MAPPING ROCK OUTCROPS FROM LANDSAT DIGITAL DATA

A Thesis

Submitted to

The Faculty of Graduate Studies

The University of Manitoba

In partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

by

Pakiraiah Chagarlamudi

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ABSTRACT

Pre-field maps showing the distribution of rock outcrops are an important aid in effective planning and conducting of geological mapping. These maps are, traditionally, prepared from aerial photographs using photogeological methods. An automatic system of producing rock outcrop maps from standardized Landsat digital data has been developed. This system employs a hierarchical classification scheme in identifying rock outcrops and in discriminating among rock types. The system developed in this study has been calibrated and tested in the Coppermine area of the Northwest Territories of Canada.

Rock outcrop and rock type maps of two intensive study areas in the Coppermine area have been produced by the automatic system. Maps have also been prepared for these areas from visual analysis of simulated color infrared images produced by a simple digital enhancement procedure developed in this study. The maps and the digitally enhanced images have been compared with aerial photographs and known geology.

The enhanced images have been found to be superior to aerial photographs in identifying large (about 30 x 30 m) rock outcrops and in discriminating among these outcrops. The accuracy of identifying rock outcrops with the automatic system was better than 90% compared to the visual analysis method, taken as standard, in both the intensive study

areas. The rock type separation accuracies were as high as 86% for dolomites and 57% for basalts with intercalated sandstones, and 77% for sandstones in typical rock outcrop areas of the intensive study areas.

Spectral signatures of nine different cover types were derived from standardized Landsat digital data for establishing threshold values used in discriminating among the cover types. The differences in signatures among rock types were subtle and susceptible to misclassification even with minor contamination due to other rock types or cover types.

The cost of generating rock outcrop maps from Landsat data by the computer method is estimated to be less than 20% of the cost of producing the maps with aerial photographs using conventional methods. A unique benefit of the method is in easily providing mensuration data on cover types identified, which are helpful in planning field mapping programs. Other benefits include the use of digitally enhanced simulated color infrared images as base maps and in field studies, although these benefits are more directly attributable to the Landsat data characteristics than to the automatic method.

It is cautioned that the system developed does not replace conventional geological mapping but rather aids the field geologist in efficiently carrying out the mapping. It is recommended that the system be tested in other areas to further validate the calibration procedures and accuracies obtained in identifying rock outcrops as well as in discriminating rock types. It should be realized that rock outcrops must be relatively large for recognition by the system as the spatial resolution of the Landsat Multi-Spectral Scanner data used is 50 m x 50 m.

DEDICATION

This thesis is dedicated to my dear wife - Vijaya and to my wonderful children - Raghu, Radhi, and Rekha. The "price" they have paid for it is extravagant and surpassed even my most optimistic estimates.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Geological mapping is of fundamental importance in economic and engineering geology, as well as in geological research. The purpose of this study is to develop a system to map rock outcrops from Landsat digital data as an aid in gelogical mapping. To be viable the system must, at least, generate maps comparable to those obtained from conventional sources and be cost effective.

Historically, geological mapping has been done entirely based on field evidence or ground-based methods. However, over the past 40 years or so, aerial photographs have been used to supplement information acquired in the field. This use of aerial photographs through photogeological interpretation has been proven to aid the geologist in field mapping and be cost effective.

Work maps or pre-field maps are prepared using information obtained through photogeological methods. Geologists spend considerable time in preparing the pre-field maps. These maps usually contain locations of rock outcrops and some structural information. The pre-field maps are used in planning the field mapping program and to augument information collected in the field. In planning the mapping program, the maps are used in estimating time requirements in the field, familiarizing the geologist with the area, and also in directing the geologist to locations of outcrops. The quality and quantity of information present on the maps greatly influences the time required in the field and how effectively this time is utilized.

The availability of aerial photographs is a prerequisite for making the pre-field maps. Aerial photographic coverage exists for almost all regions of Canada, although it may not be current, at the scale required by the agency involved in mapping, and acquired in a season suitable to extract maximum utility. However, photographic coverage does not exist for all regions of the Earth. Flying large areas to acquire aerial photography is costly. Unfortunately, in areas where aerial photography does not exist, geological mapping is generally limited.

Landsat data may now be thought of as an alternative to aerial photographs in preparing the pre-field maps for regional mapping. Landsat satellites have been providing images of almost all regions of the Earth repeatedly since 1972. The data acquired by Landsat satellites have several advantages over aerial photographs. Some of the more salient advantages are that they provide synoptic coverage under essentially the same illumination conditions, are acquired in several spectral regions of the electromagnetic spectrum thereby providing color imagery, and are in digital form allowing data manipulation using computers.

The advantages of Landsat satellite data have been quickly recognized by geologists. The Landsat data have been used enthusiastically for geological applications in general and for geological mapping in particular (Gregory, 1979). Most of the studies reported in the literature have, however, used visual analysis to extract information on rock types as well as structural features. Computer methods have also been reported in the literature to map rock types and to "enhance" imagery for use with visual analysis.

List and his colleagues (List et al, 1974) reported that visual evaluation of Landsat imagery of a mountainous terrain in Chad has provided a very useful additional source of geological information, complementary to aerial photographic interpretation and field work.

Landsat images have been found more useful in structural investigations than in mapping rock types. Several investigators have reported using the structural trends derived from Landsat in mineral exploration activities. Stancioff et al (1973) have used Landsat derived information on structural trends and alteration zones in pinpointing a number of exploration targets in a porphyry copper province of Mexico. Taranik and Trautwein (1976) demonstrated the utility of Landsat and other remotely sensed data in base metal and precious metal exploration activities in southwestern Idaho.

Visual analysis techniques have also been used in geological mapping with digitally "enhanced" images of Landsat data. This approach basically retains the inherent advantages of the human eye-brain apparatus in recognition and the power of the computer in data manipulation. Different manipulation procedures have been developed in the recent past to enhance spectral and textural information present in Landsat data. These image enhancement techniques include simple contrast stretch, band ratioing, principal components analysis, canonical analysis, and frequency filtering.

Podwysocki <u>et al</u> (1977) found the enhanced Landsat data to provide more accurate discrimination of rock and soil types than conventional computer classification methods. In enhancing the Landsat data acquired over arid and semiarid terrains, they used band ratioing, principal components analysis, and canonical analysis. Rowan <u>et al</u> (1973, 1977) mapped hydrothermally altered zones and regional rock types using band ratioed images, and contrast stretched images.

Conventional computer classification methods applied to Landsat data have been found to be of limited value in geological mapping (Siegel and Abrams, 1976). Generally, the computer methods used are the supervised and the unsupervised classification procedures. These methods usually employ only the spectral information from Landsat data with no consideration to textural or spatial information. Further, all spectral bands are used _simultaneously_, i.e. with equal weighting, in these methods.

In this study, a simpler but a more fundamental question of outcrop identification is studied rather than directly attempting the complex problem of discriminating among rock types. The sensors on Landsat satellites cannot "see through" ground cover to identify rock types unless the rocks are exposed at the surface. It appears only logical to separate rock outcrops from all other cover types before any attempts can be made in mapping rock types. If the rock outcrops can be identified consistently and with acceptable accuracy, then and only then, can one attempt mapping rock units directly. Under ideal conditions and in favourable locations, the mapped units may have conventional lithological connotation. However, it seems fair to assume that the different units may be grouped into spectro-lithological units.

The usefulness of automatically producing rock outcrop maps is well recognized now by the geoscience community and was pointed out recently by Dr. L. W. Morley (1980), the Director General of the Canada Centre for Remote Sensing, Energy, Mines and Resources Canada. If rock outcrops can be separated from all other cover types using Landsat, then this would be an important contribution to geological applications of remotely sensed data. Further, if maps showing locations or rock outcrops can be made automatically from Landsat data, then this may prove to be a cost effective method of preparing pre-field maps in geological mapping. The structural information for the pre-field maps can be added on to the automatically produced maps by conventional methods.

Calibration data are required to produce rock outcrop maps by conventional automated classification methods. Obtaining calibration data in remote areas each time to identify rock outcrops is expensive if not impossible. If, however, a universal signature set can be developed for the most frequently occurring ground features, the repetitive calibrations can be avoided in identifying rock outcrops. Landsat data are affected not only by variations due to ground features but also by variations in the atmospheric and sensor conditions at the time of data acquisition. Variations in Landsat data due to other than ground features must be minimized or eliminated to develop a univeral signature set. The Landsat data used in this study are standardized such that repeated calibrations are eliminated.

In this study, a system to automatically map rock outcrops is developed. The system identifies rock outcrops by successively eliminating all other cover types using a hierarchical classification scheme. The scheme, selectively compares pixel values in individual bands or band combinations with standard threshold values established for each cover type. The rock outcrops are then grouped into rock types. Rock outcrop and rock type maps are produced for two intensive study areas in the general study region. The accuracies obtained by the automatic scheme are calculated by comparing the maps with known geology.

Quantitative information on the relative distribution of cover types in the map area would be useful in planning field programs. The quantitative information may consist of the percentage of area covered by water bodies, vegetation and rock outcrops. If those broad cover types can be identified using Landsat digital data then the distributions can easily be computed. Automatic procedures are developed in this study to provide quantitative mensuration data on cover types identified.

Rock outcrops are not, in general, large enough to be seen from satellite altitudes. There are, however, large areas of massive outcrops in many parts of the world. The nominal spatial resolution of Landsat is about an acre. The signal received at satellite altitudes is integrated over an area that may comprise several different cover types. The signal, thus, depends upon the combination of cover types present in the resolution area. Consequently, signals of all rock outcrops may be contaminated to a certain extent. The recognizability of rock outcrops depends upon the level of contamination. A part of this study is devoted to obtaining an understanding of the tolerable level of contamination for discriminating rock outcrops.

This study does not attempt to provide a method for routine geological mapping or geological map revision. Routine geological mapping includes the identification of rock types and also mapping of structures. The automatic method developed identifies rock outcrops and provides only an indication as to the rock type. Attempts have not been made to include textural, structural or contextural information in the automatic method. The method of identifying rock outcrops is tested in one Landsat scene acquired on two different dates.

The Landsat satellite data and the study area are described in Chapter 2. The description of Landsat data includes the sensor and orbital characteristics, data reception and standard data products. The description of the study area includes the geology and the environmental setting of the area. The advantages of selecting this area for developing and testing the system to map rock outcrops are also presented.

The methods used in this study are described in Chapter 3. Visual analysis of standard and enhanced Landsat images is considered in the first section. The procedures used in standardizing the Landsat data are discussed in section 2 with the need for standardization. Section 3 describes the procedures used in obtaining spectral signatures and threshold values for the proposed scheme. The mechanics of the proposed scheme are described in Section 4. Finally, the procedures used in producing rock outcrop maps are given in Section 5, the final section of this chapter on Methods.

Results obtained in this study along with a discussion are presented in Chapter 4. Spectral signatures and threshold values of cover types are presented in Section 1 along with the expected signatures due to contamination from other cover types. The results on identifying rock outcrops are given in Section 2. The results on separating rock types in areas identified previously as rock outcrops are shown in Section 3. Finally, section 4 presents the cost benefits of the automatic method in producing pre-field maps.

The conclusions reached from the results obtained in this study are given in chapter 5 along with recommendations.

2.0 LANDSAT SATELLITE DATA AND THE STUDY AREA

Landsat satellite data acquired over an area in the Northwest Territories of Canada were used in developing and in testing the computer method of mapping rock outcrops. This chapter outlines the characteristics of the Landsat satellites and the onboard sensors, the data collection, and the standard data products available. A description of the study area and the advantages of selecting this area are given in the final section of this chapter.

2.1 LANDSAT SATELLITES

2.1.1 Historical Aspects

One of the immediate and more practical applications that has evolved out of space research is remote sensing of the earth's resources using satellites. Although proposed in the early 60's it was not until July 1972 that a satellite was launched exclusively for the purpose of high resolution remote sensing of the earth's surface. This satellite named Landsat-1, was the first of a series of six satellites proposed by the National Aeronautics and Space Administration (NASA) of the United States (U.S.). The second in the series, Landsat-2, was launched during January 1975; Landsat-3, the third satellite in the series was launched during March 1978.

Prior to the launch of the first satellite in the series, the Landsat program was designated to be experimental to evaluate the contribution of the resulting data to a wide range of earth resources disciplines. The contributions of Landsat data were found to be useful and cost effective in various disciplines. The data are now routinely used in some operational applications. Because of the demonstrated success, continued coverage of data is planned in spite of the economic restraints. Landsat-D, the fourth in the series with improved resolution and sensor capabilities is planned for launch in 1982. NASA designated Landsat-D as an operational program which implies continued coverage.

2.1.2 Orbital Characteristics

The orbital characteristics of a satellite influence the use of the data collected by the sensors on board. For maximum utility in various disciplines, the orbit must be systematic, providing repetitive global coverage under nearly uniform observation conditions. The orbital parameters for Landsat series of satellites were designed to achieve this maximum utility.

The Landsat satellites operate in a circular, near-polar orbit at a nominal altitude of 920 km. Selection of circular orbit minimizes the variations in the altitude of the spacecraft. Global coverage requirements impose nearly polar orbit i.e. inclination of the orbital plane to the equatorial plane of about 90 degrees. The nominal inclination angle for Landsat is 99 degrees.

The Landsat orbit is sun-synchronous i.e. the orbital plane will remain nearly constant relative to the earth-sun direction. As a result the mean sun time at each individual point in the orbit will remain fixed and, in fact, all points at a given latitude on descending passes will have the same mean sun time. Thus, selecting sun-synchronous orbits provide similar imaging observation conditions repetitively. The actual mean sun time at descending node achieved for the Landsat satellites was between 9:30 and 10:30 a.m.

The nominal orbital period, which is essentially the function of altitude, for Landsat is 103 min. There are approximately 14 orbits in one earth's rotation period. During the 15th orbit, which is the first orbit of the next day, the satellite images a swath to the west of the first orbit (with 10% overlap at the equator). Contiguous coverage is thus obtained. The pattern of 14 daily orbits moves westward each day and the track of the first orbit of the 18th day coincides with the track of the first day, resulting in a repetitive coverage.

2.1.3 Sensor Characteristics

The Landsat satellite contains in its payload two sensors designed to produce spectral imagery of the earth's surface. These two sensors are the Return Beam Vidicon (RBV) camera, and the Multi-Spectral Scanner (MSS). Apart from these instruments of direct interest here, the payload includes a data collection subsystem, through which communications can be received from telemetry platforms located in inaccessible places.

Data collected by only the MSS on Landsats 1 and 2 were used in this study. The MSS subsystem is discussed in detail in this section. The data collection subsystem is not included in the discussion. However, the characteristics of the RBV camera subsystem are briefly presented here for completeness.

2.1.3.1 RBV camera subsystem

The RBV camera subsystem on Landsats 1 and 2 contains three individual television type cameras mounted side by side and each operating in a different spectral band. Each camera contains a 12.5 cm focal length lens, a mechancial shutter, the RBV imaging tube, and associated electronics. Spectral filters in the lens assemblies provide separate spectral viewing regions for the cameras. The spectral intervals sensed are 0.475 - 0.575 um, 0.580 - 0.680 um, and 0.690 - 0.830 um. The three cameras are shuttered simultaneously, imaging the same 185 km square area. When the cameras are shuttered (every 25 sec) , the images are stored on the RBV photosensitive surfaces, then scanned to produce video outputs.

The RBV camera subsystem on Landsat 3 is significantly different from the RBV systems on Landsats 1 and 2. Two panachromatic cameras produce two side-by-side images rather than three overlapping multispectral images of the same scene. Each RBV camera sensor is designed to cover a 99 x 99 km area. A focal length of 23.6 cm, or nearly twice that of Landsat 1 and 2 RBV, will nearly double the resolution. The cameras are shuttered every 12.5 sec thereby providing four subscenes which correspond to 185 km square area.

2.1.3.2 The MSS subsystem

The MSS subsystem in the payload of Landsats 1 and 2 is a four-band scanner operating in the solar-reflected spectral region. It consists of six detectors for each of the four bands. The MSS scans cross track swaths 185 km wide at nominal altitude, imaging six scan lines across in each of the four bands simultaneously. This is accomplished by means of an oscillating flat mirror between the ground scene and a double-reflector telescope type of optical chain. The scanning arrangement of the MSS on Landsat is shown in Figure 1.

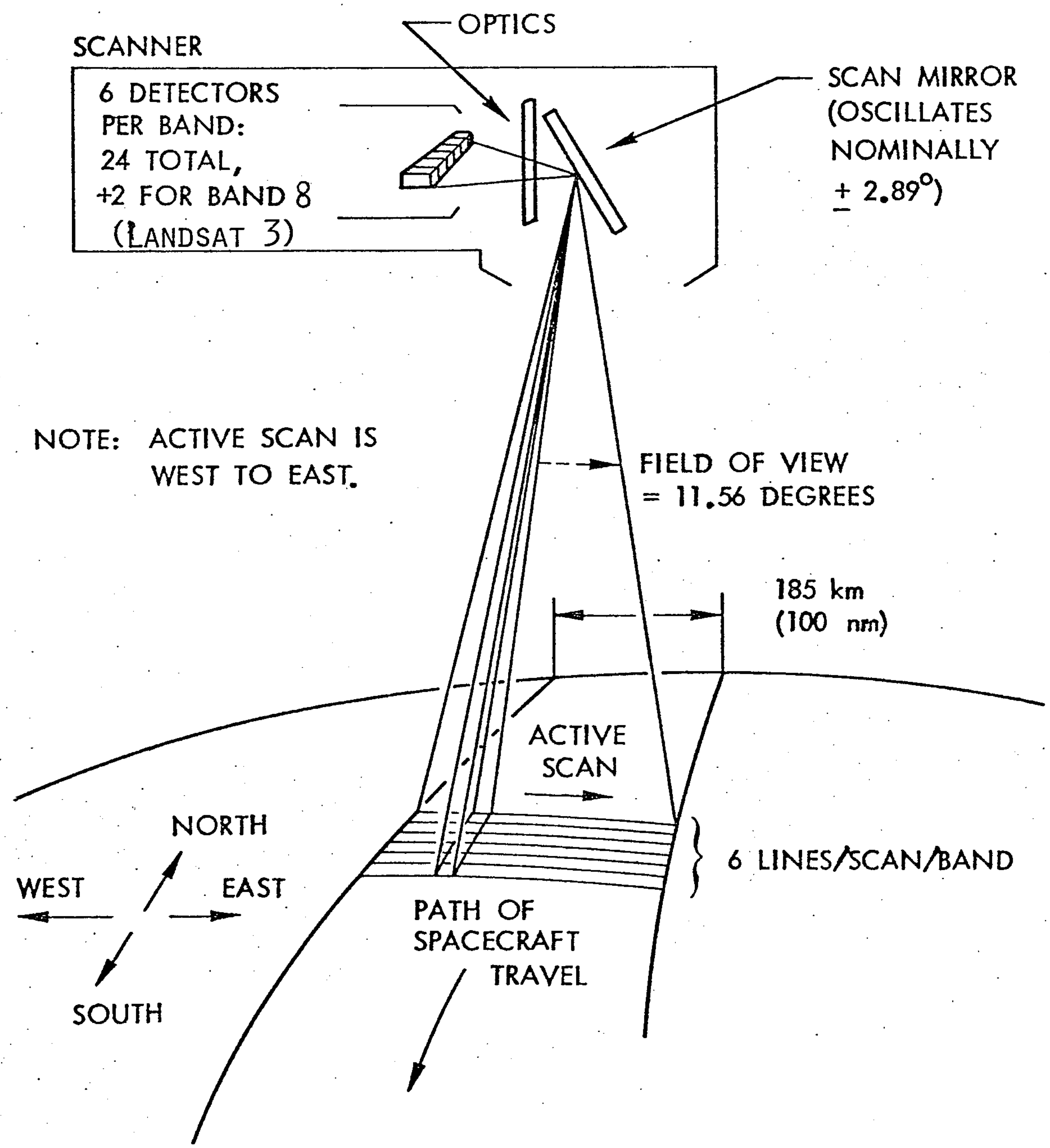


Fig. 1. Scanning arrangement of the Multi-Spectral Scanner on Landsat satellites. (adapted from Thomas, 1973)

The scan mirror operates in a scan-and-retrace cycle. The active portion of the scan is in a west-to-east direction. The full scan-and-retrace cycle of the detectors produces a 185 km sweep of the ground scene beneath the satellite. The spacecraft's near polar orbital motion produces the along-track spacing between mirror sweeps. This along-track scan pattern, when combined with the scan-and-retrace cycle provides the complete coverage of the full 185 km scene. The video outputs of each detector are sampled during the active west-to-east sweep of the mirror.

The spectral bands used in the MSS for Landsats 1 and 2 were identical. For Landsat-3 a fifth band containing two detectors was added that operates in the thermal infrared region of the spectrum. The first four spectral bands are referred to as Band 4, Band 5, Band 6, and Band 7; the fifth band as Band 8. The spectral bands in the MSS subsystem for Landsats 1,2 and 3 are shown in Table 1. The first three bands on the MSS use photomultiplier tubes as detectors; the fourth band uses silicon photodiodes. The thermal band uses mercury-cadmium-telluride, long-wave infrared detectors.

For the first four bands in the MSS subsystem the instantaneous field of view of each detector is a square on the earth's surface that is 79 m on a side. The detector signals are sampled at an interval of 10 ns, corresponding to a cross track distance of 57 m between readings. For the

TABLE 1. BAND IDENTIFICATION NUMBERS AND CORRESPONDING SPECTRAL REGIONS IN THE MSS SUBSYSTEM ON LANDSAT SATELLITES

MSS Band Identification Number	Spectral Region (Micrometers) Landsats 1 and 2	Landsat 3
Band 4	0.5 - 0.6	0.5 - 0.6
Band 5	0.6 - 0.7	0.6 - 0.7
Band 6	0.7 - 0.8	0.7 - 0.8
Band 7	0.8 - 1.1	0.8 - 1.1
Band 8	- - -	10.4 -12.6

thermal band on the MSS subsystem the instantaneous field of view dimensions are three times greater than for the first four bands.

2.1.4 Transmission and Reception of Data

2.1.4.1 Data transmission

Data collected by the RBV camera subsystem and the MSS subsystem aboard the Landsat satellites are telemetered to a ground receiving station. The RBV video data are transmitted in the frequency modulated domain and the MSS data are transmitted in six bit pulse code modulated domain. The data are transmitted to the ground station either in a direct mode or in a readout mode.

In the direct mode, the data are transmitted in real time when the sensors are operating within the reach of the ground receiving stations. In the readout mode, the data are recorded on a magnetic tape by an onboard wideband video recorder. These recorded data are later transmitted to the ground station when the satellite is within the field of view of the station.

Two wideband video tape recorders are included in the payload of each of the satellites in the Landsat series. Each of the recorders can record, store, and reproduce either RBV or MSS data upon command. Each of the recorders has a recording capacity of 30 minutes.

2.1.4.2 Data reception

Data collected by the RBV camera subsystem and the MSS subsystem are received by a suitably equipped ground receiving station. Some of the U.S. ground stations also handle communications between the spacecraft and the ground in addition to receiving the data. However, the non-U.S. stations have only receive capability.

When Landsat-1, the first satellite in the series was launched in 1972, only four sites in the world were equipped with receive capability. Three of these four sites were located in the U.S. and the fourth site in Canada at Prince Albert, Saskatchewan. The number of stations were more than doubled by 1978, when Landsat-3 was launched. Canada has acquired a second receiving station located at Shoe Cove, Newfoundland. Other countries that now have Landsat data receiving capability include Australia, Brazil, Iran, Italy, India, Japan and Sweden. Several other countries have reached agreements with the U.S. to receive Landsat data and are now acquiring receiving stations. These countries include Argentina, Chile, China, Peru, Rumania, Upper Volta, the USSR and Zaire.

At the ground station the RBV and the MSS data are received over two S-Band links operating at center frequencies of 2229.5 MHz and 2265.6 MHz. The data are monitored as they are received and recorded. Separate receiving and recording equipment are required for the RBV and MSS data (NASA, 1976).

2.2 LANDSAT DATA PRODUCTS

Canadian Landsat data are acquired by the Canada Centre for Remote Sensing (CCRS), Energy, Mines and Resources (EMR) Canada. The data are, however, distributed by a commercial organization - ISIS Ltd. of Prince Albert, Saskatchewan. The Landsat data are available to the users as photographic products and as digital data products.

2.2.1 Photographic Products

The standard photo-products are 24 cm paper-prints and transparencies. Both these standard products are produced in black and white for the individual spectral bands, and as color composites. The color composites are produced by combining three different spectral bands. Two standard color composites are now made by CCRS. The first one is produced by combining Bands 4, 5 and 6; the second composite is produced by combining Bands 5, 6 and 7.

In the Canadian Landsat data user's handbook (CCRS, 1973), it was stated that:

> All photographic products, with the exception of "quick-look" products,will be geometrically corrected as fully as possible. the geometric corrections will conform the imagery to current UTM maps in the 1:250,000 series. The radiometric

> corrections will allow a direct correlation of film density with scene radiance....Fully corrected and annotated photographs will be distributed within ten days of acquisition....The scale of the image will be accurately controlled to 1:1,000,000 to allow direct comparison to maps.

The geometric and radiometric corrections stated above are not routinely applied to the standard photographic products. This somewhat limits the usability of the photographic products for applications involving mapping. In addition, comparison of colors between images acquired at different times is difficult on the standard photographic products. The need for control of color and how it could be achieved using digital data is discussed elsewhere (Section 3.1).

Another photographic product available in Canada is a print made from a "Quick-look" system located at the Prince Albert Satellite Station (PASS). The Quick-look system is a fast method of producing Landsat imagery without applying the complicated processes of radiometric and geometric corrections. In this method the video data are displayed on a very high resolution CRT and the face of the CRT is photographed using an automatic camera (Barrington et al, 1972). The Quick-look system produces near real-time imagery which are critical for applications requiring quick feed-back based on the observed conditions.

2.2.2 Digital Data Products

Digital data from the MSS are available as computer compatible tapes (CCT). The annotated and corrected 185-km square ground scene on the CCT is a final product. A scene is made up of parallel scan lines, each containing a large number of video data points or picture elements (pixels). There are 2286 of these lines per completed MSS CCT scene. Scan lines which are projected on ground are approximately 185 km long and on average provide 3220 pixels. The variability in the number of pixels per line is due to minor changes in the mirror sweep times.

Differing levels of radiance within a scene are expressed in a binary form. In order to accommodate the wide range of radiances resulting from the wide range of illumination and reflectance conditions possible on earth, the outputs of Bands 4, 5 and 6 are normally compressed to a non-linear relationship between signal output and radiance input. These compressed values are transmitted to the earth and recorded as six bit integers on high density digital tapes. The data can be decompressed to a linear mode with published decompression tables. Band 7 data are normally transmitted in a linear mode.

The CCRS provides one ground scene on a single CCT at 1600 bpi and on two CCT's at 800 bpi densities. These are the system corrected CCT's and are commonly referred to as the Johnson Space Center (JSC) format tapes which have been available since 1975 (Strome et al, 1975). Prior to 1975, the MSS data were available on what is now called CCRS-OLD format tapes. The CCRS has stopped producing tapes in the old format since 1976. The data on the old format tapes are not system corrected and are in six bit mode.

The CCT's used in this study are the CCRS old format tapes. However, the software developed in this study uses a random access disc file for the data input. The disc files can be created from CCRS old format CCT's, JSC format CCT's and EROS Data Center (U.S.) format CCT's. The format specifications of the disc file are given in Appendix A.

Digital data are also available now as geometrically corrected CCT's. Data on the geometrically corrected CCT's are registered to the UTM projection. The MSS data are resampled such that each pixel corresponds to a ground area of 50 m x 50 m. In areal coverage, these CCT's are restricted to half a degree in latitude and one degree in longitude. Because of this restriction, the area or equivalently the amount of data on a geometrically corrected CCT varies from latitude to latitude. These CCT's produced by CCRS are referred to as the DICS CCT's (Butlin el. al. 1978).

In summary, this section dealt with the Landsat data used in this study. A brief introduction to the Landsat program was given and then the characteristics of the Landsat orbit and the primary onboard sensors were described. Next, the data transmission from Landsat and how the data are received by the ground station were presented. Finally the standard Landsat data products in photographic and digital form available to the users were narrated.

2.3 THE STUDY AREA

2.3.1 Location and General Setting

The study area is located approximately 110 km south of the town of Coppermine in the Northwest Territories of Canada (Figure 2). It is a part of an area popularly known as the "Big Bend" of the Coppermine River . The Coppermine River is in the eastern half of the study area. The area under study is bound by north latitudes 66:45 degrees to 67:30 degrees, and west longitudes 115:30 degrees to 117:30 degrees (Fig. 3).

Most of the study area is barren of trees but there is a sparse growth of spruce with some birch along the Coppermine River. Vegetation consisting of various grasses, lichen and shrub is present throughout the study area but is predominant near streams and lakes (Craig, 1960).

Relief in areas underlain by granite or by steeply inclined Proterozoic strata is generally not more than 50 to 70 m. Relief in the southern part of the study area may, however, exceed 200 m. Broad uplands, deeply dissected by streams, are characteristic of regions underlain by

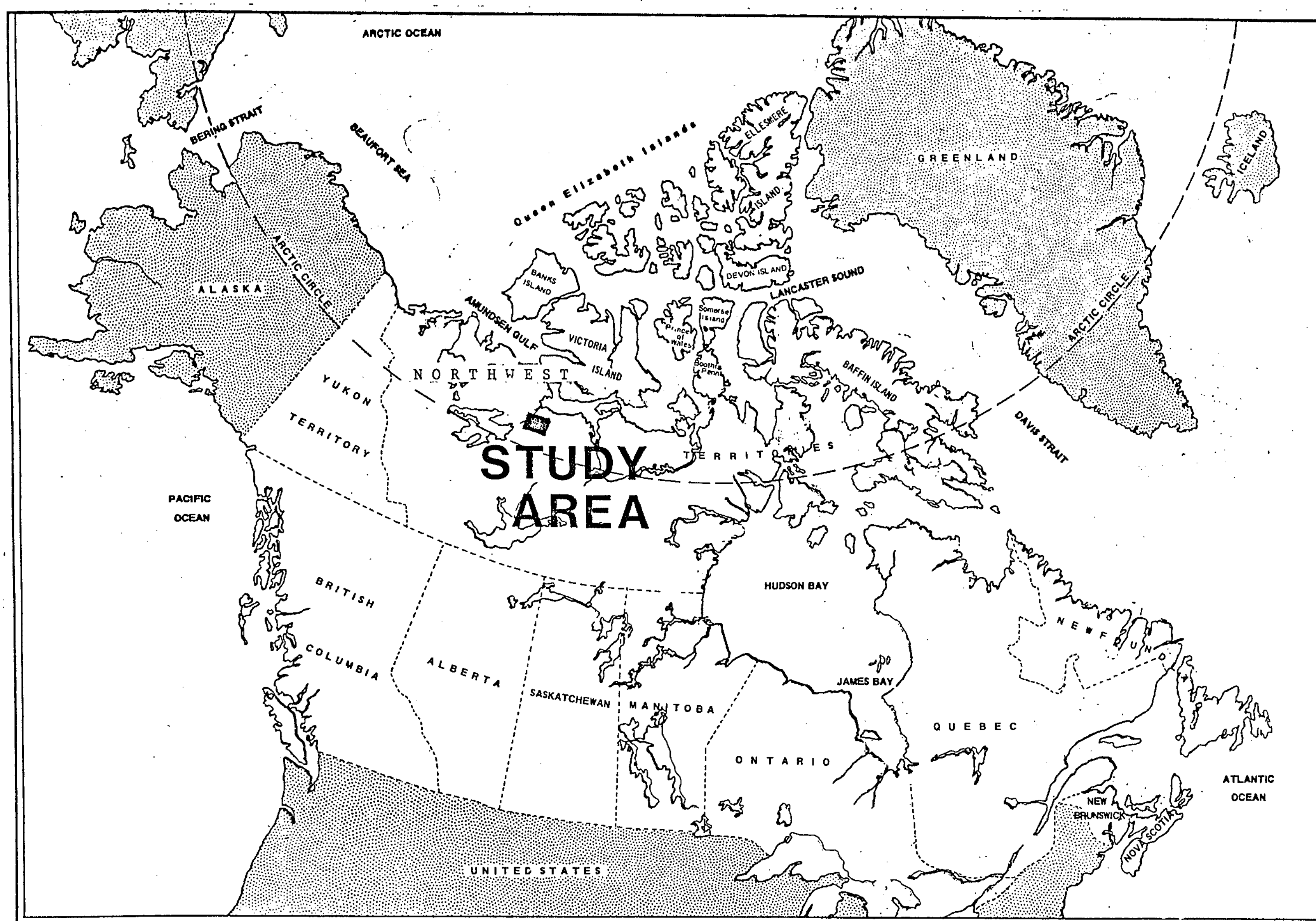


FIG. 2. Map showing location of the study area.

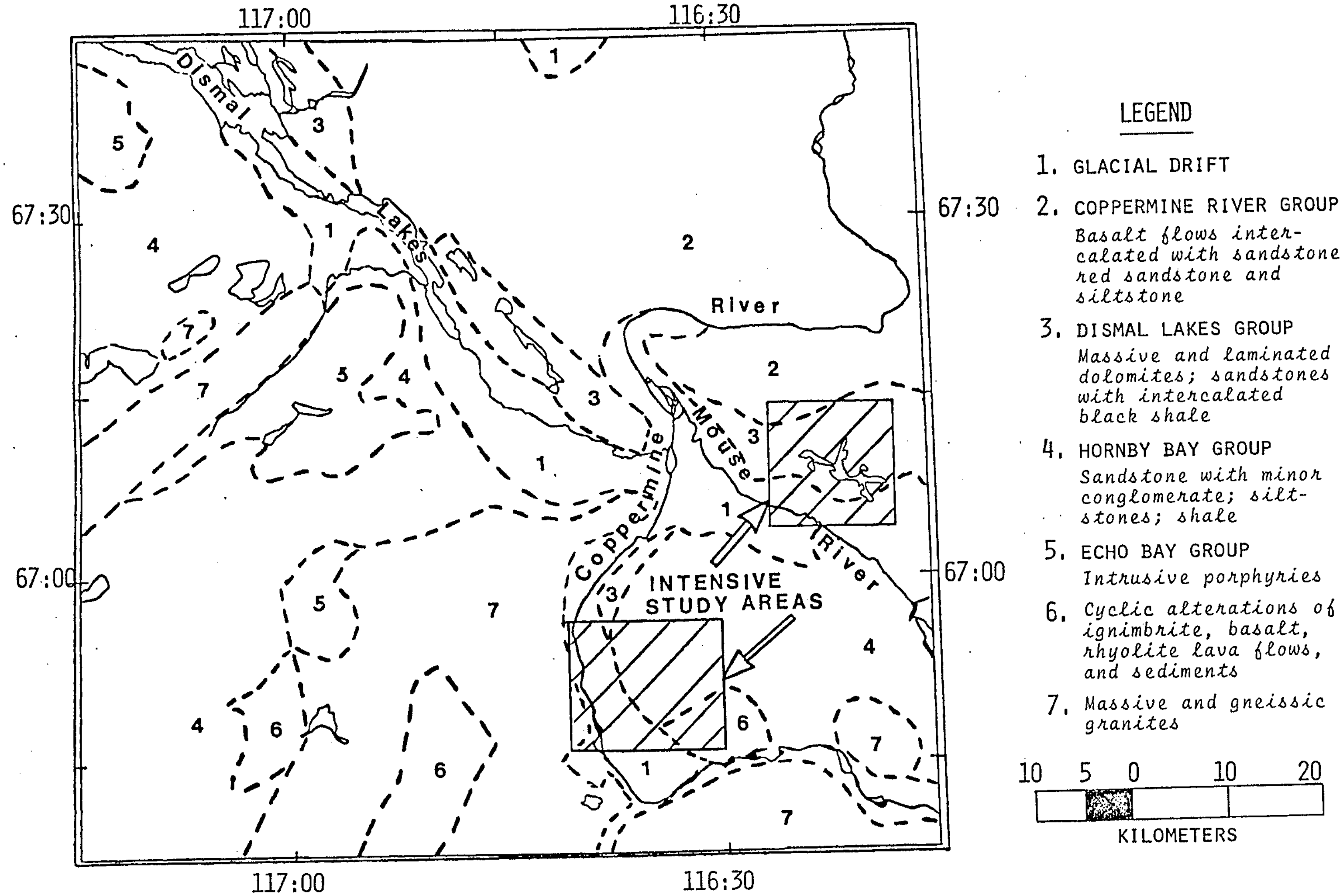


Fig. 3. Generalized geological map of the study area showing intensive study areas.

Palaeozoic and gently inclined Proterozoic strata.

2.3.2 General Geology

The gelogy of the study area and the vicinity has been extensively studied (Baragar and Donaldson, 1971; Hoffman, 1979; Craig, 1960). A generalized geological map of the entire study area (Fig. 3) has been prepared from the published maps. A description of the generalized geology is presented here based on the above cited references.

Rocks underlying the area of study span mainly Proterozoic time. Massive granites and closely associated feldspar porphyries, presumably related to the Hudsonian orogeny, are overlain unconformably by gently folded sandstones and dolomites of the Helikian Hornby Bay Group. These in turn are overlain unconformably by the Neohelikian dolomites, sandstones and mudstones of the Dismal Lakes group, and by the conformably succeeding basalts and red sandstones of the Coppermine River Group.

Porphyritic felsites of the Echo Bay Group cap several hills in the northwest part of the study area. Most contain abundant phenocrysts of feldspar and quartz; lesser amounts of biotite, amphibole and pyroxene occur in some varieties. Fresh surfaces of these rocks range from brick red to pink; weathered surfaces tend to be light pink, pinkish brown or dull orange. The color variations appear to be due largely to content and oxidation state of finely disseminated iron oxides. The porphyritic felsites together with associated, but in part older, granites (intrusive) form the basement of the Hornby Bay Group.

Hornby Bay Group consists of gently dipping beds of sandstone and conglomerate that rest on acidic volcanic rocks of the Echo Bay Group. The basal conglomerates and associated sandstones are colored deep red, largely due to haematite coatings around clasts; sandstones higher in the section are cream, buff, and pink. Cross bedding is abundant, as are ripple marks in the sandstones.

Dismal Lakes Group consists of Proterozoic strata which unconformably overlie the Hornby Bay Group, and which are conformably overlain by basalts of the Coppermine River Group. The overlying dolomites are the most continuous and best exposed strata of the Dismal Lakes Group. Different members of the dolomites have been identified and include laminated and massive dolomites. The central member which is predominant in the study area exhibits massive weathering and is buff to light gray in color.

The Coppermine River Group comprises a lower volcanic formation and an upper mainly sedimentary formation. Only the lower volcanic formation (Copper Creek Formation) is prevalent in the study area. It consists of flows which are plateau basalts. Most basalts are altered to some degree and the flows are composed essentially of plagioclase, pyroxene and magnetite. Thin beds of red sandstone are intercalated with the lavas of the Copper Creek Formation.

