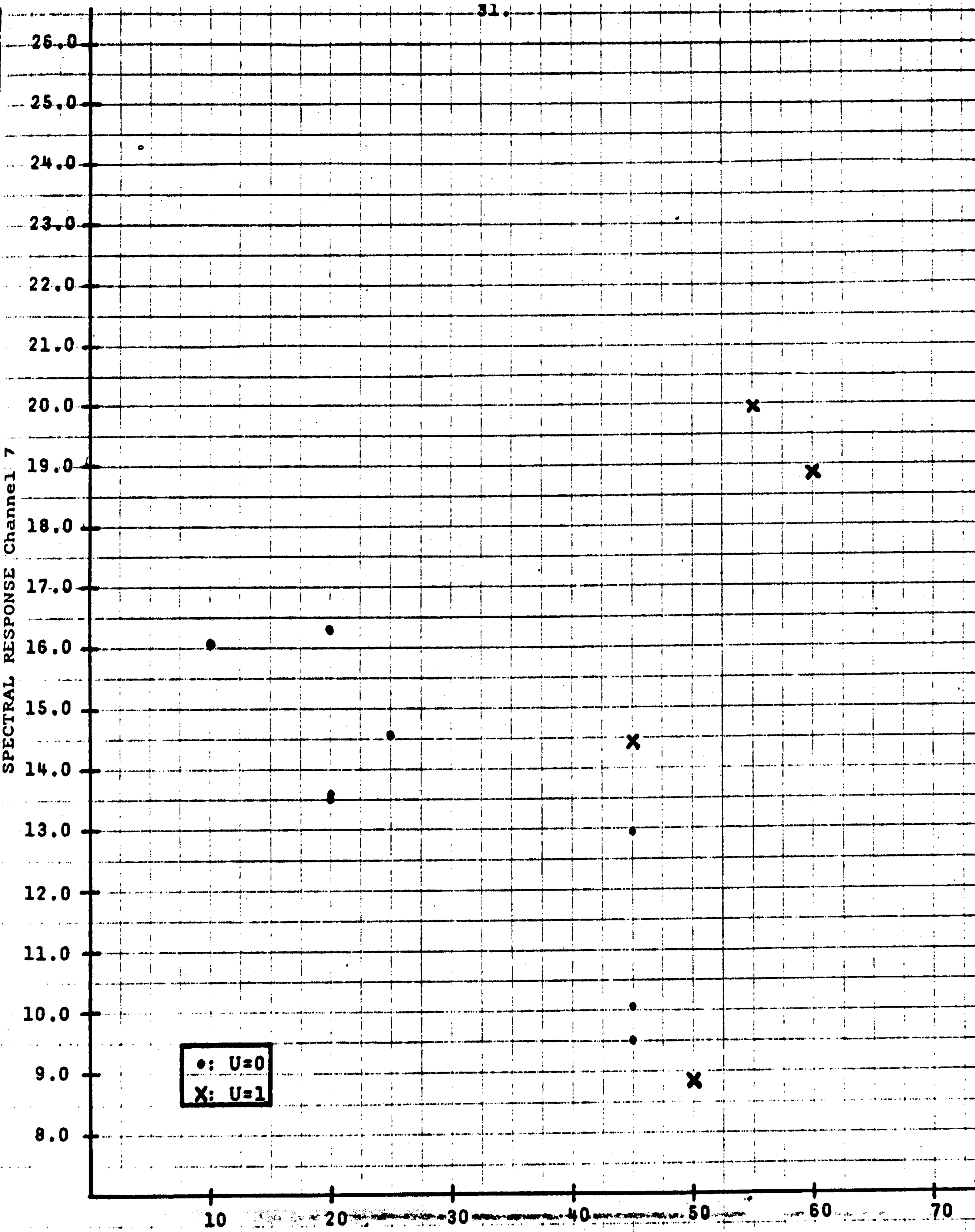


Figure 5. spectral response versus percent slope for spruce-fir data

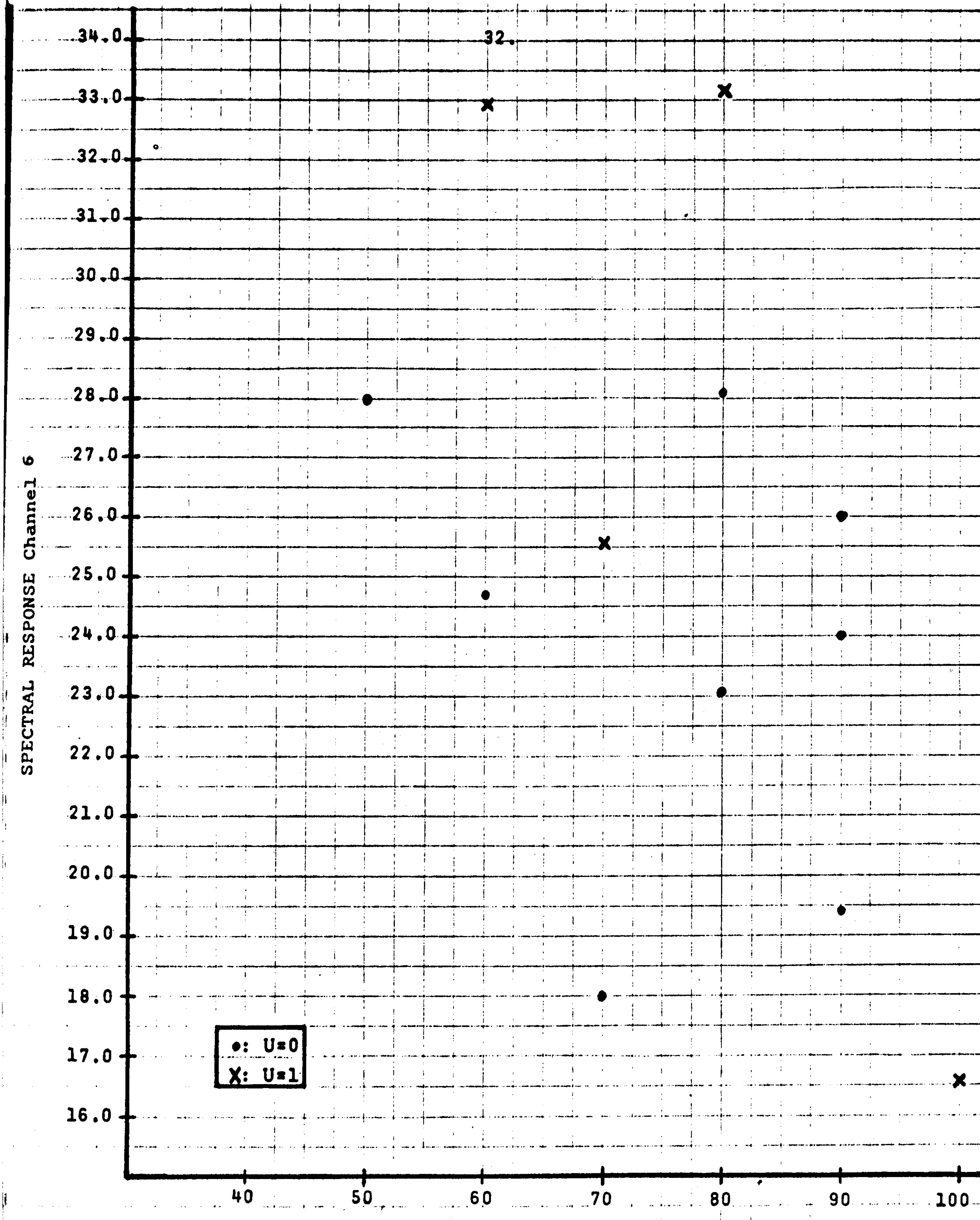


Figure 6. spectral response versus density for spruce-fir data

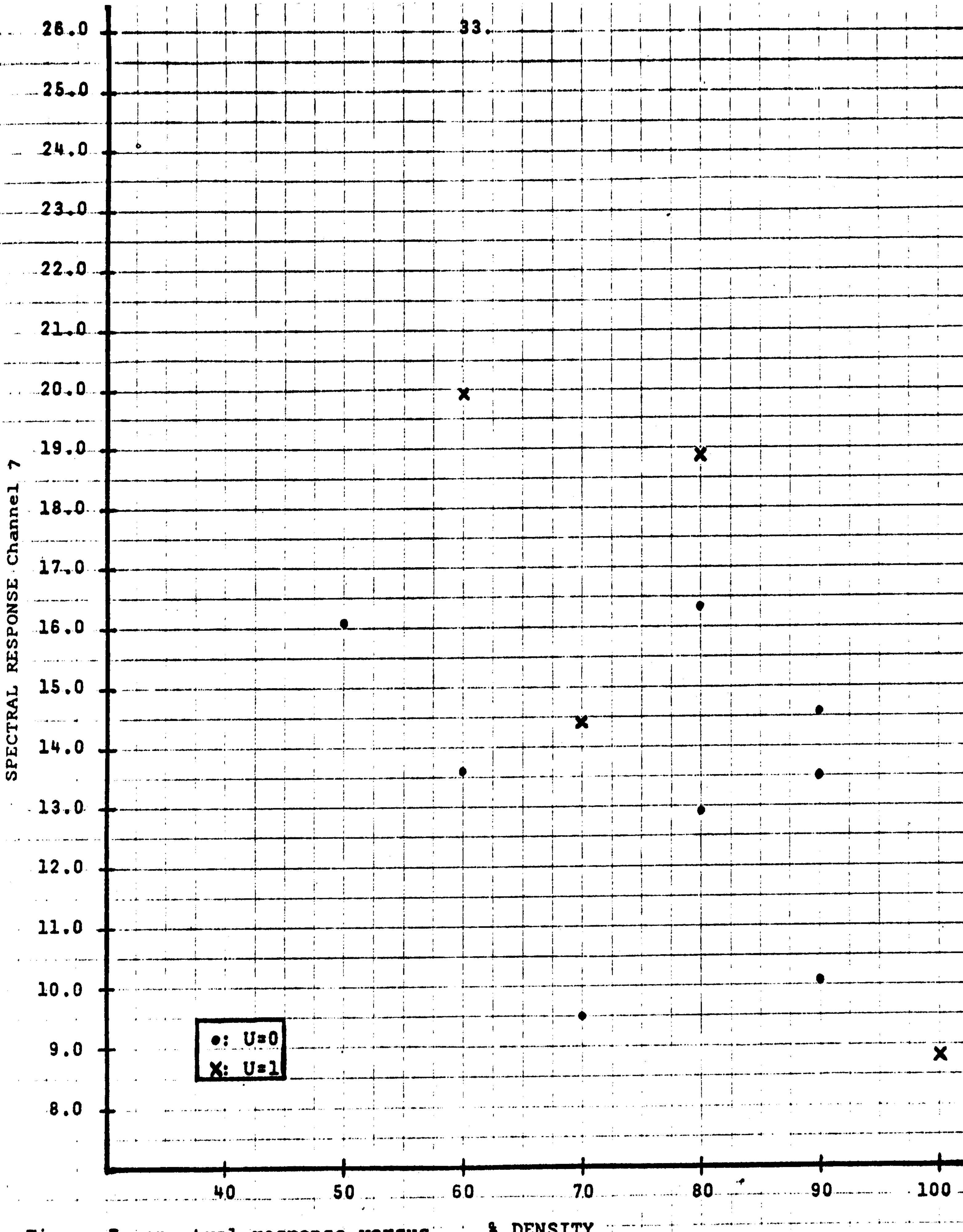


Figure 7. spectral response versus density for spruce-fir data

D.5 Data Collection Platform

Between 13 February 1973, when the interface was implemented, and 17 October 1973, 2907 transmissions were made by the data collection platform on Niwot Ridge (3500 m.a.s.l.) 3164 cards were received including 257 duplicate cards. Taking account of 51/247 days without data this represents an average of approximately 15 transmissions per day for the period.

In view of the messages occurring primarily at morning and evening hours and the consequent sampling problem in terms of temperature, solar radiation, etc., attention has been focussed on the representativeness of the wind speed data. Preliminary analysis gives the following comparison for wind data (ms^{-1}) at 8 m above ground from the DCP and estimates from corresponding analog trace based on four 6-hourly intervals:

	No. of Days	DCP Mean	DCP St. Dev.	Daily Analog Estimates Mean	Daily Analog Estimates St. Dev.	Correlation Coefficient
Mar	14	6.5	3.8	6.9	3.9	+ 0.88
Apr	27	6.7	4.5	8.3	4.3	+ 0.83
May	30	7.2	4.2	8.4	4.2	+ 0.88

This analysis indicates that, at least for monthly means, useful average wind speeds can be obtained by even the present limited sampling with ca. 15 transmissions per day concentrated in morning and evening hours. However, the DCP average should not be used for estimating individual daily means unless an accumulating run-of-wind counter is incorporated into the interface.

This analysis is now being extended to the remaining months and the other channels of data.

Use of DCP data

Meteorological/climatological data in remote mountain locations are rare. For example, the conventional station at 3750 m on Niwot Ridge, which has been serviced at weekly intervals by INSTAAR personnel (weather and manpower permitting) since 1952, represents the longest data series at this elevation in western North America. There are few stations at or above 3000 m.

Such data are of critical interest in terms of such problems as:

1. monitoring long-term climatic trends in an essentially unpolluted environment;

2. monitoring current weather conditions in the high mountains--data pertinent to tourists, foresters, highway maintenance staff, pilots of light aircraft;

and

3. predicting snow melt and water yield (the parameters we measure are directly pertinent to this problem).

E. There are no significant results to report for the past period.

F. Published articles, in-house reports, abstracts

Techniques for Computer-Aided Analysis of ERTS-1 Data, Useful for Geologic, Forest and Water Resource Surveys by Roger M. Hoffer and Staff presented at the Symposium on Significant Results of the ERTS-1 Satellite, December 10, 1973 at the Goddard Space Flight Center.

Application of Machine-Processed ERTS-1 Data to Regional Land Use Inventories in Arid Western Colorado by Wilton N. Melhorn, Scott Sinnock and Richard P. Mroczynski presented at the Fourth Annual Conference of Remote Sensing of Arid Lands, Resources and Environments, November 14-16, 1973, University of Arizona, Tucson, Arizona.

Evolution of the Upper Colorado River as Interpreted From ERTS-1 Imagery by Scott Sinnock and Wilton N. Melhorn. Presented at the Fourth Annual Conference of Remote Sensing of Arid Lands, Resources and Environments, November 14-16, 1973, University of Arizona, Tucson, Arizona.

G. There are no recommendations at this time.

H. Appropriate Data Request Forms are attached as Appendix F of this report.

I. Appropriate Image Description Forms are attached as Appendix G of this report.

APPENDIX A

GENERAL STATEMENT

This report provides permanent record of itinerary, observations, and subjective impressions of test areas now under study under the ERTS-1 and Skylab joint LARS/INSTAAR project. Ground observations and field notes are supplemented by acquisition of 260 color slides obtained by 50mm, 100mm, 400mm, 400mm, and wide-angle lens photography. We traveled 4,372 miles and made observations in these areas:

1. McPherson County, Nebraska
   This county, in the center of the Sand Hills country, is a test site for the Central States project, and no previous ground truth was available at LARS.

2. Telluride Area, Colorado
   a) Ice Lake Basin
      This is our primary target area in the San Juan Mountains for study of spectral response due to variations in lithologies, talus and mass wasting surfaces, and cover types.

   b) Wilson Mesa
      This area provides training for determining the range and number of spectral classes developed on a single geologic material, and for field comparison of relationships of material types and cover to class distributions shown on classified imagery.

3. Durango-Florida Mesa, Colorado
   This area was the subject of the paper presented at the ERTS-1 Goddard Symposium in March, 1973. Ground truth objectives were to obtain information on materials and cover types not definitely identified by reference to the geologic literature or by the machine classification previously generated.

4. San Luis Valley
   Satisfactory ERTS imagery over the San Luis Valley on 29 April 1973, plus the in-house availability of RB-57 color photography of the area taken September 1972, suggested the value of using our physical presence in the area to obtain ground truth on crops and general land use during the growing season. This provides a backup capability for future machine analysis of the area.

5. Grand Valley
   a) Ute-Uncompahgre area
   This area is of great interest geomorphologically and a general outline of the broad problem investigated is contained in our July, 1973 Type II report to NASA on the ERTS LARS-INSTAAR project. A technical presentation of results was given at the 4th Annual Conference on Remote Sensing of Arid Lands at Tucson, Arizona in November, 1973 (see Appendix C).

   b) Orchard Mesa-Uncompahgre Plateau
   This area is also the subject of a paper presented at Tucson in November, 1973 (see Appendix B) in which machine processing techniques are emphasized. Attention is focused on crop identification, soils, and vegetational zonation of the Uncompahgre Plateau, Grand Valley, and La Sal Mountains region.

Details about investigations in each of the aforelisted areas follows.

1. <u>Sand Hills, Nebraska</u>

   A 65 mile transect was made, from east to west, principally in McPherson County and Arthur County. McPherson County is one of the principal ERTS-1 test sites for the Central States project under Dr. Baumgardner. Comments on physical setting, cover types, and hydrology follow.

   The Sand Hills in this area is rolling terrain, with maximum relief of 200 ft. to 300 ft. Slopes are moderate in the east, but steeper westward as a result of change in height and form of the dune structures. Some steeper slopes are marked by "cat tracks", which in part may be cattle-trails but also may represent examples of turf-roll or soil creep. Erosion is not severe, "blow outs" covering perhaps no more than 5% of the areas. Blowout depressions occupying several acres or more are probably identifiable by analysis of ERTS imagery. In a few places, blowout stabilization is accomplished by placing of worn-out tires across the surface of the sand. Locally, clustering of cattle in field corners or along fence lines seems to promote breakdown of the grass cover and creates deflation rows or trenches. Nevertheless, present land use seems quite optimum in terms of slope, soil, moisture, and vegetation conditions. Soils are thin to non-existent, probably because of the rapid transmissibility of surface moisture to the water table; for the same reason, no distinct surface or subsurface caliche zone is evident, and there are no surface "pans".

Cover is mostly short grass, with minor amounts of low brush and a few cacti, the latter apparently most abundant where overgrazing has occurred. A little white sage was also observed, but no common Artemisia was seen. As cattle will eat white sage, it may be a recent introduction to combat effects of overgrazing and blowouts on the grassland.

Only one plowed field was observed on the entire transect. A very limited amount of alfalfa is grown. Haying operations, principally in the low areas, and particularly in western sector where the water table is nearer the surface, seem quite productive. The water table rises westward from Tryon, McPherson County, where it is at 100 feet, to western Arthur County where it is at 15 feet or less subsurface and locally intersects terrain to form lakes as long as 1 mile long and up to 3/8 mile wide. Thus a definite sequence (from east to west) exists ranging from irregular dry basins of internal drainage, to semicircular or elongate basins containing cattail or tall grass marshes, to linear, permanent open water lakes. Cottonwoods are sparse in the east but increase westward with rise in the water table. Stream channels do not exist in the east, but a few appear westward to connect marshes or linear depressions. In the east, the dunes are small and irregular but these change to longitudinal (seif) dunes in the west, some of which are several miles long. Whether the water table gradient is the result or cause of changes in dune family is unknown. No general orientation of longitudinal dunes is apparent from the ground except in the lake area of the west; satellite imagery or photos may clarify this point. Ground photography was obtained for this area.

