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Techniques for Computer-Aided Analysis of ERTS-1 Data, Useful in Geologic, Forest and Water Resource Surveys

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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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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 buildup 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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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.

			Number of Samples Classified Into							
Group	No of Samps	Pct. Corct	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.

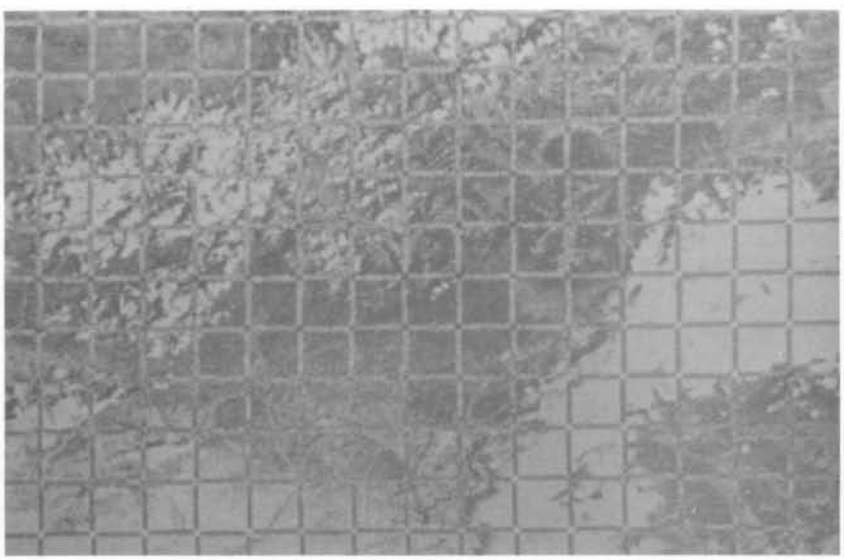

Figure 2. A grid having an interval of 200 lines and 200 columns was superimposed on the data shown in Figure 1, enabling analysts to easily determine the line and column coordinates of specific areas of interest.

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 Reservoir 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. 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.

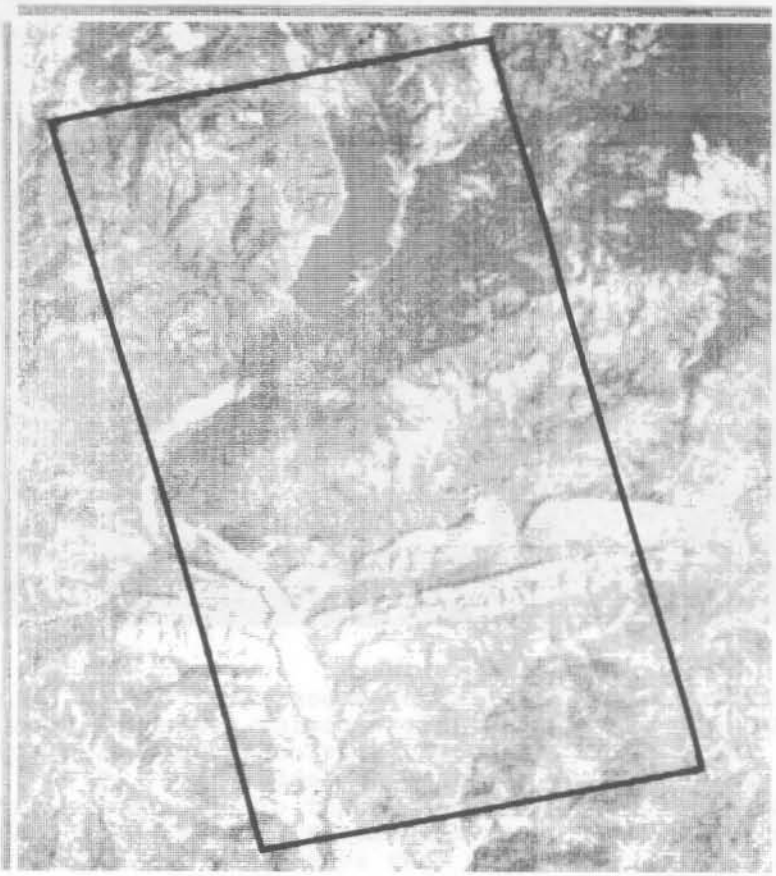

Figure 8. Uncorrected printout of ERTS data showing the Vallecito study area delineated by the heavy boundary. Compare this to the same data after it has been geometrically corrected and scaled, as shown in Figure 10.