Granitic rocks form the basement of the Hornby Bay Group. These intrusive rocks outcrop mainly in the northwest and south-central corners of the study area. Although, the granitic rocks range from granite to diorite, the most abundant rock type appears to be granodiorite. Pink to dull red colours are common, the colouration being due more to haematite staining than to an abundance of potash feldspar.

2.3.3 Economic Geology

In the Coppermine River area, long known for its native copper showings, geological exploration was extremely active during 1966 through 1969. During this period, more than 45,000 claims were staked within and in the vicinity (NTS Maps 86 N, O) of the study area (Thorpe, 1970). A number of exploration programs in one season were of enormous size, with exploration budgets of the order of $500,000 or more, and were conducted by consortiums of companies (Thorpe, 1970). Interest in potential uranium mineralization and copper mineralization of the area has been rekindled lately after a decade of relative quiet (Hoffman, 1979).

Copper is the only metal of economic significance yet found within the Coppermine River area. It occurs mainly within the Coppermine River lavas as sulphides and as native copper. The sulphides are predominantly in fractures, but native copper is found mainly as a primary constituent of the lavas (Baragar and Donaldson, 1971). Nickeliferous sulphides were also reported along the margins of an ultramafic body just east of the study area (Craig, 1960).

2.3.4 Advantages of Selecting this Area

The advantages of selecting this area are that rock exposure is abundant, the outcrops are relatively free from tree cover, different rock types are present, and reasonably detailed geological maps exist for verification. In addition field notes exist for obtaining specific details on outcrops and the area is being explored actively for minerals.

In verifying methods developed to map outcrops, it is extremely important to know the detailed locations of the outcrops. It is also important to obtain information on the nature and condition of the outcrops. However, even in relatively well mapped, areas it is not always possible to get the required field truth on all outcrops. Large scale aerial photographs would provide the necessary field truth if it cannot be obtained otherwise. Aerial photographs at a scale of approximately 1:50,000 are available for the study area from the National Air Photo Library of Canada. In fact, the published geological maps of the area are partly based on aerial photographs of the area and mainly on a helicopter-supported survey (Baragar and Donaldson, 1971).

Since the Landsat sensors can at best only see through the top few millimeters of the surface, at least some of the rock outcrops in the area should be exposed at the surface. In the Coppermine River area there are numerous outcrops that are not covered by trees and support only minimal amounts of other vegetation. Also, in order to potentially detect outcrops by Landsat sensors, the size of outcrops must at least be as large as a pixel (80 m). In the study area large outcrops do prevail.

The study area should contain different rock types. This criterion, although important, is a less critical requisite. It essentially contributes to the generality of the methods developed for separating rock outcrops. The study area contains several different rock types and surficial materials.

In summary, this section dealt with the study area used. First, the location and general setting of the area were given. Next the general and economic geology of the area were described. Finally, advantages of selecting this area for the study were presented.

3.0 METHODS

3.1 VISUAL ANALYSIS

Visual analysis forms an integral but limited part of the conventional photogeological interpretation. Visual analysis is used to elicit geological information from photographs or images such as those obtained from Landsat satellites. The images used in visual analysis may be a standard product or digitally enhanced images. Some relevant aspects of visual analysis, advantages of using digitally enhanced images, and methods useful in producing these images are discussed in this section.

3.1.1 Visual Analysis Using Standard Images

The phrase visual analysis is used here to refer to the practice of examining images for the purpose of identifying ground features. Image interpreters have extensively used standard images from Landsat for extracting geological information. The geological information included both lithological and structural aspects. The analysis methods used are very similar to those applied in conventional photogeological interpretation.

Landsat images are suited for conventional photointerpretation, either in the form of color images or as black and white images. The images can also be studied comparatively in each of the four MSS bands.

The photointerpretation methods involve the recognition of geometric patterns, color, tone, texture differences, and contextural information such as relationships to surroundings. Geometric pattern recognition is especially important in structural interpretations.

Landsat images offer a few recognized advantages over aerial photographs:

1. the capability of synoptically viewing a large area,
2. the capability of imaging practically in a vertical view, under essentially the same illumination and sensor operation conditions, and
3. the capability of repetitive coverage of the area at fixed intervals of time and at the same time of the day.

The synoptic viewing is an important advantage to a photointepreter who searches for simple geometrical features in extracting structural information. A mosaic of photographs taken at somewhat different times would tend to introduce some spurious features and mask the actual features. Geology does not change much between repetitive satellite overpasses; however, landscape cover conditions can change with seasons and over a period of years. Many geological problems require analysis of imagery from several different seasons (Gregory and Moore, 1975; Taranik, 1978). That is, certain seasons are more suitable to extract information about certain geological features.

3.1.2 Advantages of Using Digital Data

Although standard product images offer the above stated advantages over aerial photographs, digital data are more suitable in producing better image products. Digital data offer several specific advantages in visual analysis of Landsat data. The advantages discussed here are specific to producing a more suitable display of photographic product to the photo analyst.

The standard photographic product from Landsat data normally occupies a limited density range. This narrow density range results in low contrast images. This low contrast on the images can be improved by enhancing the digital data. Some of the techniques used in enhancing the images are described in the next section (3.1.3).

Standardization of colors is an important requirement to the image analyst in identifying ground features. Standardization as used here refers to the process of representing a ground feature with a specific color or shade whenever or wherever it occurs. Achieving this standardization of colors or color control is almost impossible with standard images. The reason for this is partly due to the adjustments (e.g. to sensor introduced errors) that need to be made to the data and partly due to the difficulty in standardizing the photographic process. It is, however, easier to achieve the standardization of colors when digital data are used.

Digital data are better suited to produce images at almost any desired scale. The scale of the standard image is approximately 1:1000,000. This standard image can, however, be photographically enlarged to a scale of 1:250,000. Any further enlargements to produce images at larger scales would clearly expose the individual scan lines on the image. Using Landsat digital data, images can be produced at scales as large as 1:50,000. Digital data would, thus, be useful to the image analyst in detailed mapping.

One should, however, be careful in referring to scales on mapped products. Even though Landsat digital data can be manipulated to produce images or maps at scales larger than those mentioned above, these may not be significant in terms of mapping accuracy. It must be recognized that the instantaneous field of view of the MSS subsystem is approximately an acre.

Some other advantages of using digital data are that mathematical functions and statistical analysis techniques can be applied. The data can be manipulated to produce images desired by the image analyst using mathematical functions. Computer classification methods can be used with digital data in automatically identifying ground features.

3.1.3 Computer Enhancements

The general objective of image enhancements is to optimize display of the data to the analyst. Image enhancements can be performed on photographic products using photo-optical techniques or on digital data using mathematical functions implemented as computer techniques. The advantages of using digital data for display were already described in the previous section. Some of the computer enhancement methods that are popularly used are briefly described and then the techniques used in this study are presented in detail.

3.1.3.1 Contrast enhancements

Contrast enhancement is probably the most useful operation for visual analysis of Landsat digital data. This may be performed using either a linear or a nonlinear function. Linear contrast enhancement is done more often than nonlinear contrast enhancement perhaps because the latter is restricted to specific applications. Linear contrast enhancement is done by assigning new digital values to each pixel in the scene in a manner expressed by the following equation:

$$DVO = \frac{DVI - MIN}{MAX - MIN} \times N$$

Where:

DVO = Enhanced digital value of pixel in output image

DVI = Input digital value of pixel

MIN = Minimum digital value parameter

MAX = Maximum digital value parameter

N = Maximum digital value to be expected in the output

The minimum and maximum digital value parameters are the cut-off values used in saturating to black and white respectively. These values are usually determined by an analyst and are reassigned to minimum and maximum (N) values on the output image. Thus, the range (usually smaller) of digital values retained are expanded between 0 and N. The maximum value, N is usally 255 when using computer systems that work in an 8-bit mode.

When the expanded range of digital values is recorded on film, the result is an expanded density range. Thus, features in the scene are more easily distinguished because scene contrast is higher.

3.1.3.2 Edge enhancements

Edge enhancements are employed to enhance radiometric patterns which have a certain spatial frequency in the image. Landsat data often have subtle brightness variations which are difficult to detect. These brightness variations are often related to differences in the illumination of topographic features such as landforms, drainage, and fractures.

Edge enhancement consists of filtering either low frequencies or high frequencies depending upon the application at hand. A low frequency filter examines the average brightness value of a large number of pixels surrounding the pixel to be enhanced. A high frequency filter examines the average radiance of a small number of pixels surrounding the pixel to be enhanced. For example, when a low frequency filter is used to enhance a drainage network, only major tributaries will be enhanced.

Computer techniques using moving average windows have often been used to perform edge enhancements. Fourier transforms have also been used to perform edge enhancements.

3.1.3.3 Ratio enhancements

A ratio of two Landsat bands is obtained by dividing the radiance value in one band by the radiance value in another band for each pixel within the scene. The ratioed values are usually multipliied by a factor so that all values will lie between zero and N, respectively the minimum and the maximum digital values for displays.

The ratioed values can be displayed either as a black and white image or as a color composite by combining the individual images. In generating a color composite, the ratios of Band 4 to Band 5, Band 5 to Band 6, and Band 6 to Band 7 are commonly used for the three primary colors. The assignment of the three primary colors to a specific ratio can be changed to accommodate the analyst's preference.

3.1.3.4 Simulated false color infrared images

In this study, Landsat digital data have been simulated as false color infrared images for visual analysis. The simulation has been achieved by assigning Band 4 (visible green) to blue, Band 5 (visible red) to green, and Band 7 (infrared) to red. These false color infrared images have been displayed on a color monitor for visual analysis.

The digital data used for the false color displays have been linearized and standardized using procedures explained in Section 3.2. In addition to these two steps, the rock outcrops and soils have been enhanced by intensifying digital values in Bands 4 and 5. The intensification was achieved by using multiplication factors of 2 and 1.5 respectively for Band 4 and Band 5.

On the false color infrared displays, water appears dark blue to black, vegetation appears in various shades of red depending on the vigour, snow and ice cover appears as white and so do the clouds. Rock outcrops appear in various shades of blue to bluish green. These color representations for the various cover types are listed in Table 2.

Visual analysis techniques can be used in extracting geological information from the color displays. Photographic products produced from these color displays can

TABLE 2. COLOR REPRESENTATION OF COVER TYPES ON DIGITALLY ENHANCED SIMULATED COLOR INFRARED IMAGES

COVER TYPE	REPRESENTATION
Water	Dark blue
Snow / ice	White
Vegetation	Shades of red
Rock outcrops	Blue to bluish green

also be used in visual analysis.

In summary, visual analysis techniques similar to those of conventional photogeological interpretation can be applied to Landsat data. For the visual analysis, either standard photographic products or digitally enhanced images may be used. Landsat digital data offer definite advantages, such as consistent color control for visual analysis, over standard photographic products. An outline of procedures commonly used in digitally enhancing Landsat data were presented. Finally, a procedure used in producing digitally enhanced simulated color infrared images was described. These enhanced images were used in identifying rock outcrops and in separating rock types by visual analysis.

3.2 STANDARDIZING THE LANDSAT DATA

The Landsat data used in this study were standardized. The need for standardization, the factors that require standardization, and the procedures used in standardizing the data are presented in this section.

3.2.1 Need for Standardization

Landsat data must be calibrated against surface data to produce meaningful classifications or results. Acquiring surface data for use in calibrating Landsat data is expensive. Repeated calibrations may be eliminated by using standardized Landsat data. The standardized calibration data used in this study were defined for all future applications of the method during a pre-calibration study.

Calibration procedure involves relating data acquired in the field to the Landsat data. The calibration procedure is explicitly done either during the process or after the process of classification in standard automatic classification schemes. The calibration procedure is inherently carried out in the human brain in the case of conventional visual interpretation.

Acquiring surface data for use in the calibration procedure is expensive. Collecting surface data in remote areas is very difficult if not impossible. The requirement of repeatedly collecting enough surface data exists whenever Landsat data are used repeatedly whether it be with data acquired on different dates or over new areas. Repeated temporal data are not required for mapping rock outcrops or rock types. However, the need for calibration exists both for visual interpretation and for automatic classification schemes. The need for repeated calibrations may be eliminated by using standardized data.

Standardized calibration data used in this study were defined for all future applications of the method during a pre-calibration study. In this study threshold values used in the classification scheme were defined using standardized Landsat data.

3.2.2 Factors Requiring Standardization

There are several factors that affect the radiance values obtained by Landsat. Only factors related to external sources, that is other than true variations of the ground features, require standardization. These external factors are related to the sensors, the different satellites, time and place of data acquisition, and atmospheric conditions at the time of data acquisition. The most prominent factors requiring corrections are variations in detector responses, different satellites, different sun elevation angles, and different atmospheric conditions. In the following section, the variations produced by these factors are explained along with the correction procedures applied.

3.2.3 Standardization Procedures

3.2.3.1 Detector responses

The MSS utilizes six detectors to generate an image in any one band. The detectors are, unfortunately, susceptible to drift owing to their sensitivities to operating temperatures. Consequently, the radiometric responses of the six detectors are usually not equal. The net result is radiometric striping in the imagery. This radiometric striping is not only unaesthetic to the eye making visual interpretation of the imagery difficult, but also produces misclassifications in spite of sophisticated automated classification schemes used (Shlien and Goodenough, 1974).

Another type of striping problem called sixth line striping is sometimes present in the MSS data. This striping is characterized by a variation in every sixth scan line of six quantum levels or more from the average quantum level of the other scan lines. This striping problem was caused by an intermittent hardware problem in the MSS controller (Thomas, 1973).

A third type of striping problem called intermittent problems also occur in the MSS data. These problems include loss of data due to non-synchronization of signals and loosing track of the satellite. This class of problems occur so intermittently that it would be difficult to obtain a general solution to all these problems. However, alternative adjustments can be made to alleviate some of these problems when they are detected.

One approach of performing radiometric corrections or removing striping is to use information from the scene being viewed by the MSS to remove the relative differences among the detectors in a single band. Although the six detectors in each band view different locations on the ground, the very large number of pixels in a Landsat scene insures that the statistical distribution of scene radiances will have nearly the same mean and standard deviation for all detectors in a single band. Any differences in these two parameters calculated from the scene data for all six detectors will be due to differences among the detectors.

In the method used in this study, a reference detector is selected for each spectral band. The cumulative probability distributions of the remaining five detectors for each band are adjusted to match that of the reference detector. Thus, parameters of the detector responses are estimated and a look-up table to equalize the detector responses is produced (Taylor, 1978). The look-up table consists of 64 values for each of the 24 detectors. The MSS data are transformed using this look-up table.

3.2.3.2 MSS on satellites 1, 2 and 3

Landsats 1, 2 and 3 contain identical MSS subsystems in their payload with the exception of an additional thermal band for Landsat 3. However, the response in one band on Landsat 1 is not identical to the response in the same band on Landsat 2 (NASA, 1976). This unequal response results in different radiance values for a given scene when imaged by the different satellites. These variations must be compensated for when data from different satellites are used.

The minimum and maximum radiance values expected from each of the MSS bands were published for each of the satellites (NASA, 1976). These published values were from pre-launch calibrations. These pre-launch calibration values were used in standardizing the MSS data from Landsat 1 and Landsat 2. In this standardization process Landsat 2 was taken as the standard and the data from Landsat 1 were adjusted. The adjustment consists of taking the ratio of the expected range for Landsat 1 band to the expected range for Landsat 2 band. Data collected by Landsat 1 were multiplied with this ratio to adjust the differences due to the satellites. This was repeated for all the MSS bands.

3.2.3.3 Sun-elevation angles

Changes in solar elevation angle cause variations in the lighting conditions and consequently changes in the average scene radiance. This change in radiance is influenced by both the change in intrinsic reflectance of the ground scene and by the change in atmospheric scatter. Changes in solar elevation angle are due primarily to the north/south seasonal motion of the sun.

Rigorous models have been developed to correct Landsat data for the effects of sun angle, haze and background reflectance (Potter, 1977). In this study, a simpler correction factor was applied. The correction factor standardizes the MSS data to a standard sun elevation angle. The same correction factor was applied to all the MSS bands.

At small optical thicknesses the radiant emittance increases as the solar zenith angle increases; this increase is significant when the zenith angle is greater than 37 degrees (Fraser, 1975). In order to minimize the seasonal differences in irradiance, the MSS data are normalized to a sun elevation angle of 37 degrees. The correction factor used was Cos X / Cos 37 degrees, where X is the sun elevation angle corresponding to the center of the scene. The MSS data in each band were multiplied by this correction factor.

3.2.3.4 Atmospheric conditions

Atmospheric conditions at the time of the Landsat overpass influence the scene radiance. When Landsat data are to be compared from date to date or from area to area the changes in the atmospheric conditions must be taken into account. Because of the spatial and temporal variability of the tropospheric haze, atmospheric corrections are more difficult. In order to precisely perform the atmospheric corrections, the state of the atmosphere must be determined.

This requires proper equipment and extra effort such as viewing the sun with a properly calibrated radiometer at the time of the Landsat overpass.

In this study, a simpler but reasonably effective alternative to making measurements was adapted. The correction involves using radiance values from a clear water body in the study area as a standard. The radiance values from the clear water body can be compared to the values obtained on subsequent dates. The difference from the standard values for each band were determined. These differences were removed from the scene data on the second date.

3.2.3.5 Linearizing the MSS data

As a part of the standardization procedure, the MSS data have been linearized or decompressed. MSS data from Landsat are transmitted in a "signal compression mode" for Bands 4, 5 and 6; in a "linear mode" for Band 7 (NASA, 1976). In the compression mode a non-linear relationship exists between radiance input and signal output.

The signal compression mode is used to match the detector noise with the quantization noise. That is, the compression mode is used to accommodate the wide range of radiances resulting from the wide range of illumination and reflectance conditions possible on the earth.

On a typical cloud-free Landsat scene, the data occupies a very small range of values resulting in small density range on the film or low contrast image. The data are linearized to improve the contrast in a scene. A quadratic equation given by Strome et al (1975) has been used in linearizing the data.

Video outputs of the MSS detectors are digitized onboard in 6-bit mode or 64 levels. After linearizing, the data are expanded to a range of 0-255 or 8-bit mode.

In summary, the Landsat MSS data need to be standardized for optimum use of the data. Standardizing the data may eliminate the need for repeated calibration with field data in identifying cover types. Variations in the data due to different detector responses, satellites, and sun elevation angles were minimized. Procedures used in standardizing the MSS data were described. The standardized data were linearized and presented in 8-bit mode in the final form.

3.3 SPECTRAL SIGNATURES AND THRESHOLD VALUES

Spectral signatures are useful in classifying cover types and in obtaining a better understanding of the cover types identified. The spectral signatures or some derived parameters of these signatures are used in automated or visual classification of cover types. The true spectral signatures may be obtained from laboratory measurements or crude estimates of these signatures from Landsat digitial data. Discussion on the spectral signatures and their uses, how the signatures are obtained, and how threshold values are determined for cover types using measurements from Landsat data are presented in this section.

3.3.1 Spectral Signatures and Their Uses

A spectral signature may be defined as the unique reflectance or emission response over a wavelength region characteristic of a particular object or association of features. In an ideal case then, one can think of these quantitative measurements as distinctly characteristic of the object under consideration. However, in reality an object may or may not have a distinct spectral response in the wavelength region observed. By comparing the responses in several different spectral regions, clues which are unique may be deduced. For example, the MSS on Landsats 1 and 2 collects reflectance responses in four different spectral regions or bands over a small area referred to as a pixel. One may think of these four measurements as a spectral signature.

Spectral signatures are quantitative measurements. The measurements can be made in the laboratory on a specimen collected in the field representing the true in-situ conditions, or from the air. Each of these methods of making measurements has certain associated advantages and disadvantages. The spectral signatures, irrespective of how they are collected, have certain uses and contribute to a better understanding and identification of cover types.

Probably the most direct use of spectral signatures is with automated classification procedures. In these procedures, cover types on the surface of the earth are grouped or classified using their characteristic spectral signatures. That is, with these methods, the cover types are labled based on individual spectral characteristics of the cover types in a given scene. The classification procedures may consist of automated or computer methods, or visual interpretation methods.

The spectral signatures may also be used in deriving a set of universal characteristics for each cover type. The universal set can then be used in classifying cover types using data acquired at any time or in any season. This kind of use of spectral signatures would be the most ideal one as it eliminates or at least minimizes training for cover types with each application of classification procedures.

Finally, the spectral signatures can be analyzed to determine which bands provide the best discrimination among cover types. Analyses of this nature would help in selection of spectral regions or bands for consideration on future airborne or spaceborne sensors collecting remotely sensed data.

3.3.2 Reported Laboratory Spectra of Rocks

Laboratory spectra of rocks and minerals serve a useful purpose. They define the extent to which intrinsic spectral information is optimally available from minerals, rocks and soils as a consequence of their compositions and fundamental crystal structure. The laboratory measurements typically place an upper limit on what can be achieved in the field and satellite acquired data.

Because rocks are composed of assemblages of minerals, the basic spectral data are contained in the spectra of individual minerals. Reflectance of rocks and minerals in the visible and near infrared regions of the spectrum are controlled by electronic transitions in transition metal ions; by electron transfer between ions in the shorter visible and ultraviolet wavelengths (Hunt and Salisbury, 1978). Iron in its two oxidation states is responsible for the color of most rocks and minerals in the field (Rabchevsky _et al_, 1979). In the visible and near-infrared regions, the most commonly observed spectral features in naturally occurring materials are due to the presence of iron in some form or other, or to the presence of water or hydroxyl groups (Hunt, 1977).

Hunt, Salisbury and their colleagues have published laboratory spectra, in the visible and near infrared regions, of commonly occurring minerals and rocks. These spectra with a brief description of the samples have appeared in a series of articles in the Journal of Modern Geology (Hunt et al, 1973 a, 1973 b, 1974, 1976 a, 1976 b). In a recent study, Hunt and Salisbury (1978) assessed the Landsat MSS bands for rock type discrimination on the basis of intrinsic information in their laboratory spectra. Spectral characteristics of rocks and the utility of Landsat bands for broad rock type discrimination are summarized here based on the above publications.

Most spectral features in acidic igneous rocks occur as a consequence of the presence of iron, hydroxyl and water and consequently are only indirect indicators of composition. Acidic rocks can be differentiated from basic rocks as they reflect more than the basic rocks. In Landsat MSS bands, acidic rocks have greater values in Band 7 than in Band 6; whereas basic rocks have greater values in Band 6 compared to Band 7.

Spectral features commonly found in basic igneous rock spectra are those due to iron near 1.0 um. Normally, these features are weak and broad. The basic rocks have the smallest reflectivities of any rocks. This is due to the large amounts of dark mafic minerals, particularly magnetite and other opaque minerals. The mafic rocks are also characterized by their greater range of Landsat MSS band ratios than for any other rock types.

The overall reflectivities of ultrabasic rocks are generally greater than for basic rocks, and indeed they overlap the reflectivities of intermediate and acidic rocks. Ultrabasic rocks typically contain relatively little opaque material and consequently their mafic minerals display prominent spectral features. These rocks produce a very large value for the ratio of Mss 6 to Mss 7 because of the intensive ferrous iron feature near 1.0 um.

Well defined spectral features are quite common in sedimentary rock spectra, except in those cases where they are masked by the presence of carbonaceous material. The ferrous iron feature occurs principally near 1.0 um, while the ferric oxide produces a characteristic fall off in intensity towards the blue bands discernible near 0.5 um and 0.86 um. However, over the Landsat MSS band pass range, sedimentary spectra do not differ significantly from those of the siliciic and intermediate igneous rocks.

Metamorphic rock spectra typically display well resolved features, and their absence indicates the presence of considerable quantities of opaque substances.

Caution must be exercised in extrapolating results based on laboratory spectral measurements to satellite acquired data. The published laboratory spectra have been obtained from well characterized homogeneous crushed mineral and rock samples and measurements are made only a few centimeters away from the samples. Whereas, the MSS data are acquired at satellite altitudes through a variable atmosphere and with a nominal ground resolution of about 80 m by 80 m. Because of these and other differences, the quality of the intrinsic information present in the laboratory spectra will typically be enormously degraded in satellite acquired data over that obtained in the laboratory.

Care must also be taken in extrapolating laboratory spectral measurements to in-situ field measurements. Some of the problems involved in extrapolating laboratory spectra to in-situ field spectra have recently been discussed by Longshaw (1976).

In spite of the difficulties mentioned, laboratory spectra do serve as a guide to spectral signatures obtained directly from the MSS digital data. Also, textural, geomorphic and vegetational effects, secondarily related to rock types that occur in the field, in many cases can produce effects that may be more useful for discriminating rock types than is the intrinsic spectral behaviour seen in the laboratory spectra. On account of these reasons, spectral signatures of cover types have been derived directly from the MSS digital data.

3.3.3 Derivation of Signatures from Landsat

In this study, spectral signatures have been derived directly from Landsat digital data. The Landsat data used are standardized before computing spectral signatures for cover types. Thus the signatures derived essentially represent true conditions as they exist on the ground.

In deriving the spectral signatures, it was assumed that all pixels in a sample area of a cover type are truly from the designated cover type. That is, each pixel in the entire sample area consists of only one cover type. This assumption may not be realistic as each sample area contains several pixels and each pixel represents about 59 x 79 m on the ground. However, signatures derived on this basis would be a true representation of natural conditions on the ground.

Spectral signatures have been obtained in four spectral bands of the MSS. The MSS on Landsats 1 and 2 acquires reflectance data in four spectral regions or bands. Comparison of spectral signatures among the four bands may prove to be useful in identifying cover types.

Spectral signatures have been derived for nine different cover types in the study area. Out of these nine cover types, seven cover types are of direct interest in geological mapping and the other two are of indirect interest as these two cover types will have to be eliminated before identifying rock outcrops. The cover types of direct interest in geological mapping include dolomite, sandstone, felsite, granite, basalt, soils and boulders, and sand. The two cover types which are of indirect interest in the mapping include water, and vegetation.

Several sample areas have been established throughout the Landsat scene of the area for each of the nine cover types. The sample areas have been selected based on known geology and visual identification of cover types on Landsat images. The number of sample areas and the locations of sample areas for each cover type are not selected at random but rather to represent natural conditions in the area. For example, sample areas for different rock types have been selected in areas of minimal vegetation cover on outcrop areas.

A large number of samples (pixels) have been included for each cover type to improve the reliability of the spectral signature estimates. The number of individual samples in each sample area are not, however, necessarily equal. Also, the number of sample areas selected to represent each cover type are not equal. The number of sample areas and the total number of samples used in deriving spectral signatures for each cover type in the study area are given in Table 3.

TABLE 3. NUMBER OF SAMPLE AREAS AND TOTAL NUMBER OF SAMPLES SELECTED TO DERIVE SPECTRAL SIGNATURES FOR COVER TYPES IN THE STUDY AREA

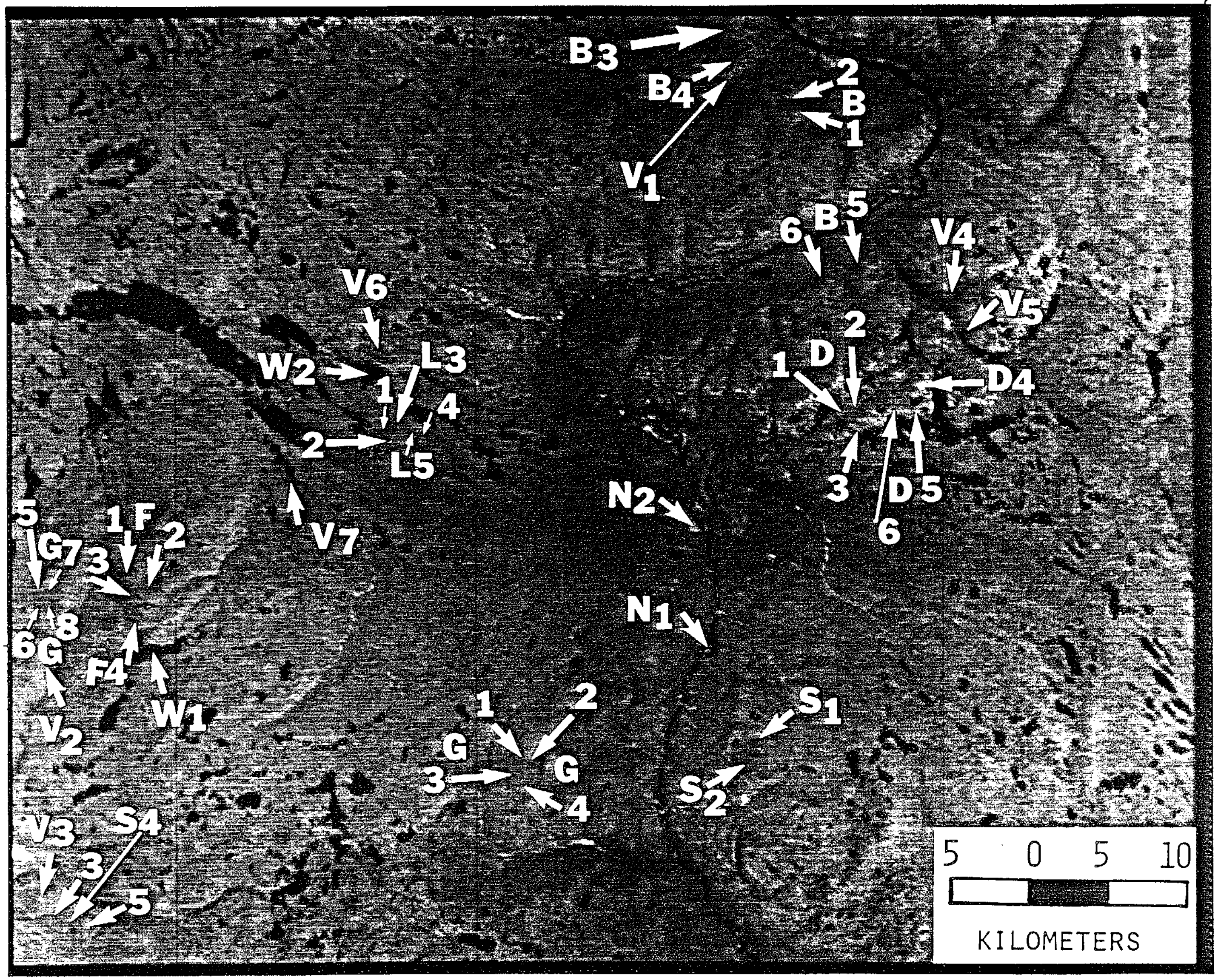
Cover Type	Number of Sample Areas	Total Number of Samples
Water	2	60
Vegetation	7	131
Soils/Boulders	5	70
Sand	2	33
Dolomite	6	132
Sandstone	5	164
Granite	8	118
Basalt	6	82
Felsite	4	119

Spectral signatures for the cover types are derived separately using Landsat digital data acquired on two different dates. The two dates of data acquisition are 5 August 1975 and 22 June 1975. On the June date, snow cover was present in most of the area and some of the lakes were still frozen. The location of sample areas and the number of sample areas were deliberately kept identical on both dates for comparing the signatures. The location of sample areas for all the cover types are shown in Figure 4.

3.3.4 Establishing Threshold Values

Spectral signatures or some derived parameters of these signatures are used in discriminating among cover types. Cut off values or threshold vaLues must be established for the spectral signatures or their derived parameters to represent each cover type in a computer classification scheme. If a cover type has unique threshold values in a band or combination of bands, then that cover type can be uniquely discriminated from the other cover types. The procedures used in establishing the threshold values are discussed here.

Spectral signature values from each sample area are averaged for each cover type. The range and the standard deviations are also computed from the signature values for each of the sample areas. Preliminary threshold values are established for each cover type in each band based on these



W WATER V VEGETATION N SAND L SOILS/BOULDERS

B BASALTS D DOLOMITES F FELSITES G GRANITES S SANDSTONES

FIG. 4. Landsat image of the study area showing locations of sample areas used in deriving spectral signatures.

computations.

The above calculations are repeated treating each sample area as one measurement. A second set of preliminary threshold values are then established for the cover types. If the threshold values in the second set are significantly different from the previously established thresholds, then the average of these two sets are used as the final set. These final threshold values have been used in a hierarchial classification scheme for discriminating rock outcrops and rock types.

3.3.5 Contamination of Spectral Signatures

It was assumed that sample areas selected for deriving spectral signatures from Landsat data were homogeneous or uncontaminated. Even though this was an idealized assumption, it is reasonable in deriving spectral signatures for use in classification of cover types. It is not, however, very common to find an area as large as a pixel to contain a homogeneous cover type, especially in rock types.

The natural surface of the earth is composed of a diversified combination of cover types. The cover types in a broad sense include water, vegetation, unconsolidated earth materials, and consolidated rocks. Unweathered, bare rock materials are, however, infrequently exposed at the surface.

The area sampled by the Landsat MSS is about the size of a football field, and thus there is an excellent probability that some combination of cover types will influence the detected spectral characteristics of rock units in a pixel. As an example, if sandstone and green vegetation were present in equal amounts within a pixel area, the resulting spectral signature would not resemble the signature for the vegetation or the signature for sandstone. The combined signature is an average of the spectral signatures for the two cover types in the pixel area.

When more than one cover type is included within a pixel area, then it is called a contaminated pixel. Contamination affects classification of cover types. The results of a classification scheme are thus based on the degree of contamination and the type of contaminant. An understanding of the effects of contamination on spectral signatures is important in utilizing the classification results to utmost benefit. To provide this understanding, the derived spectral signatures are combined to produce new signatures for contaminated pixels in various proportions. The resulting new spectral responses are assessed relative to the original spectral signatures in terms of classification scheme results.

In summary, methods used in deriving spectral signatures from Landsat digital data and threshold values from the derived signatures were described. Use of these spectral signatures in classifying cover types by establishing threshold values and in obtaining a better understanding of cover types identified was discussed. In deriving the spectral signatures, it was assumed that sample areas selected truly represent homogeneous cover conditions. Computing expected spectral signatures from contaminated pixels was included as it was recognized that the occurrence of pixels covering homogeneous rock types is infrequent. The intrinsic capability of the Landsat MSS bands in discriminating among rock types was summarized based on published laboratory spectra of rocks.

3.4 A NEW CLASSIFICATION SCHEME

A new classification scheme has been developed to discriminate rock outcrops from other cover types. This classification scheme is based on a hierarchy of cover types. It is neither a supervised technique nor an unsupervised technique in the conventional sense of automated classification methods. In this section, conventional automated classification approaches, the need for a new classification scheme, and the mechanics of the proposed classification scheme are discussed.

3.4.1 Automated Classification Approaches

Classification is the process of identifying groups or categories whose members have certain characteristics in common. If this process is carried out with or implemented on a computer then it is referred to as an automated classification approach. Ideally, the categories or classes should be mutually exclusive and exhaustive. That is, there should be one and only one class to which a pixel is assigned, and all pixels in the area of interest may be so assigned. In practice, these requirements are difficult to fulfil and often are not achieved.

Two different approaches to automated classification of Landsat data are commonly used. The classification can be supervised, in which training areas are established by the analyst, or unsupervised in which the boundaries are objectively determined from a computer algorithm to delineate natural groups or clusters.

In supervised classification, each training area, which supposedly is representative of a specific cover type of interest, is determined from _a priori_ knowledge, i.e. "field truth". Statistics are computed for each cover class and are used in various automated techniques to identify other areas within the Landsat image which have similar characteristics. The maximum likelihood decision rule (Nagy, 1972) is one such technique of supervised classification approach.

In unsupervised classification, no _a priori_ knowledge is assumed, and the classes are based on the actual relations of a selected similarity measure, among the features. In such classification schemes the number of classes can be established by the analyst or, more objectively, through the use of an algorithm in which the data themselves are used to suggest the number of natural categories, that is to find the number of clusters (Miesel, 1972). The four dimensional histogram clustering (Golderg and Shlien, 1976) is one such technique of unsupervised classification approach.

3.4.2 Need for a New Classification Scheme

Classification procedures should interpret or segment an image in terms of meaningful classes to the analyst. Perhaps the most important and difficult task in image classification is not the application of the classification algorithm, but the selection of data classes that adequately delimit the themes of interest to the analyst. This selection is particularly difficult in mapping of rock types because of the inhomogeneity of geologic units, presence of gradational boundaries, and confusing influence of both vegetative cover and soil mantling.

Automated classification procedures should also be simple and efficient. They should be simple so that the analyst or the geologist can fully appreciate and comprehend the cover type classes presented to him. The procedures must also be efficient so that they present a viable alternative to the analyst over conventional analysis techniques.

The automated classification procedures have been successfully applied in the fields of agriculture (Peet, 1975; Goodenough, 1976) and land use (Anderson, 1976; Schubert, 1978). In the field of geology, classification routines, in general, have not been so successful (Siegel and Abrams, 1976). This is primarily due to similarity of the spectral signatures of different lithologies and confusing influence of vegetative and surficial cover. These problems are absent or not so pronounced in remote sensing studies in land use or agriculture.

A study of spectral signatures showed that there are no unique four-band signatures in the MSS data for rock types in the study region (Sec 4.1.1). Conventional classification procedures employ all the four bands simultaneously, that is they assign equal weighting to all the bands. For example, any significant differences present among two classes in a band would be counteracted by any significant variations among the same two classes present in a second band. Because of this simultaneous use, conventional procedures would not normally provide useful results for mapping of rock types.

It was discovered in this study, that there were distinct patterns in some bands or combination of bands for rock types. A new classification scheme has been developed to take advantage of the distinct patterns present. There are additional and more practical reasons for developing a new classification scheme.

It is expensive and cumbersome to collect field truth for training each time a classification is attempted. It was felt that a set of signatures for general cover types would be useful for use in classification procedures. If these signatures are applicable in different areas, they can be treated as a data bank of universal signatures. To facilitate this universal applicability, the Landsat data used in deriving spectral signatures were standardized. Any new classification scheme development should incorporate or take advantage of the signature bank. That is the scheme should consist of comparing signatures from a scene to those in the data bank and assign classes on the basis of the comparisons.

Identification of rock outcrops should be carried out prior to attempting rock type classification . When rock outcrops are identified with sufficient accuracy, then one can subdivide the identified outcrop areas into different rock type areas. That is a hierarchial approach appears to be the most logical for geologic mapping purposes.

3.4.3 Mechanics of the Proposed Scheme

A hierarchical classification scheme has been developed to recognize patterns found for rock classes. In this scheme, individual bands and arithmetic combination of bands were selectively employed to classify cover types. By this selective procedure advantage can be taken in discriminating cover types even when significant differences are present only in one band. In the hierarchy, rock outcrops are first discriminated from all other classes, then the outcrops are tentatively separated into rock type classes.

In the first step of the hierarchial separation scheme rock outcrops and surficial materials are discriminated from other cover types. These other cover types included water bodies, snow and ice, and vegetation. Clouds in the image were also eliminated in this step. A similar scheme has been previously used to separate vegetated areas from non-vegetated areas on Landsat data (Schubert et al, 1976). A pixel under consideration is classified into one of the classes by successively comparing its value to the threshold values stored (signature bank) for each of the classes. When a pixel is assigned to a class, no further comparisons are made for that pixel.