2. Telluride Area, Colorado

a. Ice Lake Basin

Our primary objectives in this basin were to determine the real causes of variations between two geologic units (Telluride conglomerate (Tt) in Lower Ice Lake Basin, and the San Juan tuff (sj) in Upper Ice Lake Basin), talus on high angle slopes, and to observe spatial distribution of various spectral classes on bare rock, soil, and vegetation for comparison with previously classified imagery.

The only access to the Ice Lakes is by climbing. This was done on 11 August, from the Mineral Fork campground, and involved a climb from about 10,400 ft. to 12,700 ft. at Upper Ice Lake, with side trips to Fuller Lake and

Island Lake. Cover types were observed, compared with the classified imagery gray scale printouts, and ground photography conducted for documentation.

The flora in the two basins is very different. In the Lower Basin, there is a rather heavy and continuous coverage of skunk cabbage, tall grass, and alpine flowers, with low shrubs and berries around the margins of two small, morainal-dammed lakes in the basin. Scattered spruce-fir, mostly on the northeast facing slope completes the cover assemblage. Total vegetal cover is dense except immediately along the creek draining the basin. The Upper Basin is characterized by sparse, short grass and alpine flowers, viz. cinquefoil, mountain primrose, and edelweiss. There are extensive areas of essentially bare soil or rock. The rock surface is characterized by degraded stone rings or garlands that now form stone streams or stripes. Bare soil around snow banks is characterized by turf rolls or "tubes" of fine-grained material. There is no timber.

Slopes on the riegel, or glacial step, between the basins are dark green color, the short grass and brush nurtured by slow melt from snow banks in niches on the nearly vertical face. These glacial risers in the terrain are formed on deep gray, bare, Tsj cliffs. Talus slopes above the Upper Basin maintain sparse, short grasses with individual rock blocks either with or without lichen cover.

Classified imagery is only fair in showing distribution of the floral varieties, but there is good separation of conifers from grasses. The skunk cabbage, berries, and flowers of all classes form a confused assemblage that falls into any of 3 or 4 classes on the imagery. For example, an area of skunk cabbage (up to 4 ft. high) is shown as Tsj L1M at one element and Tsj L1R in another, whereas short grass would occupy the same two classes. However, an area in the Upper Basin composed of rock-littered grasses was separable from the surrounding area, for a yet unexplained reason. Talus can be separated very well from grasses and rock.

We conclude that the variation in spectral classes between Lower Ice Lake Basin on Tt and Upper Ice Lake Basin on Tsj is far more a function of altitude and slope than of parent material.

b. Wilson - Deep Creek Mesas

Objectives in these areas, just west of Telluride, were to determine the range and number of spectral classes developed on a single geologic unit, the Mancos shale (Km), to observe the spatial relationships of these classes to each other in the field, and then to compare these relationships to the class distribution shown on classified imagery ($DISPLAY).

We originally anticipated that 4-wheel drive would be needed to gain access to Wilson Mesa and Deep Creek Mesa to obtain information on cover types, lithology, and topography. However, no 4-wheel vehicle was available and we relied on an ordinary vehicle plus walking to obtain data and make ground-based photographs of pertinent sectors of the test area. Fortunately, parts of Wilson Mesa not directly accessible can be viewed southward across San Miguel River from Deep Creek Mesa, and it was possible by vectoring to check classification results on specific parts of Wilson Mesa from a distance.

The number of spectral classes developed on the Mancos Shale may be as many as 20 on Wilson Mesa. These include young aspen, old aspen, dense aspen, diseased aspen, sparce aspen, green grass, dry brown grass, bare soil, bare rock, and grass littered with rock. Two major vegetation types, grass and aspen, dominate the areas. These may be reasonably well separated by LARSYS, i.e. the present classification separates these two classes and spatially distributes them on the imagery, in approximately the same position as observed in the field. A third major class is the nonvegetated surface. This had been classified as tundra developed on volcanics or granite; it is <u>not</u> tundra, and it is on Mancos shale rather than either volcanic or granitic lithologies. Correction of this misclassification can now be made with minimal retraining.

It is concluded that a single geologic material may display many spectral classes, but that these classes may be grouped, after field examination, to show reasonably well the area distribution and boundaries of a particular geologic material.

3. <u>Durango - Florida Mesa</u>

Our objectives were to quickly determine the surface distribution of sandstone, shale, coal, and alluvial materials in order to check the accuracy of the machine generated classification presented at the March 1973 Goddard Symposium (see Vol. I, Sec. A, p. 473-481).

We traveled one major strike valley in the hogback sequence east of Durango, the terraces along Florida River, and made field notes on crop types and alluvial cover on

Florida Mesa. We concluded that our machine generated topographic and geologic map was fairly accurate in a general way, but that the geologic interpretation was not comparable in accuracy to data obtained by good field mapping. In the Durango area, separation of geologic materials actually is mostly a correlation of vegetation types that happen to coincide with spatial distribution of lithologies, slope aspect, structure, and general topography. Thus, field correlation with the machine generated map is very good in some places, fair to incorrect in other places. For example, in the hogback-strike valley sequences, pinyon-juniper dominate on the dip slopes, and scrub oak, commonly dense, covers cret slopes and parts of the strike valley; the remainder of the valley floor is covered with grasses. Outcrop of coaly units is mostly bare soil, and therefore, as we suspected but did not mention in the Goddard report, is possibly separable by machine analysis. In the area of the suggested fault along Florida River, ground truth indicated that a fault may exist but not of the magnitude projected by interpretation of the machine generated product. At this site, conifers grow on Mancos Shale or sandstones of the Mesa Verde Group, and we had misinterpreted this as outcrop of the Dakota (Kd) sandstones. The result had led to inference of a fault with displacement greater than the actual case.

The machine-generated map is more of a generalized vegetation map than a geologic map, though we must emphasize that geologic accuracy is reasonably good because of biotic preferences for certain materials, slopes, and exposure aspects. Thus, on our geologic map sandstone = conifer-pinyon-juniper, shale = scrub oak, grass, and sparse pinyon, and alluvium = grass and pasture. Our interpretation of areas of light-colored spectral response as gravels on Florida Mesa was accurate, but as a function of cover types rather than lithology.

4. <u>San Luis Valley</u>

A transect was made across about 30 miles of the San Luis Valley, on both sides of the Rio Grande, commencing at a point 8 miles west of Alamosa, north for 16 miles along the Mineral-Alamosa County line, thence east to Hooper, to the San Luis Lakes, Great Sand dunes, and then south from Zapata Ranch to near Blanca. Crop types were recorded on the base map and other land use practices observed. The principal crop is potatoes.

Some beans, squash, rye, and barley are also grown. One corn field was observed in a marginal dry farm area east of Hooper. Alfalfa and hay are the other products in the irrigated tracts. As average annual rainfall is only about 6 inches, the transition to saltgrass and stagebrush flats is immediate outside the irrigated zone, though the water-table is high (probably only a few feet). There are numerous seeps and marshes in the non-irrigated area around the San Luis Lakes, some perhaps owing to percolation from used irrigation water, but partly natural owing to rise of the water table in the area and spring runoff from the Sangre de Cristo Mountains.

In general, the central San Luis Valley is an attractive area for further study. The contrast of irrigated and non-irrigated areas, and presence of row crops, and channel character of the Rio Grande River lends to machine interpretation and monitoring of land-use change. Some areas near Hooper are apparently just being opened to agricultural use. Color photography obtained in September, 1972, is available at LARS and can be used as a base line for monitoring land use change in this region.

5. Grand Valley

a. Orchard Mesa - Uncompahgre Plateau

We field checked and took photographs of crop cover on the alluviated benches in these areas. Crop identification of fields was plotted on topographic maps.

The Fruita area is devoted mostly to corn, wheat, alfalfa, soybeans, and pasture. Despite the name, there are few orchards in this area, mostly peaches. Some cherry trees are present around homesteads but do not seem to be raised commerically. The Hi-Line canal bounds the upper bench at the base of the pedimented fan from the Book Cliffs, and separates agricultural land from sagebrush slopes. Drainage ditches and natural water-courses are lined with salt cedar and a few cottonwoods. Numerous abandoned homesteads suggest that land patterns are changing in the direction of fewer but larger "spreads". Pictures were taken of soil profiles in a few road cuts.

Orchard Mesa southeast of Grand Junction is aptly named, as it is dominated by groves of peach, pear, and apple. Minor acreage is in corn, barley, or alfalfa. Notes on crop distribution were entered on the 7 1/2 feet Clifton quadrangle, published 1962. As orchard areas are discriminated on this map, it is interesting to note changes in distribution to the present time. Some orchard areas have been abandoned, and trees uprooted; in other areas, new orchards have been planted. Some areas of recent "freeze-out" of peach trees were notes.

The area seems amenable to machine monitoring of crop change, inasmuch as the orchards could be discriminated from intervening areas of pasture, diverted acreage, or grain stubble. A longer-term project to monitor change in orchard acreage and new areas just being put under cultivation might be interesting.

b. <u>Ute-Uncompahgre (U2) Area</u>

This project is undoubtedly the most significant in terms of new results of all the areas studied. It involves purely manual interpretation of ERTS-1 imagery, but promises to result in one of the most important geomorphic interpretations of this decade; it may not be too presumptuous to assert that, if additional ground truth effort succeeds in discovering additional evidence to reinforce our interpretative hypothesis, we actually underestimate its significance.

The working hypothesis, which concerns the recent (Tertiary-Pleistocene) history of the evolution of the Upper Colorado-Gunnison River system, in response to diversion by volcanic flows and ash falls and by sequential caputre of the trunk streams by normal geomorphic processes, is too detailed to recite here. The hypothesis, supported by field observations during the period 6-8 and 10 August, were the subject of the paper presented at the Tucson Conference on Remote Sensing of Arid Lands. In brief, we presented evidence that the Colorado River System has freely migrated back and forth as a channel system across the entire length of the Uncompahgre uplift, the Black Canyon area, and perhaps on Grand Mesa; that remnants of the abandoned channels are still visible at levels 4,500 ft. above the present base level of the Colorado River in Grand Valley; and that stream gravels, abandoned meander loops, and of a formerly transecting, free-flowing stream, across the Uncompahgre uplift.

It is <u>imperative</u> that several more days of ground truth be devoted to exploring the headwaters of Escalante, Cottonwood, and Roubideau Creeks on the crest of the Uncompahgre Plateau. Road conditions, because of heavy showers, prevented access to this area in August. Dry conditions in the fall should permit access to most of the area over dirt roads or by walking. We cannot bring satisfactory completion of this project without additional field inspection.

The U2 project is essentially a case history in the use and misuse of ERTS-1 imagery. Without the synoptic view provided by ERTS, evidence leading to formulation of the working hypothesis would not have matured, as the scale of the problem is so large as not to lend itself to conventional map or airphoto analysis. On the other hand, some aspects of our working hypothesis were quickly shown to be erroneous in the field, despite use of geologic maps and publications as pseudo-ground truth in the early stages of the project. Above all, it is direct evidence of the fact that any interpretation of satellite imagery, either manually or machine produced, is extremely suspect until confirmed and documented by ADEQUATE ground truth.

GENERAL CONCLUSIONS

If geologic materials are covered with an abundance of vegetation, the accuracy of any machine-generated map is contingent upon the degree of correlation between vegetal class and geologic material. In many instances, this correlation is high, but not in ALL instances. Parenthetically, most earth scientists with considerable field experience are dimly aware that biotic changes probably are related to slope, exposure, lithology, and available moisture, but they are poorly acquainted with either plant identification of species, or slope and exposure, aspect, soil, and water requirements of various assemblages. The result, therefore, is poor utilization of these criteria by earth scientists, whereas proper attention could assist in preparation of more accurate maps. The spectral response interpretation required in machine mapping will, if nothing else, promote proper appreciation and use of vegetative cover by geologists in producing better map products.

OBJECTIVES OF FUTURE ANALYSIS

Based on the recent field experience, and with adequate ground-based photography and base map notations in hand, a more comprehensive and more accurate classification system of our test areas based on vegetative, topographic, and geologic criteria can be devised and implemented. Ground photos will be particularly useful, as detailed location of vegetative variations developed on each geologic material is possible by appropriate use of these photos. For example, we can now devise a more accurate machine-generated map of the Ice Lake Basin-Wilson Mesa test sites by combining classes that truly reflect the cover types of these areas, and the modification of spectral response by talus, rock blocks, or unvegetated outcrop.

APPENDIX B

APPLICATION OF MACHINE-PROCESSED ERTS-1 DATA TO REGIONAL LAND USE INVENTORIES IN ARID WESTERN COLORADO*

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ABSTRACT

The Earth Resources Technology Satellite (ERTS-1) provides timely, good quality data which can be beneficial to regional land use and resource inventory assessment. Analysis of sequential data sets by nominal photointerpretive techniques is time-consuming and limited by the ability of the human interpretation system. Computer processing techniques for analyzing multispectral scanner data have been developed at Purdue University by the Laboratory for Applications of Remote Sensing (LARS) to facilitate handling of large amounts of remote sensor information.

A study area, located near Grand Junction in west-central Colorado, is well suited for testing the capabilities of computer techniques to perform resource inventories at regional scales, and to present these data in forms compatible with management requirements. The ERTS-1 data set collected 27 September 1972 is nearly cloud-free and includes a large number of distinctive natural patterns that are economically significant. Results indicate good capability for spectrally differentiating zones of various naturally occurring vegetational assemblages from the computer compatible data tapes. Cultural patterns, both urban and agricultural, can be identified on the multispectral data. The acreage of irrigated lands can be determined. Data from the near infrared channels of the scanner are useful in identifying and mapping the extent of surface water available for the area. In arid or semiarid environments the success of this latter capability can be an important factor in influencing land use and management patterns.

After classification, information derived from the multispectral data can be displayed as computer printout comparable in scale to 7 1/2' U.S.G.S. topographic quadrangles, as a black and white image, or as a color-coded image. In addition to map output, information regarding areal extent of the various cover classifications may be obtained in tabular or graphic form, with the output then converted to acreage.

Analysis of satellite data with ADP techniques offers land managers or planners rapid access to data output. It is anticipated that as our ability to interpret these data improves, our understanding of systems required to define resource needs is also enhanced, and man will be able to better utilize this information in the development of regional land use inventory models.

INTRODUCTION

The results described in this paper pertain to automatic data processing of computer compatible tapes of ERTS-1 MSS data

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*NASA Contract NAS5-21880 Entitled: "An Interdisciplinary Analysis of ERTS Data for Colorado Mountain Environments Using ADP Techniques".

(Scene I.D. 1066-17251, 27 September 1972) for mapping vegetation and land use associations in arid west-central Colorado. This project is an outgrowth of computer-assisted geologic analysis of an area near Durango, Colorado(1). Analyses were done on an IBM 360 Model 67 computer using programs developed by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University. Results of such analysis imply great utility for inventorying natural and cultural resources. Information in the form of thematic maps, photographs, or tables, as illustrated in this paper, is applicable toward dealing with current and future resource stresses by providing regional assessments in formats compatible with management requirements.

DESCRIPTION OF THE REGION

The study area is centered around the Uncompahgre Plateau and Grand Valley, Colorado, in the transitional zone between the San Juan Mountain section of the Middle Rockies physiographic province and the Canyonlands section of the Colorado Plateau province. Grand Junction, Colorado is the major urban center within the region.

Grand Valley is bordered for the most part by mountainous terrain. From the valley, altitude 4,500 feet, terrain rises northward to the Book Cliffs escarpment at 6,500-7,000 feet and Grand Mesa (10,000+ feet) (Fig. 1). Deep box canyons flank the valley on the south, cut into the dip slope of rock units in terrain that rises gently toward the summit of the Uncompahgre Plateau at 9,700 feet. Farther to the south lies Paradox Valley and the La Sal Mountains, an eroded intrusive mass with central peaks to 12,000 feet. Regional relief exceeds 7,000 feet within the study area. Parts of alluviated Grand Valley are dissected and broken by arroyos, gravel-capped mesas, and rock benches.

The valley is cut into Mancos Shale on the downthrown side of a faulted monocline (Fig. 2). The Mancos Shale of the Book Cliffs is overlain by younger Mesozoic and Tertiary continental sediments capped by Tertiary lava flows on Grand Mesa. The Uncompahgre Plateau is a structural uplift that consists entirely of Mesozoic rocks resting unconformably on a pre-Cambrian basement complex of granite, gneiss, and amphibolite. The north flank of the plateau is only slightly deformed and dips gently towards Grand Valley; the south flank is broken by step faults descending towards the Dolores River. Hunt (1956) provides a comprehensive study of the areal geology and physiography.

Grand Valley is typically arid with long-term annual precipitation of about 9 inches. Rainfall increases with altitude and the high country may receive more than 20 inches. Vegetation is altitudinally zoned, in response to climatic variation, from Upper Sonoran assemblages in the valleys to Subalpine at the crests. This altitudinal zonation of vegetation in the Uncompahgre and Grand Valley area generally follows Middle Rocky Mountain zonation sequences as established by Daubenmire in 1943 (Fig. 3). In the La Sal Mountains, isolation and decreased moisture results in mixing and some inversion of the normal vegetative sequence. Repeated climatic shifts during Quaternary and Recent times have created transition zones between any two adjacent vegetational climaxes, which are the loci of cyclical vertical migration.

The soils tend to directly reflect moisture, cover type, rock type, and slope aspect. Soils range from aridosols of alluvial groups or series in the valleys regionally upward into alfisols or brown forest soils at higher altitudes (Fig. 4 and U.S.D.A., 1940).

Other than timber harvesting and grazing, the principal land use is agricultural, chiefly in the Grand Junction-Fruita area where local terrain peculiarities permit extensive growth of orchards and row crops subject to irrigation and vagaries of a relatively short growing season (Fig. 5).

ANALYTIC PROCEDURES

Objectives of the analysis were to: 1) implement automatic pattern recognition procedures to derive an accurate and comprehensive classification system for land use and cover types in west-central Colorado, and 2) portray the results of the analysis as maps, graphs, and charts compatible with user requirements.

Data Reduction

Based on Daubenmire's classification of vegetation sequences, the natural vegetation of the study area was separated into seven groups: 1) desert, 2) oak-mahogany savanna, 3) pinyon-juniper forest, 4) Ponderosa pine forest, 5) aspen-meadow complex, 6) dense, subalpine fir forest, and 7) alpine tundra. Two land use classes, agricultural and urban were added to the seven natural vegetational classes to essentially complete the classification scheme. Although many different classes of urban and agricultural land use are spectrally separable (Todd, etal, 1973; Bauer, etal, 1973), the small area of man's activity in the Uncompahgre region, compared with the broad expense of natural cover types, made further segregation of land use categories impractical for this study. Small sections on imagery of the study area were masked by clouds, cloud and topographic shadow, and water. Inclusion of these classes within the classification system brought the total number of classes separated to twelve.