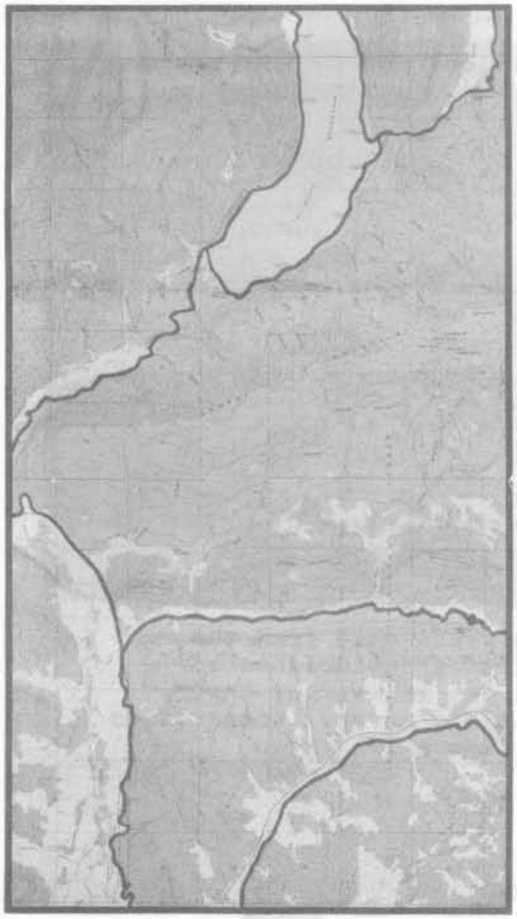

Figure 9. U.S. Geological Survey topographic maps of the Vallecito study area. Dominant features which could be easily delineated on both the topo maps and the ERTS data were delineated on an acetate overlay.

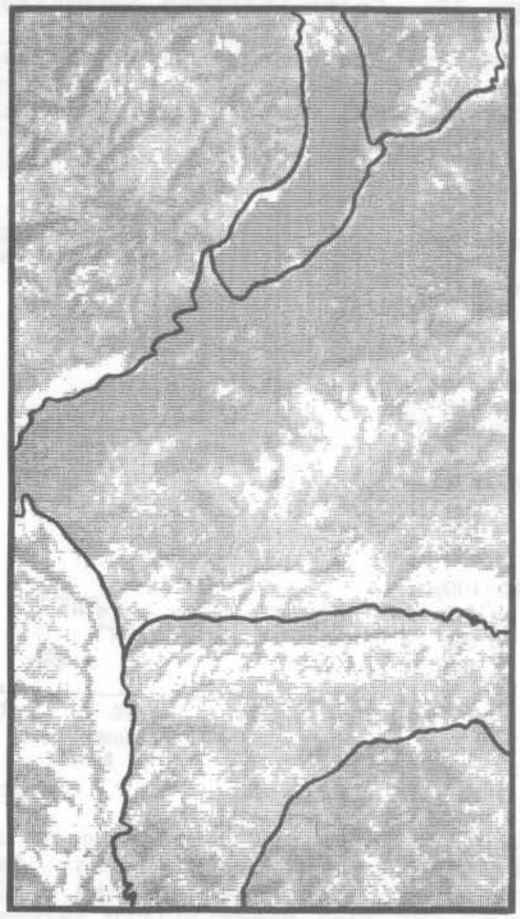

Figure 10. Geometrically corrected and scaled computer printouts of ERTS-1 data of the Vallecito study area. The scale of this printout is 1:24,000. The acetate overlay made from the U.S.G.S. topo map was superimposed on the computer printout, allowing one to verify the accuracy of the geometric correction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