Threshold values in Band 7 were used in eliminating water, as water absorbs strongly in this band. Specifically, if Band 7 value for the pixel under consideration is less than the threshold value, then that pixel is classified as water. A ratio of Band 7 and Band 5 was used to separate vegetation, as green vegetation reflects strongly in Band 7 and absorbs in Band 5. In particular, if the ratio is greater than the specified threshold value then that pixel is classified as vegetation. For snow and ice, a threshold value in Band 4 was used. When the pixel value in Band 4 is greater than the specified threshold value, then that pixel is classified as snow and ice. Clouds reflect strongly in all the four MSS bands, but Band 5 appeared to be the most consistent and was used in eliminating clouds. When the pixel value in Band 5 is greater than the specified threshold value for clouds, then the pixel is classified as cloud.

When all the above classes are successively eliminated, then the remaining pixels belong to rock outcrops and surficial material. It must be specified that the threshold values used for each of the classes are unique, that is no overlap is present. For example, when a pixel value in Band 7 is less than the threshold value specified for water, no other class has the same threshold value. This first step of the hierarchial scheme is presented schematically in Figure 5.

In the second step of the hierarchial scheme, rock outcrops and surficial materials identified in the first step are sub-divided. Again, the threshold values for the best bands and band combinations for separating the rock

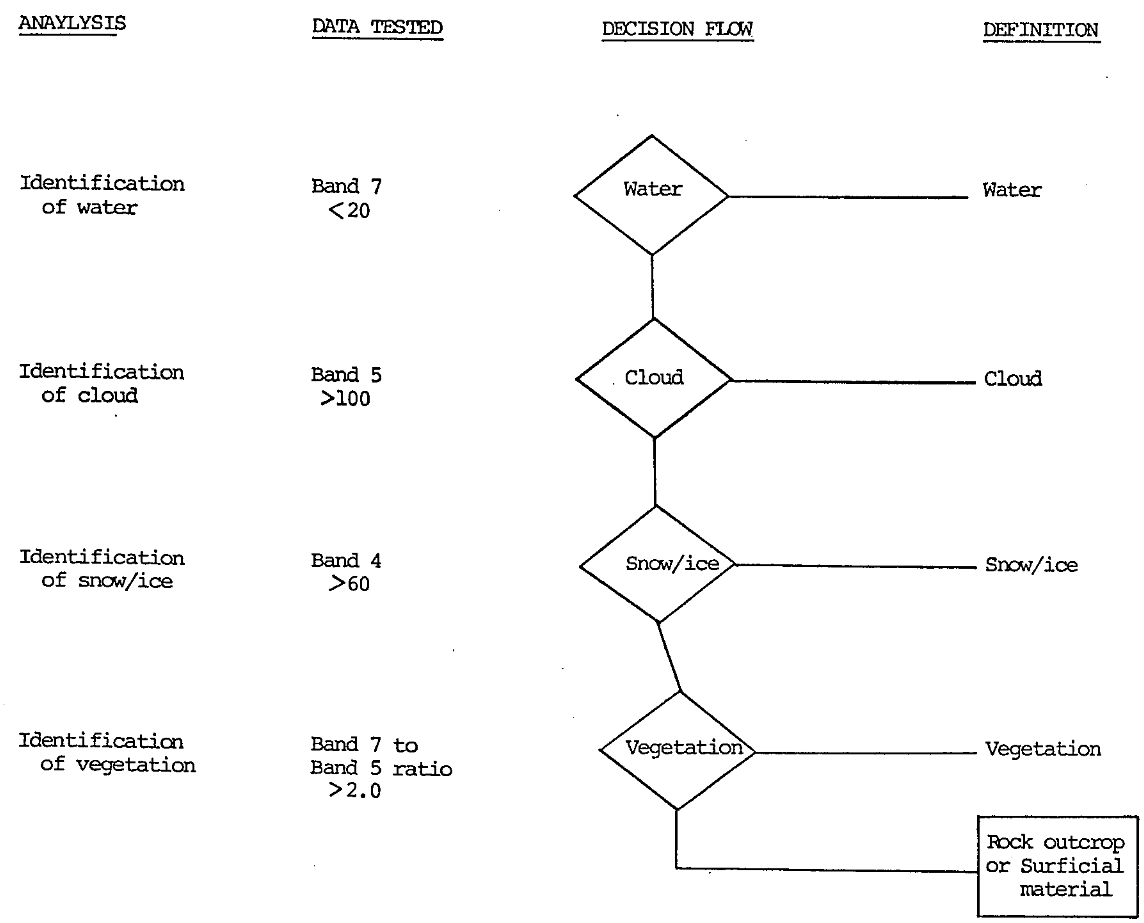


FIG. 5. *Scheme of computer classification scheme used in identifying rock outcrops and surficial materials.*

classes have been selected. In the present scheme, there are two classes for surficial materials and four classes for consolidated rocks. The surficial materials consist of soils and boulders, and sand. The consolidated rocks are dolomite, sandstone, granite, and basalt.

A pixel designated as belonging to rock outcrop or surficial material is subdivided into two groups. If the product of values in Band 4 and Band 5 is greater than the threshold value for the group, then the pixel is classified as belonging to group I; otherwise the pixel belongs to group II. Group I consists of sand and sandstones; group II consists of soils and boulders, dolomite, basalt and granite.

A pixel in group I is classified as sand when the product of band 4 and band 5 is greater than the threshold value for sand; otherwise it is classified as sandstone.

Pixels in group II are successively classified into one or the other of the four classes in this group. First, a pixel is classified as soils and boulders when the ratio of Band 7 to Band 5 is greater than the threshold value for soils and boulders. When the product of Band 6 and Band 7 of the pixel is greater than the threshold value for dolomite, then that pixel is classified as dolomite. Finally when Band 6 value for the pixel is less than the threshold value for basalt, the pixel is classified as basalt; otherwise it is classified as granite. The scheme for subdividing rock outcrops and surficial materials is shown in Figure 6.

In summary, a new classification scheme has been developed for discriminating rock outcrops from other cover types and for separating outcrops identified into rock types. This classification scheme is based on a hierarchy of cover types which are identified by comparing pixel values to standard threshold values. The need for a new classification scheme and the mechanics of the proposed scheme were also given in this section followed by an outline of the automated classification approaches.

3.5 GENERATING MAPS FROM THE MSS DATA

To be useful in mapping, results from any classification scheme must be displayed precisely in a map form. The conventional mapping approach is to use a projection of the earth's figure such as the Universal Transverse Mercator (UTM) projection. Data obtained by the MSS subsystem contain errors in the geometry and, as a result, cannot directly be displayed in a standard projection. This section dicusses briefly the distortions present in the MSS data, procedures used in correcting them, and various methods of producing thematic maps from the data.

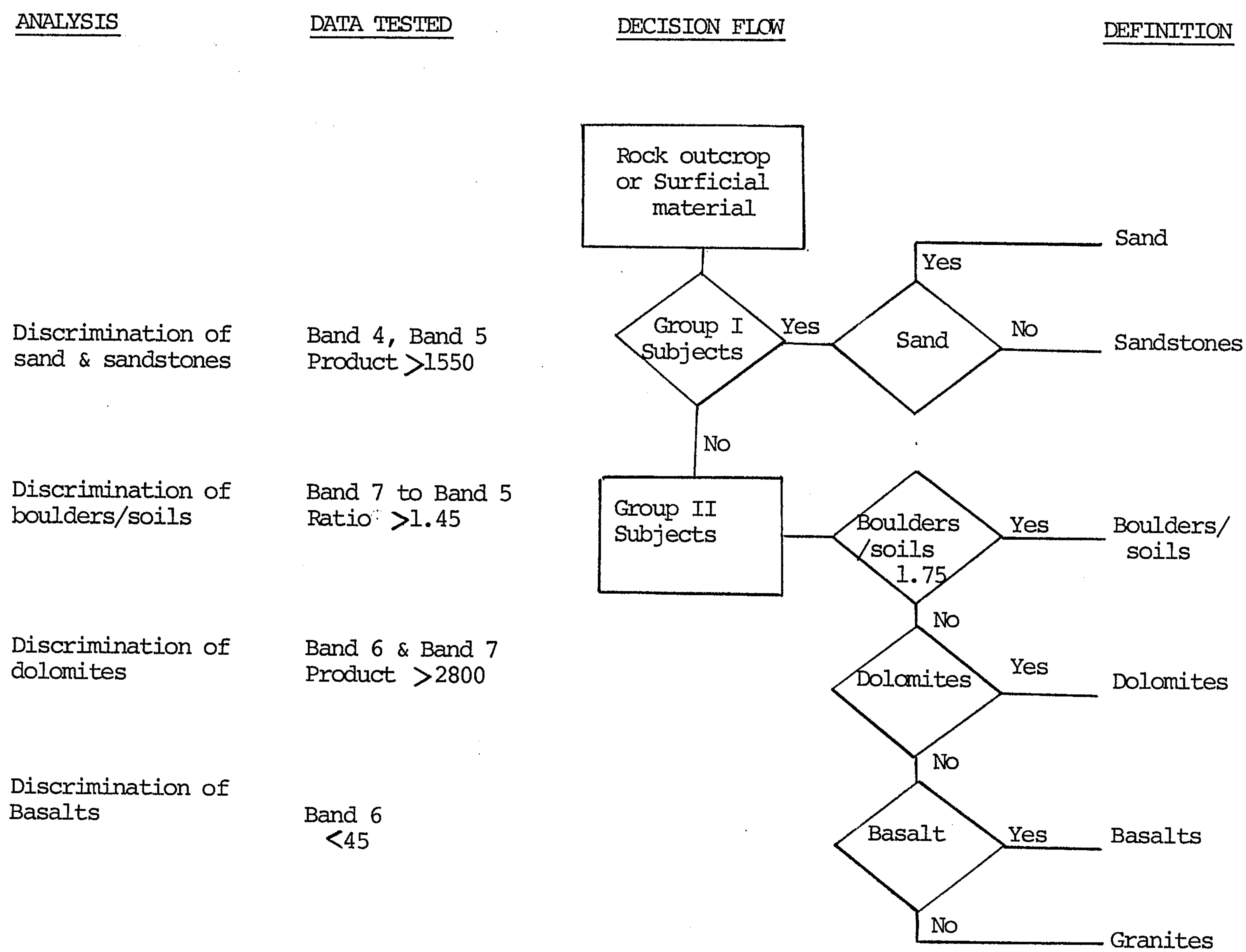


FIG. 6. *Scheme of computer classification used in discriminationg rock types.*

3.5.1 Geometric Distortions and Corrections

Geometric distortions are associated with the MSS subsystem, the spacecraft and its orbit, and the earth's surface. The distortions associated with the MSS are aspect ratio, mirror scan nonlinearity, perspective geometry and panoramic distortion. The distortions related to the Landsat spacecraft and the orbit are the platform altitude, attitude and velocity. The scene dependent distortions are the earth's curvature and rotation.

The geometric distortions result in a non-conformal projection and a different scale in different directions. The projection related distortions are corrected by registering the data to the UTM grid system; the scale related errors are corrected by resampling the data using cubic convolution.

The approach for making projection related corrections consists of defining an affine transformation and then transforming the uncorrected image to the UTM projection using this transformation (Shlien, 1979) . The affine transformation is generated between ground control points extracted manually from the uncorrected image and the corresponding UTM coordinates. The procedural details of this correction are given in Appendix A.

The scale distortions are corrected by resampling using cubic convolution. Cubic convolution is an interpolation method and has the effect of providing a smoother looking image. When the image data are registered to a particular map or grid, a one-for-one match does not occur and it becomes necessary to "fill in the blank spaces". When this occurs, it is necessary to take neighboring points and interpolate to get a best estimate for the missing values. Cubic convolution is one of the best techniques for finding such values. In this study data values are collected at 50 m spacing.

3.5.2 Methods Used in Generating Maps

To be useful in mapping or for use in the field, thematic maps generated from a classification scheme must be displayed on a hard copy. Several different methods of obtaining hard copy products are available. The methods considered in producing maps for this study include maps from line printers, hard copy computer terminals, continuous strip film recorder, and photographing a color monitor display.

3.5.2.1 Line printer maps

Maps can be produced inexpensively on a computer print-out at a suitable scale. In the proposed classification scheme, pixels are grouped into one of several classes or categories. All pixel locations that were grouped together in one class are assigned a unique symbol in producing the computer print-out.

The computer print-out is produced on a line printer. The line printer prints ten characters to an inch in the horizontal direction and six characters to an inch in the vertical direction. This discrepancy in the aspect ratio results in an unequal scale on the maps produced. This aspect ratio error can, however, be compensated for by printing one pixel in every three and one line in every five. Maps produced on the line printer with this line and pixel combination will have a scale of 1:60,000 when the pixel size is 50 m x 50 m.

The line printers can accommodate a maximum of 132 characters per line. To facilitate covering larger areas in a single run of the program, provision is made in the software to print up to a maximum of three vertical strips. These vertical strips are printed such that they can be combined after printing to provide a contiguous map.

3.5.2.2 Maps from a hard copy terminal

Maps can also be produced on a hard copy terminal using the technique described with the line printer. The number of characters printed per line varies depending upon the type of computer terminal. Provision is made in the software to vary the number of characters printed across a strip.

This method of producing maps is particularly suitable for obtaining maps quickly at a location away from the main computer facilities. Computer terminals can be connected to a main frame computer usually through telephone lines and the maps generated may be transmitted to the hard copy terminals.

3.5.2.3 Photographing a color monitor display

Results obtained from the proposed classification scheme can be displayed on a color monitor and then the display can be photographed to produce maps. In this method of producing maps, all pixels belonging to a specific class are assigned a unique color on the display. The scale of the maps produced by this method can be varied either on the monitor itself or latter by enlarging the photographic product. The Multispectral Analyzer Display (MAD) color monitor at the CCRS has been used for the display in this method.

The MAD system consists of a display unit with three parallel image processors (one for each color gun) and an internal refresh disc from which data are continaully reread to refresh the color monitor (Goodenough _et al_, 1973). The data for each of the processors must be in the range of 0 - 63 (six bit data). The MAD unit is attached to the CCRS PDP-10 time sharing system. Software was developed during this study to display areas classified on the color monitor. The software developed for this is versatile and a complete description of the different options available is given in Appendix A.

The display on the color monitor was photographed using a 35 mm camera with 100 ASA Kodacolor II film. The film was processed by a local commercial processing facility. Photographic prints were obtained at the required enlargement for use as maps.

Unfortunately, this method of photographing a color monitor introduces geometrical distortion on the maps due to the curved surface of the monitor. Consequently, the maps produced cannot be used for precise mapping.

These maps are, however, suitable for use in the field and for evaluating results obtained from classification schemes. The other disadvantages of this method include inconsistencies due to different exposure times, and non-repeatability of colors on photographic products. Fortunately, there is another method of making hard copies from the display on the MAD monitor. This method is described next.

3.5.2.4 Maps from Continuous Strip Film Recorder

Continuous Strip Film Recorder (CSFR) at the CCRS was also used in this study to produce maps from the MAD display. The CSFR produces 21 cm wide color negative of any length. On the CSFR, the scanning rate (line repeat factor) and the film speed can be controlled individually to produce the desired scale on the negatives.

In producing the negatives, line repeat factor of five and film speed of 0.42 cm was used. With this combination, the negatives are produced at a scale of 1:125,000 when the pixel size is 50 m by 50 m. Photographic enlargements of these negatives can be made to produce maps at any scale. The procedural details of obtaining the CSFR products are given in Appendix A.

It should be strssed that no geometric distortions are introduced by the CSFR in producing the maps. Representation of colors on the CSFR products is, however, not as good as it is on the MAD color monitor. The cost of making hard copies using the CSFR is not expensive; $0.85 per foot for producing negatives and $1.25 per foot for printing.

In summary, Landsat data implicitly contain certain geometrical distortions. These data are not suitable for precise thematic mapping unless the data are geometrically corrected and registered to a standard map projection. The MSS data used in this study were geometrically corrected and registered to the UTM grid system. Procedures employed in the correction and registration process were described. Various hard copy media, such as the Continuous Strip Film Recorder, may be used for producing thematic maps from the geometrically corrected data. Methods used for producing thematic maps were also described in this section.

4.0 RESULTS AND DISCUSSION

4.1 SPECTRAL SIGNATURES

Results from studies of spectral signatures derived from Landsat data are presented in this section. The spectral signatures of cover types imaged on 5 August 1975 and 22 June 1975 are presented and then compared. Finally, the effect of contamination or inhomogeneities on rock spectral signatures due to the presence of other rock types and vegetation are presented.

4.1.1 Spectral Signatures of Cover Types

Spectral signatures of nine different cover types in the study scene have been derived from standardized Landsat data. These spectral signatures have been obtained in all four MSS bands. The cover types in the study scene included water, vegetation, sand, soils/boulders, dolomite, granite, felsite, basalt and sandstone.

Several sample areas have been established for each cover type in the study scene. The number of samples areas along with the total number of samples (pixels) used in deriving spectral signatures of cover types is given in Table 3. The spectral signatures or the intensities in units of digital numbers in all four bands are plotted separately for each cover type. The sample area number (corresponds to locations shown in Fig. 4) and the number of samples within the sample area are also shown on the spectral plots. For each sample area, the mean, the standard deviation, and the range among the samples are shown on these plots.

Spectral intensities for sample areas of water imaged on 5 August 1975 are shown in Figure 7. Two sample areas containing a total of sixty samples have been used to represent water bodies in the study scene. The spectral bands in the order of increasing intensities are Band 7, Band 6, Band 5, and Band 4 respectively. The spectral intensities range from 16 to 23 in Band 4; from 8 to 12 in Band 5; from 8 to 16 in Band 6; and from 0 to 12 in Band 7. The sample areas are spectrally similar to one another in all the four bands as indicated by the uniformity of intensities. Water has the lowest intensities in all the bands among the cover types considered. Figure 7 also reiterates the fact that water absorbs strongly in Band 7.

Spectral intensities for sample areas of vegetation imaged on 5 August 1975 are shown in Figure 8. Seven sample areas containing a total of 131 samples have been used to represent vegetation in the study scene. The spectral bands in the order of increasing intensities are Band 5, Band 4, Band 6, and Band 7 respectively. The spectral intensities range from 23 to 35 in Band 4; from 19 to 31 in Band 5; from 45 to 78 in Band 6; and from 51 to 82 in Band 7. In

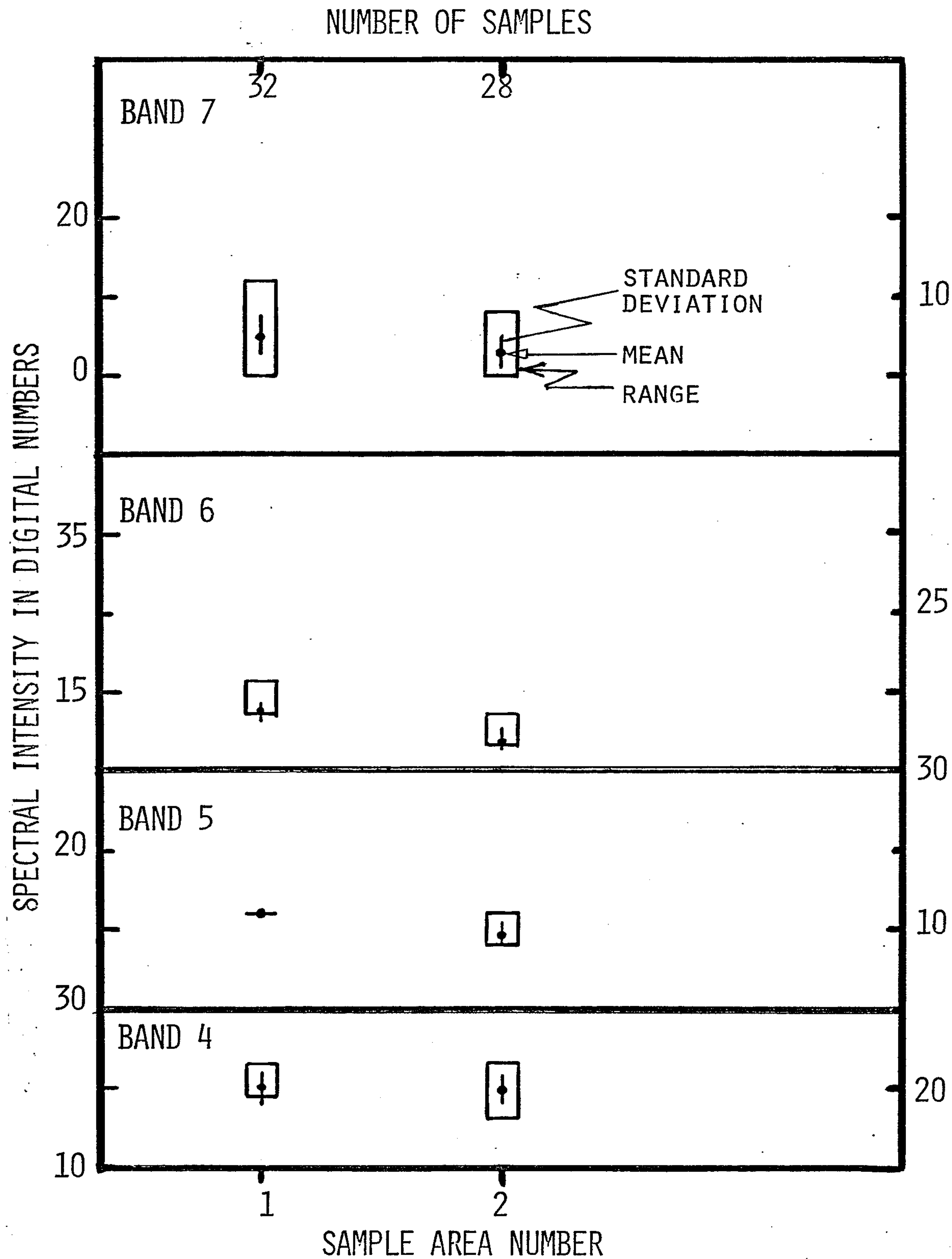


FIG. 7. Spectral intensities for sample areas of water imaged on 5 August]975.

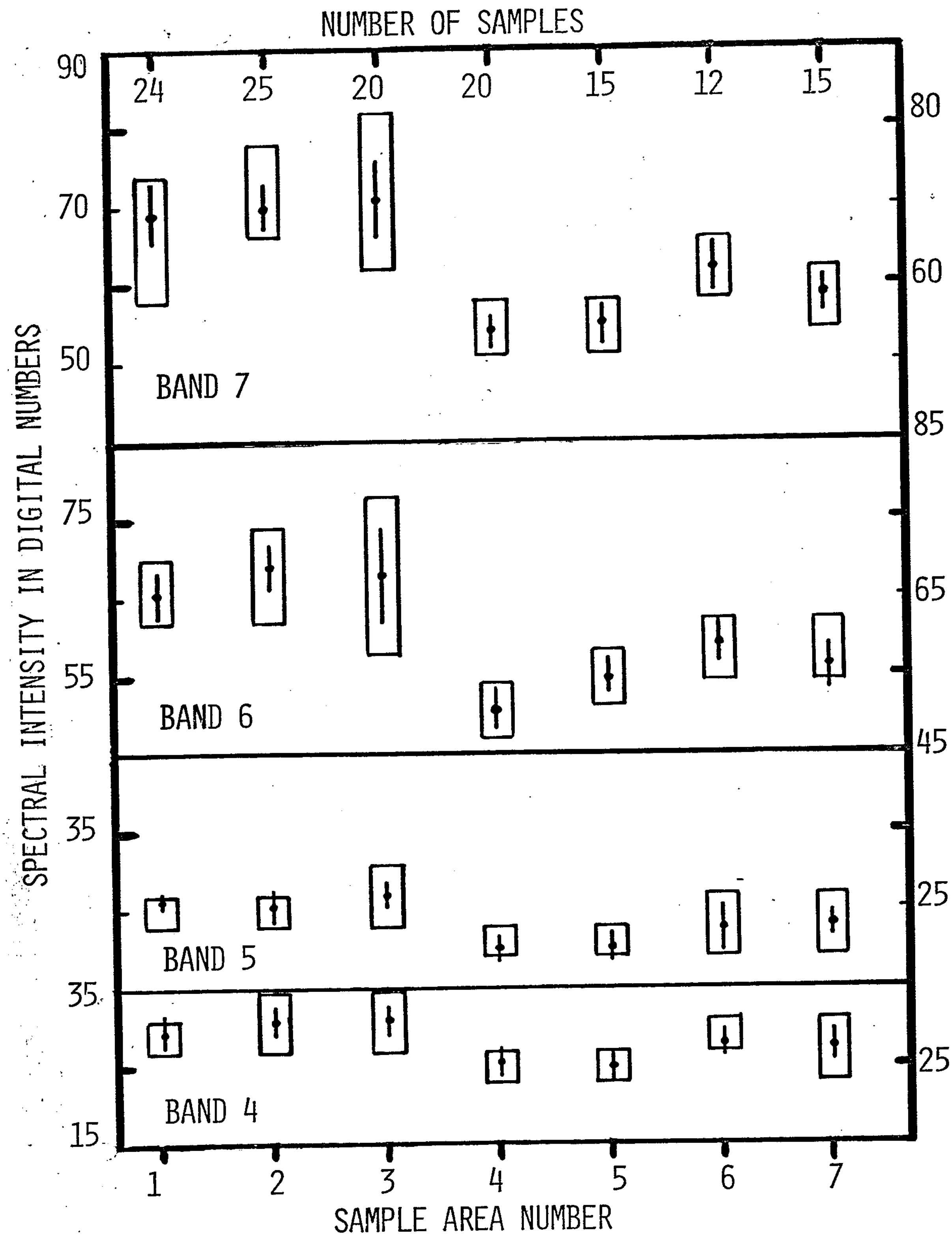


FIG. 8. Spectral intensities for sample areas of vegetation imaged on 5 August 1975.

Band 5 vegetated areas have the lowest intensities among all cover types considered excluding water bodies. Moreover, vegetated areas have the highest intensities in Band 7 among all the cover types considered. The variations among sample areas are larger in Bands 6 and 7 than they are in the other bands. These observations are consistent among all the seven sample areas. Vegetation reflects strongly in Bands 6 and 7 (reflective infrared) and the intensity is proportional to the vigor of the vegetation. The larger variations observed in Bands 6 and 7 are related to the variations in the vigor of the vegetation among the sample areas. It is also seen that vegetation absorbs strongly in Band 5 (visible red).

Spectral intensities for sample areas of sand imaged on 5 August 1975 are shown in Figure 9. Two sample areas containing a total of 33 samples have been used to represent sand in the study scene. The spectral bands in the order of increasing intensities are Band 4, Band 5, Band 7, and Band 6 respectively. The spectral intensities in the sample areas range from 31 to 47 in Band 4; from 27 to 51 in Band 5; from 31 to 70 in Band 6; and from 19 to 58 Band 7. The deviation among samples within sample area number 1 is large and indicates inhomogeneities within the area. Sand areas have higher intensities in all four bands than any rock outcrops or surficial materials examined except those for dolomites.

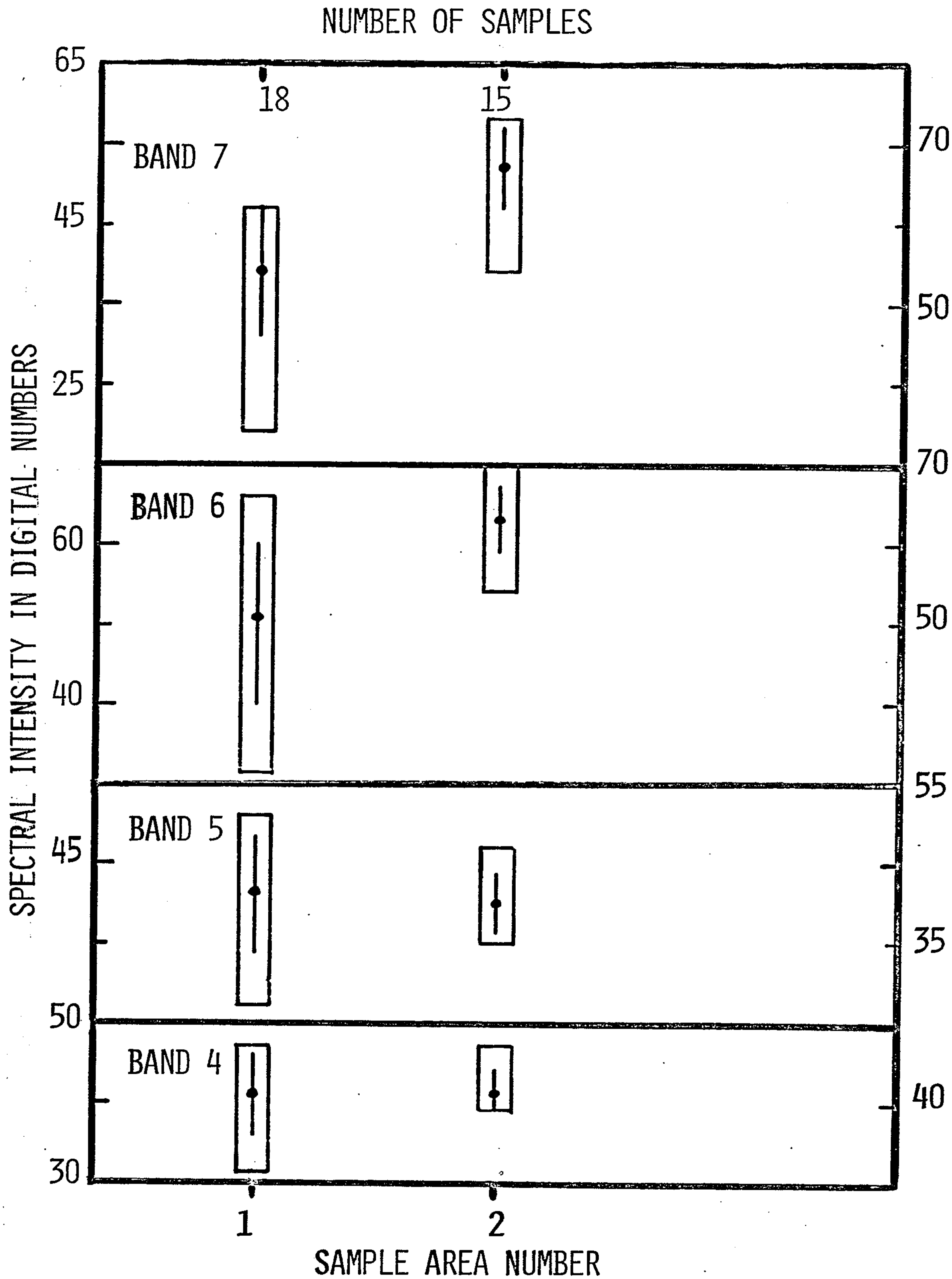


FIG. 9. Spectral intensities for sample areas of sand imaged on 5August]975.

Spectral intensities for sample areas of soils/boulders imaged on 5 August 1975 are shown in Figure 10. Five sample areas containing a total of 70 samples have been used to represent soils/boulders in the study scene. The spectral bands in the order of increasing intensities are Band 5, Band 4, Band 7, and Band 6 respectively. The spectral intensities in the sample areas range from 26 to 35 in Band 4; from 27 to 31 in Band 5; from 47 to 59 in Band 6; and from 43 to 51 in Band 7. In soils/boulders areas, the range of intensities observed in each band is remarkably low. This observation is especially noticeable in Band 5 where a value of 27 is recorded for more than 50 samples. The five sample areas are spectrally similar in all four bands as indicated by the uniformity of the intensities.

Spectral intensities for sample areas of dolomite imaged on 5 August 1975 are shown in Figure 11. Six sample areas containing a total of 132 samples have been used to represent dolomites in the study scene. The spectral intensities in the sample areas range from 31 to 47 in Band 4; from 27 to 47 in Band 5; from 47 to 66 in Band 6; and from 47 to 62 in Band 7. The intensities in Band 4 are approximately equal to the intensities observed in Band 5. Also, the intensities in Band 6 are similar to those observed in Band 7. This spectral characteristic is present only for dolomite areas and is absent for all the other cover types studied. Another unique spectral characteristic observed is that the intensities in all four spectral bands

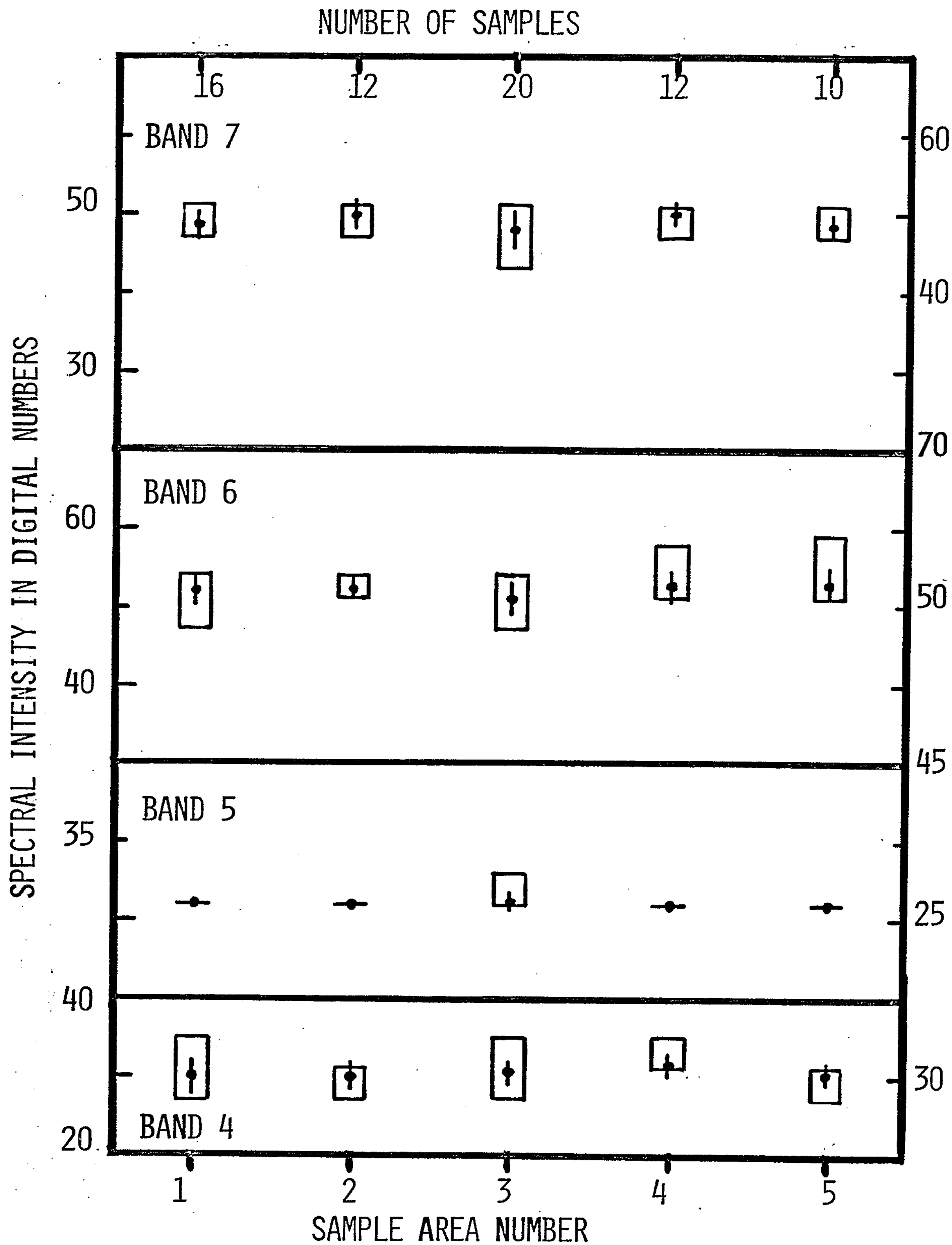


FIG. 10. Spectral intensities for sample areas of soils/boulders imaged on 5 August 1975.

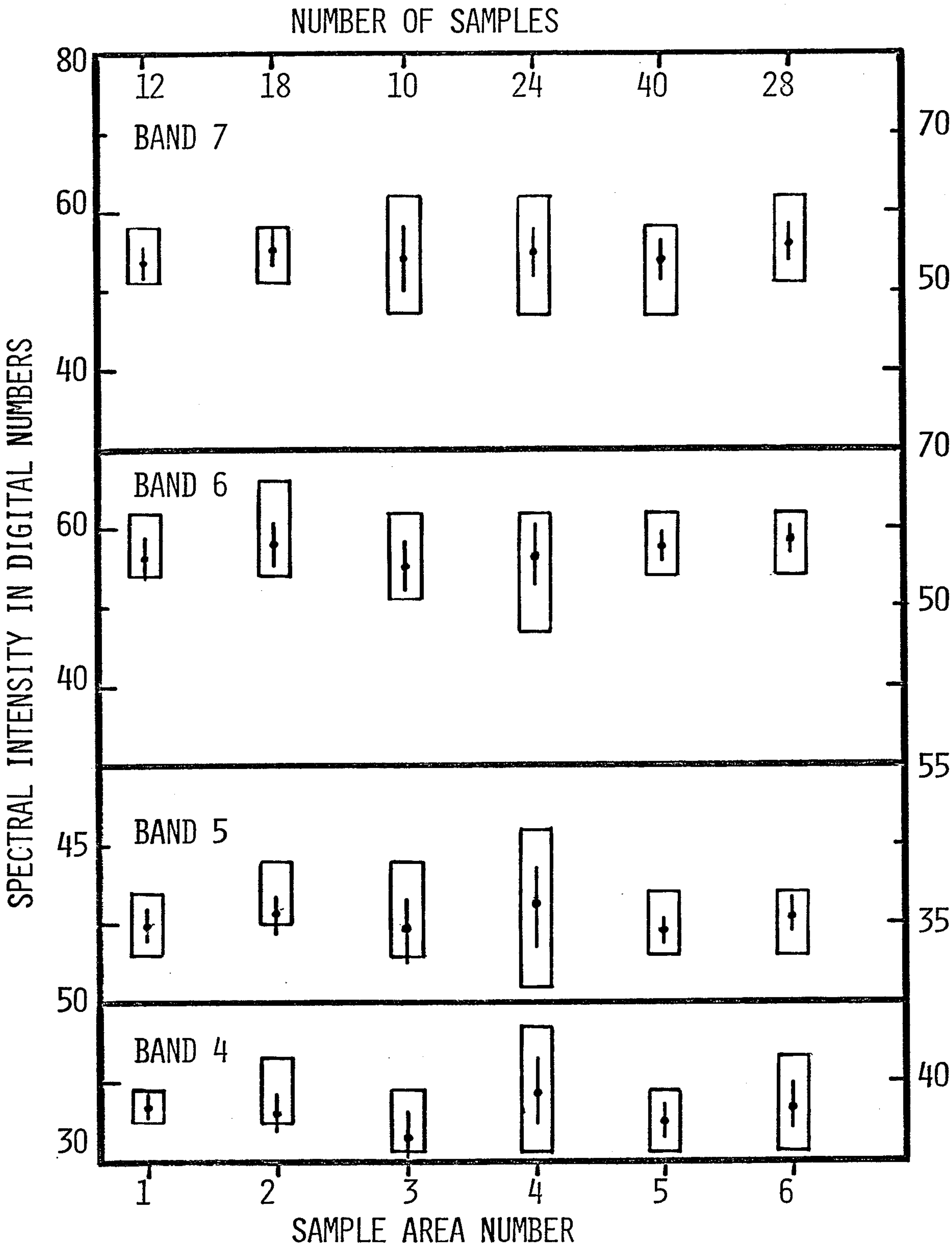


FIG. 11. Spectral intensities for sample areas of dolomites imaged on 5 August 1975.

are higher for dolomites than the other cover types, except for vegetation in Band 6 and Band 7. The sample areas, in general, are spectrally similar as indicated by the uniformity of intensities. Variation in intensities among samples within sample area number 4 is larger, particularly in Bands 4 and 5, relative to the other areas. This suggests inhomogeneities within this sample area, probably due to the presence of a different cover type within this area.