Spectral classes were defined in the following manner. For each class, sample areas of approximately 100 acres each were located on a color composite ERTS-1 image by photo interpretation techniques. The bases for determining visual correlation between class name and image pattern were: 1) field reconnaissance in August, 1973, and 2) comparison of a vegetation map of the La Sal Mountains (Richmond, 1962) with the ERTS-1 imagery.

The chance that any arbitrarily selected area of 100 acres will be composed of a completely homogeneous cover is rare, particularly in near-mountain and mountain regions. Thus, each sample area was assumed to possess a dominant cover type and a residual cover type.

Non-supervised* machine clustering into a small number of spectrally separable classes (i.e., twice the number of expected dominants) was performed individually on each sample area. The mean reflectance of each cluster was plotted as a function of the wavelength band of each ERTS-1 channel (channels 4-7) for each of the desired classes (Fig. 6A). In this manner, the "residual" reflectance elements were statistically separated from the dominant cover type within each sample area. Commonly, each "dominant" type was composed of two or more distinct spectral classes, such as the two classes evident for agricultural areas (Fig. 6B). In this manner, subclasses for many of the twelve major classes were extracted from the raw data. Next, each cluster for each sample area was displayed by a particular alphanumeric symbol on a printer image. Training fields were selected from the areas displayed on the printer image as the dominant class or subclasses;

*A non-supervised classification is obtained by a machine generated statistical separation of a continuum of reflectance values. The classification is based on the mean reflectance value of each data point and its covariance among the four ERTS-1 wavelengths.

screen, identified it as part of an oak-savanna assemblage which dominates at elevations immediately adjacent to but lower than the pinyon-juniper assemblage. The presence of an oak-savanna class within areas dominated by pinyon-juniper indicates the normal transitional nature of boundaries between zones. Thus, the oak-savanna assemblage grows in dry valleys within the lower portion of the pinyon-juniper zone; conversely, in moist valleys the upper zone extends spatially downward into adjacent but lower oak-savanna.

Regrouping the subclasses experimentally achieved desired results, allowing production of a color-coded map that accurately represents the distribution of vegetation zones as described by Daubenmire, and land use features identified by field reconnaissance.

RESULTS

The classification map of the entire area is shown in Figure 7. Each vegetation zone and land use category is shown by a specific grey level. Agricultural areas appear dark grey. A sequence of vegetation zones is clearly visible encircling the Uncompahgre Plateau in the center of the image, the La Sal Mountains in the southwest corner of the picture, and Grand Mesa in the northeast corner. The oak-savanna zone (very dark grey) is immediately above the desert areas (lightest grey). The pinyon-juniper zone is medium-grey tone. These three climax assemblages comprise the Foothill vegetation zone. Above the Foothill zone is a belt dominated by clumps of aspen interspersed with high, grassy meadows and scattered stands of Ponderosa pine. This, the Montane zone, is displayed as a dark grey tone. Above this, the Subalpine zone appears as black. Climax assemblages within this zone include Ponderosa pine, Douglas fir, subalpine fir, and Englemann spruce. Ponderosa pine is widely spread throughout the Montane and Subalpine zones, but tends to concentrate in certain areas as a distinct band between the aspen-meadow and spruce-fir climax assemblages. The spruce-fir shows a very dark grey band along the crest of the Uncompahgre Plateau, as slope dependent groups coincident with drainage lines radiating from the center of the La Sal Mountains, and as a "blanket" covering Grand Mesa. In Figures 8 through 14 each zone has been separated from all other cover types for individual display. A color display of all classes shows the relative distribution of the zones much more clearly than does the grey-scale separation shown here. Water was separated as a statistical class in this study, but its limited surface area with respect to the large area classified rendered it essentially invisible on the visual display.

The relationships of the zones is presented graphically in Figure 15. A transect of overlapping 400-acre fields (Fig. 16) extending from Uncompahgre Butte (9,732 feet) to the base of Grand Mesa (4,500 + feet) was analyzed for relative percentage of each cover type. The relative proportions of cover types within each field along this transect were plotted as a function of elevation. The appropriate peaks on the resulting graph correlate very well with elevations associated with each cover type in the purely ideal model of Daubenmire (Fig. 3). Transitional areas between various zones are evident where lines on the graph intersect, the surface cover at these points being composed of equal amounts of two adjacent zoned classes. Some secondary "peaks" which appear anomalous on the graph result from the transect crossing major topographic breaks such as valleys where, as expected, the vegetation corresponds with abrupt change in altitude and aspect of exposure. However, the graph clearly demonstrates the arbitrary nature of discrete zonal boundaries. The boundaries are actually non-existent, but their use facilitates classification and communication. Such graphs as given herein may be used to homogenize boundary definition in zones of continual variation.

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Similar LARSYS analyses may be performed on similar transects of selected fields within the classified area to obtain density factors for any classified cover type.

Richmond (1962) provides a vegetation map of the La Sal Mountains that serves as a test of accuracy of the machine classification of the Uncompahgre-Grand Valley region. Within the La Sal region the classical vegetation zones are somewhat disturbed, owning to decreasing moisture and slope exposure aspects. Areas of oak-mahogany concentrations lie above the pinyon-juniper zone; distribution of Ponderosa pine appears to be chiefly controlled by lithologic outcrop patterns and subsurface moisture retention rather than by elevation; and the aspen-meadow zone is almost absent on the west side of the La Sal Mountains. Our computer map shows vegetation patterns in the La Sal area as almost identical to those on Richmond's map (Fig. 17). However, the machine-generated map indicates a zone of savanna and desert lands which Richmond's map does not show. Lacking adequate field-based ground truth, the cause of this discrepancy has not been determined.

Figure 18 illustrates the range in scale available to users of the LARSYS digital display screen. All enlargements are performed on the television screen, and then photographed by Polaroid or 35mm camera. Enlargement capabilities of the dark room are not considered here. The smallest scale (Fig. 18A) is obtained by displaying every third line and every third column of the ERTS-1 machine compatible data on the screen, i.e. one-ninth of the data points within the displayed area. This mode of display exaggerates the geographical distortion present in raw ERTS-1 MSS data. Techniques have been developed at LARS and elsewhere (Anuta, 1973) to correct for this distortion, but were not utilized in the present analysis. Problems also arise in the larger scale television images. In Figure 18D, scale 1:125,000, each datum point is represented by 16 television picture elements. This extracts no additional information from the data than Figure 18C, scale 1:500,000, in which each datum point is represented by one picture element, but it does allow easier recognition of small spectral groups. For instance, in the 1:125,000 scale map two classes of urban land use have been displayed. On smaller scale images such separation is useless owing to the neurological threshold constraints of visual perception. Because of the "blocky" character of the data display, certain disadvantages arise in interpretation of the maximally enlarged data.

CONCLUSIONS

Infintely variable data from large areas on the Earth's surface can be statistically transformed into a limited number of discrete displayable categories which, with minimal interpretation, can aid in proper assessment and planning of man's activities. The LARSYS method of manipulation of ERTS-1 MSS data as described herein has applicability toward regional land use planning, forest management, soil science, and cropland assessment. The land use planner has at his beckon new kinds of maps showing regional distribution of cover types and land use. These maps can be helpful in directing development toward areas where the disruptive ecological effects will be minimal in tradeoff with maximized economic benefits. The forest resource manager can quickly assess potential productivity of a region by glancing at vegetation maps showing location of stands of timber species such as fir and Ponderosa pine. The agronomist can accurately locate non-productive areas within large agricultural belts, and perhaps determine the cause of non-productivity. The farmer can better predict his harvest by following maturation of crops on satellite images collected at regular intervals.

Machine analysis of satellite data may not always provide meaningful maps or other meaningfully reduced data of 80-acre farms or city blocks, but it does and will provide accurate and timely maps of regional or areal scope. In our experiment, 4.4 million acres in west-central Colorado have been classified into twenty-four distinct spectral groups. Statistically regrouping these classes into nine categories allowed determination of the relative percentages of each category (Fig. 19). This pie diagram may easily be converted into acreage covered by each vegetation type and land use (Table 1). As seen from the diagram and table, desert and near-desert areas (pinyon-juniper and oak-savanna) dominate the land surface throughout this arid region. Agricultural production is almost exclusively on converted desert, where irrigation is necessary for water is scarce. Effective management in such areas is essential to future development, and satellite technology, when coupled with machine reduction of the awesome number of data elements, provides a tool for planners and managers to draw upon in achieving their desired objectives.

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LAND USE		% OF TOTAL AREA	ACRES
Pinyon-Juniper		25.7	1,119,497
Oak-Savanna		22.8	993,173
Desert		19.6	853,780
Aspen & Meadow		10.5	457,382
Crops and Masture		8.5	370,262
Ponderosa Pine		6.0	261,361
Spruce Fir		2.7	117,613
Alpine		2.3	100,188
Urban		0.6	26,136
Cloud		0.5	21,780
Shadow		0.4	17,424
Water		0.4	17,424
	TOTAL	100.0	4,356,020

Table 1. Vegetation type and land use acres in study area of west-central Colorado. Conversion factor is 1.1 acre per datum element of satellite imagery.

LEGEND FOR ILLUSTRATIONS

Figure 1. Location map of the study area (stippled) classified by man-machine interaction. Mileages from Grand Junction, Colorado.

Figure 2. Grand Valley irrigated belt, Book Cliffs, and Grand Mesa looking northeast from the Colorado National Monument. Monoclinal fold shown in the Wingate Sandstone cliff marks the northern edge of the Uncompahgre Uplift. Altitude-dependent vegetation zones have developed in response to this uplift. From top to bottom along the left edge of the picture are the irrigated agricultural belt, desert, oak-savanna in the canyon, pinyon-juniper in foreground and along top edge of the cliff.

Figure 3. Ideal model of vegetation zones in the central Rocky Mountains (modified from Daubenmire, 1943).

Figure 4. An example of soils developed in Grand Valley. This aridisol is located on Orchard Mesa east of Grand Junction, beneath orchards as shown in the photograph.

Figure 5. Effects of irrigation on vegetation in Grand Valley, looking east from a point northeast of Fruita. The Government High Line Canal separates the desert grasslands on the left from the irrigated croplands on the right. Book Cliffs and Grand Mesa are in the background.

Figure 6. (A) Spectral plots of the non-supervised clustering algorithm performed separately on five known agricultural test areas of approximately 100 acres each. Two "dominant" classes are clearly separable from the "residual" classes.

(B) Spectral plots of the supervised classes, AG-1 and AG-2.

Figure 7. Classification map of vegetation zones in west-central Colorado. Grey-scale separation is poor. See figures 8-14 for separate display of each zoned assemblage.

Figure 8. Agricultural areas are dark. Four major agricultural areas are: 1) Grand Valley (cigar shaped area); 2) a three part strip along the Colorado River (upper right); 3) Montrose-Delta-Uncompahgre Valley (right center); and 4) Norwood region (lower right).

Figure 9. Desert areas are dark. The desert regions follow the broad Grand-Uncompahgre Valley with the irrigated agricultural areas as "holes" in the desert.

Figure 10. Oak-savanna is dark. This zone rings the Uncompahgre Plateau in the center and the La Sal Mountains in the lower left.

Figure 11. Pinyon-juniper is dark. This zone also rings the Uncompahgre Plateau and La Sal Mountains like the oak-savanna zone but, additionally, outlines Grand Mesa in the upper right portion of the picture.

Figure 12. Aspen-meadow is dark. This zone forms an extensive cover in the upper regions of the Uncompahgre Plateau, an asymmetric band around the La Sal Mountains, and a strip on the southeastern flank of Grand Mesa.

Figure 13. Ponderosa pine is dark. Ponderosa pine is widely distributed atop the Uncompahgre Plateau with concentrations along the southern flank; it displaces aspen-meadow along the northwest flank of Grand Mesa as the dominant species in the mid-altitudes (compare to figure 12), and is found below the aspen-meadow on the east slope of the La Sal Mountains.

Figure 14. Spruce-fir is dark. This zone occupies a strip along the crest of the Uncompahgre Plateau, blankets Grand Mesa, and radiates from the peaks of the La Sal Mountains.

Figure 15. Percentage of cover type assemblage as a function of elevation. The percentage of classified cover type in each of 30 overlapping 400-acre fields (20 x 20 data elements) was calculated by a LARSYS computer program. The overlapping fields defined a transect along an essentially constant topographic slope from Uncompahgre Butte to Grand Valley as shown on Figure 16. The plot of the results shows the dominant assemblage at various elevations and the transitional nature of the boundaries between zones. The secondary peak on the oak-savanna curve at 8,300' represents a misclassification of aspen-meadow-high grassland species as oak-savanna. Compare this graph with the ideal model shown in Figure 3.

Figure 16. Band 5 image of the study area showing location of a linear transect of overlapping test fields from which data were obtained to construct Fig. 15. Transect extends from Uncompahgre Butte (bottom) to Grand Valley (top).

Figure 17. Classification enlargement of La Sal Mountain Region. Light areas in center of the uplift are tundra and bare rock. Spruce-fir is represented by the radial black bands following valleys down the slopes of the high peaks. The medium light grey zone surrounding the peaks is the aspen-meadow complex with medium grey fingers of Ponderosa pine extending into this zone in the right central portion of the area south of Sinbad Valley. The light grey band is pinyon-juniper surrounded by the dark, low lying oak-savanna assemblage bordering the photograph.

Figure 18. Range in scale available through the use of LARS digital display screen. Original scales of Polaroid photographs of classification results are (A) 1:1,500,000 (B) 1:1,000,000 (C) 1:500,000 (D) 1:250,000 (E) 1:125,000. Grand Junction, Colorado (population ≈ 30,000) clearly shows up on photos (D) and (E). Colorado River is the winding black band on photo (E).

Figure 19. Pie diagram depicting the relative proportions of land use and cover type in 4.4 million acres of west-central Colorado. "Other" includes urban areas, cloud-covered regions, shadow areas, lakes and rivers.

APPENDIX C

EVOLUTION OF THE UPPER COLORADO RIVER AS INTERPRETED FROM ERTS-1 MSS IMAGERY*

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ABSTRACT

Manual interpretation of ERTS-1 MSS imagery provides a synoptic basis for recognition of anomalous drainage patterns in arid regions in west-central Colorado. These patterns suggest that numerous diversions of the Colorado River System across the Uncompahgre Plateau occurred in pre-Pleistocene time. Certain topographic characteristics, common to a series of stream channels traversing the plateau, indicate that many present-day valleys were formerly occupied by a through-flowing major stream.

Geomorphic inference, based on channel characteristics, regional structure, and physiographic relationships as interpreted from ERTS-1 imagery, suggests that prior to the San Juan Mountain and West Elk Mountain volcanic episodes, the Colorado River System flowed southward along the approximate western edge of the present mountains. Orogenic uplift combined with aggradation of volcanic sediments and flows initiated a sequence of westward diversions by blockage of the former southward flowing stream. The Colorado then migrated across the surface of the Uncompahgre region through a series of lithologically and joint controlled captures.

This process appears to have been repeated at several places until the master stream reached present Unaweep Canyon. Structural evidence suggests that uplift of the Uncompahgre Plateau commenced at this time. The subsequent history of diversion and capture of the Colorado River and its tributaries occurred as outlined in the literature.

The synoptic view provided by ERTS-1 MSS imagery demonstrates how a new perspective of the evolution of surface features may be obtained. This new perspective in a regional framework improves our understanding of geologic processes and our mapping capabilities of many important surface features.

INTRODUCTION

While performing machine analysis on ERTS-1 data obtained over a portion of the LARS San Juan Test Site (Mroczynski et al, 1973), our attention was attracted by the apparent anomalous character of certain stream channels developed on the nearby Uncompahgre Plateau. Compared with the major high order streams (Colorado, Gunnison, San Miguel, and Dolores Rivers) (Fig. 1) within the region portrayed on ERTS-1 frame 1066-17251, September 27, 1973, many drainage channels occupied by low order perennial and ephemeral streams flowing on the northeastward dipping slope of the uplifted Uncompahgre Plateau exhibit three apparently anomalous characteristics:

1. Valleys occupied by some of the ephemeral streams are more extensively developed than those cut by the major rivers.

2. The dip slope valleys commonly possess high level meander scars uncharacteristic of streams with a regimen and gradient comparable to their present day occupants; and

*NASA Contract NAS5-21880 Entitled: "An Interdisciplinary Analysis of ERTS Data for Colorado Mountain Environments Using ADP Techniques".

3. These valleys possess apparently correlative components on both sides of the present drainage divide at the crest of the Uncompahgre Plateau, a divide created by uplift along a series of faults bounding the plateau's southwest side.

Analysis of ERTS-1 imagery was paramount in leading to recognition of these anomalous patterns. The synoptic view given by ERTS-1 MSS sensors provides a basis for regional pattern recognition and comparison never before possible. Texture and tone analysis enables comparison in the horizontal plane, whereas shadow pattern analysis permits comparison in the vertical plane (e.g. the depth of valleys). However, to even partly utilize the exceptional capabilities of ERTS-1 technology as an aid in manual interpretation, it is necessary to approach any analysis with an attitude founded in synopsis before any synthesis of distantly sensed patterns can be accomplished.

INITIAL HYPOTHESIS

The observed, apparent anomalous patterns of stream channels call for explanation. In responding to this call we devised a general two part working hypothesis, as follows:

1) Anomalous surface patterns seen on ERTS-1 imagery are an effect of erosion produced by an ancient, high order, southwestward through-flowing stream; and
2) The numerous "channel scars" represent time-dependent surface locations of a single master stream.

The feasibility of such a historical occurrence was determined by comparison of the hypothesis with the existing theory of Colorado River history. Clarence Dutton (1882) verbosely and beautifully described the central Colorado Plateau region, emphasizing the unending work of erosive processes in reducing the level of the land during the "Great Denudation". He also noted and illustrated an abandoned north-south trending major valley at DeMott Park on the Kaibab Plateau. This valley is perpendicular to and predates the Grand Canyon in northern Arizona. Cater (1966) and Lohman (1961) are the most recent in a series of writers extending back to Henry Gannett (1882) and the Hayden Survey (Peale, 1877) to recognize that Unaweep Canyon cuts through the Uncompahgre Plateau as an abandoned channel of a major river. Blackwelder (1934) and Longwell (1946) discussed the origin and history of the Lower Colorado River and concurred that its present course represents a major change in regional drainage patterns since late Tertiary time. Hunt (1965) dates the canyon cutting as late Tertiary and Quaternary, introducing the term "anteposition" as a synthesis of superposition and antecedence to explain the process of entrenchment along parts of the Colorado River System. Thus, in general, we found existing theory of the Colorado Plateau's Tertiary erosional history compatible with our working hypothesis.