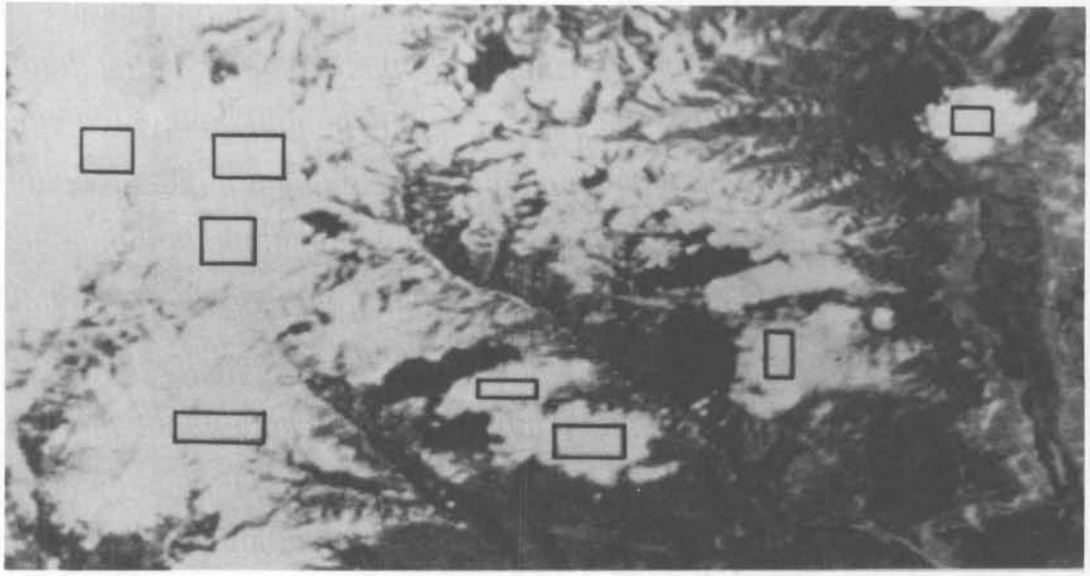

Figure 11. Color infrared composite of ERTS data from the digital display unit, with snow and cloud areas delineated. The four rectangular areas on the left designate snow cover, while the four areas on the right are cloud cover. Comparisons of the spectral response are shown in Figure 12.

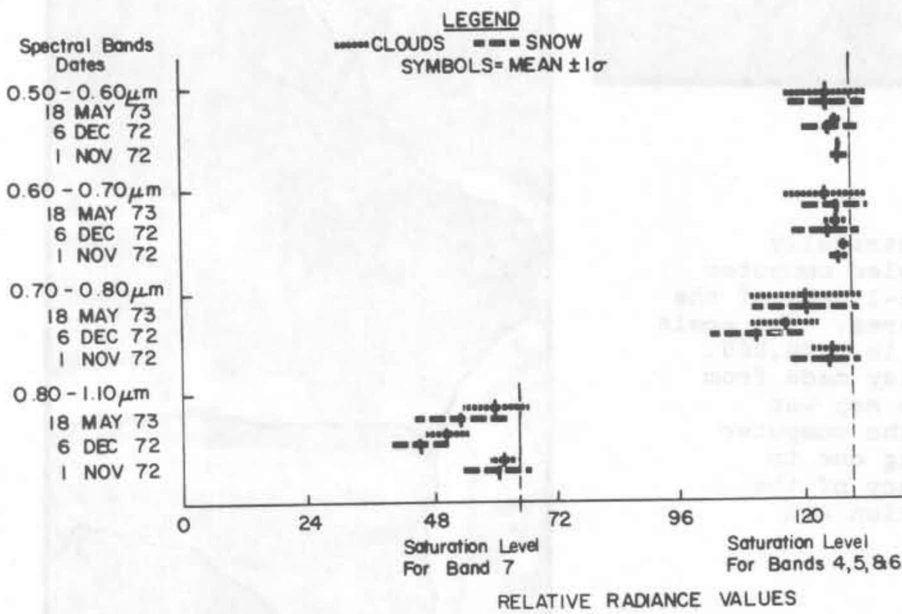

Figure 12. Spectral comparison of clouds and snow using ERTS-1 data from three different dates. Saturation level was reached in nearly all data sets and the similarity of response indicates lack of spectral separability between these two cover types.