Spectral intensities for sample areas of granite imaged on 5 August 1975 are shown in Figure 12. Eight sample areas containing a total of 118 samples have been used to represent granites in the study scene. The spectral bands in the order of increasing intensities are Band 5, Band 4, Band 7, and Band 6 respectively. The spectral intensities range from 27 to 35 in Band 4; from 23 to 31 in Band 5; from 39 to 62 in Band 6; and from 35 to 58 in Band 7. The sample areas are spectrally similar in Band 4 and Band 5 as indicated by the uniformity of the intensities in these two bands. Large variations among sample areas are present in Band 6 and Band 7 which indicate that the sample areas are not quite uniform in these two bands. Since the differences occur mainly in Band 6 and 7, it suggests the inhomogeneities may be due to the presence of different vegetative canopies among the sample areas. Another point to be noted is the large variations in intensities of Band 6 and 7 within sample areas 4 and 6. This again suggests

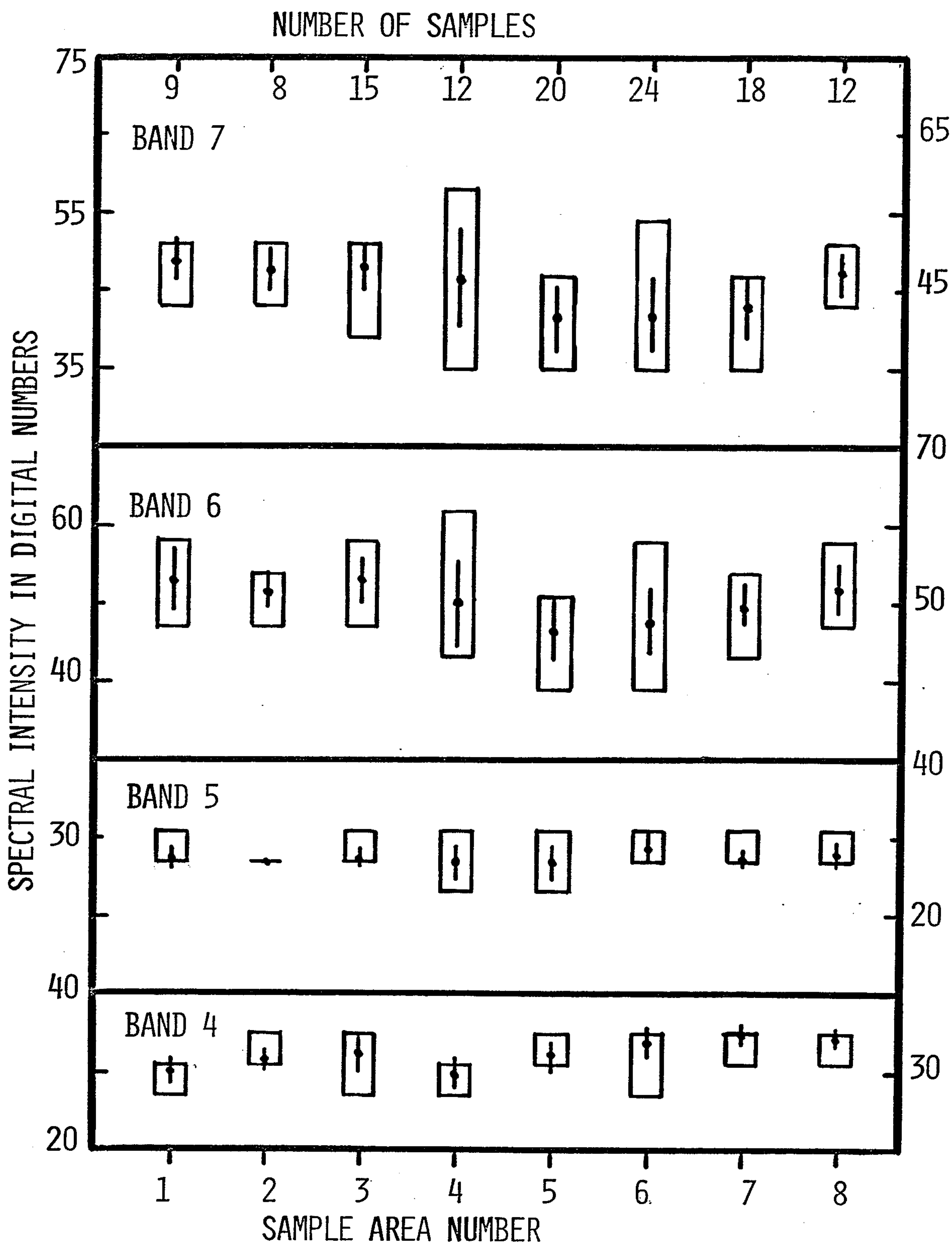


FIG. 12. Spectral intensities for sample areas of granites imaged on 5 August 1975.

pronounced inhomogeneous conditions in vegetation present within these two sample areas.

Spectral intensities for sample areas of felsite imaged on 5 August 1975 are shown in Figure 13. Four sample areas containing a total of 119 samples have been used to represent felsites in the study scene. The spectral bands in the order of increasing intensities are Band 5, Band 4, Band 7, and Band 6 respectively. The spectral intensities range from 27 to 35 in Band 4, from 23 to 35 in Band 5, from 37 to 58 in Band 6; and from 35 to 51 in Band 7. The sample areas are spectrally similar in all four bands as indicated by the uniformity of intensities among the sample areas. The variation in intensities in Band 6 and Band 7 for sample area number 2 is larger relative to the other areas. This indicates the presence of an inhomogeneity within this sample area. Because this large variation is present only in Bands 6 and 7, it may suggest the presence of considerable vegetation within this sample area.

Spectral intensities for sample areas of basalt imaged on 5 August 1975 are shown in Figure 14. Six sample areas containing a total of 82 samples have been used to represent basalts in the study scene. The spectral bands in the order of increasing intensities are Band 5, Band 4, Band 7 and Band 6 respectively. The spectral intensities range from 27 to 35 in Band 4; from 19 to 31 in Band 5; from 35 to 58 in Band 6; and from 27 to 47 in Band 7. The sample areas are

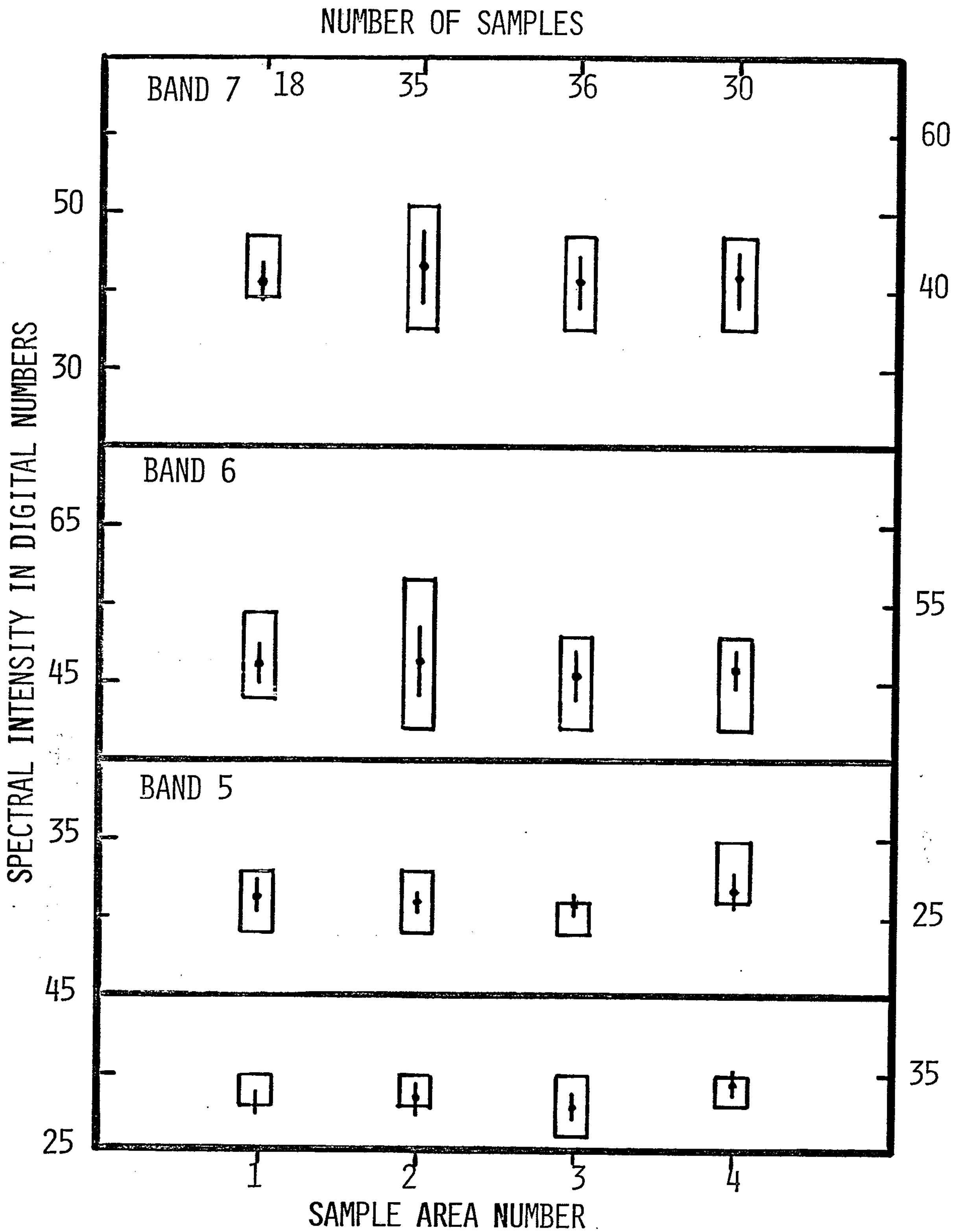


FIG. 13. Spectral intensities for sample areas of felsites imaged on 5 August 1975.

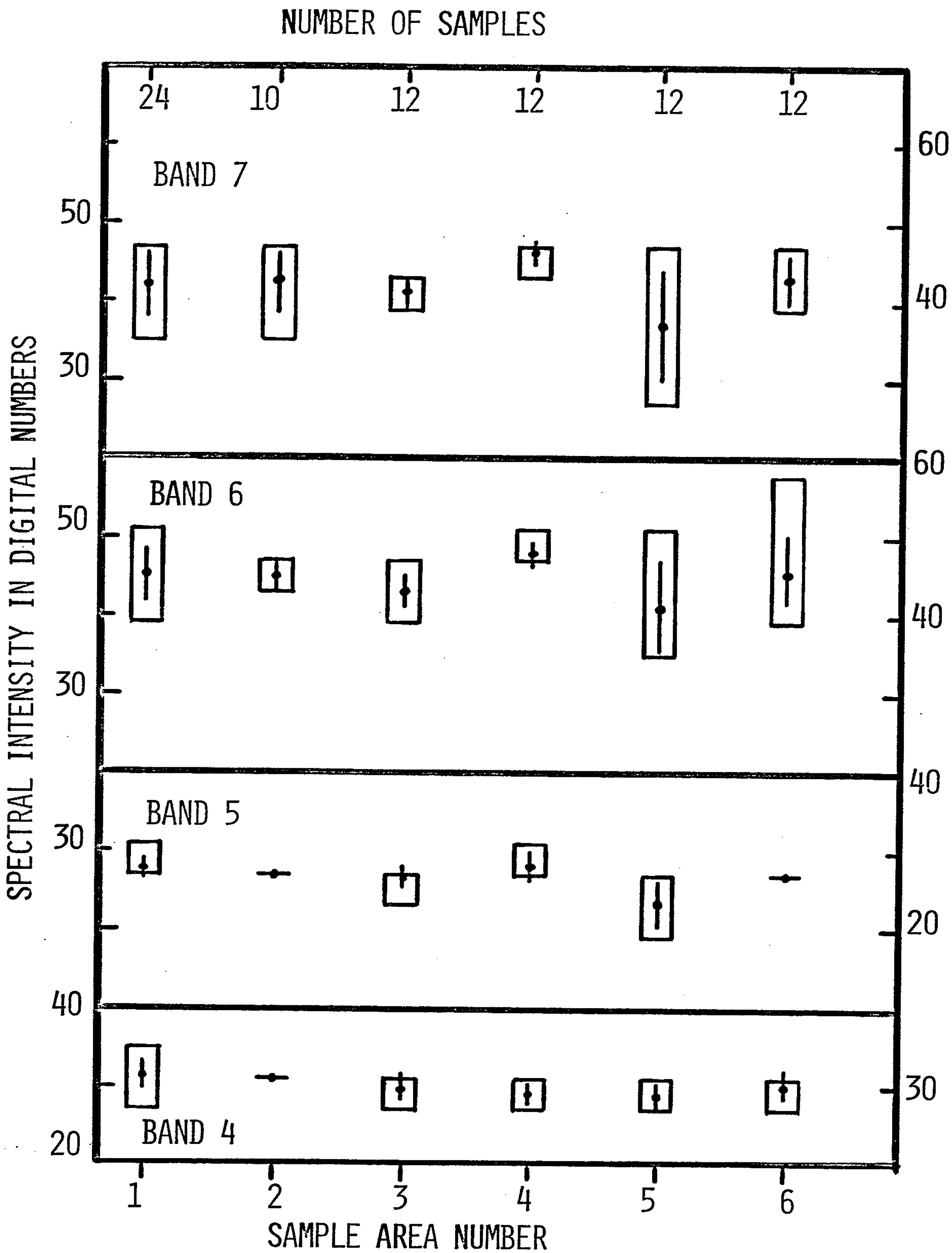


FIG. 14. Spectral intensities for sample areas of basalts imaged on 5 August 1975.

spectrally similar in all the four bands as indicated by the uniformity of intensities among the sample areas.

Spectral intensities for sample areas of sandstones imaged on 5 August 1975 are shown in Figure 15. Five sample areas containing a total of 164 samples have been used to represent sandstones in the study scene. The spectral bands in the order of increasing intensities are Band 5, Band 4, Band 7, and Band 6 respectively. The spectral intensities range from 31 to 43 in Band 4; from 27 to 39 in Band 5; from 35 to 54 in Band 6; and from 27 to 47 in Band 7. Large variations in Band 6 and Band 7 intensities occur among sample areas of sandstones. The sample areas are, however, spectrally similar in Bands 4 and 5 as indicated by the uniformity of intensities in these two bands. The intensities in these two bands are higher for sandstones than the intensities for the other rock types considered except for dolomites.

In summary, the spectral intensities are the lowest in Band 5 and the highest in Band 6 for all the cover types considered. Exeptions to this statement occur with water and vegetation; intensities in Band 7 are the lowest for water bodies and intensities in Band 7 are slightly higher than the intensities in Band 6 for vegetation. However, the differences among the bands are different for different cover types.

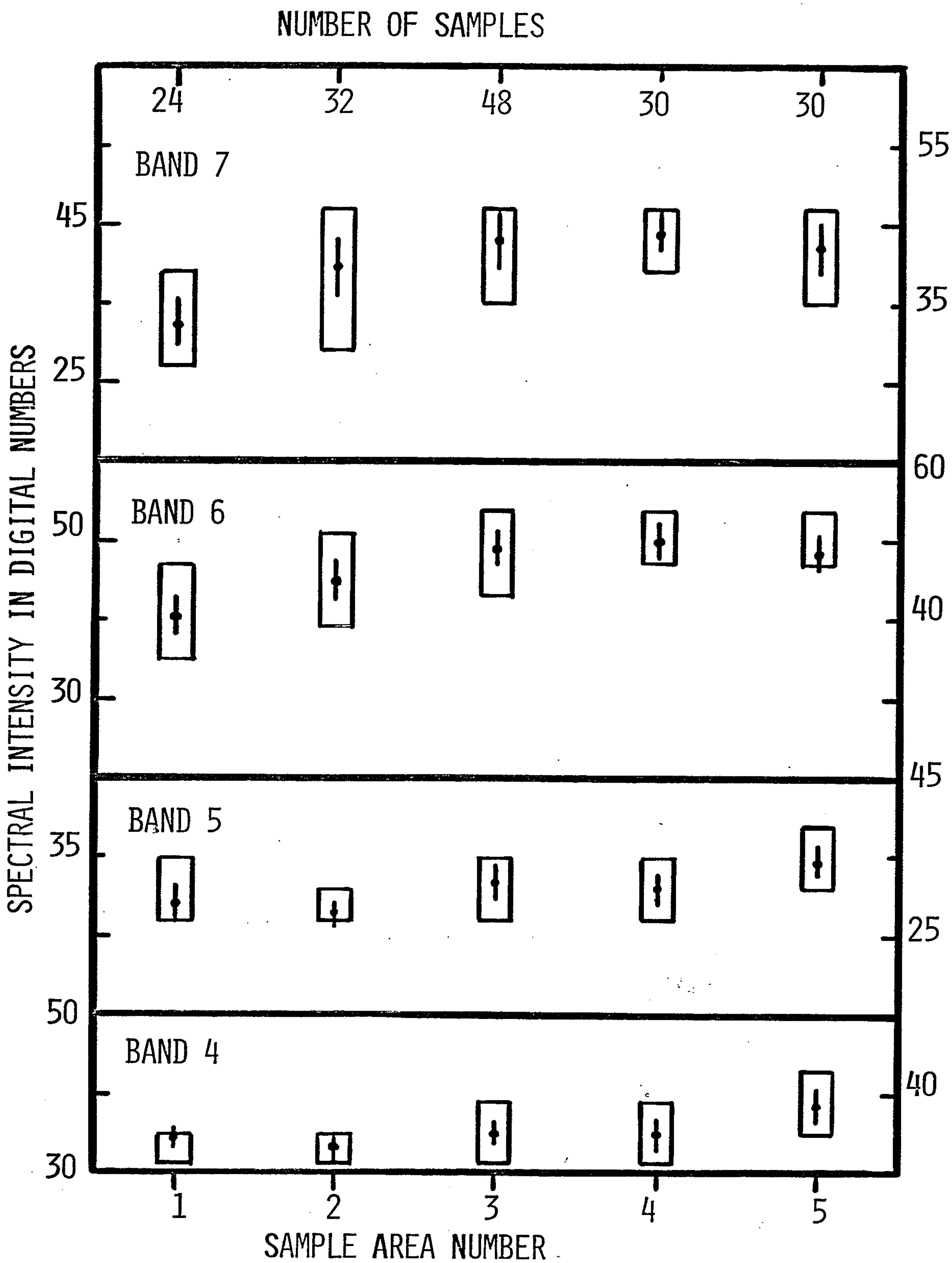


FIG. 15. Spectral intensities for sample areas of sandstones imaged on 5 August 1975.

The distribution of spectral intensities among bands for cover types imaged on 5 August 1975 is shown in Figure 16 to point out the differences among the bands. The spectral intensity in digital numbers is plotted on the abscissa and applies to all the four bands. The cover types are shown one above the other for ease of comparison. Water is not represented in this figure as intensities for water bodies are very low relative to the other cover types. In each band, the mean and range of intensities are shown. In computing the mean, and the range, each individual sample area was treated as one measurement. These spectral intensities are assumed to represent the cover types in the study scene in the following discussions.

A comparison of spectral intensities in each band among cover types shows that certain spectral patterns do exist for cover types. Spectral intensities of cover types in the sample areas imaged on 5 August 1975 are shown in Figure 17. In Band 4, the cover types in the order of increasing intensities are vegetation, basalt, soils/boulders, felsite, granite, sandstone, dolomite, and sand respectively. Similar order or pattern exists also for intensities in Band 5 among the cover types. In Band 6, the cover types in the order of increasing intensities are basalt, sandstone, felsite, granite, soil/boulder, dolomite, sand, and vegetation. In Band 7, the cover types in the order of increasing intensities are sandstone, felsite, basalt, granite, soils/boulders, dolomite, and vegetation. However,

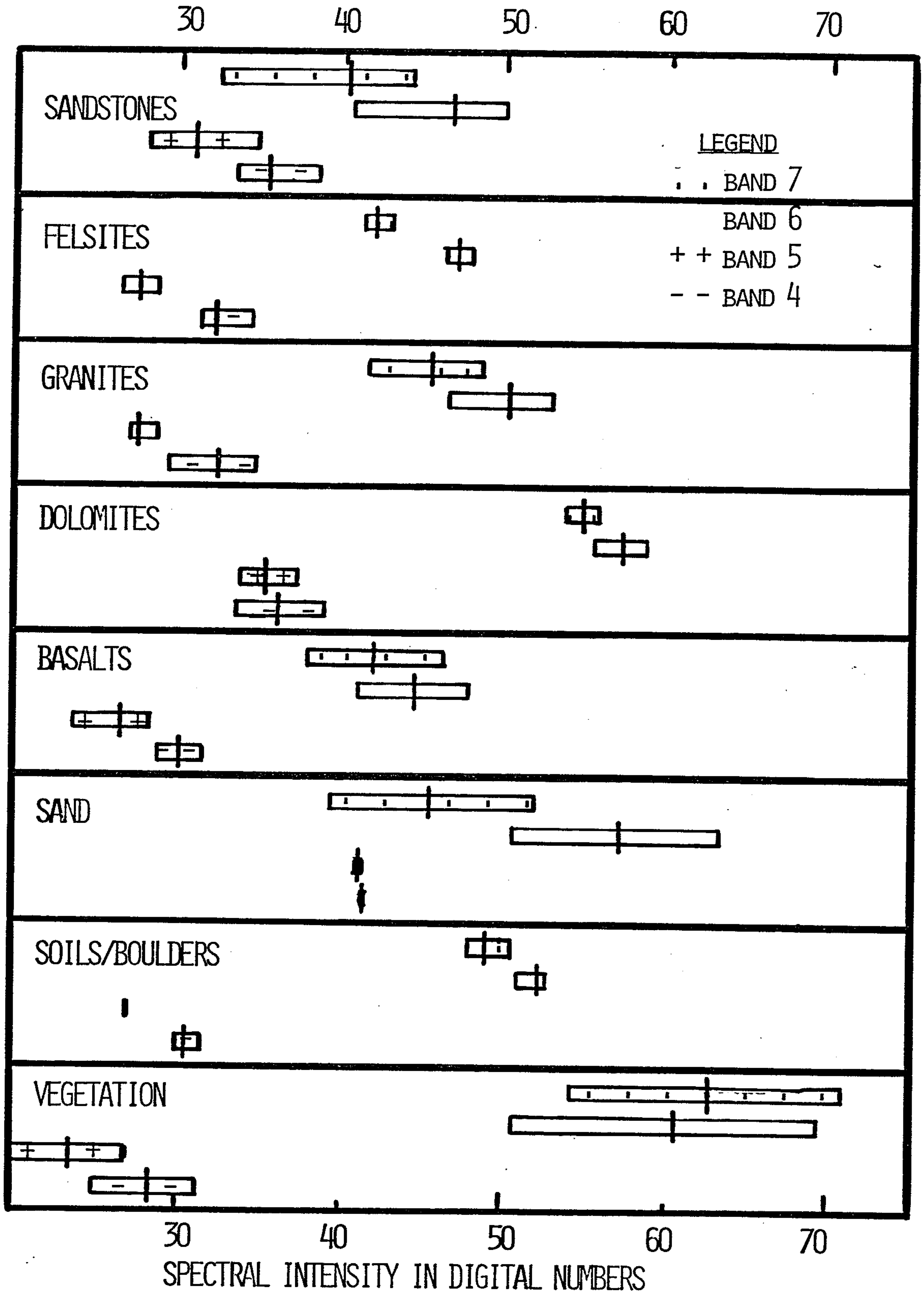


FIG. 16. *Distribution of spectral intensities among bands for cover types imaged on 5 August 1975.*

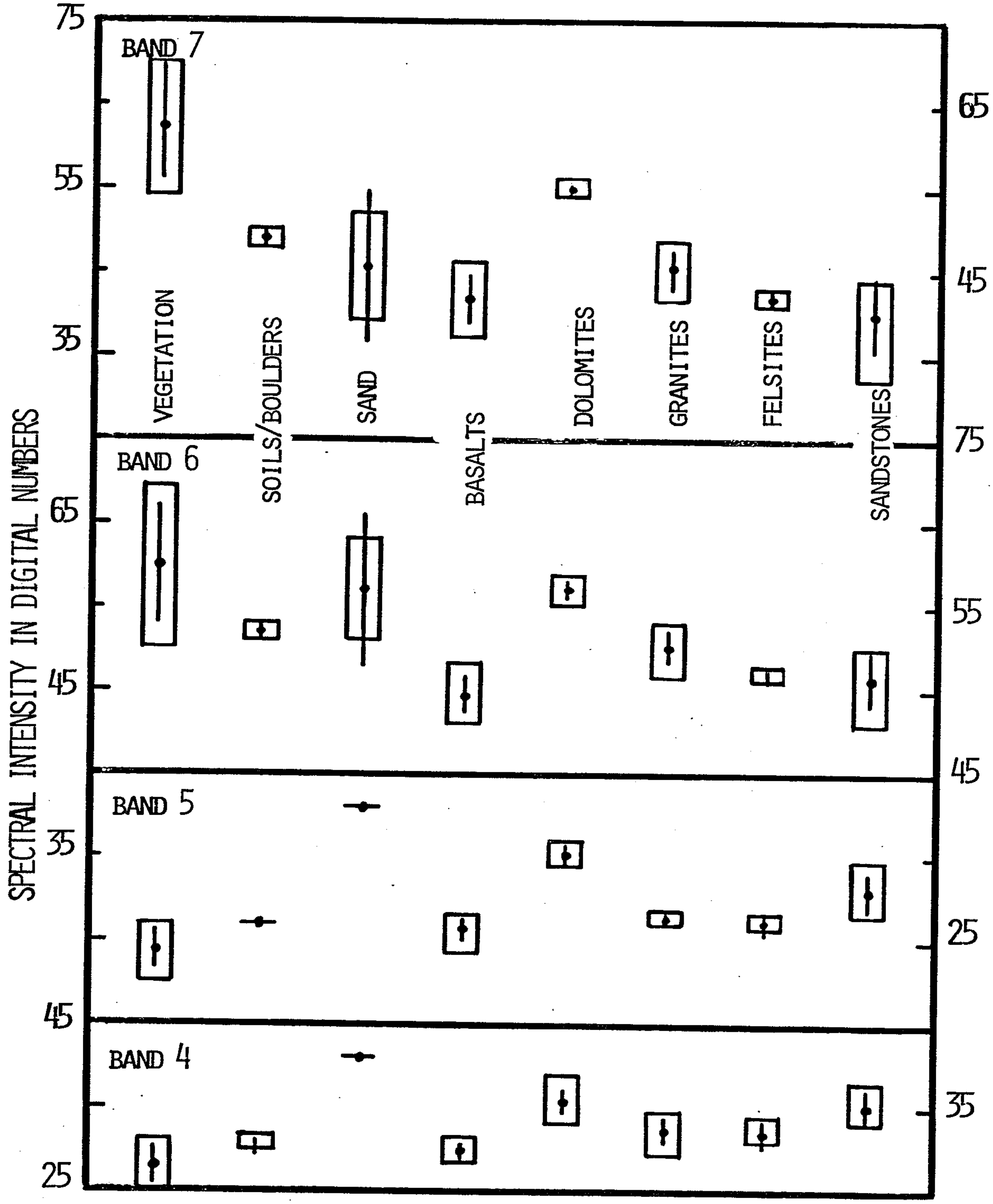


FIG. 17. Spectral intensities of cover types for sample areas imaged on 5 August 1975.

when intensity ranges are examined, overlapping intensities do occur among some cover types. Again, water is not represented in Figure 17. The spectral intensities observed for water are very low in all bands and no overlap exists with any of the other cover types.

Spectral signatures have also been obtained with Landsat data acquired on 22 June 1975 from the same locations (Fig. 4) as those used with 5 August 1975 data. The results and discussions on spectral signatures presented so far have been based on data obtained on 5 August 1975. Similar patterns have emerged from data collected on 22 June 1975. It must be emphasized, at this time, that the data used were standardized on both dates. For comparison purposes, spectral intensities of cover types for the sample areas imaged on 22 June 1975 and 5 August 1975 are shown in Figure 18. Except for minor differences in Bands 6 and 7, the intensities obtained are very similar on both the dates. The differences are probably due to the presence of light snow cover on the ground on 22 June 1975.

In summary, spectral signatures of nine different cover types have been examined on two different dates. Spectral intensities in all bands are not completely unambiguous among cover types. However, distinct patterns exist for all cover types, but the distinctions are very subtle among rock types.

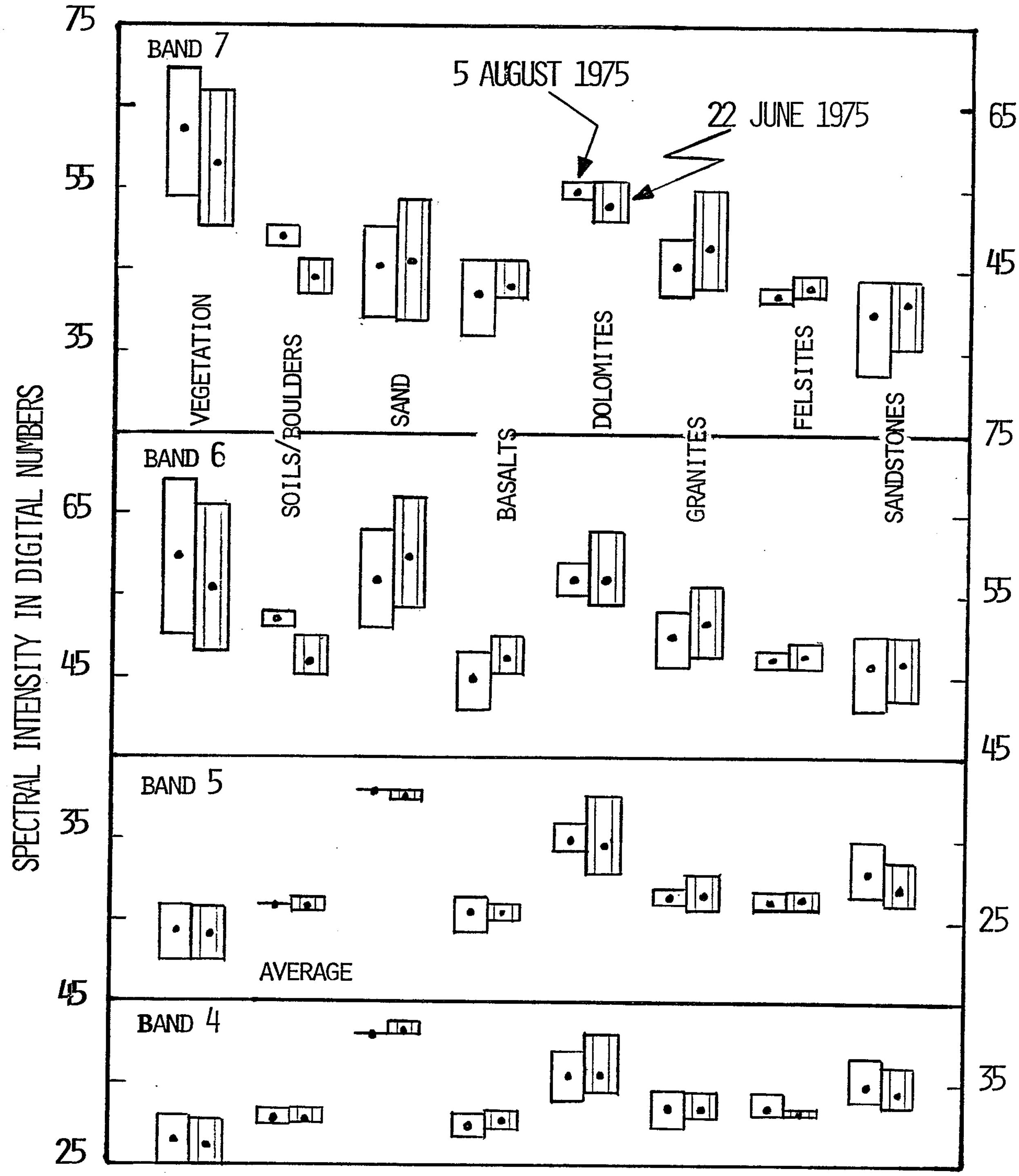


FIG. 18. Spectral intensities of cover types for sample areas imaged on 5 August and 22 June 1975.

4.1.2 Threshold Values for Identification

Threshold values have been established, based on the spectral signatures (Sec. 4.1.1) determined, for each cover type included in this study. Threshold values for a cover type consist of an upper or a lower limit, or both in a given band or a combination of bands. Threshold values have been established to facilitate the best possible discrimination among the cover types. The order in which the various cover types are separated plays a significant role in obtaining accurate separation in the proposed classification scheme. In this section, the threshold values established for each cover type with reasons for selecting a band or a combination of bands are presented.

An upper threshold value of 20 in Band 7 intensity was used in discriminating water bodies from all other cover types. That is, every pixel whose intensity falls below this threshold value is classified as water. Only water bodies have such low intensities in Band 7 as shown in Figures 7 and 17. This threshold value has also been successfully used previously for identifying water bodies (Chagarlamudi _et al_, 1979).

A lower threshold value of 100 in Band 5 intensity was used in discriminating clouds. When the intensity of a pixel in Band 5 is greater than 100, then that pixel is classified as cloud. It was found during this study and in a previous study (Schubert _et al_, 1977) that only clouds will produce such high intensties in Band 5.

A lower threshold value of 55 in Band 4 intensity was used in discriminating snow/ice from other cover types. That is every pixel whose intensity in Band 4 falls above this threshold value is classified as snow/ice. Some clouds may also satisfy this threshold condition. For this reason it is necessary to separate clouds prior to separating snow/ice.

A threshold value of 2.0 for the ratio of the intensities in Band 7 to Band 5 was used in discriminating vegetation from the remaining cover types. For vegetation, the spectral intensities are higher in Band 7 and lower in Band 5 than the other cover types; consequently a larger ratio value would be expected for vegetation. When the ratio value for a pixel is greater than 2.0, then that pixel is classified as vegetation. Spectral intensities in Bands 5 and 7 for vegetation relative to other cover types are shown in Figure 19. A line representing the ratio value of 2.0 is also shown on this plot. Ratios of vegetation sample areas fall above the line and ratios for the other cover types fall below the line. Figure 19 shows that vegetation can be uniquely discriminated from the other cover types using a threshold value of 2.0 for the ratio of Band 7 to Band 5 intensities.

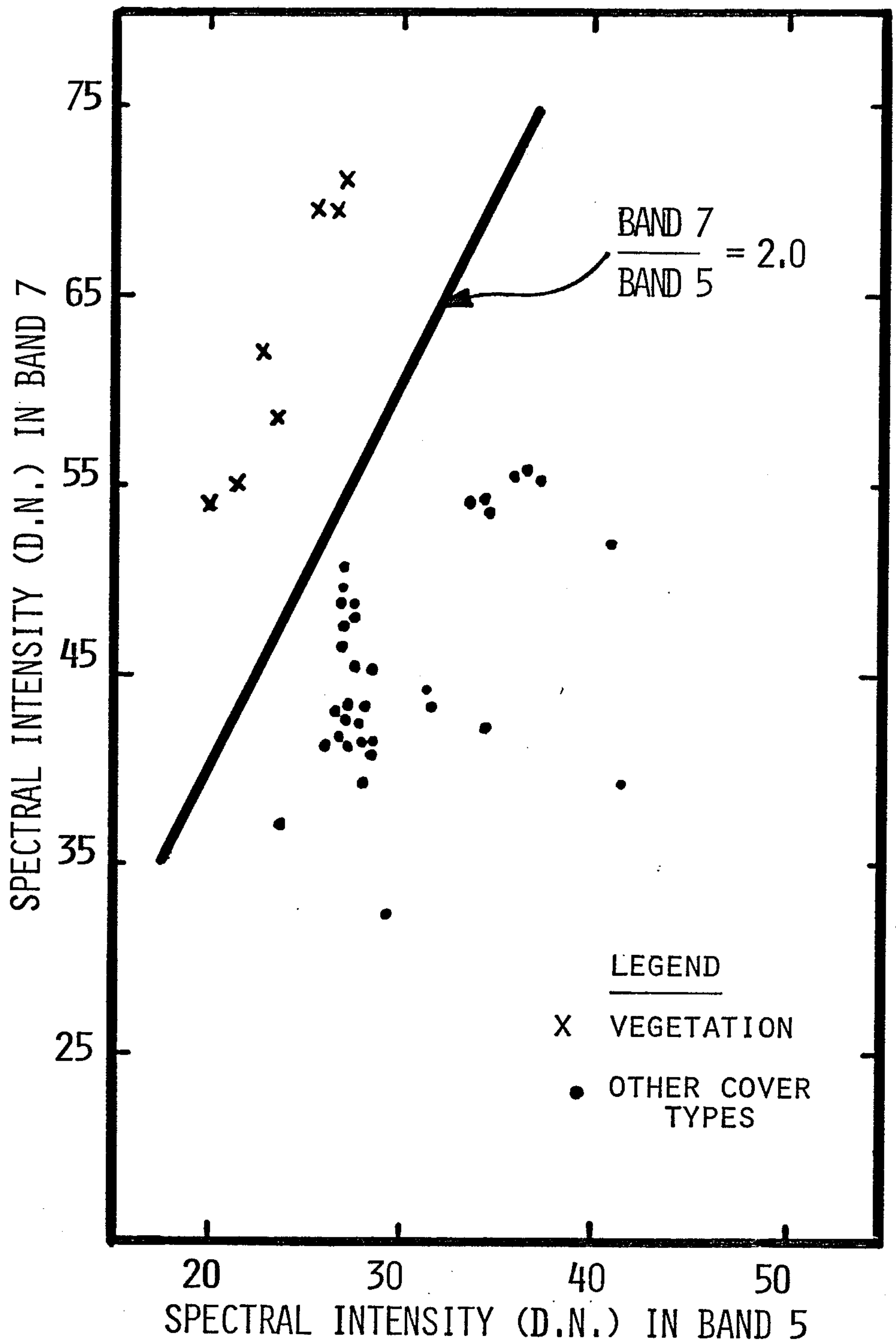


FIG. 19. Spectral intensities of vegetation in Bands 7 and 5 relative to other cover types.

A threshold value of 1550 for the product of the intensities in Bands 4 and 5 was used in discriminating sand from the remaining cover types. A pixel is classified as sand when the product is greater than this threshold value. Spectral intensities in Bands 4 and 5 for sand relative to other cover types are shown in Figure 20. A curve representing the threshold value of 1550 used in discriminating sand is also shown on this plot. It is noted that, all cover types have lower values for the product compared to that of sand. This shows that sand can be uniquely discriminated from other cover types using this threshold value of 1550 for the product of the intensities in Bands 4 and 5.