Emboldened by absence of any immediately evident contraindications from the literature, we extended the initial hypothesis to begin an accounting for geologic process. Williams (1964) and Lohman (1965) provided structural and stratigraphic tools necessary to proceed with a more detailed explanation (Figs. 2 and 3). The result of our extended thinking was submitted in preliminary abstract to this symposium as follows: A southward through-flowing Tertiary drainage system in southwestern Colorado was blocked by extrusion of the Oligocene (Steven, et al. 1967) San Juan and West Elk Mountain volcanic lahars, ash deposits, and flows. Contiguous with the volcanic activity to the east, a westward dipping structural slope formed in the Uncompahgre region, possibly owing to doming around the volcanic center. Resistant preCambrian crystalline rocks acted as an impeding level of erosion for the master stream. Any downstream westward tributary, being downdip, could thus cut to the same topographic level as the master stream and remain in softer Mesozoic rocks which overlie the preCambrian in the area of the

Paleozoic Uncompahgre highland. The tributary, being able to cut more quickly than the master stream retarded by the preCambrian, could capture the waters of the master channel. This progressive process of downstream tributary capture was repeated at several places including Roubideau, Escalante, and Dominguez Canyons (Fig. 4) until the master stream reached Unaweep Canyon. At this point in time the Uncompahgre Plateau began to rise and the master stream became antecedent, entrenching itself into the preCambrian rocks at Unaweep Canyon. Subsequent evolution of the Colorado River system occurred as outlined by Cater (1966) and Lohman (1961).

FIELD RECONNAISSANCE

To seriously consider any validity of the initial hypothesis, the time had come to leave our library armchairs and visit the Uncompahgre to look at the "immutable" historical evidence, as recorded in surface deposits and landforms. Objectives of the field work were:

1) To search for old river gravels at or near the present divide between the San Miguel-Dolores drainage basin and the Uncompahgre-Gunnison-Colorado drainage basin (i.e. along the crest of the Uncompahgre Plateau).

2) To seek high level erosion scars that could represent surfaces graded to or correlative with the level of a major ancient, throughflowing stream; and

3) To collect ground based photography for future use in the development or modification of the initial working hypothesis.

The results of the field reconnaissance were quite encouraging. Old river gravels occur at several of the hypothesized ancient channel locations. On the Uncompahgre Plateau, well-rounded pebbles, cobbles, and boulders were found in a multi-story valley 2 miles northeast of Divide Road along Colorado Highway 90 in the vicinity of Silesca Ranger Station at elevations 500 to 1,500 feet above Dry Creek (Figs. 5 and 6). The rounded gravels included many varieties of all major rock types; intrusive and extrusive igneous, metamorphic, and sedimentary. The only rock type within reach of the present drainage is sedimentary. Volcanics, granites, and metamorphic rocks at Silesca must have been carried to their present location by a major river no longer serving the drainage requirements of southwestern Colorado. Similar gravel deposits occur also at Glade Park and Unaweep Canyon at the northwestern end of the Uncompahgre Plateau, along Crystal Creek north of the Black Canyon of the Gunnison, and near Gould Reservoir on Fruitland Mesa. All these deposits were found within areas previously interpreted from the ERTS-1 imagery as probable ancient channel locations.

High level surfaces, interpreted from their field characteristics as erosion scars of a major river, were also found in their appropriate geographic positions. However, the scars were not cut on the preCambrian as originally hypothesized. The preCambrian surface, as realized from field observations, could not be a resistant level to impede downcutting of a major throughflowing stream on the Uncompahgre Plateau. Headward eroding box canyon nickpoints, along the present ephemeral and perennial streams flowing down the plateau dip slope, are defined by layers of resistant sandstones within the Mesozoic System. The recent canyons are cut to the preCambrian but do not extend across the present divide at the crest of the plateau. The high level surfaces, as well as their coincident nickpoints on the present tributary streams, are located stratigraphically on the most resistant sandstone in the uppermost part of the section as locally exposed. These surfaces do cross the divide.

No single individual geologic unit defines the high level surface throughout the Uncompahgre region. The surface drops stratigraphically from east to west, being successively cut on: the Cretaceous Dakota Sandstone at Silesca along Dry Creek, with the Mancos Shale forming the old "valley walls"; the Triassic Kayenta Sandstone in the headwaters of Dominguez Creek just east of Unaweep Canyon, with the Jurassic Morrison Formation forming old "valley walls"; and the Triassic Chinle Formation in Glade Park, in the headwater region of the Little Dolores River.

A correlative high level surface occurs south of the divide along the present course of the Dolores River between its confluence with the San Miguel River and Gateway. This surface is 1,200 to 1,800 feet above the present river, possesses meander scars of larger magnitude than those on the present river, and cuts across beds of varying resistance where the river crosses a broad, gentle syncline 10-15 miles west of the Uravan milling plant. If Cater (1966) is correct in correlation of latest Unaweep Canyon erosion by a major stream (i.e. the floor of the present canyon) with the erosion surface 100-200 feet above the present Dolores River at Gateway, then the high level surface along the Dolores is correlative with pre-Unaweep entrenchment erosion levels (Fig. 7). The meander scars and stratigraphic cross-cutting characteristics of this high bench indicate a graded surface produced by river erosion along a regional master throughflowing stream. The direction of flow in this old river may have been opposite to the present flow direction, but for the purpose of the present argument the establishment of an ancient major stream at the location of the present Dolores River is sufficient.

Other field observations germane to the discussion were obtained during field reconnaissance. Distinct, high level abandoned valleys are present in the Casto Reservoir area (Fig. 8) on the Uncompahgre Plateau and along Grizzly Gulch (Fig. 9) and Crystal Creek north of the Black Canyon on the Gunnison. A valley-in-valley form within the preCambrian gorge of Unaweep Canyon (Fig. 10) indicates antecedent entrenchment during multiepisodic uplift of the region. Windgap notches (Fig. 11, 12) cutting across the crest of the Uncompahgre Plateau and connecting the headwaters of Dry Creek-Horsefly Creek, and Roubideau Creek-Tabeguache Creek drainages are reminiscent of the classical windgaps of the Appalachian folded belt. We infer that all these surface characteristics are evidence from which the Tertiary drainage of the Uncompahgre region may begin to be reconstructed.

MODIFIED HYPOTHESIS

Two possible explanations can be invoked to explain the stratigraphic drop from east to west of the described high level erosion surface on the Uncompahgre Plateau.

1. Each drop represents a nickpoint supported by a resistant sandstone unit, and developed on a westward flowing drainage system (i.e. all levels were present on the same system at a given instant of time). In this case, the master drainage system of the area flowed parallel to the axis of the present Uncompahgre Plateau and was graded to a regional base level somewhere west of the present Colorado River.

2. Each level represents a time dependent stratigraphic location of a westward migrating, southward flowing river system. The levels are time dependent in that as time progressed the regional base level was cut deeper into the section simultaneously with westward diversion of the master stream. In this event, the levels do not represent nickpoints that migrated headward from a static, regional base level to the west, but rather a series of actual ancient regional base levels progressively defined by a laterally migrating master stream.

All facts being equal, the Law of Parsimony demands that we choose the first alternative for explanation of the Colorado River's ancestral drainage; however, we choose the second. As seen from ERTS-1, almost all streams in the area, flowing on preCambrian to Tertiary rocks, follow one of three master joint sets: 1) NE-SW, 2) NW-SE, and 3) E-W (Fig. 13).

Present high order streams conform almost entirely to the NE-SW and NW-SE sets. Many intermediate order streams such as Tabeguache and Horsefly Creeks follow the E-W joint set. From drainage patterns as shown on ERTS-1 imagery, we infer that the master joint system is inherited from the preCambrian basement rocks, with two master sets, NE-SW and NW-SE, determining the course for any major stream that has flowed in the area since preCambrian time.

The high level surface along the Dolores River places a major stream in this area preceding the entrenchment of Unaweep Canyon. If this ancient river course represents the master stream at that time, and if the headwaters of the drainage system were, as today, in volcanic mountains to the northeast (both seem reasonable assumptions), then the master stream must have occupied the NE-SW joint set along much of its course between the San Juan-West Elk Mountain source area and the high level Dolores River erosion surface. This joint set is well developed across the surface of the Uncompahgre Plateau. Abundant gravels of dispersed origin (volcanics, granites, quartzites, and sedimentaries) located near the Silesca Ranger Station in a high level valley indicate a major throughflowing stream once was at this topographic level (9,000+ feet). Windgaps, cut across the crest of the Uncompahgre Plateau, suggest that a major river flowed perpendicular or oblique to the axis of the present uplift at some earlier time. The weight of the evidence requires abandonment of the nickpoint hypothesis and adoption of the alternative. Thus, an ancestor of the Colorado River flowed southward across the Uncompahgre Plateau along the NE-SW master joint set.

EVOLUTIONARY SEQUENCE

Projection to a sequential series of events is highly inferential and based only on general geomorphic and structural processes and certain assumptions concerning the regional geologic history of the region. The assumptions are 1) a westward sloping structural surface with very low dip away from the San Juan-West Elk region existed during the time of the migration, 2) the Uncompahgre region was tectonically stable until uplift of the plateau was initiated, 3) slow epirogenic uplift and/or slow regional base level lowering occurred during the migration interval, 4) migration of the master stream post-dates the San Juan-West Elk Mountain volcanic episodes and predates the laccolithic intrusion of the La Sal Mountains, and 5) an outlet or depositional basin through or into which the master stream flowed existed somewhere to the south. With these assumptions in mind, we can now outline our current interpretation of the evolution of the ancestral Colorado River in southwestern Colorado (see Figs. 4 and 14 for the following discussion).

Prior to the San Juan-West Elk Mountain volcanic outpourings, the master stream of the region flowed southward along the approximate location of the present western edge of these mountains. Surficial aggradation by volcanic debris blocked the southward flow of this ancient stream and diverted its waters through a newly formed channel to the west, at the approximate location of the present town of Ridgway, Colorado. This river flowed upon the Cretaceous Dakota Sandstone. A tributary, downdip from the master stream, was flowing in the NE-SW joint set along the general trend of present Dry Creek. This downstream tributary easily cut to the same level as the master stream, while remaining in the easily erodible Mancos Shale. When northward tributary erosion reached the present Grand-Uncompahgre Valley area, its headward migration turned eastward and followed the NW-SE joint set, the flow direction of the stream at this point being down the structural slope. Eventually, headward migration produced intersection with the master stream, causing downstream tributary capture of the master stream's waters. This process of joint-controlled, downstream tributary capture was repeated at Roubideau, Escalante, Dominguez, and Unaweep Canyons, and possibly Glade Park. In the Dominguez Canyon area, the Triassic Kayenta Sandstone was the resistant layer impeding downcutting of the master stream, with the downdip tributary cutting headward in soft Morrison shales and siltstones. By the time the master stream reached Glade Park, the Kayenta had been breached and sandstone units in the Chinle acted as the retardant to downcutting. While the master stream was in Glade Park, intrusion of the La Sal Mountains laccolith began. A subsurface portion of this intrusion uplifted Glade Park, forcing the stream to reestablish its course on the preCambrian surface at Unaweep Canyon. The stream exhumed a slightly stripped preCambrian surface at this location before new tectonic forces initiated uplift of the present Uncompahgre Plateau (Fig. 15). During early stages of this uplift downcutting by the master stream kept pace with pulses of uplift, causing valley-in-valley forms to be cut in the preCambrian rocks of Unaweep Canyon as antecedent entrenchment proceeded (Fig. 10). Eventually the forces of uplift dominated, and the master stream was forced out of Unaweep Canyon by capture around the western end of the plateau, bringing the Colorado River to its present position.

Uplift of the plateau continued, raising the floor of Unaweep Canyon 2,000± feet above the present major stream levels and causing entrenchment of the present Colorado River across the northwest end of the plateau. This hypothetical sequence of events is intuitive and inferential, but is employable as a useful working model in a reconstruction of actual events comprising the Tertiary evolution of the Colorado River system.

REGIONAL RIVER DEPOSITS AND CHANNEL SCARS

Upon return from field reconnaissance of the Uncompahgre, we perused the literature for any mention of old river deposits or abandoned channels in adjacent areas. Yeend (1969) describes a high level, north-south trending abandoned valley containing old river gravels of igneous and metamorphic materials. This valley, which predates Quaternary glaciation, is located atop Grand Mesa across Grand Valley from the Uncompahgre Plateau. Yeend also states that 3,000 feet of downcutting occurred between the time of abandonment of this valley and the earliest evidences of Pleistocene erosion and deposition. This high level valley on Grand Mesa could represent a northern extension of the drainage system that migrated across the Uncompahgre Plateau. The 3,000 feet of erosion between recognizable Pliocene and Pleistocene erosion surfaces would then correlate with the 1,800 foot difference between the high level Dolores River surface and the Quaternary benches 200 feet above the present Dolores River. The Dolores River is downstream on the ancient profile from Grand Mesa, which accounts for the difference in vertical erosion at the two localities during the same time interval (Fig. 7).

A surficial deposit of questionable origin "rests upon an erosion surface, most of which has been carried away by streams since...earliest Pleistocene", and whose distribution is "suggestive of a valley system quite different from that of the present day" (Atwood, 1916, p. 15). This deposit, called the "Cerro Till", was mapped by Atwood and Mather (1932) in a line extending from the Black Canyon of the Gunnison to Horsefly Peak on the Uncompahgre Plateau, and is along the alignment of one of our hypothesized channels of the ancient Colorado River. Dickinson (1965) challenges the origin of the "Cerro Till" at its type locality on Cerro Summit, maintaining that the deposits are landslide material. Could the elusive Cerro Till be, in part, fluvial deposits of a pre-Pleistocene Colorado River?

Southward from the Uncompahgre Plateau are other old surficial deposits of questionable origin, resting 2,000 feet above the Animas River. Bridgetimber Mountain southwest of Durango, Colorado is covered with sorted gravels of volcanic, intrusive, and pre-Cambrian metamorphic rocks. This gravel, the Bridgetimber Gravel, was considered by Atwood and Mather (1932) to represent deposits of a Pliocene river system flowing southward from the San Juan region. Richmond (1965) reconsidered this deposit as Nebraskan glacial outwash, but is unconvincing in establishing a glacial event to coincide with the gravel deposits. Do these gravels represent the southern extension of a river that crossed the Uncompahgre?

Thus, both north and south of the Uncompahgre region, gravels of supposed Pliocene to early Pleistocene age have been described. The old channel on Grand Mesa pre-dates the earliest glaciation. Inversion of topography at Bridgetimber Mountain places a major stream to the south in a previous erosional epoch. Midway, numerous channel scars transgress the Uncompahgre Plateau. We here posit that all these river marks are evidence of a Pliocene drainage system which, as has been described, underwent complex changes during its transition from the ancient drainage system to the fluvial network now draining southwestern Colorado.

CONCLUSIONS CONCERNING ERTS INTERPRETATIONS

We have outlined essentially in case history format a hypothesis to explain the distribution of certain land forms, and to account for the genesis of geomorphically anomalous surface patterns as recognized from analysis of ERTS-1 imagery.

Utilization of ERTS-1 imagery toward these ends has provided some clues as to the possible uses and misuses of products derived from satellite technology. On the positive side, ERTS provides the synoptic view necessary to collate hitherto seemingly unrelated surface patterns. The anomalous patterns, which led us to recognize the problems of Tertiary drainage evolution in the region, appear anomalous only if viewed from the ERTS-1 perspective. Patterns displayed on the horizontal plane are most obvious and least subject to misinterpretation. However, given the unfamiliar scale and resolution of ERTS-1 imagery, many tonal and textural variations may be randomly distributed, but subjectively forced into "patterns" which exist only in the interpreter's mind, rather than being actual distinct patterns of tone and texture of the surface represented on MSS imagery. By analogy, a perfectly random distribution of dots on a piece of paper can be subjectively organized into any pattern of the viewer's choosing. When analyzing subtle tone and texture variations, care must be taken not to assign patterns to random distributions.

In the vertical plane, the difficulty in interpreting quantitatively accurate variations is obvious. Shadow pattern analysis is useful but limited in this respect. From 560 miles altitude, differences in distances parallel to the line of sight are extremely difficult to recognize. Stereoscopic quality of ERTS-1 image pairs is poor owing in part to geographic distortions inherent in the imagery. Geographical correction decreases image quality, also impairing stereoscopic analysis. As an example of misuse of imagery, our initial interpretation of the preCambrian as the impeding level of fluvial erosion across the Uncompahgre Plateau was based on faulty vertical dimension analysis. Interpretation of regional patterns from ERTS-1 imagery should be accepted with caution, especially until the new perspective becomes familiar.

To derive meaningful pattern recognition procedures for use in conjunction with ERTS and Skylab imagery, patterns recognized on the imagery should be used to plan and direct adequate observations in the field, on larger, more familiar scale remote sensing imagery such as conventional aerial photography, and on compiled maps of the study area. Nothing definitive can be stated nor conclusions drawn based solely on interpretation of ERTS-1 data, but with ERTS-directed field observations, a basis for regional pattern recognition can be obtained. The surface characteristics of repetitive patterns seen on the imagery must be defined and evaluated in the field. Interpretation of similar patterns may then be extended to the imagery. Only with caution can we proceed to develop working hypotheses or synthesize regional patterns into a cohesive historical framework.

APPLICATIONS CONSIDERATIONS

We cannot predict precisely how basic landform studies of arid regions, such as presented herein, will find application. However, it is reasonable to expect that better understanding of regional surface landform patterns and geomorphic processes will be used in the future search for water and mineral resources, and solution of engineering and land use problems in arid zones.

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LEGEND FOR ILLUSTRATIONS

Fig. 1. General physiographic and land use features of southwestern Colorado, manually interpreted from ERTS-1 Frames 1066-17251 (top half) and 1066-17254 (bottom half). The Uncompahgre Plateau region trends NW-SE across the upper middle portion and is marked as (18). See following page for explanation of numbering.

Fig. 2. Geologic cross-section subparallel to axis of the Uncompahgre Plateau.

Fig. 3. Stratigraphic section of the Uncompahgre region. From Lohman (1965).

Fig. 4. Drainage diversion channels of westward migrating Tertiary Colorado River system: 1 = Roubideau Canyon, 2 = Escalante Canyon, 3 = Big Dominguez Canyon, 4 = Unaweep Canyon, Present Colorado and Gunnison rivers shown by heavy, solid lines. Details are superposed on ERTS-1 Frame 1066-17251, channel 7.

Fig. 5. Large, subrounded rhyolite boulder 30 yards south of entrance to Silesca Ranger Station on Colorado Highway 90; elevation 9,000 feet.

Fig. 6. Stream-rounded pebbles, cobbles, and boulders on west side of Colorado Highway 90, 5 miles north of Silesca Ranger Station. Quartzite and granite cobbles manually placed atop the volcanic boulder in center of picture. Elevation 7,500 feet.

Fig. 7. Generalized graded profiles of ancient and modern Colorado River systems at times t_1, t_2, and t_3. Time t_1 represents pre-Unaweep Canyon entrenchment surface, t_2 the post-Unaweep entrenchment surface, and t_3 the present north-south profile of Colorado River. A = high level abandoned valley on Grand Mesa, B = highest alluviated bench (pediment ?) along the flank of Grand Mesa, C = high level surface along Dolores River, D = low level bench 100 to 200 feet above present Dolores River, E = stripped Kayenta surface along Unaweep Canyon, F = floor of Unaweep Canyon. Arrows represent amount of vertical erosion in Grand Mesa, Unaweep, and Gateway areas during time interval t_1 - t_2. Fig. 7A restores profiles to their pre-Uncompahgre uplift relations. Fig. 7B shows relationships of the three surfaces as they now exist.