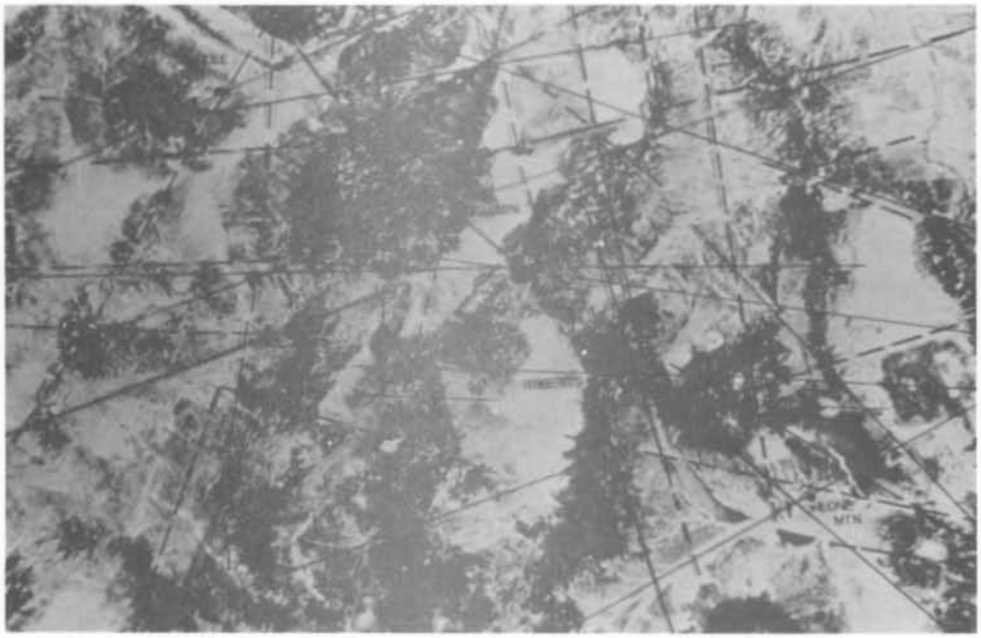

Figure 13. Computer enhanced color infrared composite of ERTS data with lineaments mapped by all three geologists analyzing this data set. A grid was superimposed upon this map and lineament intersections were tabulated for each cell.

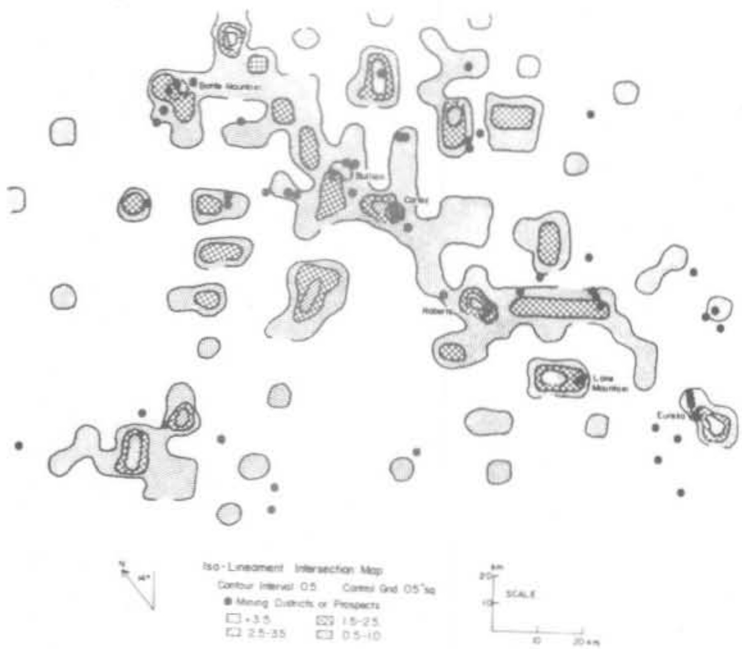

Figure 14. Iso-lineament intersection map and overlay of known minearl deposits. Good relationship was observed between the areas with frequent lineament intersections and known mineral deposits.