A Threshold value of 2800 for the product of Bands 6 and 7 intensities was used in discriminating dolomites from other cover types. A pixel is classified as dolomite when the product of the intensities in Bands 6 and 7 is greater than the threshold value. Spectral intensities in Bands 6 and 7 for dolomite relative to other cover types are shown in Figure 21. A curve representing a value of 2800 for the product of these two bands is also shown on this plot. The products for all the cover types except dolomites fall below the curve. That is dolomites can be discriminated from the remaining cover types using the threshold of 2800 for the product of intensities in Bands 6 and 7.

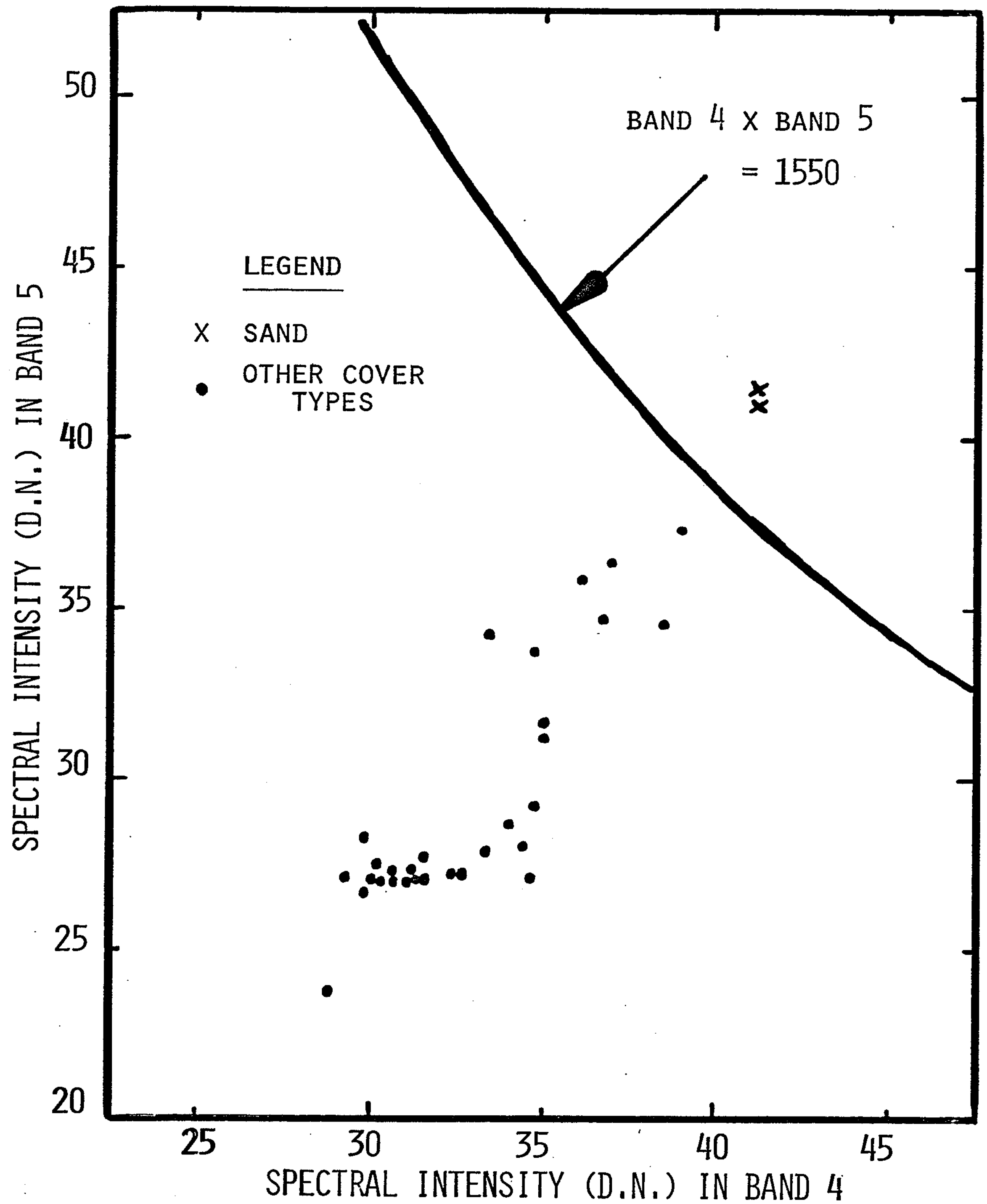


FIG. 20. Spectral intensities of sand in Bands 5 and 4 relative to other cover types.

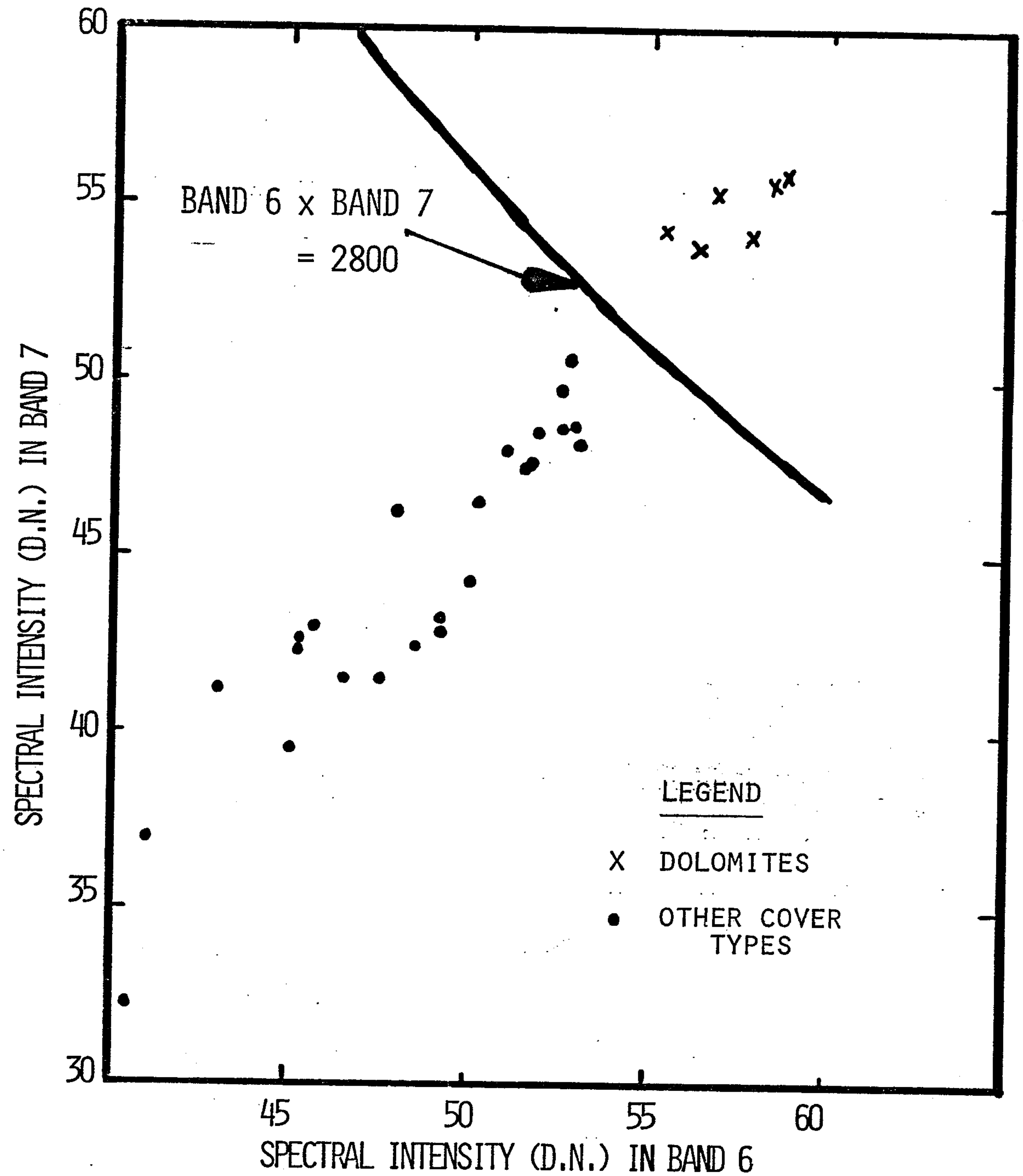


FIG. 21. *Spectral intensities of dolomites in Bands 7 & 6 relative to other cover types.*

A threshold value of 1.44 for the ratio of the intensities in Band 7 to Band 5 was used in discriminating sandstones from the remaining cover types. A pixel is classified as sandstone when the ratio is less than than this threshold value. Spectral intensities in Bands 5 and 7 for sandstone relative to other cover types are shown in Figure 22. A line representing the ratio of 1.44 is also shown on this plot. The ratios for all cover types except for sandstone fall above the line. That is the threshold value of 1.44 for the ratio of Band 7 to Band 5 intensities can be used in discriminating sandstones from the other cover types.

A threshold value of 1.77 for the ratio of the intensities in Band 7 to Band 5 was used in discriminating soils/boulders from granites and basalts. A pixel is classified as soils/boulders when the ratio is higher than this threshold value. Spectral intensities in Bands 5 and 7 for soils/boulders relative to other cover types are shown in Figure 23. A line representing the ratio value of 1.77 is also shown on this plot. Intensities of basalt and granite samples fall above the threshold line. However, it should be pointed out that there is some confusion between granites and soils/boulders using this threshold value of 1.77 for the ratio of Band 7 to Band 5 intensities.

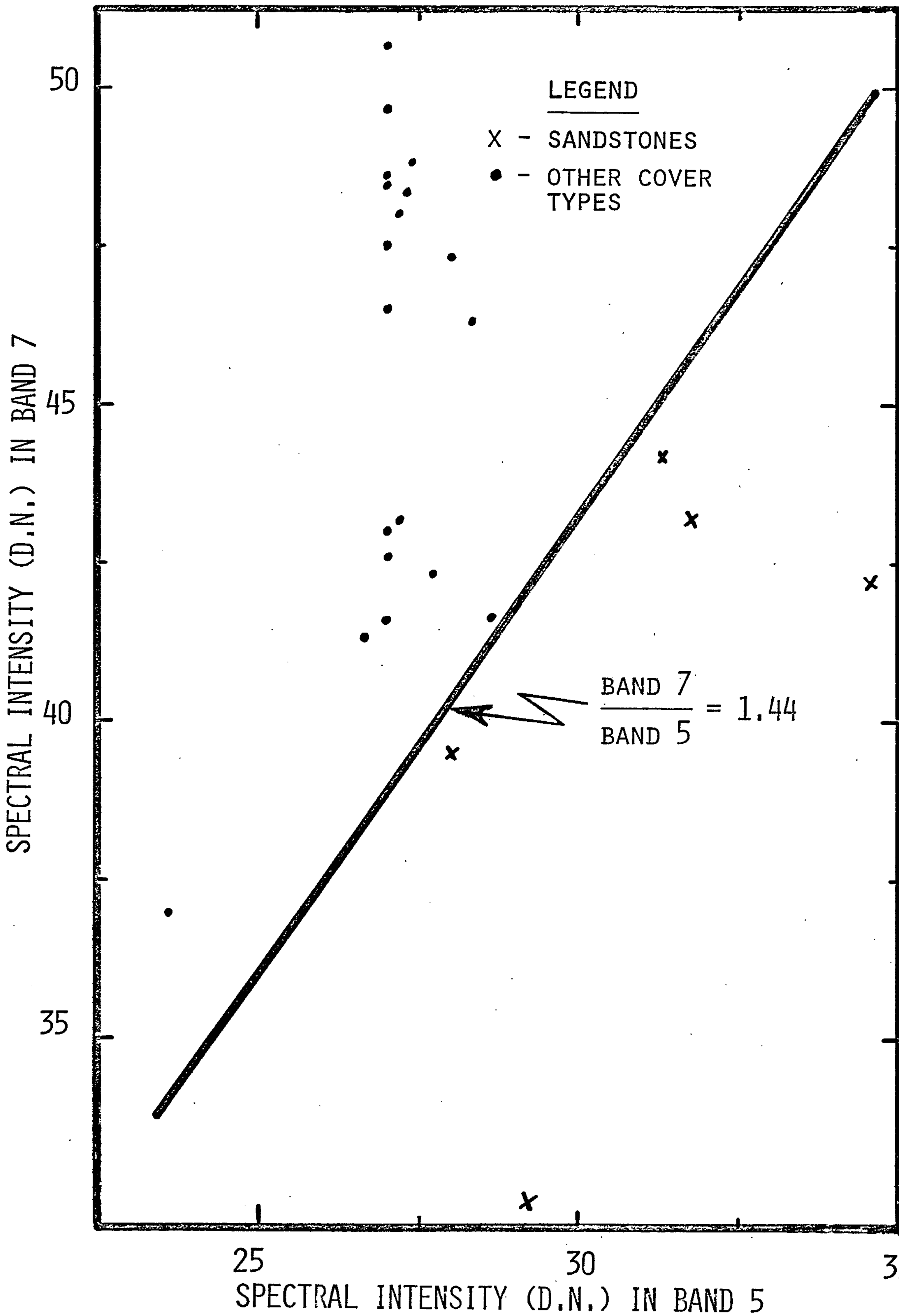


FIG. 22. Spectral intensities of sandstones in Bands 7 and 5 relative to other cover types.

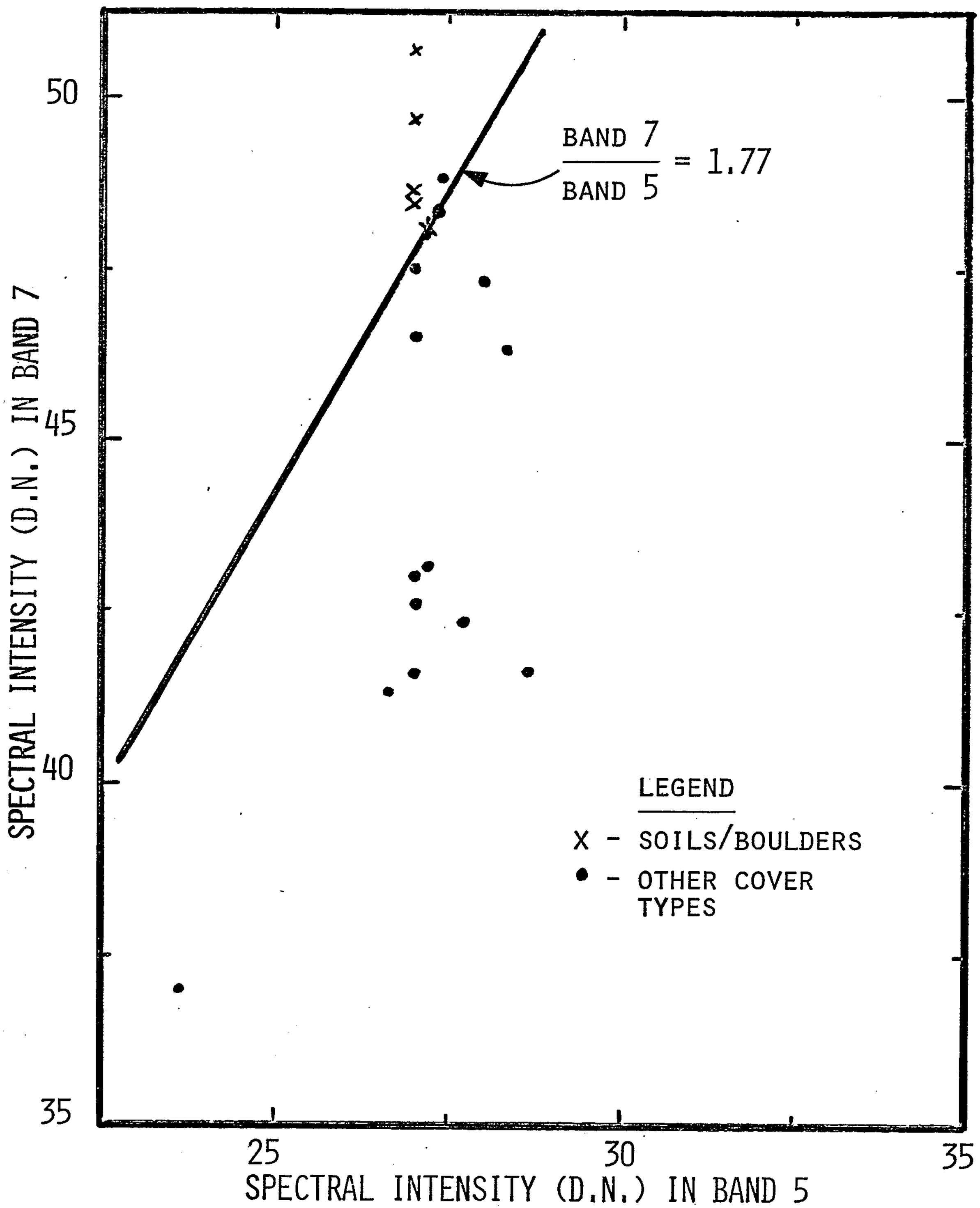


FIG. 23. *Spectral intensities of soils/boulders in Bands 7 and 5 relative to other cover types.*

A threshold value of 46 in Band 6 intensity was used in discriminating basalt from granites. A pixel classified as basalt when the intensity in Band 6 is less than 46; otherwise granite. In Band 6, granites have higher intensities than basalts. It should be pointed out one of the six sample areas of basalts has similar values to granite sample areas.

In summary, individual threshold values were established for all cover types considered in this study. Average spectral intensities in a single band or an arithmetic combination of bands were selected in establishing the threshold values. This selection allowed the best possible discrimination among cover types in sample areas. These threshold values are stored in a signature bank and are used as standards by the automated classification scheme in producing thematic maps.

4.1.3 Contamination of Rock Spectral Signatures

Spectral intensity of a cover type from a sample (pixel) area changes when a portion of the area is occupied by another cover type. The change or the resulting spectral intensity depends on the proportion and the type of contaminant. If we know the spectral intensities of both the original and the contaminant cover types, then the expected spectral intensity of the sample area can be computed for any given proportion of the contaminant.

However, the spectral intensities of the original and contaminant cover types are usually not known, since the sample area is contaminated. Further, since we are considering the smallest sample areas (pixels) possible with the Landsat system, the proportion of the contaminant within the sample area is also unknown. However, generalizations can be made from average spectral intensities of homogeneous (or "pure") cover types.

Contamination of rock spectral signatures due to other rock types or vegetation is discussed in this section. The rock types considered are dolomites, basalts, granites, and sandstones. Felsites are not included in this discussion as their spectral signatures resemble closely those of granites. In the following discussion, for simplicity, only one contaminant is considered. However, the ideas do extend to multiple contaminants.

Average spectral intensities of the four different rock types and vegetation are shown in Figure 24. As pointed out in the previous section, the spectral bands in the order of increasing intensities for these cover types are Band 5, Band 4, Band 6, and Band 7 respectively. Exceptions to this are that vegetation has higher intensities in Band 7 than in Band 6, and dolomites have equal intensities in both Band 6 and Band 7. An observation regarding the spectral intensities of rock types is that dolomites have the highest intensities of any of the rock types considered in all four

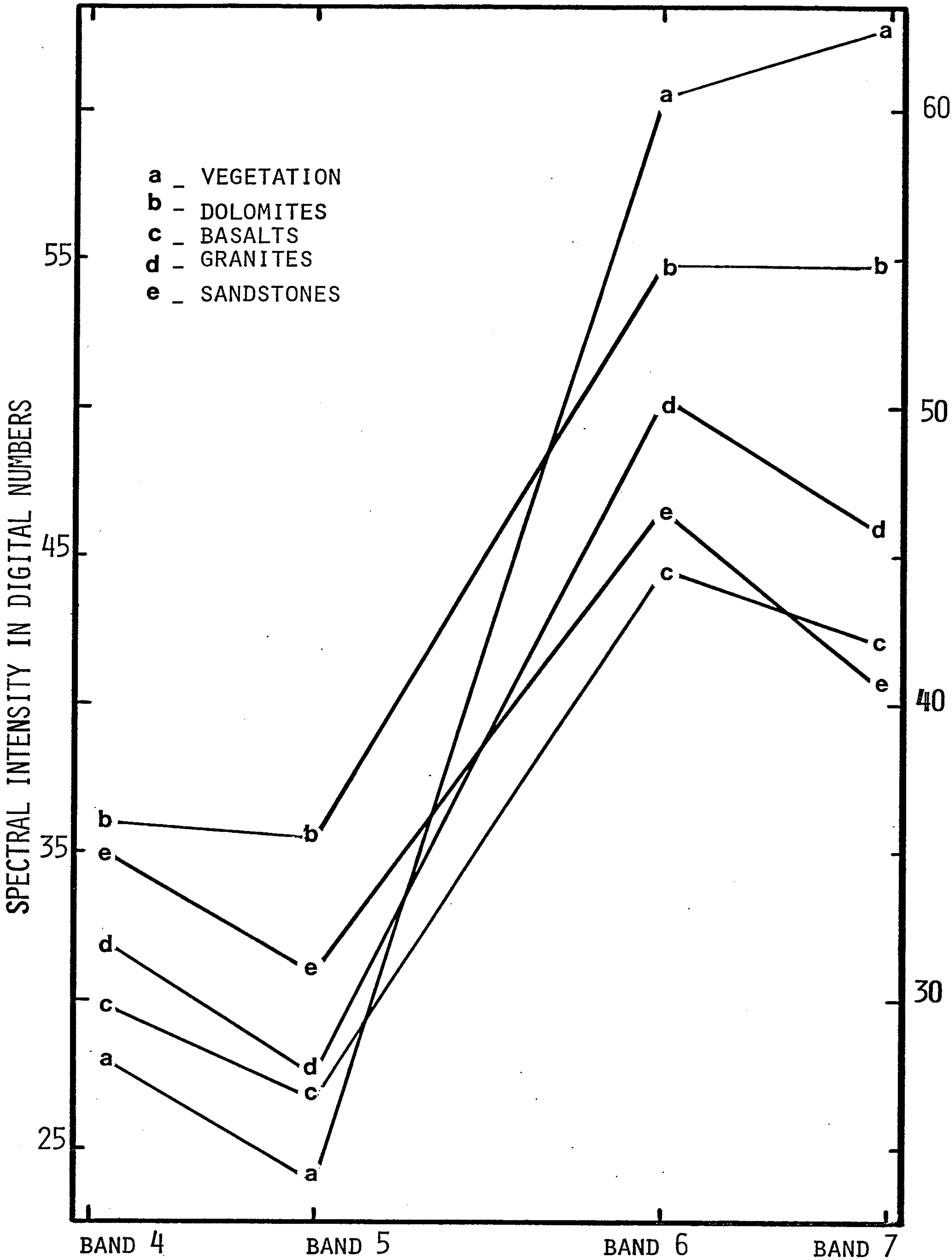


FIG. 24. *Average spectral intensities of four different rock types and vegetation.*

bands. Another observation to be pointed out is that basalts have the lowest intensities of the rock types considered in all the four bands. The exception to this statement is that sandstones have slightly lower intensities in Band 7 than basalts.

Changes which would occur in the average spectral intensities (Fig. 24) of the four rock types are calculated assuming one of the three remaining rock types or vegetation as the contaminant. These changes are computed for the presence of 10% and 40% of contaminant within the sample area. When the change is positive, the spectral intensity of the rock type would be increased as a result of the contamination; the spectral intensity would be reduced when the change is negative. The spectral intensity of the contaminated sample (pixel) area can be calculated in any band using the following simple formula:

$$IC = IH\,(1 - N) + C$$

where,

IC = the spectral intensity of the contaminated sample area

IH = the average spectral intensity of the homogeneous rock type

N = the proportion of contamination (0.1 or 0.4)

C = the change (positive or negative) in intensity for proportion N shown on the appropriate plot.

Changes in the average spectral intensities of dolomites due to contamination from other cover types are shown in Figure 25. Since dolomites have higher intensities in all bands than any of the contaminants, all the changes are negative except due to vegetation in Bands 6 and 7. That is when a dolomite sample area contains any of the other rock types within the sample area, the resulting spectral intensities will be lower than for an otherwise dolomite area.

Changes in the average spectral intensities of basalts due to contamination from other cover types are shown in Figure 26. In general, these changes are positive. The only negative changes are due to vegetation in Band 4, Band 5, and due to sandstone in Band 7. For basalt areas larger changes occur due to the contamination of dolomites or vegetation. In other words, basalts are spectrally quite different from vegetation and dolomites.

Changes in the average spectral intensities of granites due to contamination from other cover types are shown in Figure 27. In Band 4, spectral intensity of granites increases due to the presence of dolomites or sandstones and decreases due to the presence of basalts or vegetation; the same changes occur in the spectral intensity of Band 5. In Bands 6 and 7, the intensities increase due to the presence

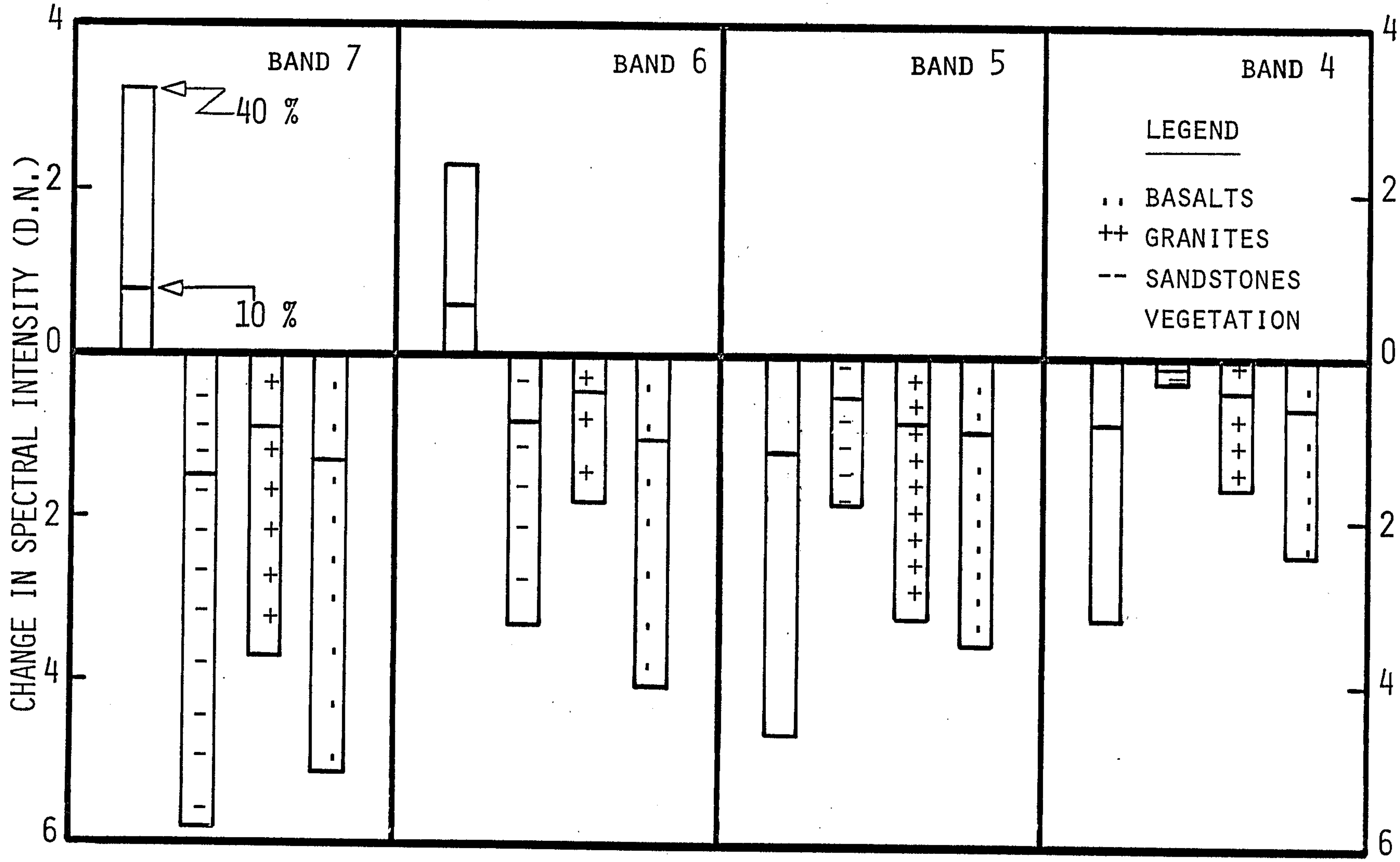


FIG. 25. *Change in the average spectral intensities of dolomites due to contamination from other cover types.*

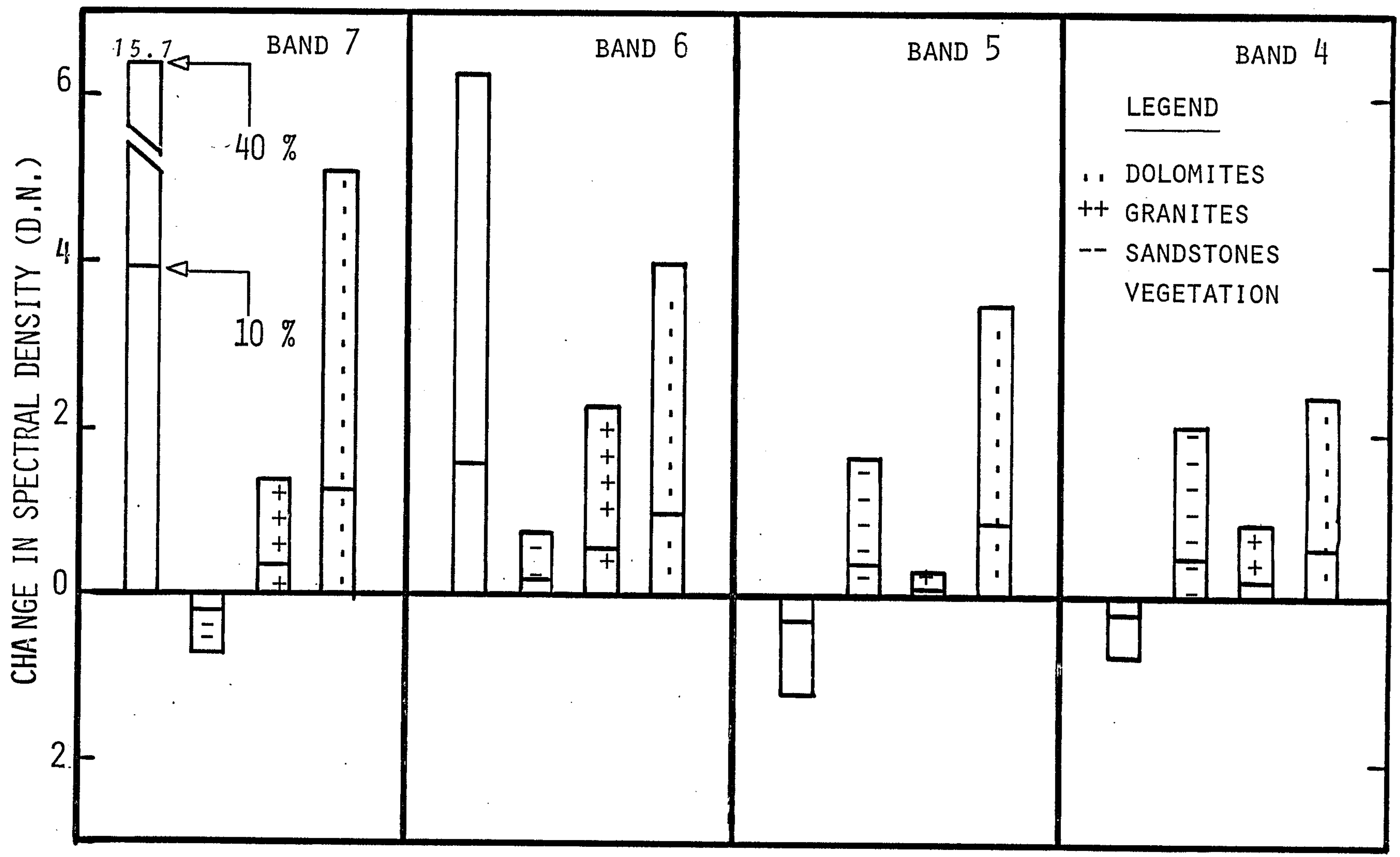


FIG. 26. Change in the average spectral intensities of basalts due to contamination from other cover types.

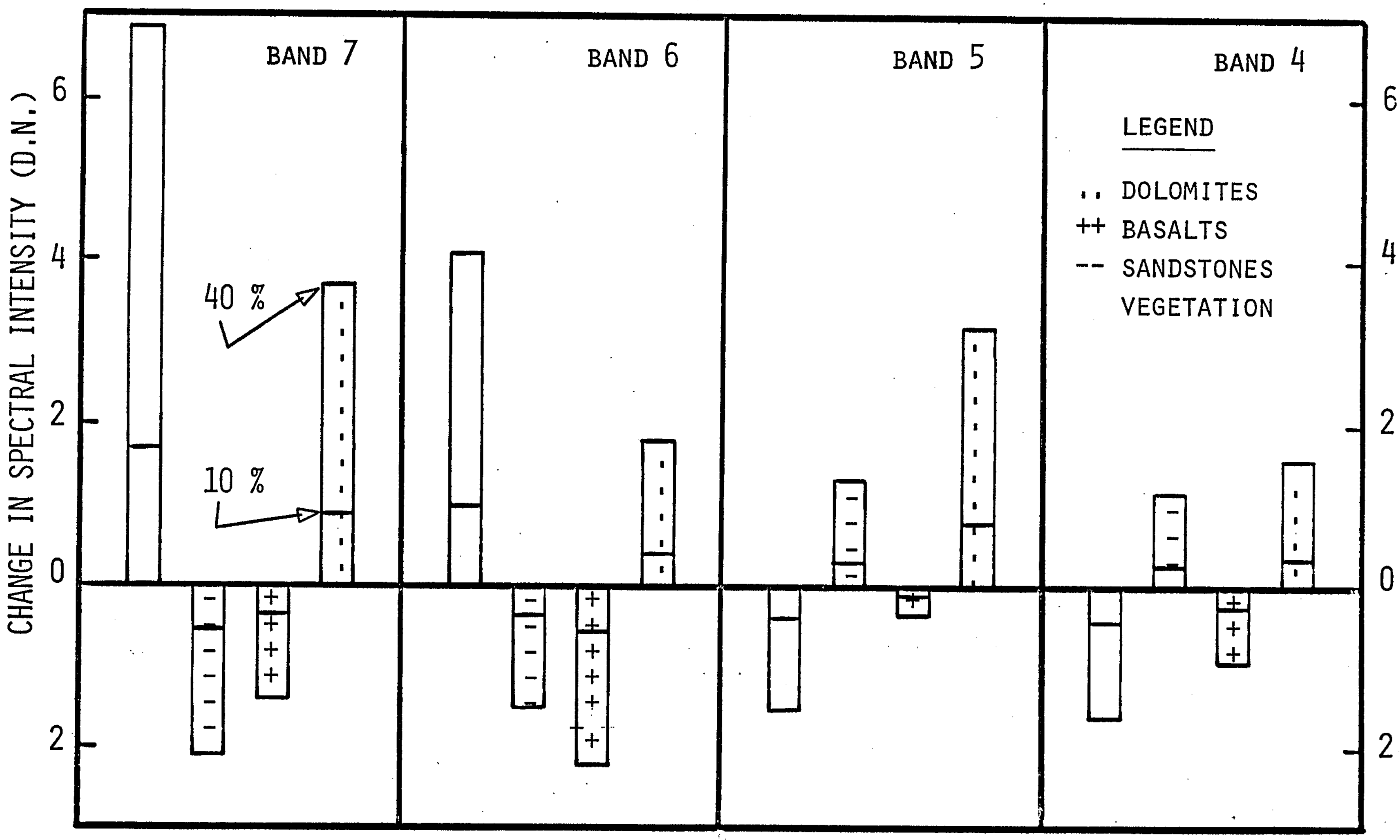


FIG. 27. *Change in the average spectral intensities of granites due to contamination from other cover types.*

of dolomites and vegetation and decrease due to the presence of basalts and sandstone.

Changes in the average spectral intensities of sandstones due to contamination from other cover types are shown in Figure 28. In Bands 4 and 5, the spectral intensities of sandstones increase due to the presence of dolomites and decrease due to the presence of basalts, granites, or vegetation. In Band 6, and intensity decreases if the contaminant is basalt, otherwise the intensity of the sample area increases. In Band 7, however, sandstones have the lowest spectral intensities; consequently the presence of any of the contaminanats increases the intensity.

In summary, changes expected in the average spectral intensities of rock types due to contamination from a different rock type or vegetation were computed. In these computations, the contaminant was assumed to cover 10%, and 40% of the area of an otherwise homogeneous sample. When the contaminant occupies only 10% of the sample area, the changes are, in general, small enough to maintain rock type separation. However, with 40% contamination, rock type separation is difficult in most cases.

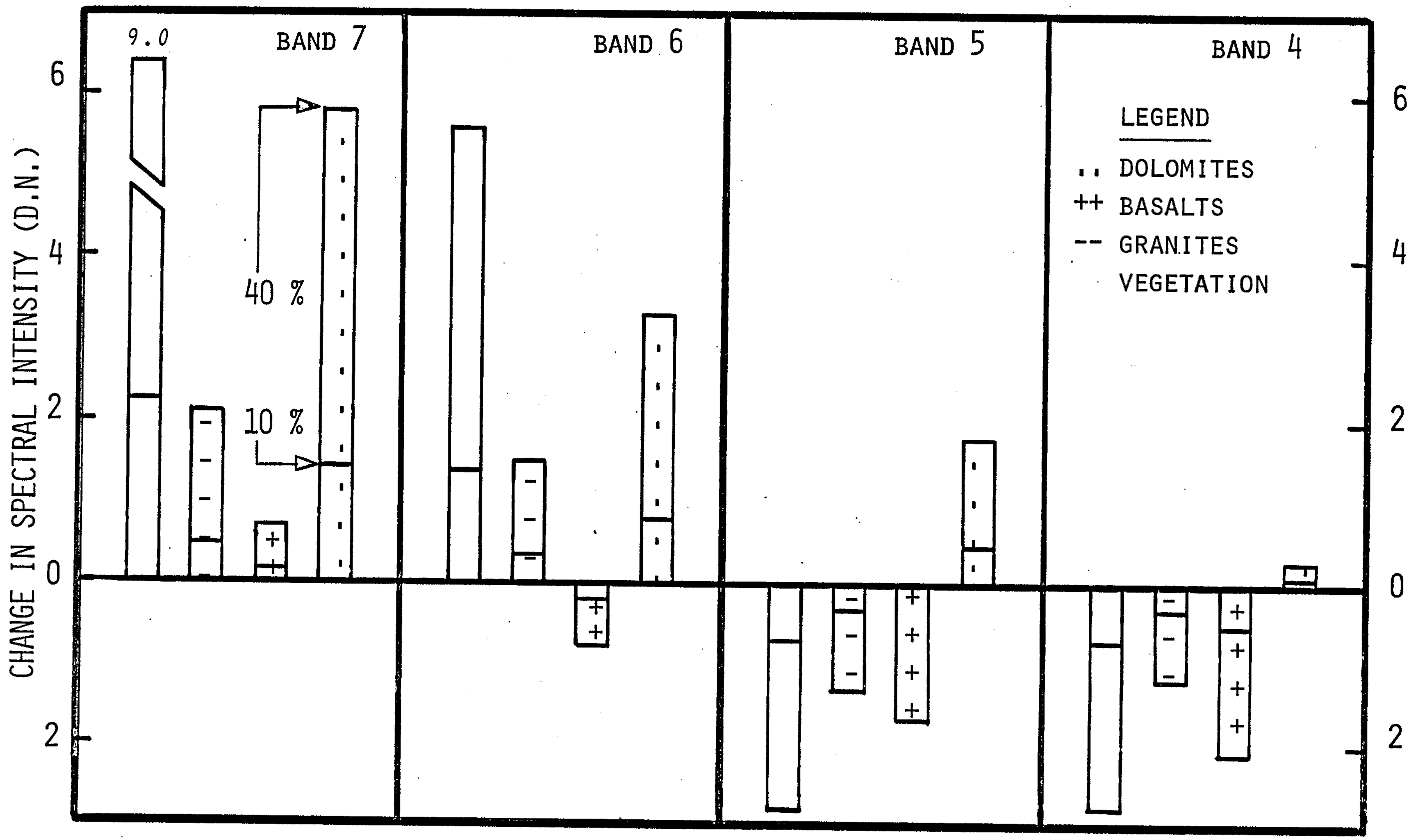


FIG. 28. *Change in the average spectral intensities of sandstones due to contamination from other cover types.*

4.2 ROCK OUTCROP IDENTIFICATION

Rock outcrops were identified using visual analysis and computer classification scheme developed in this study. Maps showing the distribution of rock outcrops have been prepared for two intensive study areas (Fig. 3). Landsat data acquired on 5 August 1975 and 22 June 1975 were used in the identification of rock outcrops. Results obtained on rock outcrop identification are presented and discussed in this section. Results of visual analysis are discussed first followed by a discussion of results obtained from the computer methods.