Fig. 8. Abandoned high level valley near Casto Reservoir, 5 miles east of Unaweep Canyon. Valley floor is cut on Triassic Kayenta Sandstone with Jurassic Entrada Sandstone forming low valley walls.

Fig. 9. Grizzly Gulch, looking south towards Black Canyon of the Gunnison River. Present stream is underfit. Line of hills on horizon is across Black Canyon, which drops 2,000 feet and runs normal to line of sight 1.5 miles distant from point of photography.

Fig. 10. Valley-in-valley form cut in preCambrian rocks of Unaweep Canyon.

Fig. 11. Windgap notches cut into crest of the Uncompahgre Plateau. Left notch connects headwaters of Roubideau Creek and Tabeguache Creek. Right notch connects Deep Creek and Horsefly Creek.

Fig. 12. Telephoto view of windgap, showing valley-in-valley characteristics.

Fig. 13. ERTS-1 Frame 1066-17251, channel 6, showing joint control of drainage system. Rose diagram of regional jointing from Badgley (1962), compiled from air photo analysis of outlined portion of the Uncompahgre Plateau.

Fig. 14. Enlargement of ERTS-1 Frame 1066-17251 showing the Uncompahgre Plateau. Enlargement obtained through use of LARS/Purdue LARSYS program DISPLAY and digital display television screen. Each ERTS-1 data element is represented by four gray scale picture elements on the video screen. The town of Ridgway is just off picture to the right. The first diversion channel described in text is the lower left hand corner of the picture.

Fig. 15. Unaweep Canyon, looking west from point along secondary road leading out of canyon to Divide Road on the Uncompahgre Plateau. The stripped preCambrian surface is in the immediate foreground and along the top of cliffs to the right. Cutting of the sharp canyon walls in preCambrian rocks occurred during entrenchment coincident with uplift of the plateau. West Creek is the present underfit stream flowing in the canyon. Colorado 141 is the highway.

LEGEND FOR FIGURE 1

RIVERS

1) Colorado River
2) Gunnison River
3) Uncompahgre River
4) San Miguel River
5) Dolores River
6) Mancos River
7) Animas River
8) San Juan River
9) Chinle Creek

MOUNTAINS

10) West Elk Mountains
11) La Sal Mountains (laccolith)
12) San Juan Mountains
13) Abajo Mountains (laccolith)
14) La Plata Mountains (laccol.)
15) El Late (Ute) Mountains (laccolith)
16) Carrizo Mountains (laccol.)
17) Shiprock (volcanic neck)

PLATEAUS AND MESAS

18) Uncompahgre Plateau
19) Battlement Mesa (volcanic flow)
20) Grand Mesa (volcanic flow)
21) Mesa Verde
22) Monument Uplift

STRUCTURAL VALLEYS

23) Sinbad Valley (anticlinal graben)
24) Castle Valley (anticline)
25) Paradox Valley (anticlinal graben)
26) Spanish Valley (anticlinal graben)
27) Lisbon Valley (anticline)
28) Gypsum Valley (anticlinal graben)

LINEARS

29) Roan Cliffs
30) Book Cliffs
31) Comb Ridge
32) Black Canyon of the Gunnison
33) Unaweep Canyon (abandoned Colorado River Channel)

MUNICIPALITIES

County Seats in Colorado
34) Grand Junction (Mesa Co.)
35) Delta (Delta Co.)
36) Montrose (Montrose Co.)
37) Ouray (Ouray Co.)
38) Telluride (San Miguel Co.)
39) Silverton (San Juan Co.)
40) Dove Creek (Dolores Co.)
41) Cortez (Montezuma Co.)
42) Durango (La Plata Co.)

Outside Colorado
43) Moab, Utah
44) Farmington, New Mexico

LAND USE

!!!!! Crop Land

////// Pasture Land

Appendix D Evaluation of Aircraft Photography

Table 1. Vegetation symbol system for wide range usage with corresponding ERTS categories.

Numerical code	ERTS #	Category	ERTS category
00.	B.1 B.2	Non-vegetated	Exposed Rock Exposed Soil
01.	W	Water	Water
02.	U	Urban	Urban
110	161	Grasslands	Agricultural
121	C.6	Colorado Blue Spruce	Colorado Blue Spruce
122	D.1	Cottonwood-Willow	Cottonwood-Willow
130	N.1	Montane/Subalpine meadow	Meadow
141	N.2I	0-30% vegetative cover tundra	0-30% vegetated tundra
142	N.2II	30-70% vegetative cover tundra	30-70% vegetated tundra
143	N.2III	70-100% vegetative cover tundra	70-100% vegetated tundra
144	N.3	Graminoid wet meadow Usually tundra	Wet meadow
145	D.2	Alpine shrub	Alpine shrub-Willow
151	D.6	Wet shrub	Wet shrub
152	D.3	Dry shrub	Oak-shrub
153	D.4	Oak	Oak
211	D.5	Aspen	Aspen
221	C.1	Piñon Pine/Rocky Mountain Juniper	Piñon Pine/Rocky Mountain Juniper
222	C.2	Ponderosa Pine	Ponderosa Pine
222.1	C.2	Ponderosa Pine with shrub	Ponderosa Pine
223	C.2	Ponderosa Pine/Rocky Mountain Juniper	Ponderosa Pine

Numerical code	ERTS #	Category	ERTS category
224	C.2.3	Ponderosa Pine/Douglasfir	Ponderosa Pine/Douglasfir
225	C.4	Engelmann Spruce-Subalpine Fir	Spruce/Fir
Zipatone	C.5	Krummholz	Krummholz
225.1	C.4	Engelmann Spruce/Douglasfir	Spruce/Fir
226	C.7	Lodge Pole Pine	Lodge Pole Pine
227		Limber Pine/Bristlecone Pine	Not extensive
228	C.3	Douglasfir/White Fir	Douglasfir/White Fir
229		Mixed Coniferous (DF/WF/ESP/PP)	Special analysis required
231	M.1	Douglasfir/Ponderosa Pine/Aspen	DWF, P. Pine, other conifer
232	M.1	Douglasfir/White Fir/Aspen	DWF, Aspen/Oak
233	M.1	Lodge Pole/Aspen	DWF
234	M.1	Mixed Coniferous-Deciduous	DWF
161	A.3	Pasture	Pasture
162	A.1	Cultivated crop	Cultivated crop
163	A.2	Cultivated pasture	Cultivated pasture

Table 2. ERTS-1 Vegetation map categories and cover type breakdown

General		Level 1		Level 2		Level 3
Forest	C	Conifer (Con)	.1	Pinon-Juniper (PJ)	I	0-30%
			.2	Ponderosa Pine (P. Pine)	II	30-70%
			.2.3	Ponderosa Pine/Douglasfir	III	70-100%
			.4	Spruce - Fir (SF)		
			.5	Krummholz (Krum)		
			.6	Col. Blue Spruce (CBS)		as above
			.7	Lodge Pole Pine		
	M	Deciduous-Coniferous (De-Con)	.1	Coniferous species and Aspen		as above
	D	Deciduous (Decid)	.1	Cottonwood-Willow		
			.2	Alpine Shrub (AS)		
			.3	Oak Shrub (OS)		
			.4	Oak (O)		
			.5	Aspen (A)		
			.6	Wet Shrub (WS)		
Herbaceous	A	Agricultural (Agrl)	.1	Cultivated Crops (Cul. Crop)		
			.2	Cultivated Pasture (Cul. Past)		
			.3	Pasture (Past)		
	N	Non-Agricultural (Non-Ag)	.1	Meadow (M)		
			.2	Tundra (T)	I	0-30%
					II	30-70%
					III	70-100%
			.3	Wet Meadow (Wet Mead)		
Non-Vegetated	B	Rock-Soil (Bare)	.1	Exposed Rock (B. Rock)		
			.2	Exposed Soil (B. Soil)		Wet
						Dry
		Shadow		Ridge Shadow (Shadow R)		
				Cloud Shadow (Shadow C)		
	W	Water		Clear		
				Turbid		
	S	Snow		Snow only		
				Snow-Forest Mix (Snow-For)		
	C	Cloud				
	U	Urban				

Table 3. Films Evaluation

Mission	Roll	Type	Date	Frames used	Description
238	48	CP	6-6-73	0017-0018	Good contrast in greens, both coniferous and deciduous types. Easily distinguished large scale is very good. One can see individual trees for crown shape and color discrimination (note CIR of same mission has poor contrast in reds. Used for northern Ludwig Mountain (Lake Simpatico and north). Wide range of green values and saturation.
	48	CP	6-6-73	0057-0058 0072-0073 0109-0110	Used in conjunction with smaller scale CIR for coniferous distinction (CIR used for deciduous due to extremely good contrast in reds was the more recently acquired 48-roll 23).
238	49	CIR	6-6-73		Generally less separability in reds between deciduous and coniferous, especially in mixed communities. Douglasfir is difficult to distinguish from aspen.
239	30	CIR	6-6-73	0111-0112 0113	Used for southern Ludwig Mountain due to lack of larger scale color (238 roll 48 does not go far enough south). Good contrast between deciduous and coniferous except in higher elevations where vernalization has been delayed by late snow. Poor contrast in coniferous among species due to smallness of scale (about 1/2 the size of 238 roll 48).
239	29	CPOS	6-6-73	None	Distinction between shades of green not as good as distinction between shades of red on 239-30. Thus not used for vegetation mapping. Film otherwise good.

Mission	Roll	Type	Date	Frames used	Description
248	23	CIR	8-4-73	0110-0111	Very good contrast between coniferous and deciduous (twice as good as 239-30 which was good). Used instead of 239-30 since it arrived in all areas where coverage occurs. It is especially much better in higher elevations than 239-30. Unfortunately 248-23 misses the tundra area on Vallecito by a very small margin. There was also some difficulty separating oak from meadow due to smoothness of texture on both and similarity of red tones.
248	22	CPOS	8-4-73	None	Distinction between shades of greens on this roll not as good as corresponding red shades on 248-23.

Table 4. Photointerpretation criteria of NASA aircraft coverage for vegetation mapping of Ludwig Mountain and Vallecito Reservoir quads, San Juan Mountains Test Site.

Cover type (Levels 1 & 2)	Mission/Roll	ISCC-NBC color for cover type relatively level full sunlight conditions	Hue and Value		Texture	Observed elevational limits	Community description and remarks
			CPOS	CIR			
Forest **Coniferous** Piñon-Juniper C.1	239/30	17.v.d. Red with 19.gy. Red and 185.p. Blue	-	grey-red red & blue mixture	mixed scattered speckled Rounded crowns visible	7,200-7,800	Found on Ludwig Mountain quad. Usually vegetation is sparse (density = I, II) and bare soil or rock is visible between the vegetation. Stands occur in xeric sites on exposed south facing slopes or hilltops on southern edge of quad.
Ponderosa Pine C.2	238/48	147.v.d.G or 166.v.d.bG 151.d.gy.G*	deep slightly greyish green	-	same as above except larger scale allows analysis of crown shape which is broad and rounded	7,000-9,400	Found on Ludwig Mountain and Vallecito Reservoir quads. Densities of growth may vary abruptly from 100% crown closure to very open conditions. (I, II, III). Open to moderately dense stands (I, II) may have oak or shrub understory visible through the crowns of the Ponderosa Pine. Recent disturbance may generate very dense

Forest (con'd) Coniferous (con'd) Ponderosa Pine C.2 (con'd)	239/30	17.v.d. Red with 16.d. Red 19.gy. Red 186.gy. Blue	-	dominant color deep red of Ponderosa Pine	III nearly continuous, rounded crowns visible II mod. continuous, rounded crowns visible I discon-tinuous, rounded crowns visible, understory visible		stands due to closely seeded young trees. Stand sites occur in all aspects of low relief in southern Ludwig Mountain quad. Further north it is replaced by other cover types on north, east and west facing slopes. Its most northern occurrence is on south facing slopes. Sites are generally mesic. Occurs with Colorado Blue Spruce on flood plains in south.
	248/23	14.v.deep Red may grade to 17.v.d. Red or 16.d. Red*	-	dark brownish red varies with aspect and density			
Forest Coniferous Douglasfir/ Ponderosa Pine C.2.3	238/48	147.v.d.G 166.v.d.bG 151.d.gy.G*	slightly greyish deep green	-	nearly continuous mottled rounded crowns visible. Ponderosa crowns resemble Douglasfir	7,200-9,400	Found on both Ludwig Mountain and Vallecito Reservoir quads. In the south it appears on the north sides of hills gradually assuming eastern and western exposures at higher elevations. Usually occurs in dense stands (III). It may grade into either Doug-lasfir/ White Fir or

Forest (con'd) Coniferous (con'd) Douglasfir/ Ponderosa Pine (con'd) C.2.3 (con'd)	239/30	17.v.d. Red 14.v. deep Red	-	deep red, slightly bluish on slopes	mottled by crowns, individual crowns visible but not useful for distin-guishing type		Ponderosa Pine cover types. Distinguish from Ponderosa Pine mostly by aspect and density from ground observations.
	248/23	17 v.d. Red 14.v. deep 41. deep r.Br	-	deep red to reddish brown	mottled by crowns individual crowns visible but not useful for distin-guishing type		
Forest Coniferous Douglasfir/ White Fir C.3	238/48	151.d.gy.G (white fir) 151.d.gy.G 147.v.d.G*	white fir greyish blue-green	-	uneven crowns quite mot-tled, white fir and Douglasfir similar except for color	7,200-9,400	Found on Ludwig Mountain and Vallecito Reservoir quad. Replaces Ponderosa Pine/Douglasfir on steep north, east and west facing slopes. Generally occurs at higher eleva-vations than Ponderosa Pine/Douglasfir. Densi-ties of stand usually III. Uneven crown heights and White Fir's distinctive grey-green color makes it distinguishable.
	239/30	17.v.d. Red 41.deep r.Br with a slightly bluish cast	-	Douglasfir and White Fir similar shade deep red slightly brown or blue	uneven crowns visible, color differences more dif-icult to tell		

Forest (con'd) Coniferous (con'd) Douglasfir/ White Fir (con'd) C.3 (con'd)	298/23	17.v.d. Red 14.v. deep Red 41. deep r.Br	-	deep reddish brown	uneven crowns visible, color differences more difficult to tell		
Forest Coniferous Spruce/Fir C.4	238/48	147.v.d.G 152.Blackish G. 151.d.gy.G* depending upon slope and aspect	from deep forest green to grayish green	-	mottled, but crowns fairly even and pointed	9,000-11,000	Found on Vallecito Reservoir at higher elevations. First appears on north and then east and west facing slopes, later on south facing slopes. Densities usually III. Grades into Douglasfir/ White Fir. Pointed crowns on 1:40,000 scale imagery distinguishes it from other conifers.
	239/30	17.v.d. Red 14.v.deep Red 41.deep r.Br 186.gy.Blue	-	grades from red-blue to red-brown with blue understory	mottled but crowns fairly even and pointed		
	248/23	41.deep r.Br 14.v.deep Red	-	deep reddish brown	mottled but crowns fairly even and pointed		
Forest Coniferous Colorado Blue Spruce C.6	238/48	147.v.d.G 151.d.gy.G*	from deep forest green to grayish green	-	mottled, crowns pointed may be discontinuous	7,000-7,800	Found on Ludwig Mountain and Vallecito Reservoir quads along major rivers on flood plains. Densities vary from I-III. It may be mixed with Ponderosa Pine or Cottonwood. Not extensive.

[illegible] Coniferous (con'd) Colorado Blue Spruce (con'd) C.5 (con'd)	[illegible]	[illegible].v.d. Red [illegible].v. deep Red	-	[illegible]	mottled, [illegible] crowns may be discon-tinuous		
	248/23	41.deep r.Br 14.v.deep Red	-	deep reddish brown	mottled, [illegible] crowns may be discon-tinuous		
Forest Deciduous-Coniferous M.1	238/42	[illegible].v.d.G [illegible].d.gr.G and 14[illegible].d.G [illegible] 126.d.Ol.G or 137.d.[illegible].G	dark green conifers mixed with more yellow green or brighter green aspen	-	mottled with patches of smooth aspen mixed	7,400-11,900	Found on Ludwig Mountain and Vallecito Reservoir quads. Occurs mostly in logged or burned areas where conifers mix with aspen. Very extensive on western Vallecito Reservoir. Densities vary from I to III. All slopes and aspects are included. Sites are mesic.
	239/30	17.v.d. Red 14.v. deep Red with 16.d. Red 13.deep Red	-	darker red conifers with pinkish red to bluish pink aspen	mottled with patches of smoother aspen mixed		
	248/23	41.deep r.Br 14.v. deep Red with 13.deep Red and 11.v. Red	-	darker brown-red conifers with bril-liant to deep red			

Forest (con'd) Deciduous Riparian Cottonwood (Willow) D.1	238/48	164.m.b.G to 147.v.d.G	varies from lighter bluish green to deep green	-	discontinuous puffy crowned, mottled	7,000-7,800	Found on Ludwig Mountain and Vallecito Reservoir quads along major river flood plains. Densities may vary from I to III. Mixing occurs with coniferous species and cover type grades into tall willow with increased elevation. Sites are quite moist, with high water table.
	239/30	16.d. Red	-	medium pinkish red	discontinuous puffy crowned, mottled		
	248/23	11.v. Red	-	Bright red	mottled, may be discontinuous		
Forest Deciduous Oak-shrub D.3	239/30	184.v.p.B 263.White 6.d. Pink	-	mottled blue-grey and light pink	rough discontinuous	7,000-8,000	Occurs on Ludwig Mountain quad on dry, south facing slopes on southern half of quad. Densities usually I or II. Much bare soil or rock may be visible. Occasional Ponderosa Pine may occur.
Forest Deciduous Oak D.4	238/48	150.gy Green to a brighter grey green	pale grey green to a brighter grey green, varies with elevation	-	mottled slightly rough surface	7,000-9,800	Occurs more extensively on Ludwig Mountain than on Vallecito Reservoir quad. Forest stands on north facing slopes of hog backs. To a lesser

<u>Forest</u> (con'd) <u>Deciduous</u> (con'd) Oak (con'd) D.4 (con'd)	239/30	slightly pinker than 19.gy. Red and 15.m. Red	-	greyish red	mottled, slightly rough surface		extent appears relatively frequently on all exposures and usually as understory in Ponderosa Pine stands. On south facing slopes grades into sparser and perhaps drier oak-shrub cover type. Community shape may be lobate or elongate, especially on hogback slopes.
	248/23	none apply	-	bright to dark red orange	mottled, slightly rough surface		
<u>Forest</u> <u>Deciduous</u> Aspen D.5	238/48	145.m.G 146.d.G*	fairly bright grey green	-	rounded crowns visible	7,600- 11,700	Found on Ludwig Mountain and Vallecito Reservoir quads. Usually occurs on north facing slopes at lower elevations and gradually moves to all aspects with increasing elevation. May be associated with moist or disturbed areas. Occurs mixed with conifers very extensively in disturbed areas of upper elevations on Vallecito Reservoir quad. Densities are generally III. Communities have rounded or lobed form due to clonal growth habit.
	239/30	12.s. Red to 19.gy. Red and 186.gy. Blue	-	varies from bright pinkish red to grey-blue at high elevations where vernalization is incomplete	rough, rounded crowns visible		
	248/23	none apply	-	bright orange red, may be darker	rough, rounded crowns visible		

Forest (con'd) Deciduous (con'd) Wet Shrub D.6	248/23	none apply	-	bright orange red, may be mottled	nearly smooth	7,800-11,900	Category added to bridge a gap between Alpine shrub (above timberline) and Cottonwood Willow communities along rivers below 7,800. This cover type occurs in subalpine meadows, forest clearings, mesic hill sides and small floodplains. Can be distinguished from meadow, oak and aspen by textural differences.
Herbaceous Non-Agricultural Cultivated Crops A.1	238/30	146.d.G or bare soil from recent cultivation	bright deep green or bare soil brown	-	fairly smooth	7,000-7,500	Occurs on Ludwig Mountain quad. Usually limited to floodplains. May show recent cultivation or row crop configuration. Usually rectangular fields.
	239/48	11.v. Red or 185.p. Blue	-	either bright red or pale blue (recently cultivated)	fairly smooth		
Herbaceous Non-Agricultural Cultivated Pasture A.2	238/30	146.d.G	bright green	-	fairly smooth	7,000-7,500	Occurs on Ludwig Mountain quad. Usually limited to floodplains. Planted to a few species within last decade. Irrigated by system of ditches.

Herbaceous (con'd) Non-Agricultural (con'd) Pasture A.3	238/30	none apply	mottled shades of yellow to grey green	-	fairly smooth	7,000-9,200	Occurs on Ludwig Mountain and Vallecito Reservoir quads. May actually occur in any meadow up to and onto the tundra. However, this cover type is reserved for use on moderate to heavily grazed areas by virtue of proximity to farm areas and ease of access for animal transport. Non-cultivated irregular areas on floodplains with mottled (pale) color.
	239/48	none apply	-	mottled shades of pinkish red to blue	fairly smooth		
	248/23	mottled 11.v. Red to 16.d. Red or 19.gy. Red	-	mottled shades of bright red to brown or grey-red	fairly smooth		
Herbaceous Non-Agricultural Meadow N.1	238/30	none apply	mottled shades of grey greens	-	fairly smooth	7,000-11,900	Occurs on Ludwig Mountain and Vallecito Reservoir quads. Most meadow areas are grazed domestically to a limited extent. Where grazing is moderate the "meadow" may be classified A.3. Some clear cut areas appear classed as meadows because of the dominant vegetation. Some shrubs or rocks may interrupt the herbaceous growth of a meadow.
	239/48	none apply	-	mottled shades pinkish red to blue	fairly smooth		
	248/23	19.gy. Red 15.m. Red 12.s. Red 13.deep Red to 11.v. Red	-	mottled shades of bright red	fairly smooth		

Non-Vegetated Rock-Soil Exposed Rock B.1	238/30	29.m.y. Pink to 263. White	from reddish yellow pink to white	-	rough or smooth	7,000-12,300	Occurs on Ludwig Mountain and Vallecito Reservoir quads. Usually appears as cliff face or under sparse cover such as Piñon-Juniper.
	239/48	185.p.Blue to 263. White	-	shades of blue to white	rough or smooth		
	248/23	185.p. Blue to 263. White	-	shades of blue to white may appear slightly yellow			
Non-Vegetated Rock-Soil Exposed Soil B.2	238/30	31.p.y Pink to 263. White	from pale yellow pink to white	-	fairly smooth	7,000-12,300	Occurs on Ludwig Mountain and Vallecito Reservoir quad. Appears on flood-plains, road cuts, blowouts, reservoir margins freshly plowed fields, and between vegetation of sparsely vegetated cover types.
	239/48	184.v.p. B to 263. White	-	pale blue to white	fairly smooth		
	248/23	184.v.p. B to 263. White	-	pale blue white	fairly smooth		

Non-Vegetated (con'd) Urban Urban U.1	238/30	263. White	roofs appear white, yards green	-	rough with linear roads	7,000-7,600	Occurs on Ludwig Mountain and Vallecito Reservoir quads. Small clusters of building occur on several sites. No major towns are within these quads.
	239/48	263. White	-	roofs appear white, yards red	rough with linear roads		
	248/23	263. White	-	roofs appear white, yards red	rough with linear roads		

* Film colors somewhat greyer than color chips.

APPENDIX E

TECHNIQUES FOR COMPUTER-AIDED ANALYSIS OF ERTS-1 DATA, USEFUL IN GEOLOGIC, FOREST AND WATER RESOURCE SURVEYS

Roger M. Hoffer* and Staff**

ABSTRACT

Forestry, geology, and water resource applications were the focus of this study, which involved the use of computer-implemented pattern-recognition techniques to analyze ERTS-1 data. The results have proven the value of computer-aided analysis techniques, even in areas of mountainous terrain.

Several analysis capabilities have been developed during these ERTS-1 investigations. A procedure to rotate, deskew, and geometrically scale the MSS data results in 1:24,000 scale printouts that can be directly overlayed on 7 1/2 minute U.S.G.S. topographic maps. Several scales of computer-enhanced "false color-infrared" composites of MSS data can be obtained from a digital display unit, and emphasize the tremendous detail present in the ERTS-1 data. A grid can also be superimposed on the displayed data to aid in specifying areas of interest, such as avalanche tracks or areas of burned-over timberland. Temporal overlays of six sets of data have allowed both qualitative and quantitative analysis of changes in the areal extent of the snowpack.

Computer-aided analysis of the data allows one to obtain both cover-type maps and tables showing acreage of the various cover types, even for areas having irregular boundaries, such as individual watersheds. Spectral analysis of snow and clouds, water and shadow areas, and forest cover of varying overstory density have revealed several important results.

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** Personnel involved in this study were from both the Laboratory for Applications of Remote Sensing, Purdue University and from the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado.

This study was supported by NASA Contract NAS5-21880 and by NASA Grant NGL 15-005-112.

INTRODUCTION

This is an interdisciplinary study designed to test the applicability of computer-aided analysis techniques to identify, classify, and map major cover types in the Colorado Rocky Mountains, using multispectral scanner data from ERTS-1. Emphasis has been placed upon a development of analysis techniques useful for processing ERTS-1 data to meet geologic, forest and water resource applications objectives.

Previous work has proven the value of computer-aided analysis of remote sensor data using pattern recognition techniques, but most of this work has been restricted to areas having little topographic relief (1,2,3). It was believed that variations in aspect and slope would have a significant impact upon the spectral response measured by the ERTS-1 scanner. If computer-aided analysis techniques are to be utilized on an operational basis, the relationships between topographic relief and spectral response must be determined. Therefore a key aspect of this study has been the evaluation of computer-aided analysis techniques, to determine their operational utility in areas of mountainous terrain, where so many of our valuable water, forest, and geologic resources are located.

Several different analysis techniques have been developed which have allowed more effective use of ERTS-1 data in the various discipline applications of importance. The major techniques developed are as follows:

- Reformat data to place a full ERTS frame onto a single data tape.
- Display system grid to aid in location of the specific areas of the data tapes.
- Computer-aided enlargement capabilities.
- Geometric correction and scaling.
- Irregular boundary delineation for obtaining area calculations.
- Multiple overlays of digital data.
- Merging of classification results to show temporal change.
- Shadow mapping program as an aid in data interpretation.

The following paragraphs will briefly describe some of the more important of these analysis techniques that were developed and the manner in which they were utilized to meet the objectives of the various discipline groups.

DATA REFORMATTING AND DISPLAY SYSTEM GRID

The original four data tapes containing a single frame of ERTS-1 data are reformatted and the data is placed on a single 1600 b.p.i. data tape. No changes are made in the radiometric quality of the data. This procedure allows easier and more convenient analysis of the data in various portions of a single frame.

After reformatting, the usual procedure has been to go through an enhancement sequence in which individual channels of ERTS data are displayed on the LARS digital display unit and photographed through appropriate filters to produce a false color-infrared composite image of the frame or portion of the frame of interest. To assist in defining the location on the data tape of a particular area of interest, a procedure was developed to superimpose an X-Y grid on the data being displayed. Such a grid can have any desired degree of detail, since every Nth line and Mth column of the investigator's choosing can be displayed. For example, if the entire frame were being displayed, usually a grid of every 200 lines and 200 columns would be superimposed on this data, as shown in Figures 1 & 2. On enlargements of the ERTS data a much finer grid system could be utilized, as for example, every 20th line and column. In some cases, a one square mile grid has been found to be extremely useful. Similarly, one could superimpose a latitude and longitude grid onto the data, if this were more convenient for the investigator.

COMPUTER-AIDED ENLARGEMENT OF DIGITAL DATA

One data processing capability that has proven to be of particular importance in our investigations involves use of the digital data tapes to display data at enlarged scales. Since the digital display unit has the capability of displaying about 800 pixels per line and 500 lines of data, to fit an entire ERTS frame on the screen requires that only 5th line and 5th column initially be displayed. An example of this was shown in Figure 1. Then, by starting with a certain line and column number of the users choice, one can display a subset of the entire frame of data for example, every third line and column, or every line and column as shown in Figures 3 & 4. The next step in enlarging a designated area would involve displaying every ERTS resolution element as two pixel elements along each line of data displayed, and repeating the display of that line of data. In effect, this causes every ERTS resolution element to be displayed as four pixel elements on the display unit. This results in a considerable enlargement of the ERTS data, as shown in Figure 5. One can also go to 16 pixel elements per resolution element but at this scale the data becomes somewhat blocky in appearance, as seen in Figure 6.

We have found that by enlarging the ERTS data with these digital techniques, a large amount of detail can be seen in the ERTS data. In many cases this detail cannot be seen on the original ERTS imagery or even on 1:250,000 scale photographic enlargements of the original imagery. It is our belief that by using the digital computer to display individual resolution elements of ERTS data, one can obtain a great deal more information than would be possible through normal optical enlargements of the original imagery. There is a tremendous amount of detail present in the ERTS data that is not evident and will simply be missed if one is limited to working with the 1:1,000,000 scale imagery format. This fact has had a significant impact on many of our studies. In developing materials to use in working with the U.S. Forest Service and various state and county land use agencies, we could display the ERTS data at scales large enough to show forest burned areas and avalanche tracks (Figure 7). Location and delineation of such avalanche tracks is of great importance in land use planning activities in these mountain areas, because of the number of houses being built in and near the bottom of these highly hazardous areas.

GEOMETRIC CORRECTION AND SCALING

A particularly significant procedure to allow effective analysis of the ERTS-1 data involves the geometric correction and scaling of the MSS data. This program involves five steps, in which a 1200 line by 1200 column block of data is rotated, deskewed, and rescaled to the users' specifications (4). Use of the system corrected data tapes allows these geometric correction steps to be done without loss in radiometric quality of the data. The only input required for this program, along with the reformatted data tape, is the latitude and longitude of the center point of the data frame involved. The usual output is a geometrically corrected data tape which, if every line and column are displayed on the line printer, allows one to obtain a 1:24,000 scale gray scale printout, oriented with north at the top. Use of this scale allows the analyst to overlay the printout directly on 7 1/2 minute U.S. Geological Survey topographic maps, or other 1:24,000 scale maps and images. This has proven to be extremely beneficial in helping the investigator locate particular, small features of interest, or to define known boundary lines (such as roads) that may not be particularly obvious on the ERTS data. In our studies, we found that proper evaluation of our forest cover classification results from the ERTS data would have been nearly impossible without the use of geometrically corrected and scaled data. This was due to the great difficulty experienced in reliably locating particular stands of forest cover on the uncorrected ERTS data.

Figure 8 shows a portion of an uncorrected computer printout in which the Vallecito study area has been outlined. The U.S. topographic maps of this 1 1/2 quadrangle study area were overlayed by an acetate sheet and many of the features which could be easily delineated on the map and could also be seen on the gray scale printouts of ERTS imagery were defined (Figure 9). Next, the data was put through the geometric correction and scaling routine and a gray scale printout of this study area was produced. The acetate overlay obtained from the topographic map was then overlayed on the computer printout and the high degree of accuracy of the geometric correction and scaling procedure can be shown (Figure 10). All of the features previously delineated from the topographic map are clearly defined in the same positions on the printout of the ERTS data.

APPLICATION OF ANALYSIS TECHNIQUES TO COVER TYPE MAPPING

As indicated previously, many of the analysis techniques were developed in order to satisfactorily carry out our analysis of ERTS-1 data. One of the major thrusts of the investigation involved ecological inventory, with emphasis on forest cover type mapping. Discussions with U.S. Forest Service personnel indicated as immediate need for general cover type mapping (Level 1) as shown on Table 1, and also the need for maps of various forest types (Level 2 of Table 1). The Forest Service also indicated that many of their planning activities require various levels of detail, much of which could largely be met by maps showing the Level 1 and Level 2 cover types. Several other groups also indicated a similar need for vegetative cover type maps. These included the National Park Service (who needs such information for long range planning and for evaluating and aiding in policy decisions on the use of lands under their jurisdiction), the Bureau of Land Management (who are particularly interested in an inventory of vegetative cover types and present land use, and were also interested in lands having potential for oil shale development), the Division of Wildlife for the Colorado State Government, and several land use planning groups.

Computer-Aided Analysis Results

Based upon input provided by the various user agencies, concerning vegetative cover type mapping, we have emphasized determination of the accuracy and reliability for using computer-aided analysis techniques to map cover types defined by Level 1 and Level 2 categories.

Much of the analysis has involved a four quadrangle area around Lemon and Vallecito Reservoirs in the San Juan Test Site. Detailed cover type maps were prepared, using the WB-57 photography provided by NASA. Field crews then selected 168 test areas to use in assessing the accuracy of the classification results and for studying slope-aspect-stand density relationships. Classification results indicated that in spite of very distinct variations in spectral response due to the effects of slope, aspect, and differences in density of the forest stands, the various Level 1 categories of cover type could be identified to better than 80% accuracy in most cases. The exception to this was the non-agricultural land, which includes meadows and tundra lands. These were classified as forest cover in many cases. Classification results for the test fields defined within the four quadrangle study area are shown in Table 2. These test field results are a means to quantitatively indicate the classification accuracy obtained over the entire study area.

Classification to the Level 2 degree of refinement has shown many variations in spectral response among the coniferous forest cover groups because of the effects of varying slope, aspect, and density of the forest stands. There appears to be a high degree of correlation between aspect, slope, and density in the spectral response. The interrelationships between these factors are still being studied. It appears that models will have to be developed to take such interrelationships into account before accurate classification can be obtained for the Level 2 categories of coniferous forest cover.

ANALYSIS TECHNIQUES APPLIED TO SNOW MAPPING AND WATER RESOURCE SURVEYS

Computer-aided analysis of ERTS-1 data involving water resource applications has involved several studies including the following:

- Mapping and tabulating the areal extent of snow cover
- Overlaying multiple passes of ERTS data and mapping and tabulating the temporal change in snow cover
- Assessing the capabilities to spectrally differentiate snow from clouds using ERTS-1 data
- Studying and characterizing the reliability of mapping surface water distribution, given the spatial characteristics of ERTS-1 data
- Studying the temporal aspects of freezing and thawing of mountain lakes.

Snow-Cloud Separability

Interpretation and analysis of many data sets have indicated that the detectors on the ERTS-1 satellite system tend to saturate when the scanner is looking at either snow or clouds. Therefore, one cannot reliably separate these two cover types using the dynamic range and spectral characteristics available in ERTS-1 data. (preliminary work with SKYLAB data does indicate that these materials can be easily differentiated in the middle infrared wavelengths, including 1.55 - 1.75 micrometers.)

To quantitatively illustrate the inability to separate clouds from snow, several areas of cloud cover and snow cover were defined on a small portion of one data set, as shown in Figure 11, and the spectral characteristics of these areas were summarized using the statistics processor of the LARSYS programs. Table 3 shows the mean plus or minus one standard deviation for several areas which are identified as cloud cover and several areas identified as snow cover on each of three different dates. A relative response level of 128 indicates saturation level for Channels 4, 5 and 6 of ERTS data and a relative response level of 64 indicates saturation in Channel 7. As can be seen from Figure 12, both snow and clouds tend to saturate all four detectors on two of the dates examined and approach the saturation level for the third date. Thus, the areal extent of snow cover cannot be reliably determined with ERTS-1 data sets in which moderate amounts of cloud cover is present. In many cases, clouds can be identified by their shadow effects, but this does not appear to be a reliable technique.

Digital Data Overlay To Map And Assess Temporal Changes in Snow Cover

Utilizing cloud-free data sets, we made use of our computer-aided analysis techniques to map and tabulate acreages of snow cover in the San Juan Test Site area. Six different data sets were involved in this study, as indicated in Table 4. These data sets were digitally overlaid to produce a single data tape containing 24 channels of data (four channels from each of the six data sets involved). A program was then developed to allow the snow cover changes from one date to the next to be mapped. The output was in the form of a color-coded image, indicating areas in which snow is present on both data sets, areas in which snow was not present on either data set, and areas of change from non-snow to snow, and from snow to non-snow.

Next, a program was developed to allow delineation of an irregular boundary, such as an individual watershed, on the ERTS data. The Animas Watershed near Howardsville, Colorado was utilized in this phase of the study. Initially the boundary was defined using U.S. topographic maps. By overlaying the 1:24,000 scale computer printouts of ERTS data directly on the map, the same boundary was defined as a series of X-Y coordinates for the ERTS data. Using an average figure of .453 hectares (1.12 acres) per ERTS resolution element, the total area within the watershed was calculated to be 14,706 hectares (36,311 acres). This can be compared to the acreage figure of 35,776 acres which was published in the U.S. Geological Survey literature. The error of 1.5% between these two figures could be attributed to many different sources, the most probable ones being error in the average area figure utilized for each ERTS resolution element or a human error in defining the watershed boundaries of the ERTS data.

Areal calculations for the amount of snow cover within the Animas Watershed on each of the six dates involved in the study indicated that some of the early fall snows had resulted in a broad, shallow snow cover which then partially melted during the late fall before the major snowpack build-up throughout the winter months. By 18 May 1973, only 19% of the area was still snow covered and the following ERTS pass on the 5th of June indicated only 12 1/2% snow cover in the Animas Watershed. Unfortunately, key data sets in March and April were not useable because of the cloud cover. It does appear, however, that reasonably reliable techniques have been developed and are available to provide much of the information needed by the several agencies involved in monitoring and predicting water yield from the snowpack in the upper mountain watershed areas.

GEOLOGIC ANALYSIS AND INTERPRETATION OF ERTS-1 DATA

In the geologic and geomorphic studies, results have indicated a close correlation between the surface cover of vegetation and the geomorphologic characteristics of the area, as was expected. Thus, use of computer-aided analysis techniques to map the surface vegetative features can be followed by manual interpretation of the data by qualified geomorphologists to produce useful geomorphologic maps of the area. Manual interpretation of much of this data is required in order to effectively take into account the spatial characteristics of the data, since our current computer-aided analysis techniques are primarily involved with the spectral features of the data.