4.2.1 Visual Analysis

Visual analysis of digitally enhanced Landsat images has been used in the identification of rock outcrops. The procedure used in producing the enhanced images was described in detail in Section 3.1.3. The enhanced images are presented here as simulated color infrared images using Band 4, Band 5, and Band 7 respectively for the blue, green, and red colors. The color representation of the various cover types on the digitally enhanced images was given in Table 2. Rock outcrops have been identified using the color and the contextural information present on the enhanced images. This methodology of visual analysis has been outlined earlier in Section 3.1.

Maps showing the distribution of rock outcrops have been prepared using visual analysis. These maps were compared with aerial photographs and known geology. Rock outcrop maps have been prepared for two intensive study areas - the Mouse River area and the Coppermine River area.

4.2.1.1 Mouse River area

The enhanced image of Landsat data acquired on 5 August 1975 over the Mouse River area is shown in Figure 29. An aerial photograph of this area is shown in Figure 30 for comparison with the enhanced image. On the black and white aerial photograph, rock outcrops appear in lighter tones compared to other cover types. On the enhanced image rock outcrops appear in blue to bluish green colors. Rock exposure is abundant in the area as seen on the aerial photograph and on the enhanced image. In depicting rock outcrop areas, the correspondence between the aerial photograph and the enhanced image is almost one to one.

Most of the northern part of this intensive study area is covered with rock outcrops. These rock outcrops appear in two distinct spectral units of blue and bluish green in color. The rock outcrops are spectrally separable from other cover types such as vegetation and water bodies in the area. The southern portion of the area is mainly covered with glacial drift. On the enhanced image, the drift areas are seen as vegetation which is identified by shades of red

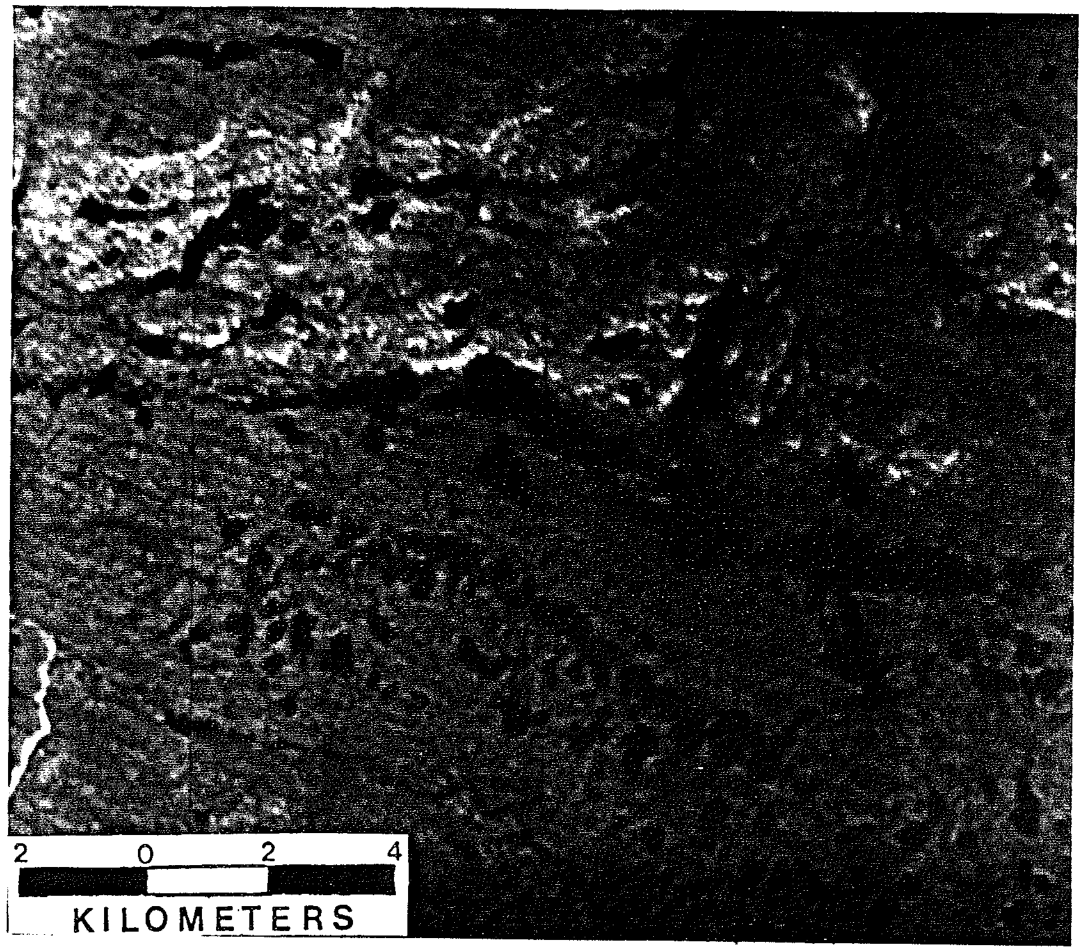


FIG. 29. Enhanced image of Landsat data acquired on 5 August 1975 over Mouse River area.

FIG. 30. Aerial photograph of Mouse River area.

color. The drift areas thus support vegetation except when the drift consists mainly of boulders.

Locations of rock outcrops obtained from visual analysis agree well with known locations of outcrops. Map showing rock outcrops prepared from visual analysis of the enhanced image over the Mouse River area is given in Figure 31. Generalized geological map of the Mouse River area showing known locations of rock outcrops is given in Figure 32. The locations of rock outcrops shown on this geological map were obtained from published geological maps, field notes, and aerial photographs.

The enhanced image of Landsat data acquired on 22 June 1975 over the Mouse River area is shown in Figure 33. Most of the water bodies in the area were frozen. Snow was present on some of the vegetated and rock outcrop areas identified previously using the data acquired in August. Snow and ice covered areas appear in white color on the enhanced image. In the snow free areas, cover types on June date appear in comparable colors to those on the August image. As a result, rock outcrops in the snow free areas were identified consistently using visual analysis of the enhanced image acquired in June.

In summary, rock outcrops in the Mouse River area were identified accurately by visual analysis of the enhanced images. Rock outcrops and other cover types appear in comparable colors on the enhanced images acquired in June

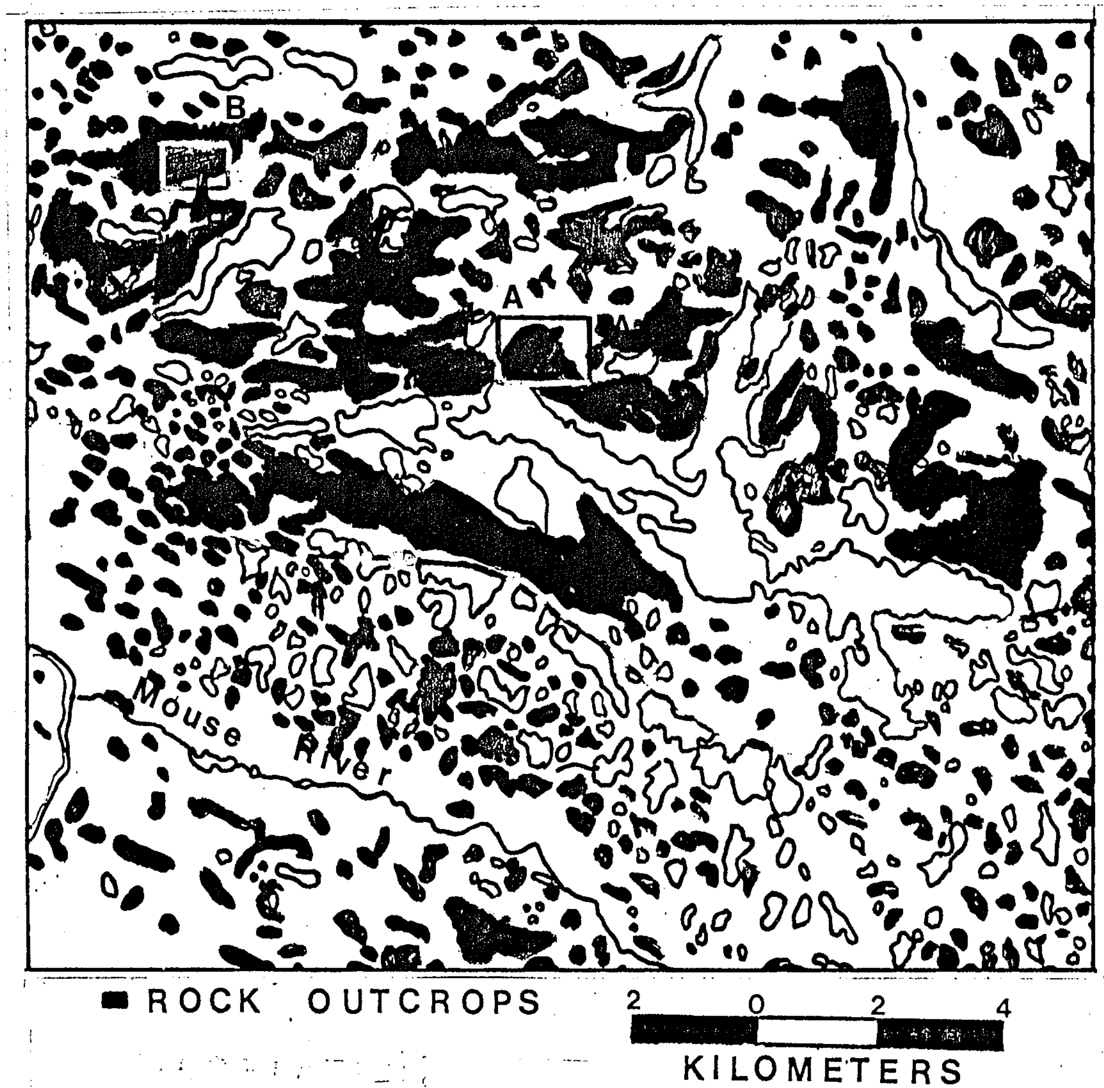


FIG. 31. *Map showing rock outcrops prepared from visual analysis of enhanced image over Mouse River area.*

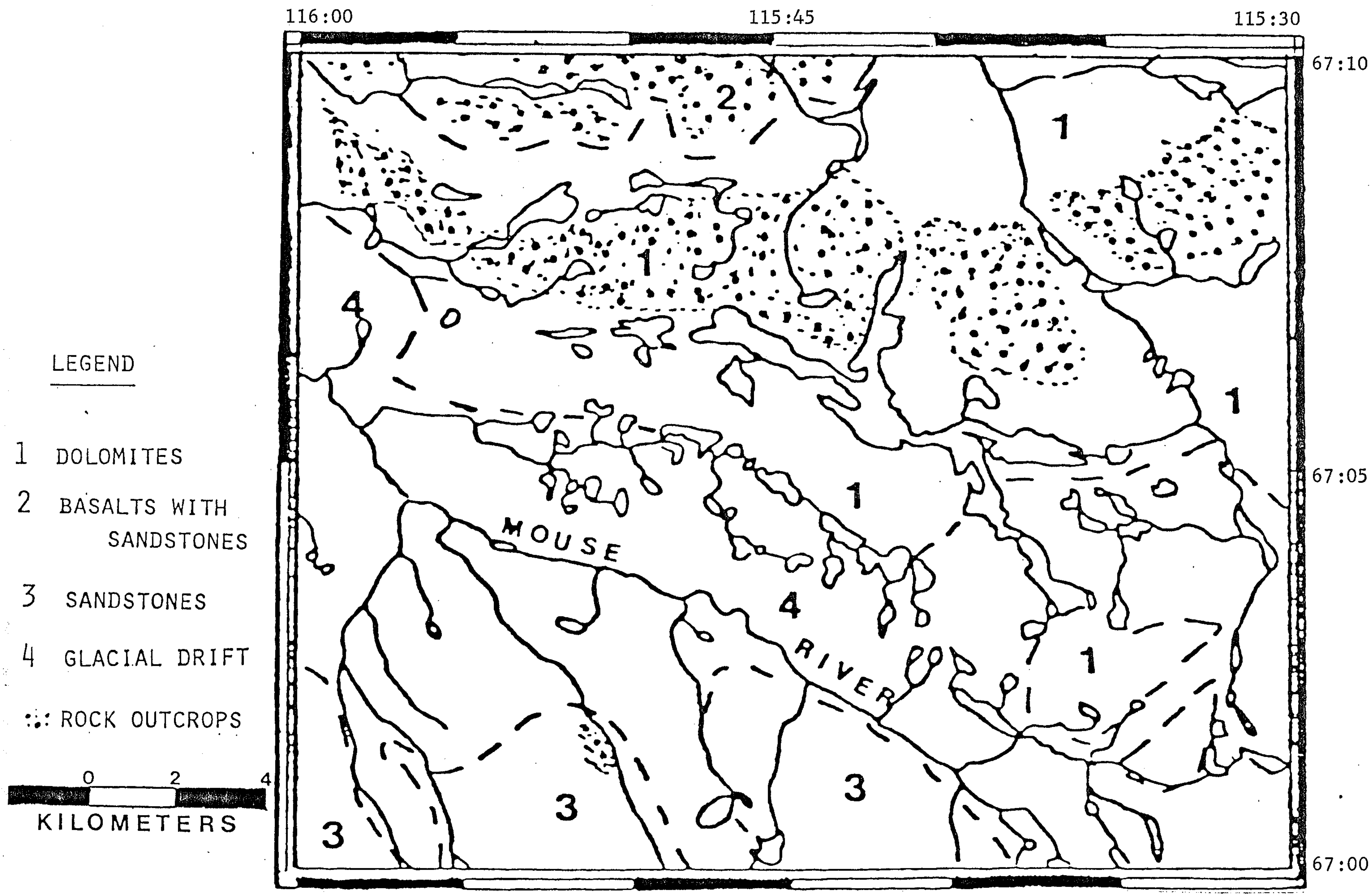


FIG. 32. *Generalized geological map of Mouse River area showing known locations of rock outcrops.*

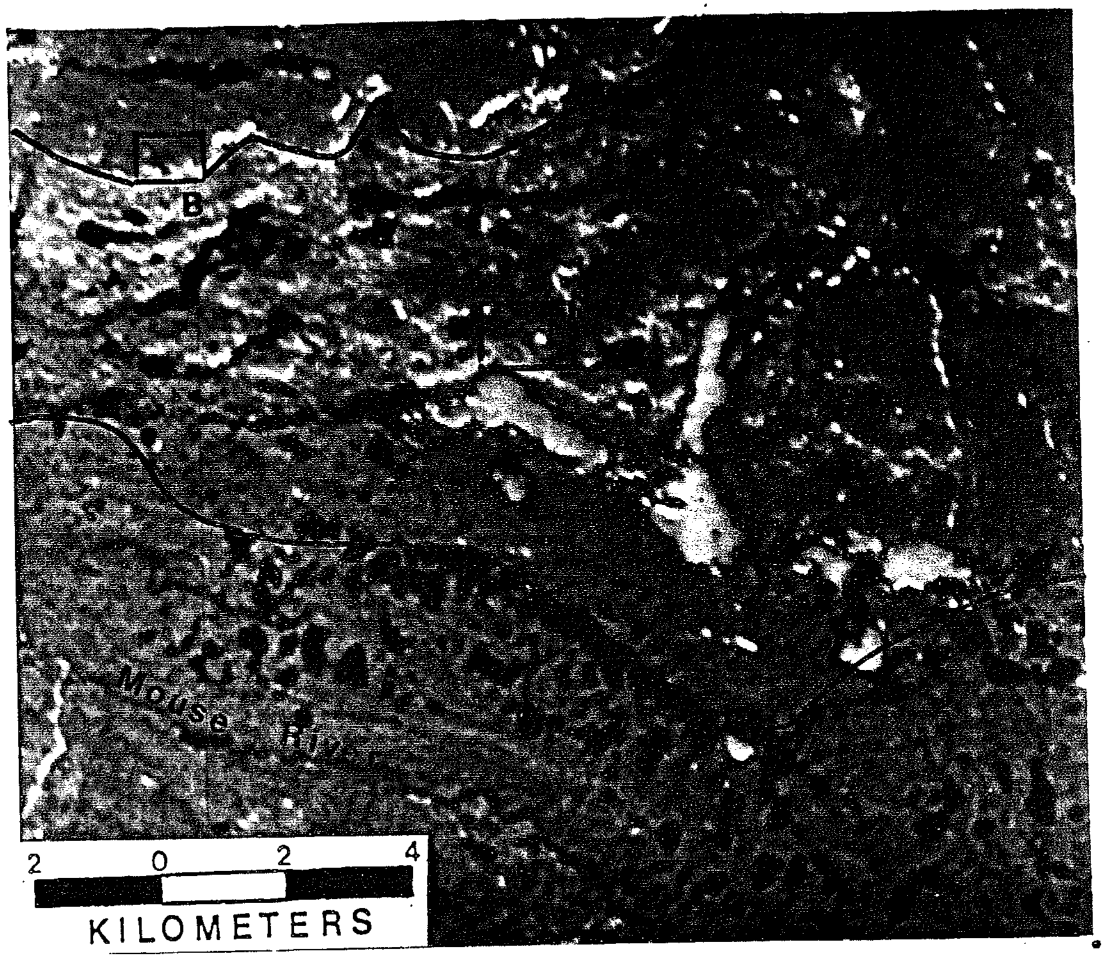


FIG. 33. Enhanced image of Landsat data acquired on 22 June 1975 over Mouse River area.

and in August. Glacial drift areas shown on the generalized geological map were covered mainly with vegetation.

4.2.1.2 Coppermine River area

The enhanced image of Landsat data acquired on 5 August 1975 over the Coppermine River area is shown in Figure 34. An aerial photograph of this area is shown in Figure 35 for comparison with the enhanced image. On the black and white aerial photograph, rock outcrops appear in lighter tones relative to other cover types, but not as prominently as they did on the aerial photograph of the Mouse River area. On the enhanced image rock outcrop areas are distinctly separable by their spectral characteristics. In the Coppermine River area, the enhanced image is superior to the aerial photograph for identifying rock outcrops. Rock exposure is abundant in the Coppermine River area as seen on the aerial photograph and on the enhanced image.

The locations of rock outcrops obtained by visual analysis agree well with known locations. Map of rock outcrops derived from visual analysis of the enhanced image over the Coppermine River area is shown in Figure 36. Generalized geological map showing known locations of rock outcrops in Coppermine River area is given in Figure 37. The locations of rock outcrops shown on the geological map were obtained from published geological maps, field notes, and aerial photographs.

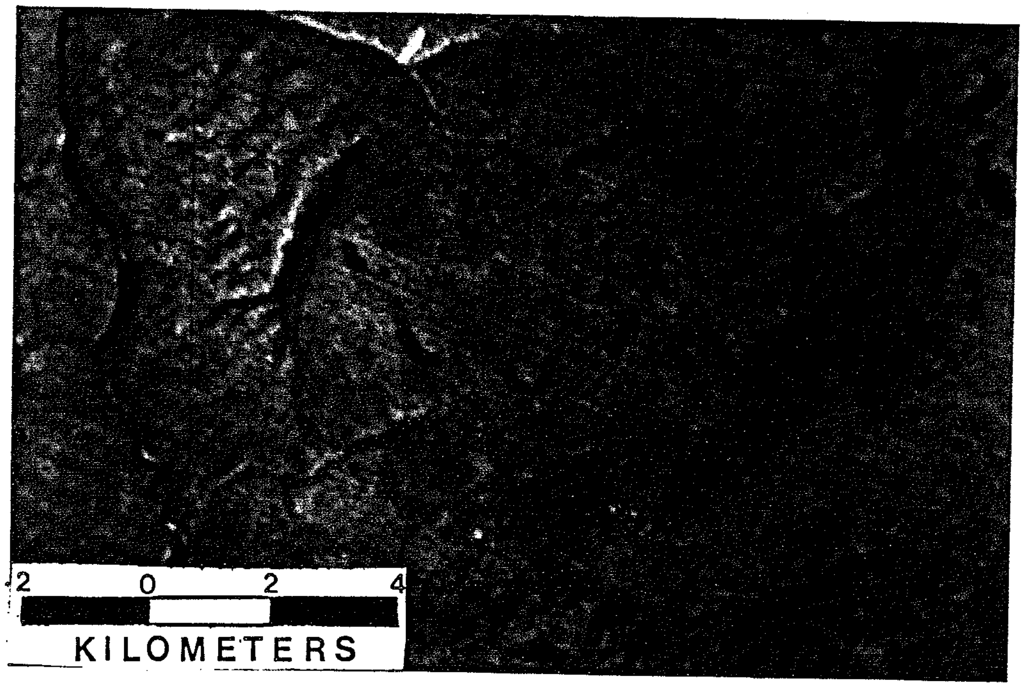


FIG. 34. Enhanced image of Landsat data acquired on 5 August 1975 over Coppermine River area.

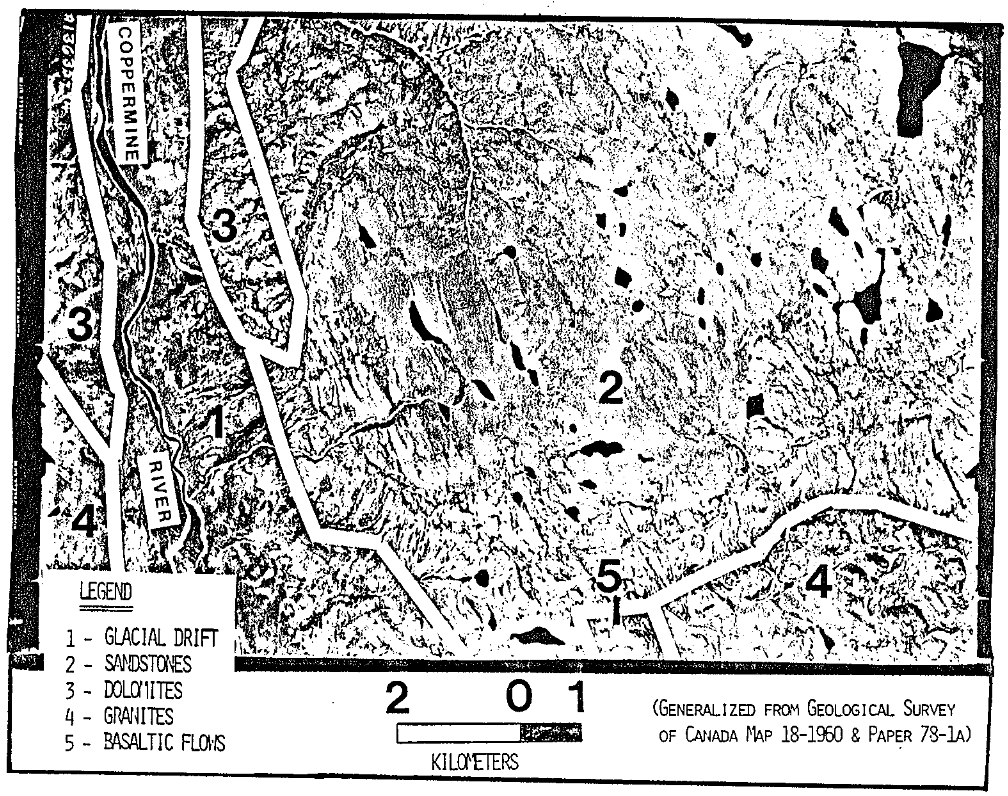


FIG. 35. *Aerial photograph of Coppermine River area.*

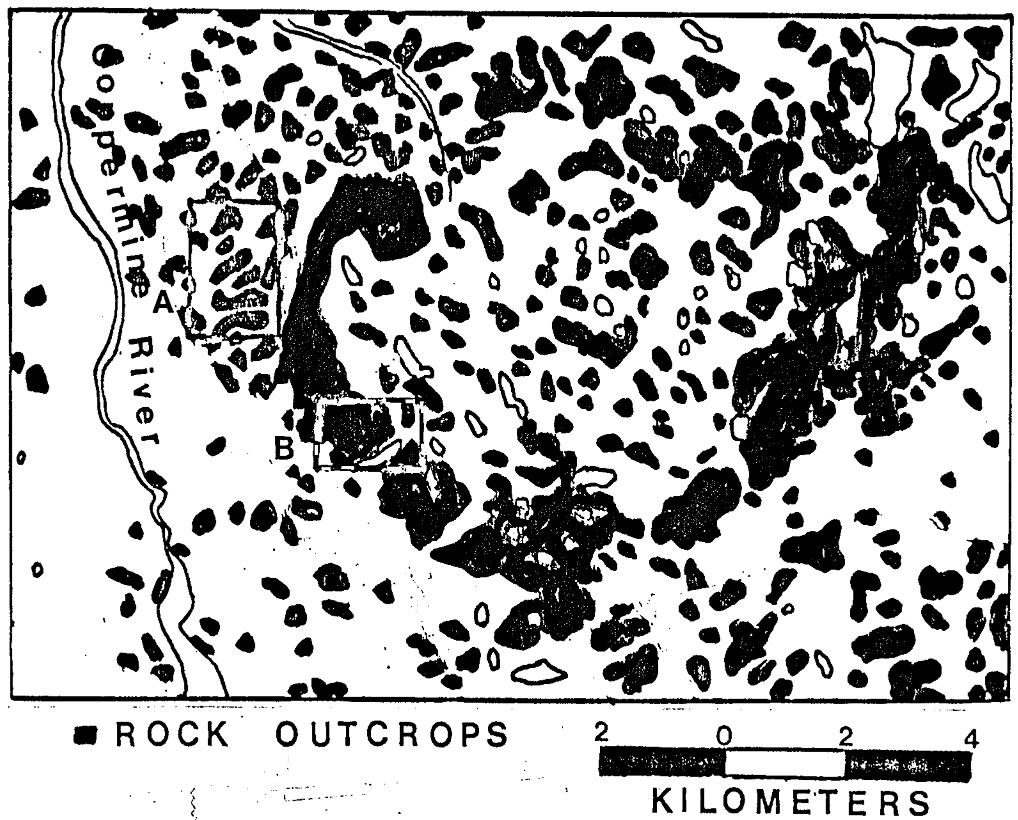


FIG. 36. Map showing rock outcrops prepared from visual analysis of enhanced image over Coppermine River area.

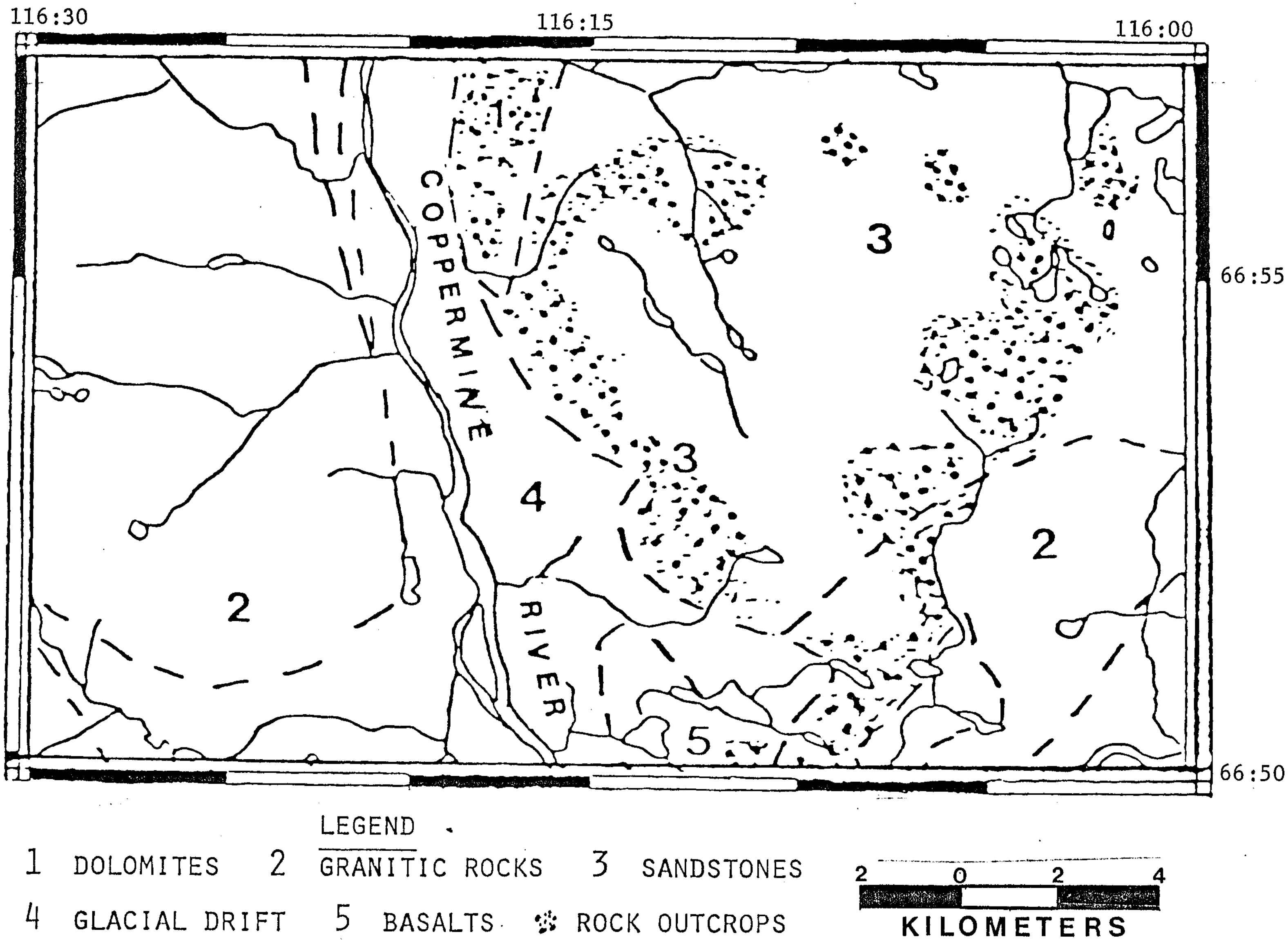


FIG. 37. *Generalized geological map of Coppermine River area showing known locations of rock outcrops.*

The enhanced image of Landsat data acquired on 22 June 1975 over the Coppermine River area is shown in Figure 38. Most of the water bodies in the area were frozen as seen on the June image. Snow was present in some of the vegetated and rock outcrop areas identified previously using the data acquired in August. On the enhanced image, snow and ice covered areas were indentified easily by their white color and absence of shadows. In the snow free areas, cover types on the June data appear in comparable colors to those on the August image. Rock outcrops in the snow free areas were thus identified accurately and consistently using visual analysis of the enhanced image acquired in June.

In summary, rock outcrops in the Coppermine River area were identified accurately by visual analysis of the enhanced Landsat images. Rock outcrops as well as other cover types appear in comparable colors on the enhanced images acquired in June and in August. Glacial drift areas in the Coppermine River area were identified mainly as vegetation on the enhanced Landsat images. The enhanced Landsat image is far superior to the aerial photograph for identification of rock outcrops in the Coppermine River area.

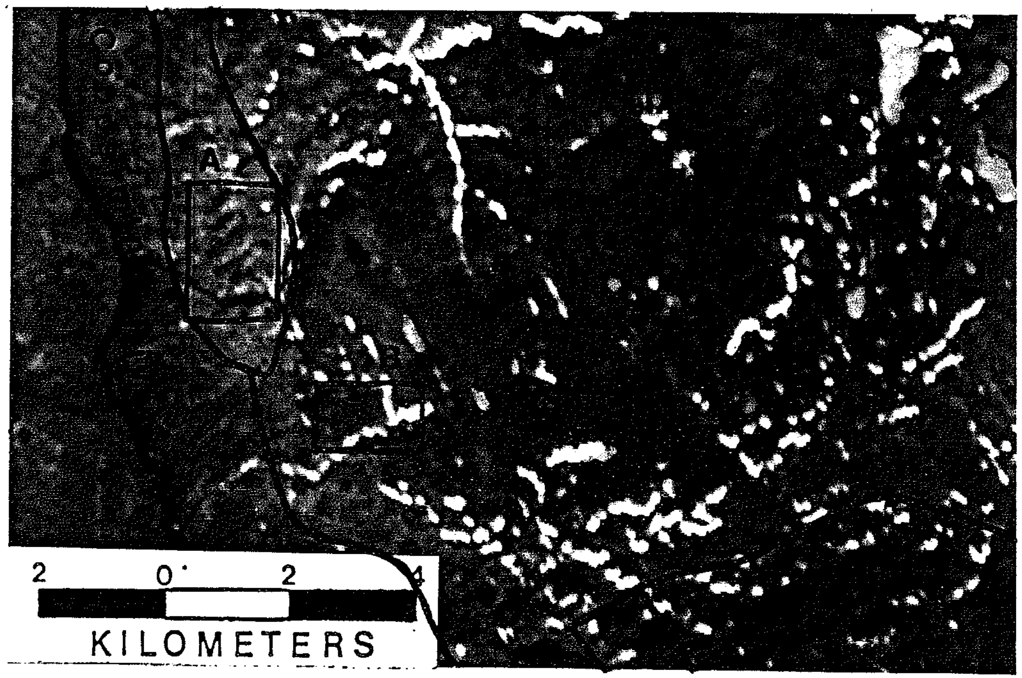


FIG. 38. Enhanced image of Landsat data acquired on 22 June 1975 over Coppermine River area.

4.2.2 Computer Analysis

Rock outcrops were identified using the computer analysis system developed in this study. Rock outcrops were discriminated from all other cover types using the hierarchical classification scheme of the analysis system. Maps showing the locations of rock outcrops have been prepared from Landsat data acquired on two different dates. These maps were compared with the rock outcrop maps prepared by visual analysis of enhanced imagery, with aerial photographs, and with known locations of rock outcrops. Using the computer analysis system, maps showing rock outcrops have been produced in the two intensive study areas - the Mouse River area and the Coppermine River area.

4.2.2.1 Mouse River area

The rock outcrop map produced from computer analysis of Landsat data acquired on 5 August 1975 over the Mouse River area is shown in Figure 39. Comparison of this map with the map (Fig. 31) produced by visual analysis shows that rock outcrops are identified accurately by the computer analysis system (for comparison purposes, overlays of the maps were prepared). Indeed, the agreement between the two maps is almost one to one in areas of rock outcrops. Comparison of this map with the aerial photograph (Fig. 30) shows that, in general, the lighter tone areas are identified as rock outcrops by the computer analysis system. Comparison of the

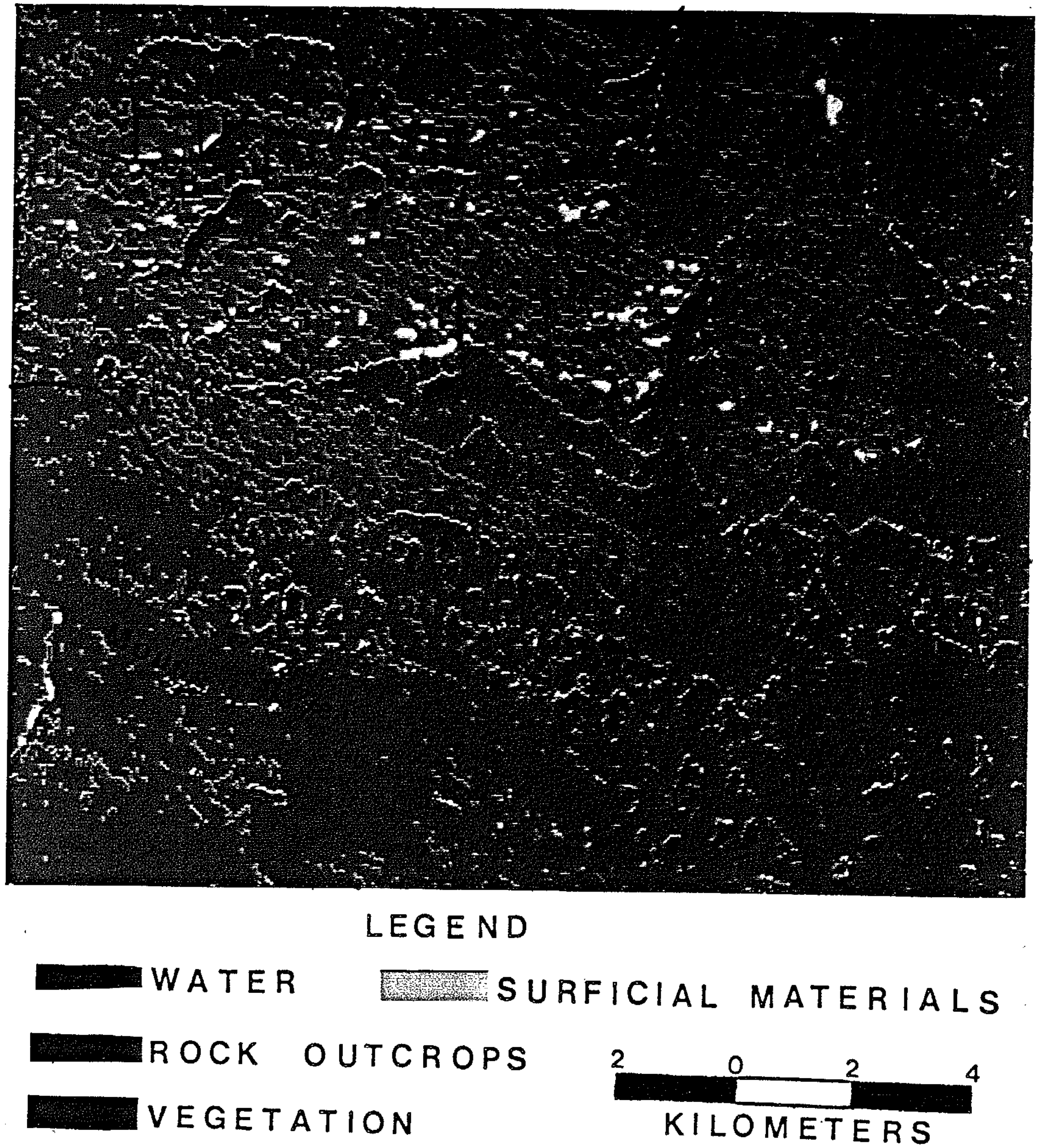


FIG. 39. Rock outcrop map produced from computer analysis of Landsat data acquired on 5 August 1975 over Mouse River area.

map with the enhanced image reveals that blue to bluish green areas on the image are identified as rock outcrops. The computer analysis system has also identified water bodies and vegetated areas accurately.

To provide a measure of quantitative accuracy of the classification scheme, two typical areas of rock outcrops have been examined in detail. These two areas are outlined as A and B on the rock outcrop map (Fig. 39). The proportions of rock outcrops identified in these two areas by visual analysis and the computer ananlysis system were computed. In area, A, the proportions are 0.78 and 0.73. In area B, the proportions are 0.84 and 0.78. Assuming that the results of visual analysis to be the field truth or the standard, the computer classification is 94% correct in area A and 93% in area B. That is, on the average the computer classification results are better than 93% accurate in identifying rock outcrops in the Mouse River area. It should be stated that the commission errors are negligible. That is, no areas, which have not been identified as rock outcrops by visual analysis, are committed to rock outcrops by the computer classification scheme.

The computer analysis system produces mensuration data on cover types identified. The mensuration data on cover types identified using 5 August 1975 data in the Mouse River area is given in Table 4. The dimensions of the Mouse River area are 15 km X 16.5 km. As shown in Table 4, 19% of this

TABLE 4. MENSURATION DATA ON COVER TYPES IDENTIFIED USING 5 AUGUST 1975 DATA IN THE MOUSE RIVER AREA.

COVER TYPE	MENSURATION DATA *
Water	9
Snow / Ice	0
Vegetation	71
Surficial Materials	1
Rock Outcrops	19

* Given in percentage of total mapped area, 247 kilometer square.

area was identified as rock outcrops. This percentage represents only outcrops which are large enough to be seen from satellite altitudes. That is, rocks are well exposed in the Mouse River area as shown by the relatively high percentage of outcrops in the area.

Rock outcrop map produced from computer analysis of Landsat data acquired on 22 June 1975 over the Mouse River area is shown in Figure 40. Some of the pixels identified as rock outcrops on August data were mis-identified as surficial deposits, since the area was covered with snow and ice in June. However, most rock outcrop areas were correctly identified. Mensuration data on cover types identitied with June data are given in Table 5. The percentage of rock outcrops identified in the area was reduced to 10 compared to 19 with August data.

In summary, maps showing rock outcrops were prepared for the Mouse River area from the computer analysis system developed in this study. The computer classification accuracy was better than 93% in identifying rock outcrops in typical areas of rock outcrops. In this intensive study area, rock outcrops were exposed in 19% of the area. Some of these outcrops were not identified with data collected in June due mainly to contamination of spectral signatures with the presence of snow and ice.

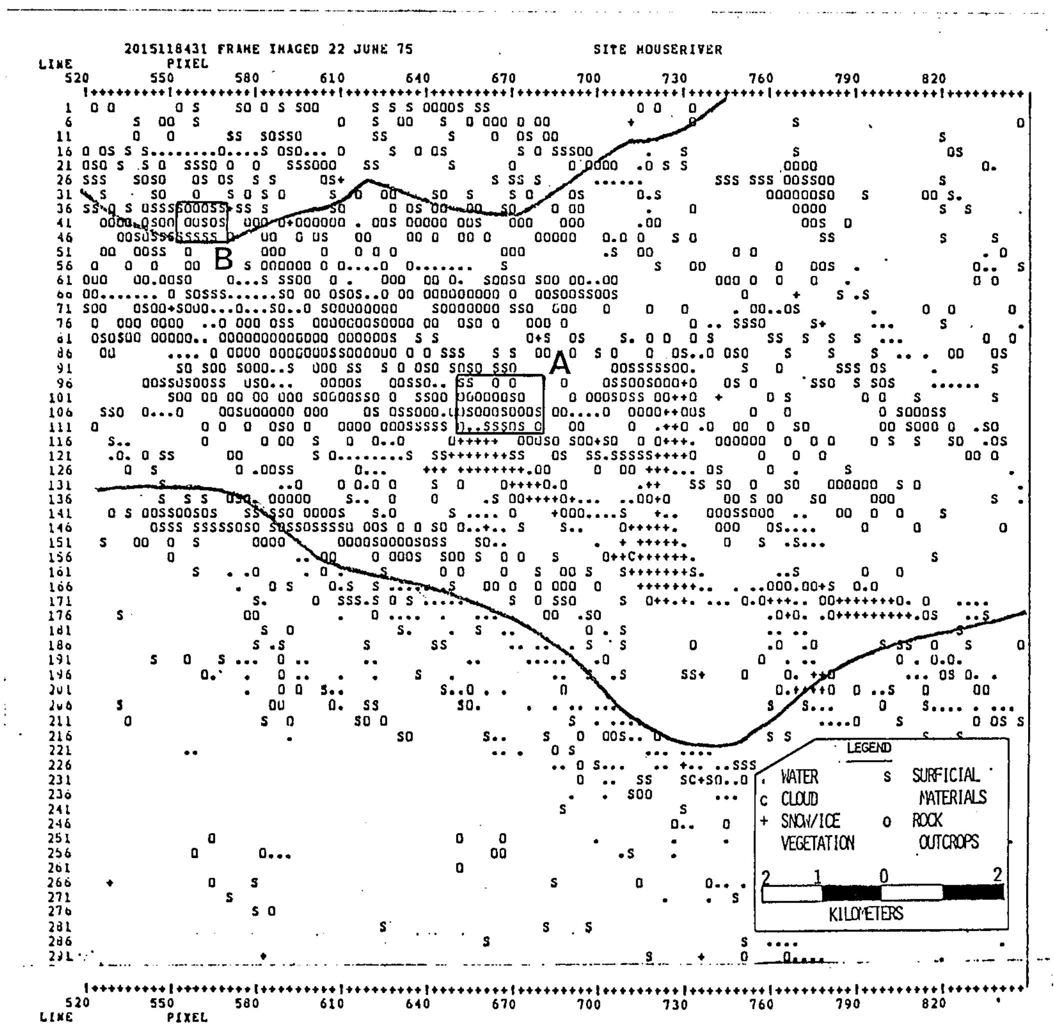


FIG. 40. Rock outcrop map produced from computer analysis of Landsat data acquired on 22 June 1975 over Mouse River area.

TABLE 5. MENSURATION DATA ON COVER TYPES IDENTIFIED USING 22 JUNE 1975 DATA IN THE MOUSE RIVER AREA.

COVER TYPE	MENSURATION DATA *
Water	7
Snow / Ice	2
Vegetation	70
Surficial Materials	7
Rock Outcrops	14

* Given in percentage of total mapped area, 247 kilometer square.

4.2.2.2 Coppermine River area

Rock outcrop map produced from computer analysis of Landsat data acquired on 5 August 1975 over the Coppermine River area is shown in Figure 41. Comparison of this map with the map (Fig. 36) produced by visual analysis shows that the rock outcrops are identified accurately in this area by the computer analysis system. Comparison of the map with the aerial photograph of the area (Fig. 35) shows that all the lighter tone areas are identified as rock outcrops. Areas of rock outcrops identified on the map correspond to the blue to bluish green areas on the enhanced image (Fig. 34). All these observations are consistent with the observations made previously in the Mouse River area. Rock outcrops are identified accurately and consistently using the computer analysis system in the Coppermine River area.

To provide a measure of quantitative accuracy of classification, again, two typical areas of rock outcrops in the Coppermine River area are examined in detail. These two areas are outlined as A and B on the rock outcrop maps produced by visual analysis (Fig. 36) and from computer analysis system (Fig. 41). Proportions of rock outcrops identified in area A and area B were computed on these two maps. In area A, the proportions are 0.35 and 0.32 respectively on the maps produced from visual analysis and computer analysis. In area B, the corresponding proportions are 0.80 and 0.72. Assuming that the results of the visual

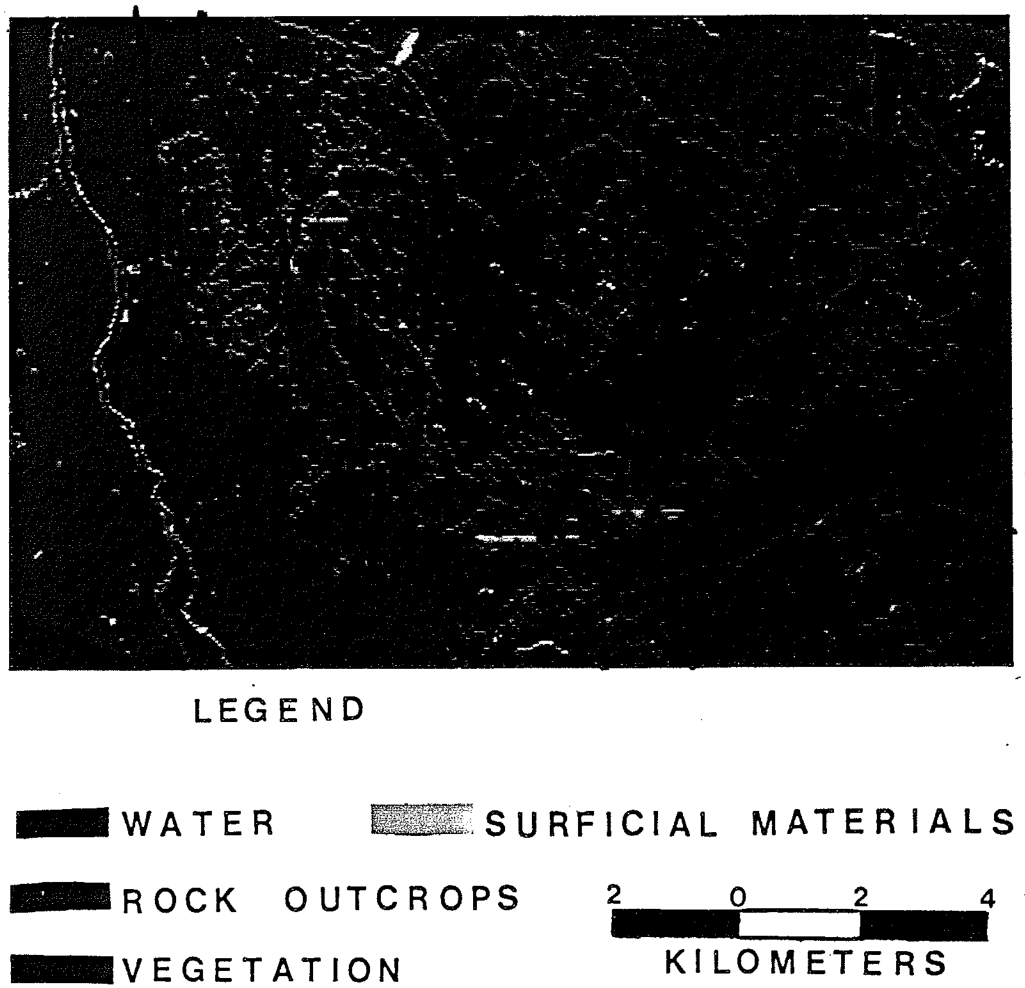


FIG. 41. Rock outcrop map produced from computer analysis of Landsat data acquired on 5 August 1975 over Coppermine River area.

analysis as the field truth, the computer classification accuracy is 91% in area A and 90% in area B. That is, on the average, the computer classification results are better than 90% accurate in identifying rock outcrops in this area. No areas, which have not been identified as rock outcrops by visual analysis are committed to rock outcrops by the computer classification scheme.

Mensuration data on cover types identified in the Coppermine River area from 5 August 1975 data are given in Table 6. The dimensions of the Coppermine River map area are 10.8 km X 16.5 km. As shown in Table 6, 17% of the map area is covered with rock outcrops. This relatively high percentage of outcrops shows that rocks are well exposed in the Coppermine River area. Only 1% of the area is identified as surficial deposits. Most of the surficial deposits were covered with vegetation and were identified as such by the automated classification scheme.

Rock outcrop map produced from computer analysis of Landsat data acquired on 22 June 1975 over Coppermine River area is shown in Figure 42. Some parts of the area were covered with snow and ice. As a result, some of the rock outcrops identified on August data were misclassified as surficial deposits using the June data. However, most of the rock outcrop areas are identified accurately. Mensuration data on cover types identified in the Coppermine River area using 22 June 1975 data are shown in Table 7. On

TABLE 6. MENSURATION DATA ON COVER TYPES IDENTIFIED USING 5 AUGUST 1975 DATA IN THE COPPERMINE RIVER AREA.

COVER TYPE	MENSURATION DATA *
Water	5
Snow / Ice	0
Vegetation	77
Surficial Materials	1
Rock Outcrops	17

* Given in percentage of total mapped area, 178 kilometer square.

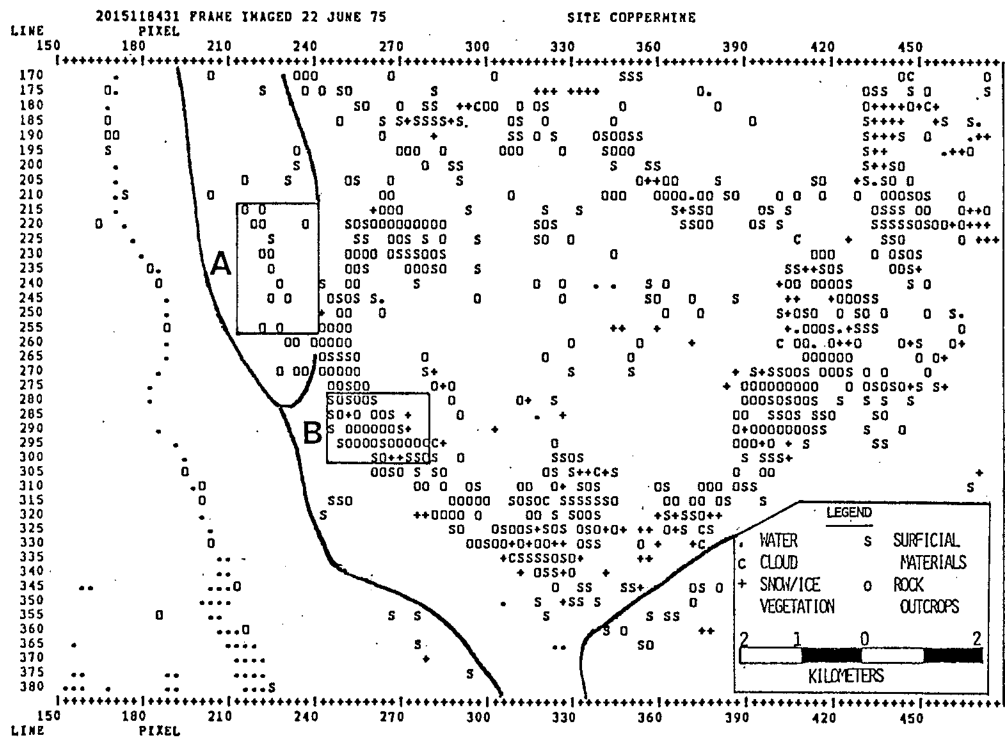


FIG. 42. *Rock outcrop map produced from computer analysis of Landsat data acquired on 22 June 1975 over Coppermine River area.*

TABLE 7. MENSURATION DATA ON COVER TYPES IDENTIFIED USING 22 JUNE 1975 DATA IN THE COPPERMINE RIVER AREA.

COVER TYPE	MENSURATION DATA *
Water	2
Snow / Ice	3
Vegetation	81
Surficial Materials	6
Rock Outcrops	8

* Given in percentage of total mapped area, 178 kilometer square.

the June data rock outcrops cover only 8% of the area compared to 17% with August data. Areas identified as surficial deposits on June data have, however, increased to 6% from 1% obtained with August data.

In summary, maps showing rock outcrops were prepared for the Coppermine River area from the computer analysis system. The computer classification accuracy was better than 90% in identifying rock outcrops in typical rock outcrop areas of the Coppermine River area. In this intensive study area rock outcrops were exposed in 17% of the area. Some of these outcrops were not identified with data collected in June due mainly to contamination of spectral signatures by the presence of snow and ice.

4.3 ROCK TYPE DISCRIMINATION

The rock outcrops identified have been discriminated as different rock types. This discrimination was carried out using both the visual analysis and the computer classification scheme developed in this study. Maps have been prepared showing the different rock types separated in the two intensive study areas used previously in the rock outcrop identification. Landsat data acquired on two different dates - 5 August 1975 and 22 June 1975 - were used in the discrimination of rock types. Results obtained on the discrimination of rock type are presented and discussed in this section. Results based on visual analysis are presented in the first part; the results based on the computer methods are presented in the second and the final part.

4.3.1 Visual Analysis

Visual analysis of digitally enhanced images has been used in the separation of rock types. The images were previously used in the identification of rock outcrops. The methodology of visual analysis used in separating rock types has been outlined in Section 3.1. Maps showing rock types separated have been produced using this methodology and then compared with the aerial photographs and the known geology. These maps have been prepared for two intensive study areas - the Mouse River area and the Coppermine River area.

4.3.1.1 Mouse River area

The enhanced images used in separating rock types in the Mouse River area by visual analysis is shown in Figure 29. On this image only two distinctly separable spectral units are identified in the rock outcrop areas. The first one of these spectral units appears in bluish green corresponding to dolomite outcrops in the area. The other spectral unit of rock outcrops appears in blue color corresponding to outcrops of other rock types in the area. These other rock types in the area include basalts and basalts with intercalated sandstones (Fig. 32). Comparison of the enhanced imagery with the generalized geological map of the area shows that dolomites always appear distinctly separable (bluish green in color) from other rock types. On the aerial photograph (Fig. 30) of this area, dolomites are lighter in tone than outcrops of the other rock types. It should be emphasized that the distinction between dolomites and other rock types is easier on the enhanced images than on the aerial photographs.

Rock types identified by visual analysis of the enhanced image of Landsat data acquired on 5 August 1975 over the Mouse River area are shown in Figure 43. On this map, rock unit 1 corresponds to dolomite outcrops and rock unit 2 corresponds to other rock types in the area. It should be stressed that the rock type identification is not possible on the enhanced image without training in calibration sites. Even with calibration, only dolomite outcrops can separated from outcrops of other rock types. These comments apply as well to the aerial photograph of the study area. Most of the glacial drift areas are covered with vegetation which appear in shades of red on the enhanced image. However, areas devoid of vegetation and rock outcrops do correspond to bouldery terrain in the study area (Donaldson, 1978).

The enhanced image of Landsat data acquired on 22 June 1975 over the Mouse River area is shown in Figure 33. In the snow free areas, the color representation of outcrops of

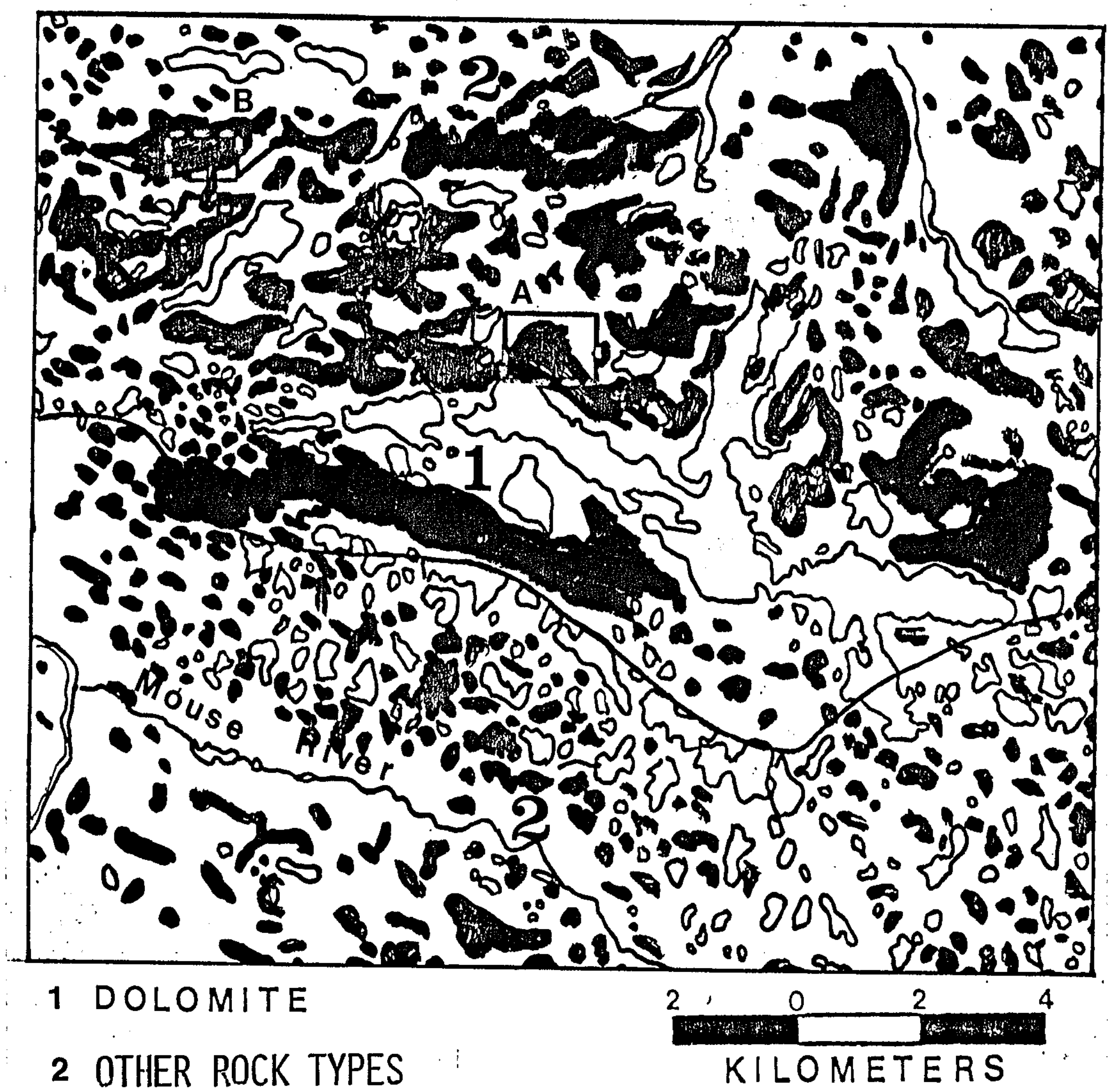


FIG. 43. Rock type map prepared from visual analysis of enhanced image over Mouse River area.

different rock types is the same on the enhanced images produced from data acquired in June and in August. This comparability of colors was achieved by standardizing the Landsat data.

In summary, a map showing rock type was prepared by visual analysis of the enhanced image acquired over the Mouse River area. Dolomites in the area were mapped as a distinctly separable spectral unit. Basalts and basalts with intercalated sandstones appear as one spectral unit, but different from dolomites, in the area. These findings were consistent with data acquired on two different dates in the Mouse River area.

4.3.1.2 Coppermine River area

The enhanced image used in separating rock types in the Coppermine River area by visual analysis is shown in Figure 34. On this image, only two distinctly separable spectral units are seen in the rock outcrop areas identified previously. The first one of these spectral units is characteristically bluish green in color corresponding to dolomite outcrops in the area. The second spectral unit is blue in color and corresponds mainly to sandstone outcrops in the area. In addition to these two units, a third spectral unit corresponding to granitic rocks and basaltic flows (Fig. 37) in the area is observed. This third unit is also blue in color but appears in a slightly darker shade. It should be pointed out that even though subtle color differences exist for grantic and basaltic rocks from sandstones, these differences are not consistent throughout the area.

Comparison of the enhanced image (Fig. 34) with the generalized geological map shows that dolomites always appear as a distinctly separable spectral unit from the other rock types. On the aerial photograph (Fig. 35) of this area, dolomites are lighter in tone compared to the other rock types; but most sandstone outcrops are similar in appearance to surficial deposits or vegetation.

Rock types identified by visual analysis of the enhanced image of Landsat data acquired on 5 August 1975 over the Coppermine River area is shown in Figure 44. On this map, rock unit 1 corresponds to dolomite outcrops, rock unit 2 corresponds to sandstones, and unit 3 corresponds to granites and basalts. Even with training in calibration sites, only dolomites and sandstones can be identified with any certainty. Identification of basalts and granitic rocks in the area is questionable. Identification of any rock types other than dolomites is also not feasible from the aerial photograph of this area.

In summary, rock types in the Coppermine River area were mapped from visual analysis of the enhanced images. Dolomites and sandstones in the area were identified as two distinctly separable spectral units. Granites and basalts

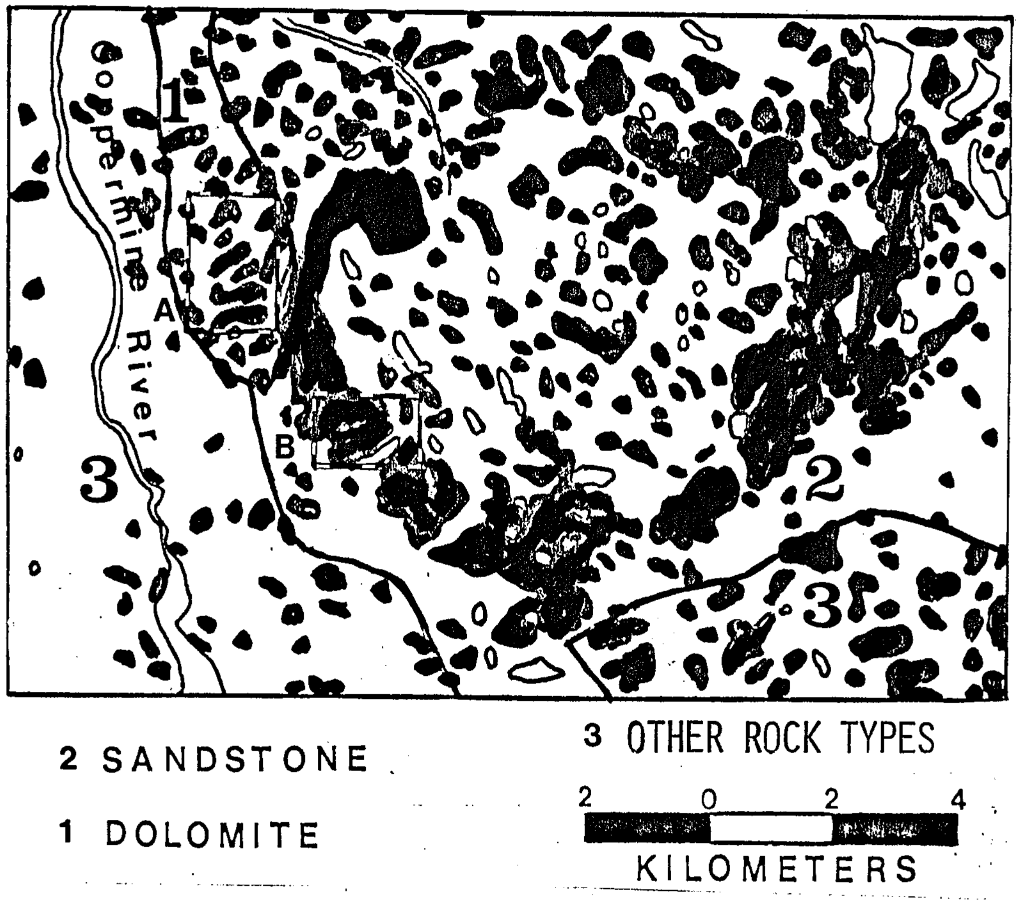


FIG. 44. Rock type map prepared from visual analysis of the enhanced image over Coppermine River area.

in the area appear as one unit but not too distanct from sandstones. These findings were consistent with data acquired on two different dates in the Coppermine River area. The various rock units appear in comparable colors on different dates as the Landsat data used were standardized.

4.3.2 Computer Analysis

Computer classification scheme developed in this study has been used in discriminating rock outcrops as different rock types. This discrimination was based only on spectral characteristics. Maps showing locations of these tentatively separated rock types were produced. These maps are computer generated and different cover types identified are depicted in different colors. The maps were compared with maps produced from visual analysis and with known geology by simple overlaying of the maps. Rock types were mapped in the Mouse river area and in the Coppermine River area from Landsat data acquired on two different dates.

4.3.2.1 Mouse River area

Rock types discriminated by computer analysis of Landsat data acquired on 5 August 1975 over Mouse River area are shown in Figure 45. Four different spectral units in the rock outcrop areas were identified. These spectral units are tentatively identified as dolomites, basalts, sandstones, and granites on the map showing rock types (Fig.

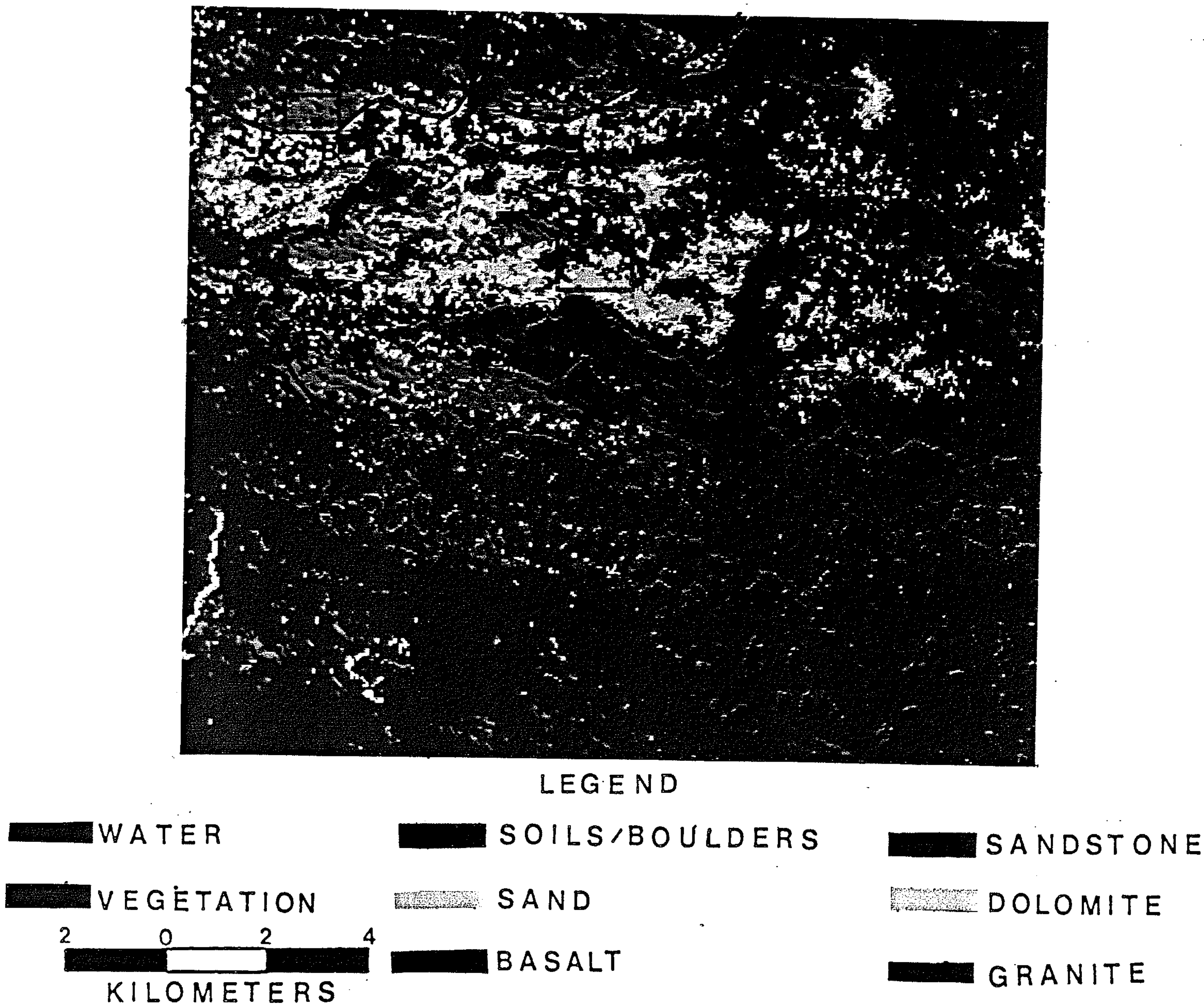


FIG. 45. Rock type map produced from computer analysis of Landsat data acquired on 5 August 1975 over Mouse River area.

45). As seen on the generalized geological map (Fig. 32), two major rock units occur in this area. These are dolomites and basalts with intercalated sandstones. Comparison of the map with the known geology shows that dolomites were identified accurately. Basalts with intercalated sandstones were identified mainly as basalts or sandstones.

In the classification scheme no provision was made to create classes which consist of two separate rock types. For lack of detailed field truth, it was assumed that classifying either as basalts or sandstones is correct for the rock unit corresponding to basalts with intercalated sandstones. On the rock type map (Fig. 43) produced by visual analysis, no distinction could be made between basalts and sandstones.

To provide a measure of quantitative accuracy of classification, two areas of typical rock types were examined in detail. These areas, outlined as A and B on the rock type map, contain dolomites and basalts wth intercalated sandstones respectively. In area A, 86% of the outcrops were classified as dolomites. In area B, 57% of the outcrops were correctly classified; the classification was considered correct when rock types werre identified as either basalts or sandstones. These accuracy figures on rock types are considerably lower than these obtained for identifying rock outcrops (Sec. 4.2.2.1) in this intensive study area.

Mensuration data on rock types separated using 5 August 1975 data in the Mouse River area is given in Table 8. This data are given as a percentage of total rock outcrops identified in the area. As seen from this table, dolomites, basalts, and sandstones cover most of the rock outcrop area in agreement with the known geology.

Map of rock types discriminated by computer analysis of Landsat data acquired on 22 June 1975 over Mouse River area is shown in Figure 46. This map when compared with known geology shows that, in snow free areas, rock types were identified fairly consistently. However, the classification accuracies were not as good as those obtained with August data. Classification accuracies were evaluated in areas A and B as was done with August data. In area A, corresponding to dolomites, the accuracy was slightly reduced to 84% from 86% obtained with August data. In area B, corresponding to basalts intercalated with sandstones, the accuracy was reduced to 50% from 57% obtained with August data.

Mensuration data on rock types separated using 22 June 1975 in Mouse River area is given in Table 9. Dolomites, basalts, and sandstones cover most of the rock outcrop area, in general agreement with known geology of the Mouse River area.

TABLE 8. MENSURATION DATA ON ROCK TYPES SEPARATED USING 5 AUGUST 1975 DATA IN THE MOUSE RIVER AREA.

ROCK TYPE	MENSURATION DATA "
Basalts	10
Dolomites	36
Granites	40
Sandstones	13

" Given in percentage of identified rock outcrop area, 46 kilometer square.

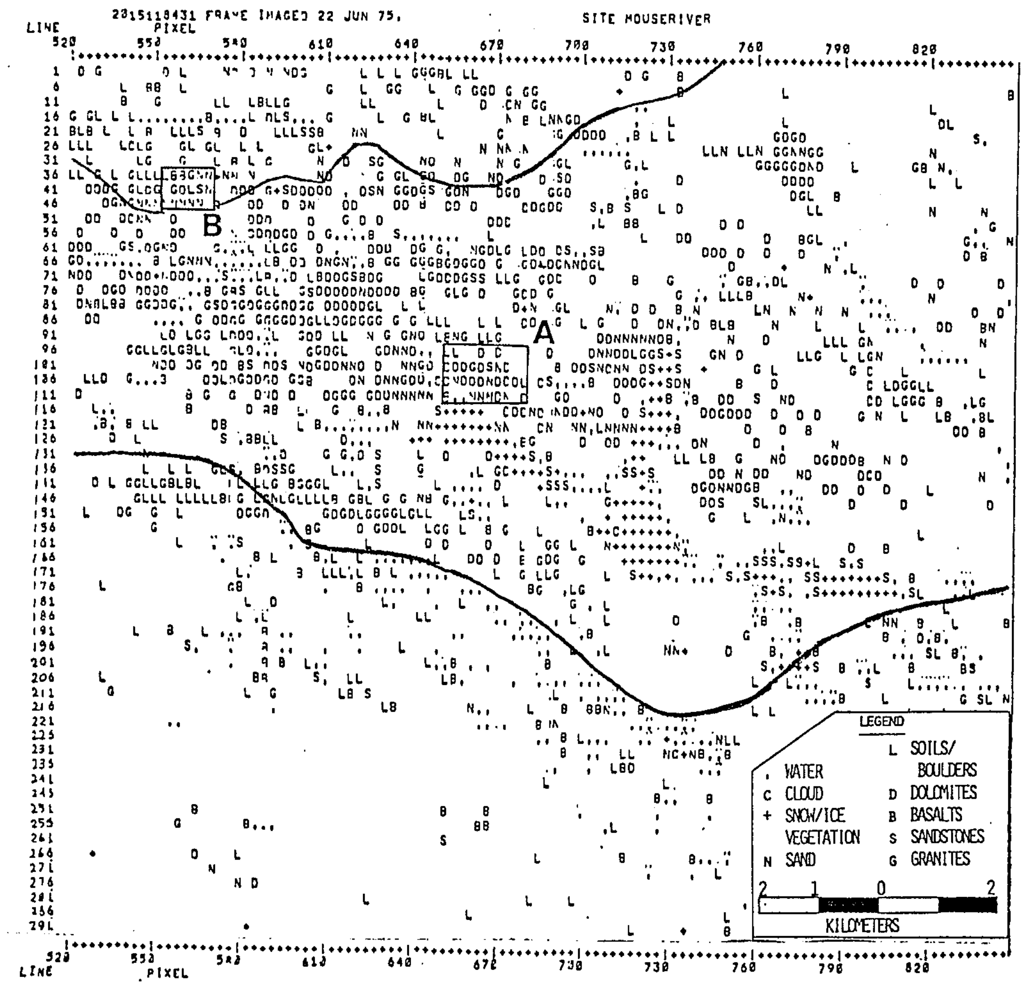


FIG. 46. *Rock type map produced from computer analysis of Landsat data acquired on 22 June 1975 over Mouse River area.*

TABLE 9. MENSURATION DATA ON ROCK TYPES SEPARATED USING 22 JUNE 1975 DATA IN THE MOUSE RIVER AREA.

ROCK TYPE	MENSURATION DATA *
Basalts	18
Dolomites	43
Granites	29
Sandstones	10

* Given in percentage of identified rock outcrop area, 33 kilometer square.