In one of the most exciting potential applications of this combination of manual and machine-aided analysis techniques, a study was made to define areas of primary interest for further, more detailed geologic exploration for mineral deposits (5). In this study, the computer is used to produce enhanced large scale infrared composites from the ERTS-1 data tapes. Three geologists then used manual interpretation techniques to define all lineaments that could be discerned in the data. Comparison of these results produced a single lineament map showing only those lineaments that all three analysts had mapped (Figure 13). A grid was then superimposed upon this map and the number of lineament intersections within each cell of the grid were tabulated and an iso-lineament intersection map was developed. Known mineral deposits were plotted upon the iso-lineament map (Figure 14). A good relationship was observed between the location of a large number of lineament intersections and the known mineral deposits. One particular area of interest showed a large number of lineament intersections where mineral deposits were not known to exist. Field work by the geologists involved indicated that this did appear to be an area of high potential for further geologic exploration. It was later found that another team of geologists, using conventional techniques, had also defined this same area as one of extremely good potential for more detailed geologic exploration. Additionally, a mineral exploration company had already made plans to do more detailed study of this particular area, because of their belief that the area defined in our study of ERTS data is one of high geologic potential.

It would thus appear that the use of this relatively simple technique could offer tremendous geologic potentials for defining areas of interest for more intensive conventional geologic exploration.

SUMMARY AND CONCLUSIONS

In summary, several different analysis techniques have been developed to allow for more effective utilization of ERTS-1 data and computer-aided analysis techniques. The analysis of ERTS-1 data has been directed toward geologic, forest and water resource applications, in accordance with the needs of several user agencies. Contact has been established with many different user agencies and, as appropriate ERTS-1 analysis results are generated, these materials are being utilized as a basis for further discussions on the potential application of ERTS-1 data to meet particular user agency needs. Of particular interest are the contacts that have been established with the following agencies:

- U. S. Forest Service
- National Park Service
- Bureau of Land Management
- Several Colorado state governmental groups
- Several state and county land use planning groups.

In many cases, use of computer-aided techniques to enhance and enlarge ERTS-1 data is of particular interest (e.g. imagery showing avalanche tracks such as shown in Figure 7, forest burn areas, areas of timber clearcutting, and many other land use changes). In many other cases, the ability to tabulate the areal extent of certain features which can be defined and mapped on the ERTS imagery is of most value to the user agency. The ability to overlay multiple data sets is of particular value for mapping and tabulating temporal changes of various surface conditions. The results obtained thus far during this investigation have proven the value of computer-aided analysis techniques, even in areas of mountainous terrain. Although tentative, many of these conclusions can be summarized as follows:

- Reasonable accuracy (80-90%) can be achieved in areas of rugged relief for Level 1 cover type or land use classification, using machine-aided analysis techniques.

- In mountainous areas, spectral response of Level 2 forest cover types is significantly influenced by variations in stand density, aspect, and slope as well as differences between species.

- Snow cover and clouds cannot be reliably differentiated on a spectral basis in ERTS-1 data, due to detector saturation and available spectral range.

- Similar spectral response is found for many water bodies, terrain shadow areas, and cloud shadow areas, thereby making spectral differentiation difficult, particularly in the infrared wavelengths.

- Computer-aided analysis techniques are very effective for determinations of area and temporal variations of snow cover, over entire regions or individual watersheds.

- Geomorphological features can be effectively mapped with ERTS data through the use of a combination of computer-aided and manual interpretation techniques, and also utilizing knowledge of the vegetative preferences for certain parent materials, slopes, and aspects.

- Delineation of geologic lineaments and domal features can be done very effectively with ERTS data due to the synoptic view, even in heavily vegetated areas, and offers economic potential for mineral resource exploration.

- Analysis of ERTS-1 data could not have progressed satisfactorily without the development of geometric correction and other data handling and analysis techniques.

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ACKNOWLEDGEMENTS

Personnel from LARS and INSTAAR who need to be particularly recognized for their contributions to this paper include Richard Mroczynski, project coordinator for LARS; Tina Cary, Michael Fleming, Donald Levandowski, and Terry Lehman, who were involved in various aspects of the data analysis; Dr. Jack Ives, principal investigator of the sub-contract to INSTAAR, Dr. Paula Krebs, project coordinator for INSTAAR, and Debbie Keamerer, research ecologist. Many other personnel from both LARS and INSTAAR have been involved in this research, and their contributions are gratefully acknowledged.

Table 1. Cover Type Categories Utilized in Computer-Aided Analysis of ERTS-1 Data in the San Juan Mountain Test Site.

General	Level 1	Level 2
FOREST	Conifer	Pinyon-Juniper Ponderosa Pine Douglas and White Fir Spruce-Fir Krummholtz Colorado Blue Spruce
	Deciduous-Conifer	Douglas and White Fir, Ponderosa Pine, and Aspen
	Deciduous	Cottonwood-Willow Alpine Shrub Oak-Shrub Oak Aspen
HERBACEOUS	Agricultural	Cultivated Crops Cultivated Pasture Pasture
	Non-Agricultural	Meadow Tundra Wet Meadow
NON-VEGETATED	Rock and Soil	Exposed Rock Exposed Soil
	Shadow	Ridge Shadow Cloud Shadow
	Water	Clear Turbid
	Snow	Snow Only Snow-Forest Mix
	Cloud	Cloud
	Urban	Urban

Table 2. Test Class Performance for Four Quadrangle Test Site in San Juan Mountains.

Group	No of Samps	Pct. Corct	Number of Samples Classified Into Conifer	Decid	Non-Ag	Agri	Cloud	Shad	Bare	Water
1 Conifer	2031	83.0	1686	180	154	0	0	10	1	0
2 Decid	459	81.7	75	375	6	2	1	0	0	0
3 Non-Ag	276	62.0	60	44	171	0	0	0	1	0
4 Agri	60	86.7	0	8	0	52	0	0	0	0
5 Cloud	123	99.2	0	1	0	0	122	0	0	0
6 Shad	135	96.3	5	0	0	0	0	130	0	0
7 Bare	105	90.5	0	0	2	0	0	0	95	8
8 Water	236	97.9	0	0	0	0	0	0	5	231
TOTAL	3425		1826	608	333	54	123	140	102	239

Overall Performance (2862/3425) = 83.6

Average Performance by Class (697.2/8) = 87.1

168 Test Fields = 3% of Total Area (1554 Hectares or 3836 Acres)

Table 3. Comparison of Spectral Response of Clouds and Snow Using ERTS-1 Data.

	Channel			
	4 (0.5-0.6μm)	5 (0.6-0.7μm)	6 (0.7-0.8μm)	7 (0.8-1.1μm)
Clouds	126.6 ± 2.3[1]	126.2 ± 2.8	118.2 ± 6.8	55.6 ± 6.7
Snow	125.4 ± 5.2	125.0 ± 5.6	116.2 ± 10.2	51.2 ± 9.0

[1]Numbers indicate mean relative response ± 1 standard deviation using a combination of approximately 3000 data resolution elements, representing several areas of clouds and snow on each of these dates (1 Nov. '72, 6 Dec '72, and 18 May '73). Saturation level is 128 for Channels 4, 5, and 6, and is 64 for Channel 7.

Table 4. Snow Area Calculations for the Animas Watershed near Howardsville, Colorado

Date of ERTS-1 Data Utilized	Hectares (Acres) of Snow Cover Within the Watershed[1]		Percentage of Watershed Covered by Snow
1 Nov. 1972	11,193	(27,636)	76.1%
19 Nov. 1972	10,040	(24,791)	68.3%
12 Jan. 1973	9,206	(22,731)	62.6%
30 Jan. 1973	10,027	(24,757)	68.1%
18 May 1973	12,876	(31,771)	87.5%
5 Jun. 1973	11,911	(29,411)	81.0%

[1] Total area of Animas Watershed = 14,695 hectares (36,611 acres), based on ERTS-1 data calculations, and 14,478 hectares (35,776 acres) reported by U.S.G.S., indicating a difference of only 1.5%.

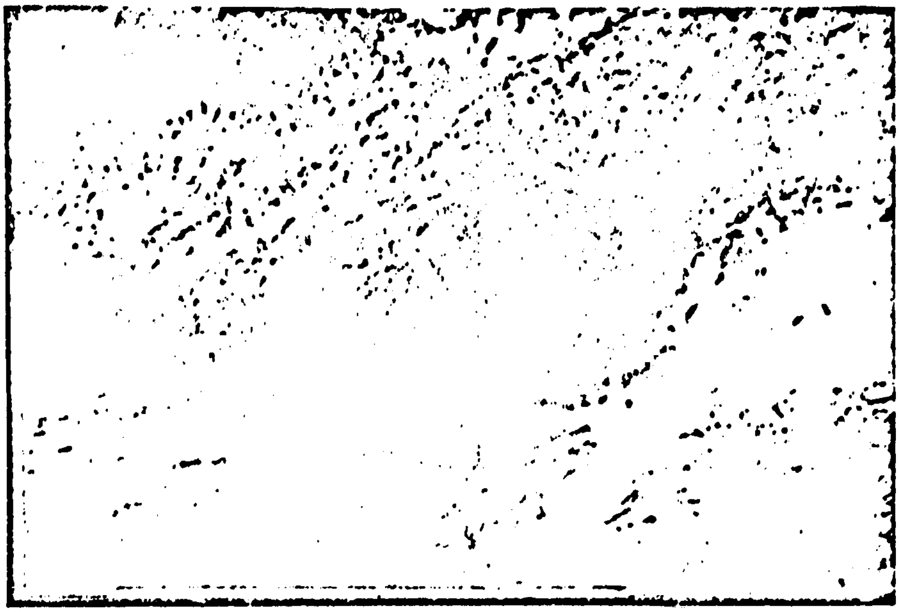

Figure 1. Color-infrared composite of September 8, 1972 ERTS-1 data from the San Juan Test Site in southwestern Colorado, taken from the LARS Digital Display Unit. The scale lines indicate a 100 kilometer (62 statute miles) length. Two different scale lines are necessary because rectangular ERTS-1 data elements are being displayed as square picture elements on the digital display.

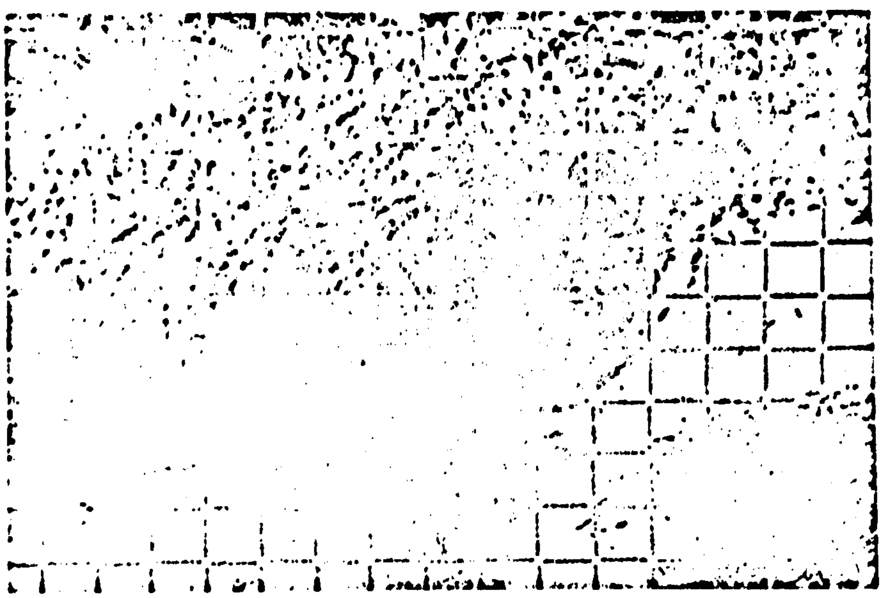

Figure 2. A grid having an interval of 200 lines and 200 columns was superimposed on the data shown in Figure 1, enabling analysts to easily determine the line and column coordinates of specific areas of interest.

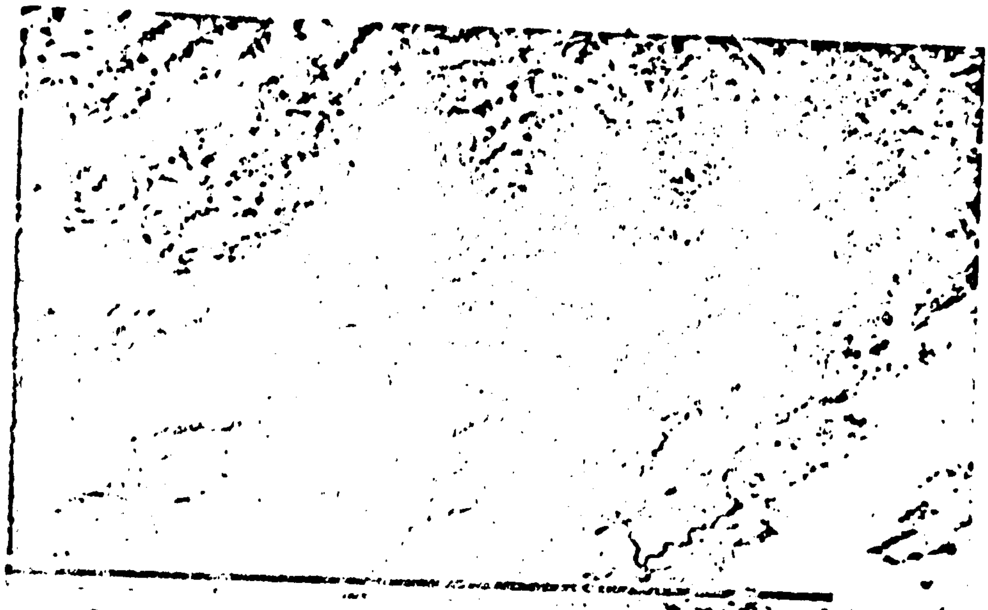

Figure 3. A portion of the data shown in Figure 1 has been enlarged by using every third line and column of data. The scale lines indicates a 100 kilometer distance, giving a horizontal scale to this illustration of 1:800,000. Further enlargement is shown in Figures 4, 5, and 6.

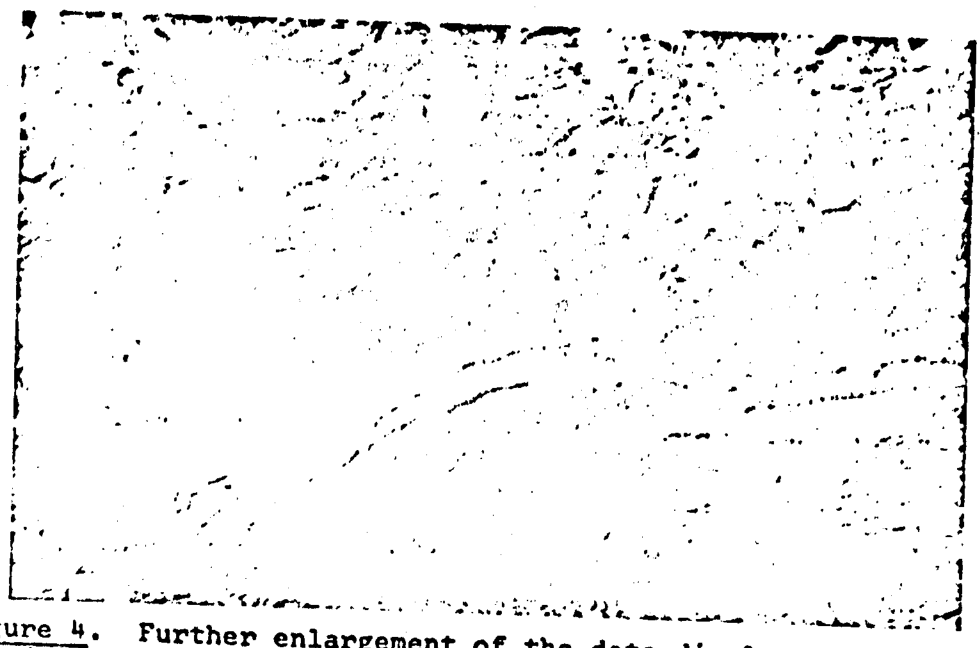

Figure 4. Further enlargement of the data displayed in Figures 1 and 3 shows Vallecito Reserovir and the surrounding area in more detail. Every line and column of data is displayed. The scale lines here represent only a 10 kilometer distance. The Horizontal scale of this illustration is approximately 1:300,000.

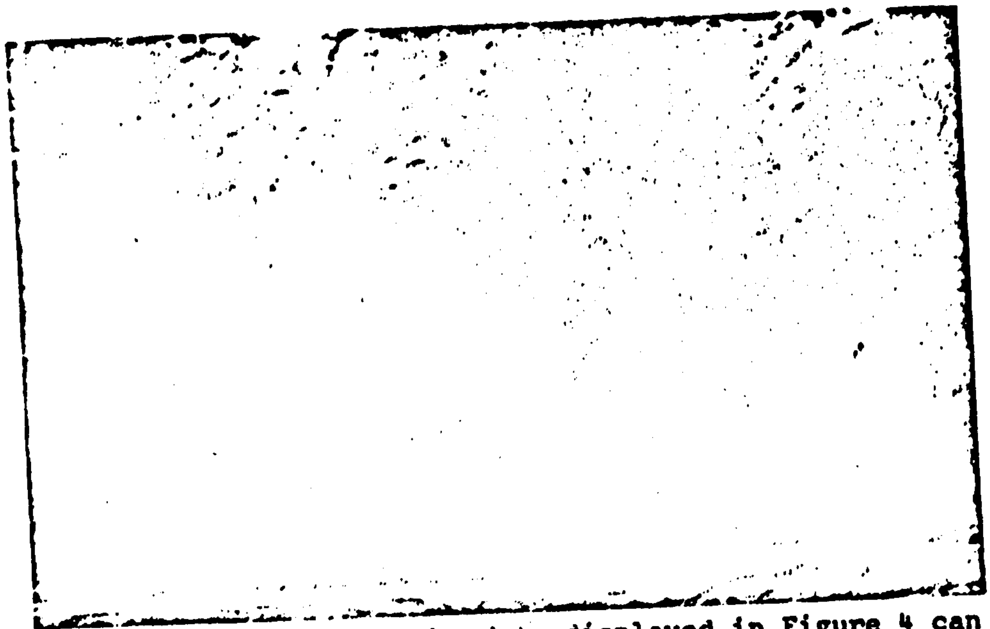

Figure 5. One fourth of the data displayed in Figure 4 can be displayed onto the full screen by using four pixels per data point. The scale lines again indicate 10 kilometers, giving this figure a horizontal scale of approximately 1:143,000.

Figure 6. Maximum enlargement capability, in which each ERTS resolution element is displayed as 16 pixel elements on the digital display. Horizontal scale of this illustration is approximately 1:72,500.

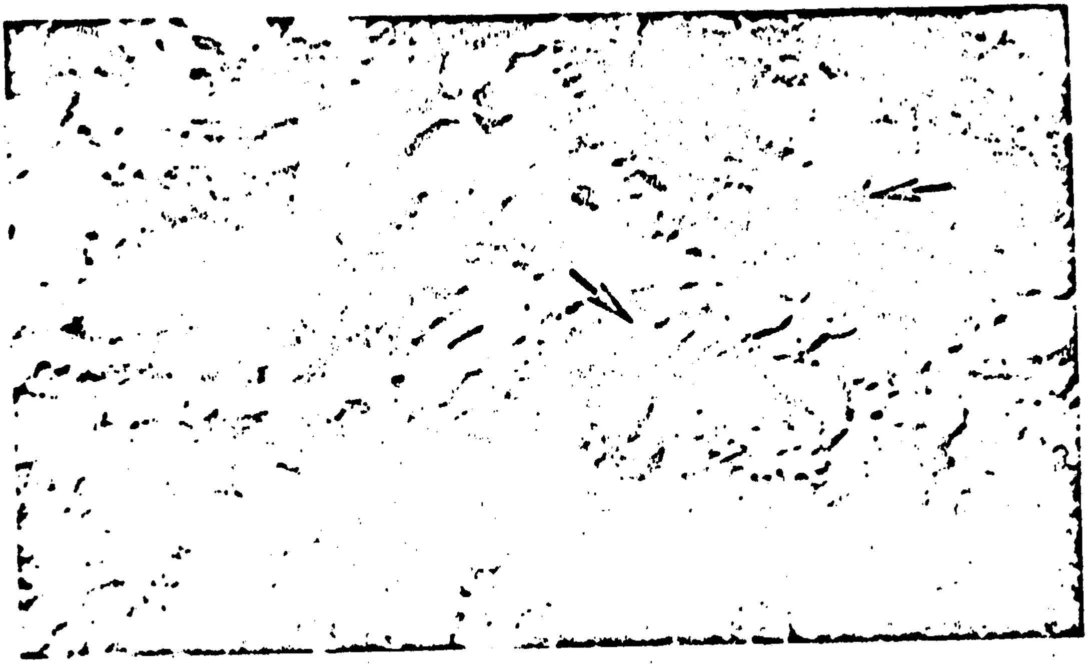

Figure 7. Enhanced color infrared composite of ERTS-1 imagery from the LARS digital display unit, showing avalanche track locations. The scale of this illustration is approximately 1:150,000. This data was obtained on September 8, 1972. Similar enlargements have allowed forest clear-cuts and burned areas to be delineated. Such computer-aided enhancement and enlargement capabilities offer many advantages for effective utilization of ERTS data in various application areas.

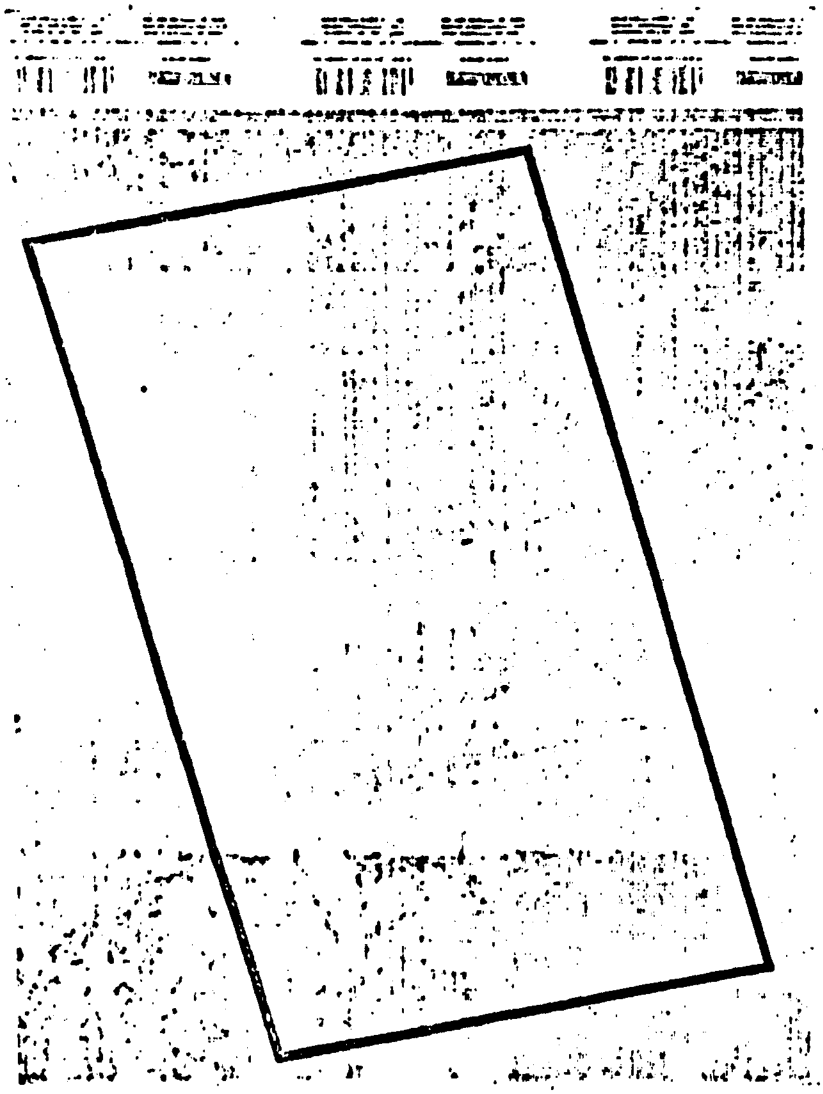

Figure 8. Uncorrected printout of ERTS data showing the Vallecito study area delineated by the heavy boundary. Compare this to the same data after it has been geometrically corrected and scaled, as shown in Figure 10.

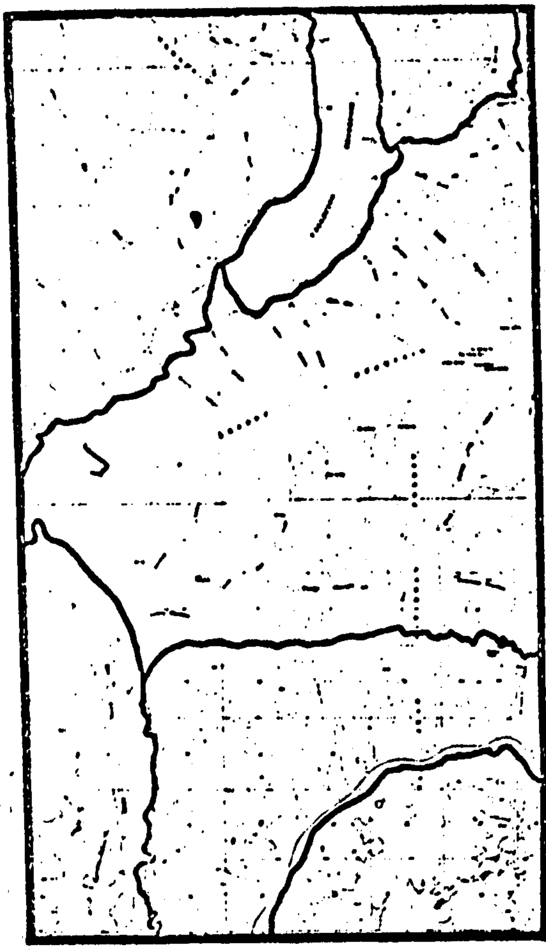

Figure 9. U.S. Geological Survey topographic maps of the Vallecito study area. Dominant features which could be easily delineated on both the topo maps and the ERTS data were delineated on an acetate overlay.

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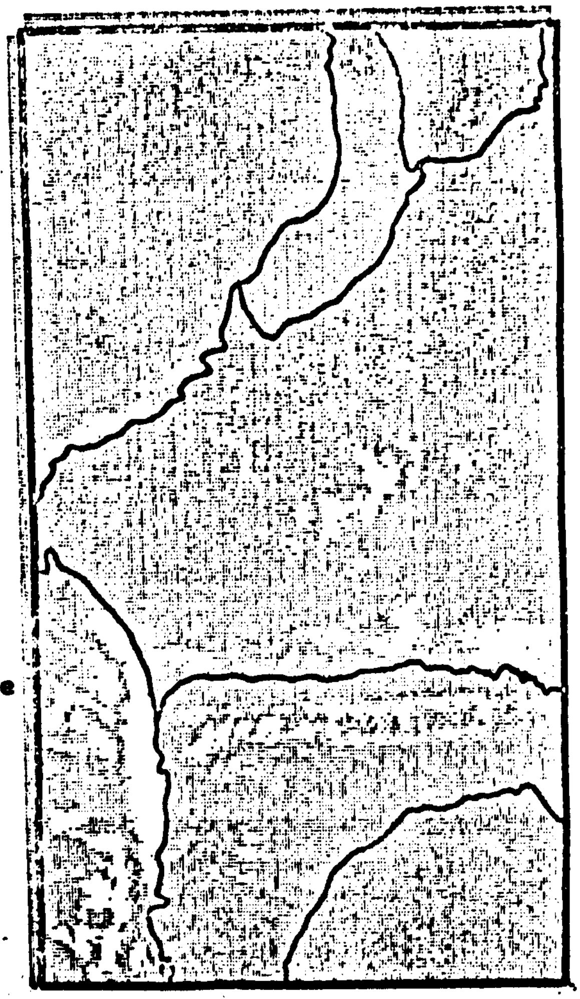

Figure 10. Geometrically corrected and scaled computer printouts of ERTS-1 data of the Vallecito study area. The scale of this printout is 1:24,000. The acetate overlay made from the U.S.G.S. topo map was superimposed on the computer printout, allowing one to verify the accuracy of the geometric correction and scaling process.

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Figure 11. Color infrared composite of ERTS data from the digital display unit, with snow and cloud areas delineated. The four rectangular areas on the left designate snow cover, while the four areas on the right are cloud cover. Comparisons of the spectral response are shown in Figure 12.

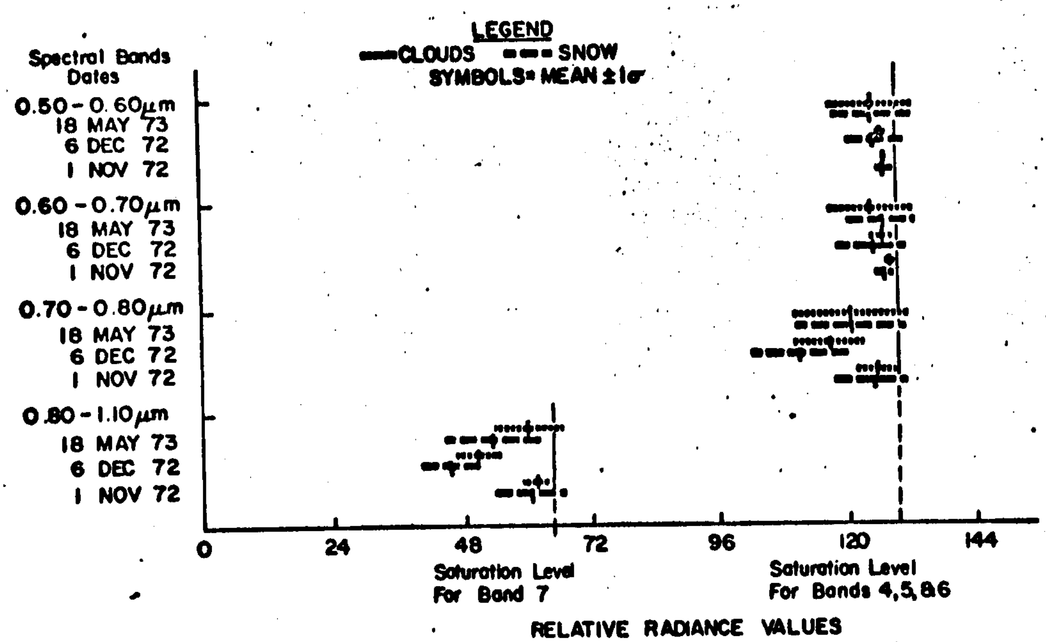

Figure 12. Spectral comparison of clouds and snow using ERTS-1 data from three different dates. Saturation level was reached in nearly all data sets and the similarity of response indicates lack of spectral separability between these two cover types.

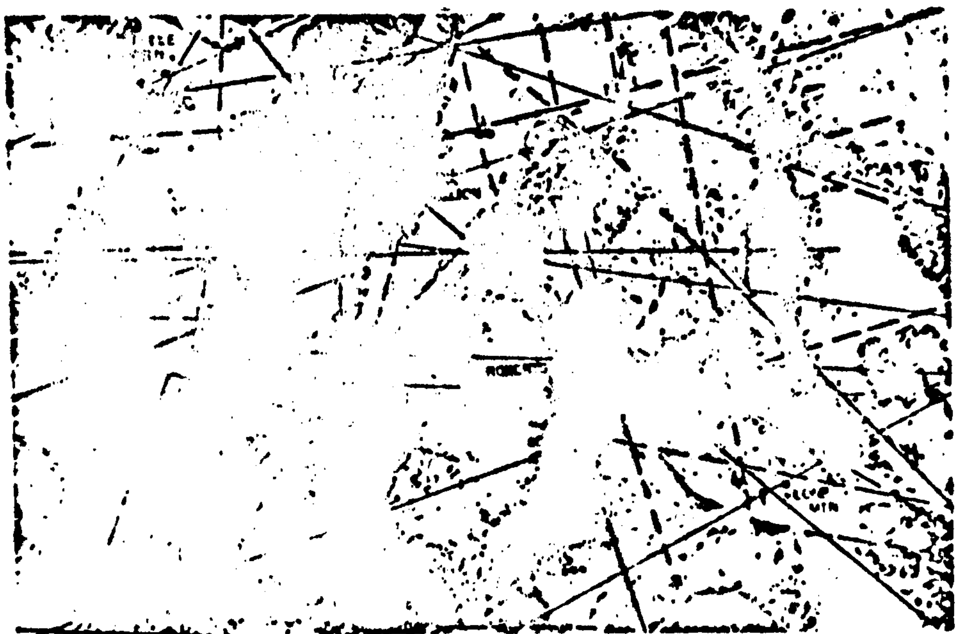

Figure 13. Computer enhanced color infrared composite of ERTS data with lineaments mapped by all three geologists analyzing this data set. A grid was superimposed upon this map and lineament intersections were tabulated for each cell.

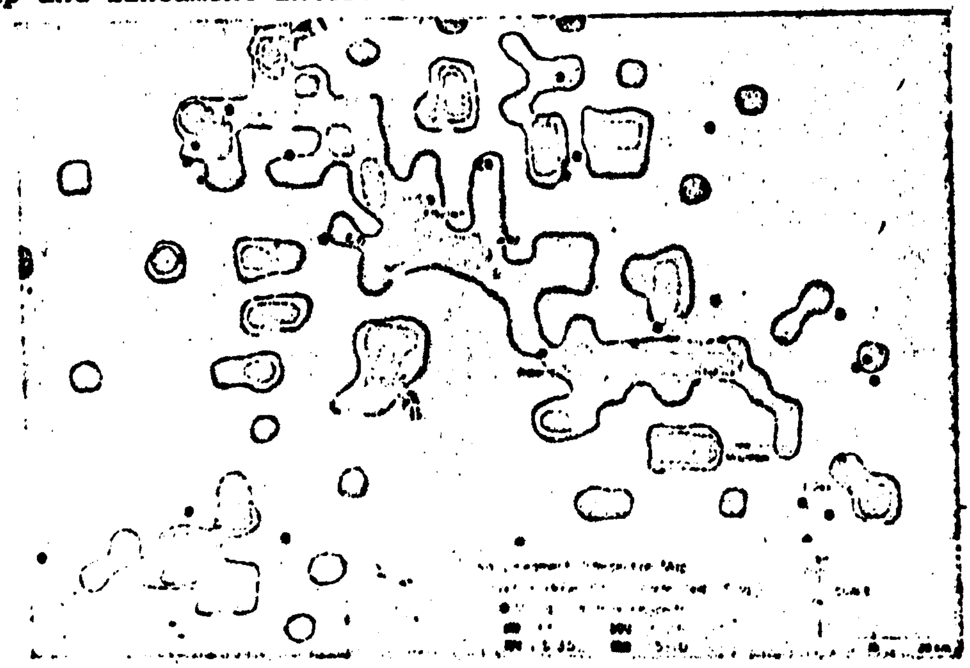

Figure 14. Iso-lineament intersection map and overlay of known mineral deposits. Good relationship was observed between the areas with frequent lineament intersections and known mineral deposits.

APPENDIX F

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

1. DATE February 1, 1974

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2. USER ID UN 103

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LARS/ Purdue University

1220 Potter Drive

West Lafayette, IN 47906

PROGRAMMS OBSERVATION IDENTIFIER	C CENTER POINT COORDINATES	B SENSOR BAND	P PRODUCT TYPE	F PRODUCT FORMAT	T TICK MARKS	NN NUMBER OF COPIES
[illegible]	37 - 28 N 108 - 47 W	7	B	T		1
[illegible]	37 - 28 N 108 - 47 W	7	B	P		1

ERTS DATA REQUEST FORM
680-213 (7/72)

1. DATE February 1, 1974
2. USER ID IN 103
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LARS/Purdue University
1220 Potter Drive
West Lafayette, IN 47906
NEW

5. TELEPHONE NO. (317) 749-2[illegible]
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DCS ☐
MICROFILM ☐ U.S. ☐

[illegible]	C CENTER POINT COORDINATES	D SENSOR BAND	P PRODUCT TYPE	F PRODUCT FORMAT	T TICK MARKS	NUMBER OF COPIES
[illegible]-17210	37-29N 107-31W	M	D	9		1
[illegible]-17211	37-30N 107-38W	M	D	9		1
[illegible]-17211	37-32N 107-42W	M	D	9		1
[illegible]2	37-38N 109-14W	M	D	9		1

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   West Lafayette, IN 47906
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   DCS ☐
   MICROFILM ☐ U.S. ☐ NON-U.S.

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..21-15595	39-03 N 087-05 W	M		P		1	
..21-15595	39-03 N 087-05 W	7	B	P		1	

APPENDIX G

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

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ID

DATE February 1, 1974

PRINCIPAL INVESTIGATOR Dr. R. M. Hoffer

GSFC UN 103

ORGANIZATION LARS/PURDUE

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* Hydrology	Forestry	Geomorphology	DESCRIPTORS
1191-17195 M-A,D	✓	✓	✓	Avalanches, forest fire damage, mountains, snow
1352-17134	✓	✓	✓	Timberline, talus, landforms, lakes
1047-17200 M-A,C,D		✓		Conifer, Deciduous, tundra meadow, grassland, timberline, lumbering
1066-17251 } M-D 1066-17254 }			✓	Anticlinal valley lacolith, river, mountains, escarpment, subsequent, mesa, meander, graben, intrusion
1299-17205 } M-D 1317-17204 }	✓			Snow, mountains, river

*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
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GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)