In summary, rock types were mapped from computer analysis of Landsat data acquired on 5 August 1975 and 22 June 1975 over the Mouse River area. In typical areas of outcrops, the computer classification accuracy was better than 86% for dolomites and better than 57% for basalts with intercalated sandstones. These accuracies were somewhat reduced when the data acquired in June were used. This lower accuracy was probably due mainly to contamination of signatures with the presence of snow. In the Mouse River area, 36% of the rock outcrop area was identified as dolomites and 23% as basalts with intercalated sandstones.

4.3.2.2 Coppermine River area

Map of rock types discriminated by computer analysis of Landsat data acquired on 5 August 1975 over Coppermine River area is shown in Figure 47. Four different spectral units of rock outcrop areas were identified on this map. These spectral units are tentatively identified as dolomites, sandstones, basalts, and granites on the map. As seen on the generalized geological map, most of the area is covered with two rock units. These are the sandstones and the dolomites. The other rock types in the area are granites and basalts.

Again, to provide a measure of quantitative accuracy of classification, two typical areas were examined in detail. These areas, outlined as A and B on the map showing rock

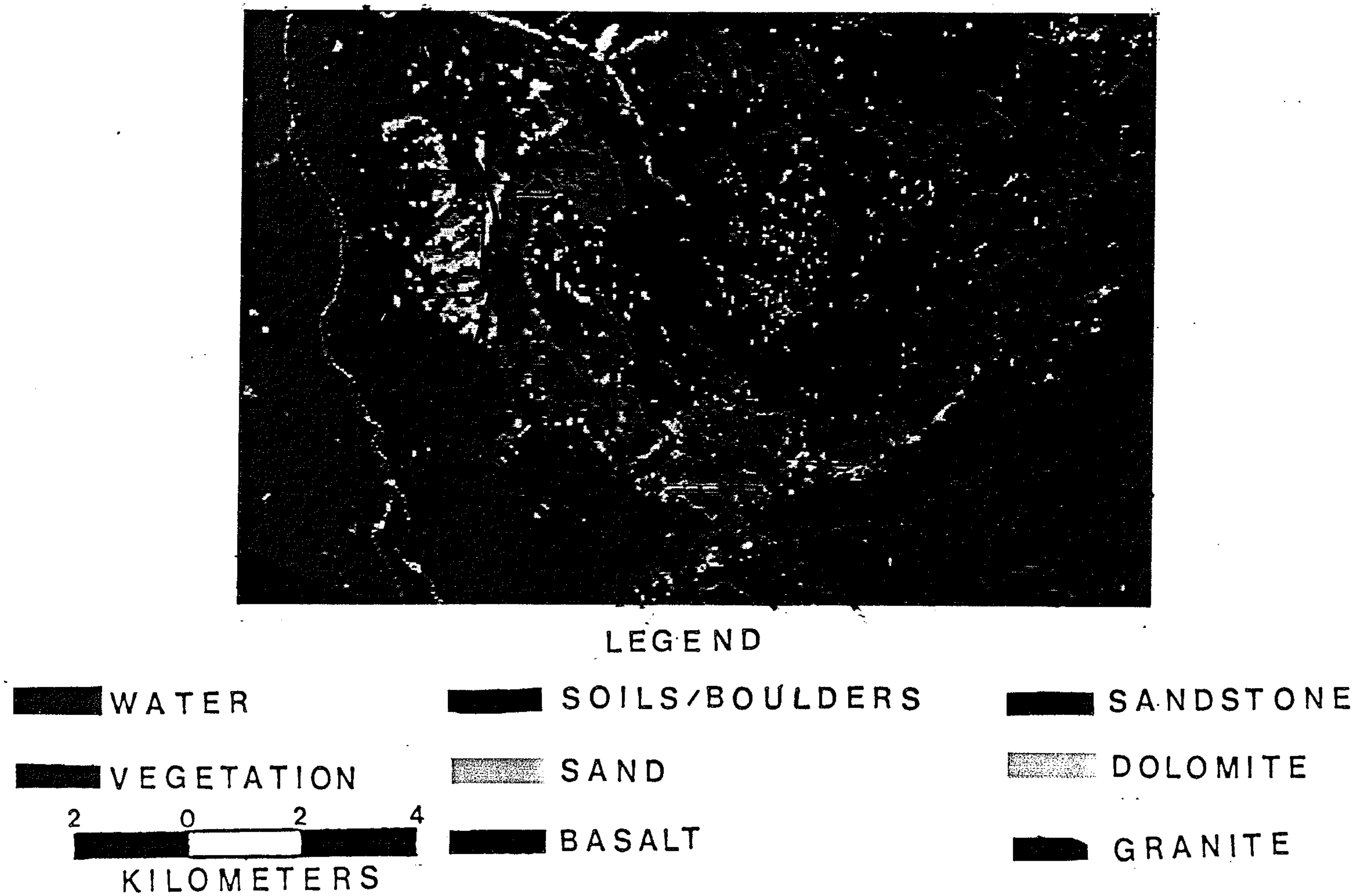


FIG. 47. *Rock type map produced from computer analysis of Landsat data acquired on 5 August 1975 over Coppermine River area.*

types, contain dolomites and sandstones respectively. In area A, 66% was correctly classified as dolomites. In area B, 77% was correctly classified as sandstones. The classification accuracies on rock types are considerably lower than those obtained in identifying rock outcrops (Sec. 4.2.2.2) in this intensive study area.

Mensuration data on rock types separated using 5 August 1975 data in Coppermine River area are given in Table 10. The data are given as a percentage of total rock outcrops identified in the area. Sandstones and granites are the predominent rock types in the area folllowed by dolomites. These results are consistent with the known geology.

Map of rock types discriminated by computer analysis of Landsat data acquired on 22 June 1975 over Coppermine River area is shown in Figure 48. This map when compared with known geology shows that, in snow free areas, rock types were identified fairly accurately. However, the rock type separation accuracies were considerably lower for sandstones and higher for dolomites than those obtained with August data. Classification accuracies in dolomite and sandstone areas were evaluated respectively in areas A and B outlined on the rock type map. The classification accuracy was 100% for dolomites and 13% for sandstones.

Mensuration data on rock types separated with 22 June 1975 data are given in Table 11. Granite and sandstone outcrops dominate the area followed by dolomites. These

TABLE 10. MENSURATION DATA ON ROCK TYPES SEPARATED USING 5 AUGUST 1975 DATA IN THE COPPERMINE RIVER AREA.

ROCK TYPE	MENSURATION DATA "
Basalts	5
Dolomites	12
Granites	42
Sandstones	40

" Given in percentage of identified rock outcrop area, 30 kilometer square.

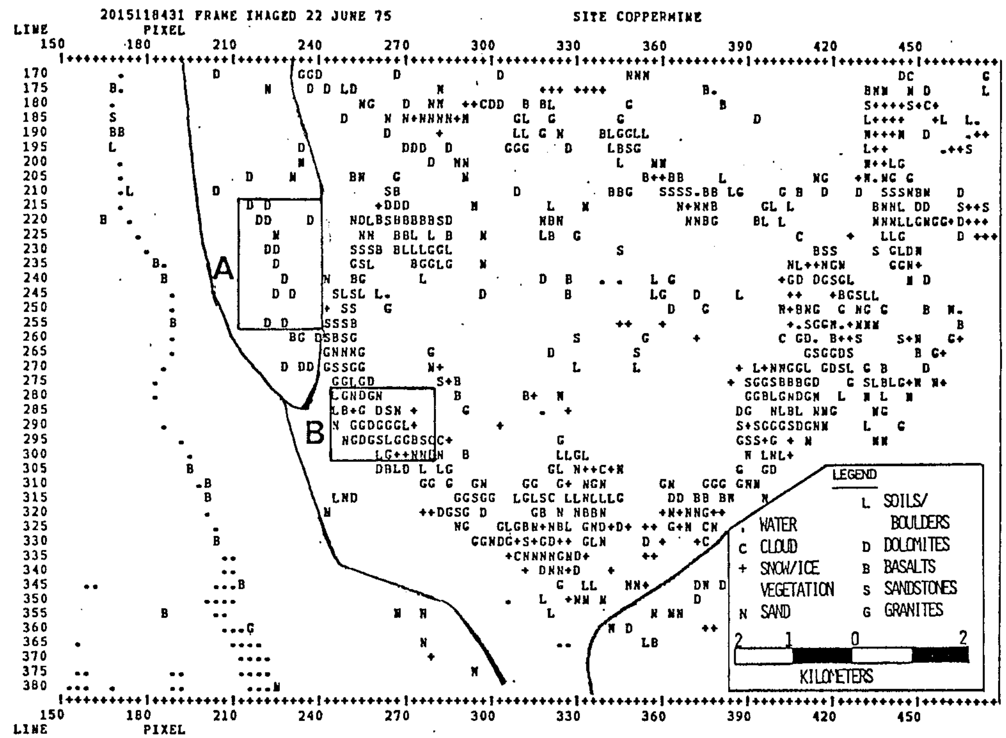


FIG. 48. Rock type map produced from computer analysis of Landsat data acquired on 22 June 1975 over Coppermine River area.

TABLE 11. MENSURATION DATA ON ROCK TYPES SEPARATED USING 22 JUNE 1975 DATA IN THE COPPERMINE RIVER AREA.

ROCK TYPE	MENSURATION DATA "
Basalts	22
Dolomites	25
Granites	38
Sandstones	16

" Given in percentage of identified rock outcrop area, 15 kilometer square.

results are, in general, consistent with the known geology and the results obtained with August data.

In summary, rock types were mapped from computer analysis of Landsat data acquired on 5 August 1975 and 22 June 1975 over the Coppermine River area. In typical areas of rock outcrops, the computer classification accuracy was better than 66% for dolomites and 77% for sandstones. These accuracies were reduced considerably when data acquired on 22 June 1975 were used. This reduction was perhaps due to contamination of spectral signatures with the presence of snow. In the Coppermine River area 40% of the rock outcrop area was identified as sandstones, 42% as granites, and 12% as dolomites.

4.4 COST ANALYSIS AND BENEFITS

In planning to use any new system, one must ask the crucial question "are there suffcent benefits to utilize the new system?". In order to provide an equitable answer to this question, one would have to examine the costs involved and benefits attainable through an economic evaluation or cost analysis of both the new and the conventional systems. This task becomes complicated if the conventional and the new systems are not compatible in terms of information generated. Also, with any new system, some benefits may be indirect and may require years of gestation time. The costs and benefits of producing rock outcrop maps using the Landsat based automatic method and the conventional method using aerial photographs are considered in this section. The cost analysis and benefits aspects are presented in Sections 4.4.1 and 4.4.2 respectively.

4.4.1 Cost Analysis

Cost analysis is usually carried out to determine if a new system is cost effective over the conventional system. This analysis involves examining cost aspects of both the conventional and the new system. In this study, the systems involved produce maps showing the distribution of rock outcrops. The conventional system uses aerial photographs and manual interpretation methods to produce the maps. The new system uses Landsat digital data and the automatic method developed to produce the maps. If the new system can provide the maps at less cost than the conventional system, while providing directly comparable information, and, in addition, other worthwhile information difficult to obtain by the conventional system, then the new system might truly be termed cost-effective.

Three separate components are involved in producing rock outcrop maps either by the conventional method or by the Landsat-based automatic method. The components are data acquisition, data interpretation, and map preparation. The costs involved are estimated for each of these three components with both the systems.

Since a mapping application is under examination, for comparing costs, the size of the area must be specified. The size of the area considered is 80 km X 80 km. This size is chosen for the area because it is approximately the area contained on a geometrically corrected Landsat CCT as produced in Canada.

4.4.1.1 Data acquisition costs

The new system developed in this study uses Landsat digital data that are geometrically corrected. The corrected Landsat CCT data covering the area costs $110 in Canada. However, in the United States the geometrically corrected CCT's cost $200, but these CCT's cover approximately four times the area covered on the Canadian CCT's. The geometrically corrected data would directly fit the UTM grid and normally the positional accuracy is better than 50 m.

The conventional system uses aerial photographic data. The aerial photographic coverage for the area of interest may or may not be available. For comparison purposes, it is assumed that photos at approximately 1:60,000 scale are used. This scale is comparable to the maps produced by the Landsat based method. This is also a scale that is most commonly used in detailed geological mapping; photographs at this scale are available for almost all regions of Canada from the National Air Photo Library (NAPL) of Canada. Fifty photographs at 1:60,000 scale are required to cover the area. If stereo coverage is required the number of photographs required would be more than 150 to cover the same area. It is, however, assumed that stereo coverage is not required to simply identify rock outcrops. The cost of the 50 aerial photographs, when they are available through NAPL, would be $100. However, this cost would be $300 or more when photographs are obtained from provincial sources.

If photographic coverage is not available (several regions of the world have poor or no coverage!) for the area of interest, the area will have to be flown separately. This is also true if suitable coverage is not available. The costs involved are in general enormously high, but the exact costs depend upon the location of the area relative to the base of operations, the size of the area, and the actual coverage included. Peters (1969) reports average costs for aerial coverage of $0.80 - $3.10 per square kilometer for areas from 135,000 down to 5,200 square kilometers. Craib(1972) estimates the cost at $1.40 per square kilometer for an 80 X 160 kilometer block. However, in Canada the present day rates are approximately $6 - $15 for the northern regions and $3 to $7 for the southern regions (Landreville, 1979). Based upon these figures, it appears reasonable to estimate the cost to be $5.00 per square kilometer for 80 km X 80 km block. That is the total cost of acquiring photographic coverage for the area would be $32,000.

4.4.1.2 Data interpretation costs

The Landsat based method uses a computer to identify rock outcrops. The experiments described in this study have been carried out on a PDP-10 computer system at CCRS. The interpretation costs are relatively fixed even though they do depend on the percentage of rock outcrops present in the area and on the computer used. On the PDP-10 computer, the identification of rock outcrops in a 80 km X 80 km area takes less than 5 minutes of CPU time. The interpretation costs are thus estimated at $30 for the computer time and $20 for the technician's time. This brings the cost of interpretation to $50 for the entire area.

It must be emphasized that this method does not require a display or any special peripherals for producing the maps. The software developed can be implemented on any computer system and maps can be produced on either a line printer or a computer terminal. In fact, the maps can be transmitted to a remote location through telephone lines for printing on a hard copy terminal.

With the conventional system the interpretation can be carried out by a photo analyst but usually is carried out by a photogeologist. It is estimated that it would take two-person days at $200/day to interpret 50 photographs for outcrop identification. Thus the interpretation costs are estimated at $400 for the area.

4.4.1.3 Map preparation costs

With the automated method of identifying rock outcrops, the maps are produced on a computer line printer at 1:60,000 scale. The maps are geometrically correct and would fit the UTM grid. Since these maps are geometrically accurate, transfer of information to a base map is not required. However, it should be pointed out that these maps can also be produced in photographic form in colour. If this is required, maps can be produced at 1:60,000 or smaller scales; these may also be used as base maps. For example the CSFR can be used to produce the maps in color.

When the data are interpreted using conventional methods, the outcrop locations will have to be transferred to a base map. The annotated aerial photographs cannot be directly used as either base maps or other maps. It is estimated that it would take two-person days at $150/day to transfer the information to a base map. That is the map transfer costs would be $300 for the area.

4.4.1.4 Comparative Costs with the two methods

The costs involved in the three individual components have been outlined for both the methods. These individual costs are combined to estimate the total cost for each of the two methods.

The total cost for the Landsat based automatic method is $160. The total cost for the conventional method is $800, when aerial coverage is available. Thus, the cost of producing outcrop maps using the Landsat based automatic method is one fifth of the cost of producing maps with the conventional method.

However, when aerial photographic coverage is not available for the area of interest, the cost of the conventional method shoots up to $32,700. In this case, the conventional method costs 210 times as much as the Landsat based method. The comparative costs and the cost per square kilometer for each method are given in Table 12. The minimum cost benefit ratio is estimated to be 5:1. This ratio would increase as the mapping area is increased.

4.4.2 Benefits

There are several benefits resulting from the Landsat based automatic method apart from the cost benefits discussed in section 4.4.1. Some of these benefits are directly attributable to the automatic method and others are general in nature and stem from inherent characteristics of Landsat data.

TABLE 12. COMPARATIVE COSTS OF PRODUCING OUTCROP MAPS WITH LANDSAT AND AIRPHOTO BASED METHODS

Tasks in Producing maps	COST IN DOLLARS With Landsat	With Airphotos OPtion 1	With Airphotos Option 2
Data Acquisition	110	100	32,000
Interpretation	50	400	400
Map Preparation	0	300	300
Total for 80 x 80 km area	160	800	32,700
Cost for square kilometer	0.025	0.125	5.250

Option 1 - Assumes the availability of suitable aerial coverage.

Option 2 - Includes the cost of flying to acquire photographs.

4.4.2.1 Usefulness in field studies

The enhanced images and the rock outcrop maps would be useful in field studies both in planning and in field mapping activities. Black and white aerial photographs are conventionally used in these activities. However, the photographs obtained from the NAPL are often out-dated. Latest available coverage such as the enhanced images of Landsat data would be more useful in the field studies. The cost of producing the enhanced images is minimal compared to the cost of acquiring aerial data.

The digitally enhanced images can be used in planning the activities of field personnel. In the field, the images can be used to mark traverses and field observations. More recent coverage of the area can be obtained relatively inexpensively from Landsat. Recent coverage is important in the field for locating geographical and cultural features. Also since the enhanced images contain color information, they would be more useful in the field compared to the conventional black and white photographs.

The maps showing rock outcrops and rock types would assist field personnel by saving the time required in the field. From the maps of rock outcrops, the field personnel would know in advance the locations of large rock outcrops. This enables the field personnel to go to the outcrops directly rather than spending time looking for outcrops. Since an indication as to the rock type is given on the maps of rock types, field personnel need not necessarily spend time checking all outcrops. These two aspects would result in considerable time saving for the field personnel.

4.4.2.2 Usefulness as base maps

The enhanced images can be used as base maps when mapping is done at a scale of 1:50,000 or smaller. Since the data used in producing the enhanced images are geometrically corrected, the images do not contain significant distortion at the scales specified. The enhanced images produced would fit the UTM grid.

Aerial photographs acquired routinely would not have this geometric precision for mapping. Since the enhanced imagery can be used both in the field and as base maps, no transfer of information is required to prepare final maps. Further, latest available coverage can be acquired at no additional cost, information on cultural and geographical features would be current on the base maps.

4.4.2.3 Other benefits

One of the direct benefits of the automatic method is that it provides mensuration data on cover types in the area. The aggregate coverage of each cover type identified in the area is automatically produced by the system in tabular form. This kind of data are useful in any field programs. For example, a quantitative estimate of the percentage of rock outcrop in the area would be helpful in planning the time required for the geological field investigations. Quantitative mensuration data can neither easily nor inexpensively be obtained with the conventional method.

The automatic method is also useful in engineering surveys such as pipeline route selection. Selecting a pipeline route is a major decision and is based on several factors. One such factor is costs involved in the construction. The construction costs are influenced by the presence of water bodies and rock outcrops along the pipeline route. The method developed here produces maps showing the distribution of rock outcrops and water bodies. The maps thus aid in selecting an optimal route with minimal costs.

Color information which may be useful for some applications can be obtained easily from Landsat data. Since the MSS on Landsat images in four different spectral regions, these can be combined to produce color composites. For example, a simulated color infrared image can be generated from Landsat digital data. These color images can be interpreted using conventional photointerpretation techniques. Color information can be obtained from Landsat digital data at a nominal cost relative to acquiring color photographs.

In summary, the cost benefits of mapping rock outcrop maps by a conventional and a new method were analysed. The conventional method is based on visual analysis of aerial photographs. The new method produces maps of rock outcrop by computer analysis of Landsat digital data. The cost of producing rock outcrop maps by the new method is estimated to be 20% of the cost of producing the maps by the conventional method. The cost effectiveness is improved further when large areas are mapped; the improvement is dramatic when no aerial coverage exists for the area. Several other benefits which are unique either to the Landsat data or to the new method were outlined.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions were reached on the basis of the results obtained in this study:

1. Rock outcrops in the Coppermine River area can be uniquely discriminated from all other cover types using Landsat digital data.
2. Spectral signatures of rock outcrops are distinctly different from the signatures of other cover types, facilitating not only easy but also consistent identification of rock outcrops.
3. Maps showing the distribution of rock outcrops can be produced either by visual analysis of digitally enhanced Landsat images or automatically by the computer method using digital data.
4. The need for repeated calibration in identifying rock outcrops is eliminated by employing standardized Landsat digital data.
5. The simulated color infrared images produced from digitally enhanced Landsat data are superior to the aerial photographs in identifying rock outcrops.
6. Maps of rock outcrops produced by the computer method are as good and in some cases better than maps produced from aerial photographs.
7. In addition to providing the spatial distribution of

rock outcrops, the computer method determines the aggregate coverage of outcrops and rock types in the map area.

8. Rock outcrops identified by the computer method can be further separated into different rock types based only on spectral characteristics.
9. Differences in spectral signatures among rock types examined were subtle and susceptible to mis-classification even with minor contamination from other rock types or cover types.
10. In the Mouse River area, the rock type separation accuracies were 86% and 57% respectively for dolomites and basalts with intercalated sandstones.
11. In the Coppermine River area, the accuracies obtained in separating rock types were 66% and 77% respectively for dolomites and sandstones.
12. The accuracies obtained in separating rock types were reduced when snow cover was present in the map area.
13. The cost of generating rock outcrop maps from Landsat data by the computer method is estimated to be less than 20% of the cost of generating the maps with aerial photographs using conventional methods.
14. There are other benefits of using Landsat data in addition to the cost effectiveness. These benefits include the use of digitally enhanced images directly as base maps and providing more recent coverage of the area relatively inexpensively.

5.2 RECOMMENDATIONS

The following recommendations are made based on this study:

1. The computer method should be tested in other areas to further validate the calibration and accuracies obtained in identifying rock outcrops.
2. Rock outcrop maps should be produced using the computer method, prior to launching a field program in any new area.
3. The computer method should also be used in obtaining mensuration data on cover types in the map area as an aid in planning the field mapping program.
4. Digitally enhanced simulated color infrared images should be used in the field for recording data gathered.
5. Use of geometrically corrected images as base maps, when mapping at scales of 1:50,000 or smaller, should be encouraged. This useage as base maps is particularly ideal in areas such as the Yukon and the Northwest Territories where maps at scales larger than 1:250,000 do not exist.
6. Maps of rock outcrops produced should be used in field in directing the personnel to specific rock outcrops.
7. Spectral signatures of commonly occuring rock types not examined in this study should be obtained from Landsat data to determine the feasibility of discriminating among other rock types.

8. It must be recognized that the rock outcrops must be very large for identification by the method, as the spatial resolution of the data used is 50 m X 50 m.
9. It is emphasized that the computer method developed does not replace conventional geological mapping but aids the field geologist in effectively carrying out the field mapping.

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APPENDIX A: COMPUTER PROCESSING METHODS

A1.0 INTRODUCTION

Computer methods for processing the Landsat data were discussed in Chapter 3. Additional details on implementation of the various methods on the computer and details on executing the software are given here. A sample run and a brief description of the programs developed for this project are also included. Listings of the software developed are given in Appendix B.

Two different formats of disc files with which the software developed can function are described in Section A2. Procedures that must be used in creating these disc files from CCT's are given in A3. An analysis program to produce histograms or listings of the MSS data are presented in A4. Software for mapping rock outcrops and rock types is described in A5. A program to generate enhanced images is presented in A6. Procedures followed in applying geometric corrections are discussed in A7.

In showing the interactions with the computer system (PDP-10), the user inputs are underlined. The symbols used are ↲ for carriage return, ^c for control C, and $ for altmode.

A2.0 DISC FILE FORMATS

The software written for this project works with two different disc file formats. The two disc file formats are referred to here as the CCRS OLD format and the CCRS JSC. The OLD format disc file is created for use with Landsat data on OLD format CCT's produced by CCRS until about 1976. The JSC format disc file is created for use with the CCRS JSC , DICS, and EROS data tapes. The formats for these two different disc files are presented here along with a brief description.

A2.1 OLD FORMAT DISC FILE

OLD format disc file is a data set created on disc from OLD format Landsat CCT. The OLD format disc file contains a portion of a Landsat image along with pertinent ancillary information. This disc file is created in a pre-defined format by running program LOADPK in the MICA package on the CCRS PDP-10 system.

The OLD format disc file consists of one header block, a number of data blocks, and an end of file mark at the end. The disc file organization is schematically shown in Figure A-1. Details on the header block and the data blocks are presented here.

A2.1.1 Header Block

The header block is located at the beginning of the OLD format disc file. There is only one such block in a file and the block size is always 128 words. The header block contains house keeping data, some of which would be copied direcly from the tape, and the remaing would be supplied by the user in response to prompts from the LOADPK program. Additional information on the contents of the header block may be obtained from the source coding of the program.

A2.1.2 Data Block

The number of data blocks in the OLD format disc file is equivalent to the number of scan lines copied from the CCT. Each data block contains four data segments for the four wavelength bands corresponding to a scan line with a data block header word in the beginning. The data block size is always 2432 data words. The organization of all the data in this block is in 6-bit bytes combined into words 36 bits long. Data in this form are accessible only by PDP-10 MACRO. The schematic organization of data block is shown in Figure A-2.

The data block header consists of one word at the beginning of the block. The last two bits of this word indicate which sensor in the band recorded the data. This number is needed when the radiometric corrections are made.

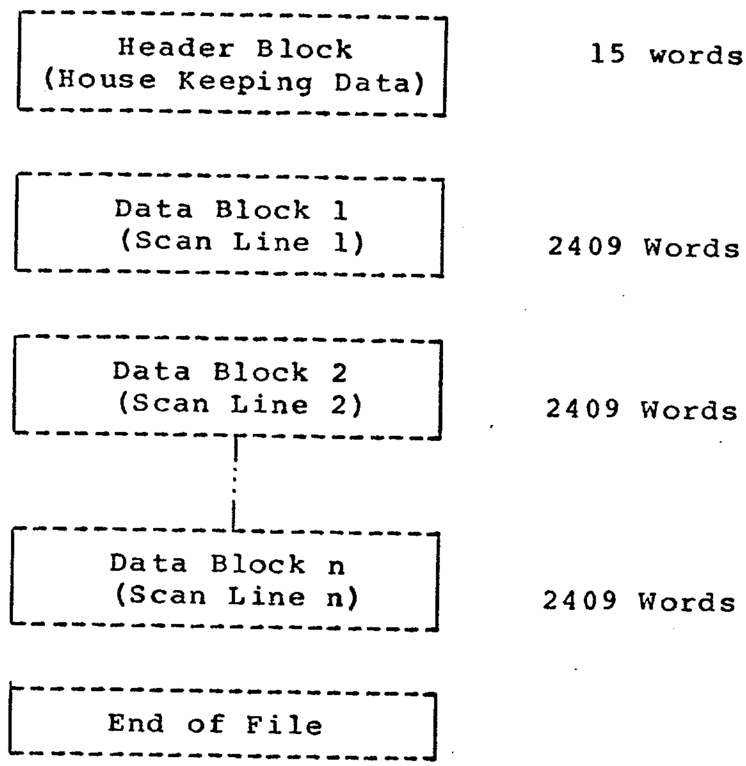

Fig. A-1. Schematic representation of the OLD format disc file

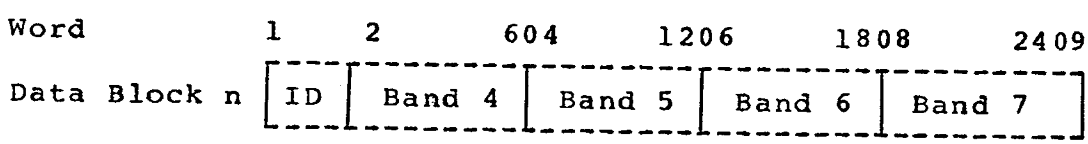

Fig. A-2. Organization of a data block in the OLD format disc file

A2.1.3 End of File

An end of file mark, indicating the end of the disc file, is placed after the last scan line is copied onto the disc.

A2.2 JSC FORMAT DISC FILE

JSC format disc file is a data set created on disc from JSC format Landsat CCT. The JSC disc file contains a portion of a Landsat image along with pertinent ancillary information. The disc file is created in a pre-defined format by running program CCTLOD in the MICA package at CCRS.

The JSC disc file consists of one header block, a number of data blocks, and an end of file mark at the end. The disc file organization is schematically shown in Figure A-3. Details on the header block and the data blocks are presented here.

A2.2.1 Header Block

The header block is located at the beginning of the JSC disc file. There is only one such block in a file and the block size is always 256 words. The header block contains house keeping data, some of which would be copied directly from the tape, and the remaining would be supplied by the user in response to prompts from the CCTLOD program.

Additional details on the contents of the header block may be obtained from the source coding of the CCTLOD program.

A2.2.2 Data Block

The number of data blocks in the JSC format disc file is equivalent to the number of scan lines copied from the CCT. Each data block contains four data segments for the four wavelength bands corresponding to a scan line. Each of the four data segments include its segment number within the data block and video data for the segment. The segments are numbered sequentially; the first segment corresponds to Band 4, the second to Band 5 and so on.

The organization of all data in a data block is in 8-bit bytes combined into 36 bits long word. Data in this form are accessible only by PDP-10 MACRO. The data block size is always 3712 words. The organization of data block is schematically shown in Figure A-4.

A2.2.2.1 Data segment A

Data segment A, the first segment in a data block, occupies 945 PDP-10 words. Segment A starts at word 1 and ends at word 945 of the data block. This segment contains the segment number, ancillary data, and video data for the segment. Segment A is a copy of the first data record in the MSS data set for a scan line on the JSC format CCT. The organization of segment A is shown in Figure A-5.

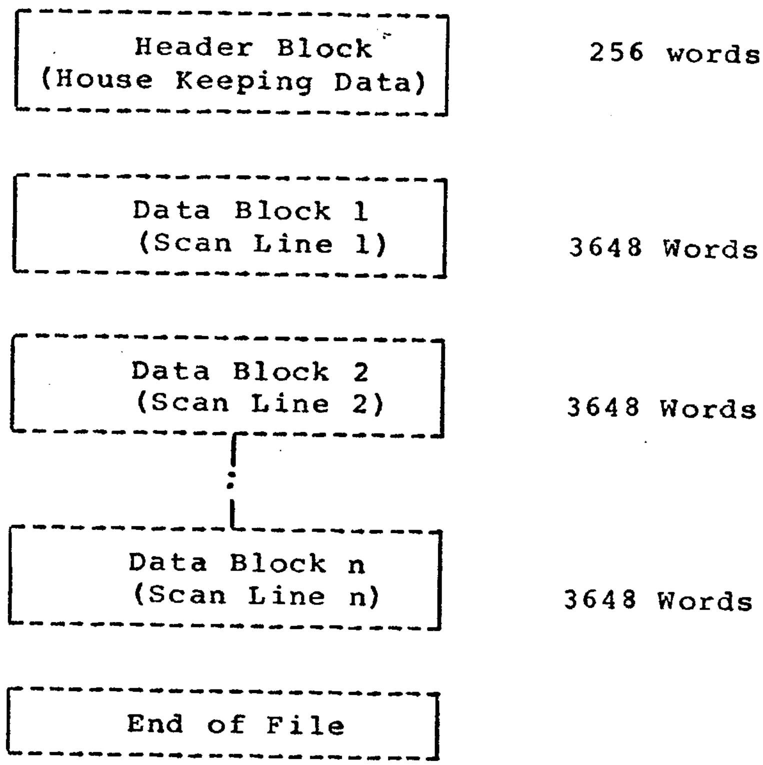

Fig. A-3. Schematic representation of the JSC format disc file

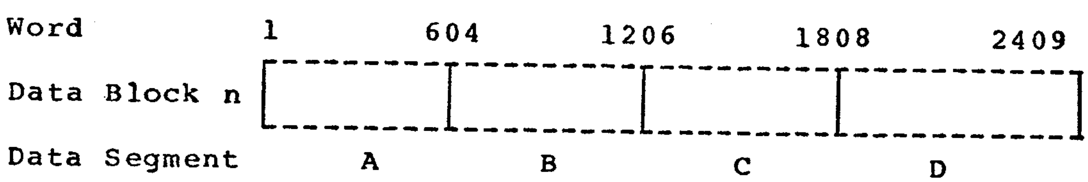

Fig. A-4. Organization of a data block in the JSC format disc file

A2.2.2.2 Data Segment B

Data segment B, the second segment in a data block, occupies 901 PDP-10 words. The segment starts at word 946 and ends at word 1846 of the data block. It contains the data segment number and the video data for the segment. It is a copy of the second record in the MSS data set for a scan line on the CCT; the auxiliary data at the end of the second record are, however, not copied. The organization of segment B is shown in Figure A-6.

A2.2.2.3 Data Segment C

Data segment C, the third segment in a data block, has the same length and organizational structure as segment B. Segment B starts at word 1847 and ends at word 2747 of the data block.

A2.2.2.4 Data Segment D

Data Segment D, the fourth and the final segment in a data block, has the same length and organizational structure as segments B and C. Segment D starts at word 2748 and ends at word 3648 of the data block.

A2.2.3 End of File

An end of file mark, indicating the end of the disc file, is placed after the last scan line is copied onto the disc file.

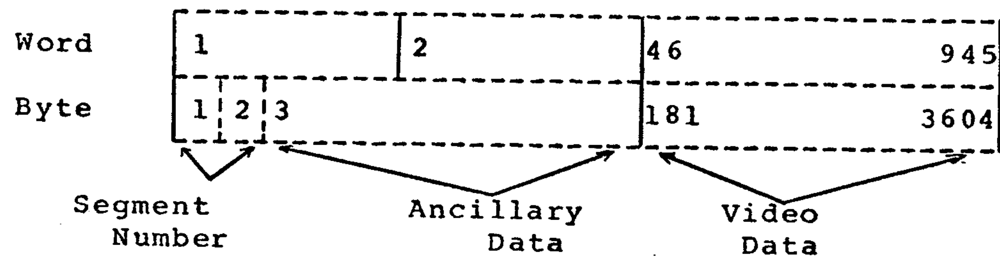

Fig. A-5. Organization of data in segment A

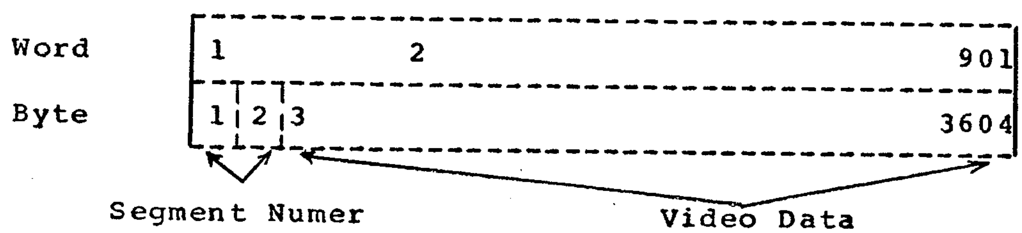

Fig. A-6. Organization of data in segment B

A3.0 CREATING LANDSAT DATA FILES ON DISC

After approximate coordinates of the study area are obtained, the required portion of the CCT is copied onto a disc for analysis. Access to the desired data is faster when the data are located on a disc file.

Two disc files were created for the study area data acquired on two dates. These two disc files were used in this project. Both the input Landsat CCT's are in OLD format. Program LOADPK from the MICA package was used in creating the OLD format disc files. The execution procedures for this program are documented clearly in the HELP files of the MICA package at CCRS (PDP-10 system).

If the Landsat CCT's are in the JSC format or from the EROS Data Center, program CCTLOD must be used in creating the disc files. Documentation on the execution procedures for this program are also available in the HELP files of the MICA package.

A4.0 PRODUCING HISTOGRAMS OR LISTINGS OF THE MSS DATA

A software package named CVALUE was written as an aid in the analysis of the Landsat data. This package allows the analyst to create histograms of the data or examine digital values from a specified area on the disc files.

The analysis program, CVALUE, can be executed by the RUN command on the PDP-10 system. The input data are from a disc file. The digital data listings generated by the program are stored on file (maximum of three files) for later retrieval. Each of these files can accommodate a maximum of 25 values. The pre-assigned names of the three files are STAT1.MAP, STAT2.MAP, and STAT3.MAP. The histograms generated by CVALUE are written only on one file - STAT1.MAP.

CVALUE is an interactive program. User input is required to prompts by the program. Provisions were made throughout the interactive part of the program allowing corrective actions to any erroneous input.

CVALUE has several built-in options which makes it more general and therefore more useful in different stages of the analysis. Some of the more salient options are listed below:

1. Accept data from either a JSC or an OLD format disc file,
2. Accept either the CCRS or the EROS data,

3. Data amy be decimated when not interested in using every line and pixel,
4. Standardize the data,
5. Produce either histograms or listing of the digital values, and
6. When the histogram option is chosen, additional selection of the following options can be made:
   (a) number of levels in the histogram (max. 256),
   (b) number of levels in the radiance values (max. 8-bit), and
   (c) histogram of any or all of the MSS bands.

A4.1 SAMPLE PROCEDURE

```
.MOUNT CHAG
Structure already mounted
[Mount count = 1]

CHAG Mounted

.RUN CVALUE

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@


 This program was written by P. Chagarlamudi of
Deloitte Haskins & Sells Associates .
It may not be reproduced in any form without the written consent
 of Deloitte Haskins & Sells Associates.
Use by employees of the Government of Canada at the Canada Centre
 for Remote Sensing is expressly permitted.

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@


MSS INPUT FILE NAME ?:U622AL
STRUCTURE ON WHICH FILE IS LOCATED ?:CHAG
LANDSAT FRAME NUMBER ?2015118431
DATE IMAGED ?22 JUNE 75
SITE NAME(2A5) ?COPPERMINE
SPECIFY THE AREA OF INTEREST -
1ST LINE,LAST LINE,LEFT PIX, RIGHT PIX -
```

```
200 220 400 424
FIRST LINE              :   200
LAST LINE               :   220
LEFTMOST PIXEL          :   400
RIGHTMOST PIXEL         :   424

       ARE THESE CORRECT (Y/N) ?Y
LINE & PIXEL DECIMATION FACTORS
 (N FOR 1 OUT OF N):1 1
LINE & PIXEL DECIM. FACTORS R :  1    1
ARE THESE CORRECT (Y/N)?Y
NAME OF RAD CORR LOOK UP TABLE ?DUMMY.DAT
WANT SUN EL CORRECTIONS (Y/N) ?Y
SUN EL. ANGLE IN DEGREES ?:46
FORMAT OPTN. (0-JSC CCRS;1-JSC EROS;2-OLD CCRS)>2
SATELLITE NUMBER (1/2/3) >2
4*  3.479226    ,
SELECT OPTN.(1-LIST VALS;2-HISTOGRAMS)>1

END OF EXECUTION
CPU TIME: 1.78  ELAPSED TIME: 2:23.17
EXIT

.Q STAT1.MAP
Total of 17 blocks in 1 file in LPT request

.
```

A5.0 MAPPING ROCK OUTCROPS AND ROCK TYPES

Software was developed to map rock outcrops and rock types using the methodology described in Chapter 3. Briefly, the method consists of discriminating rock outcrops from all other cover types by comparing computed threshold values to standard values for cover types using a hierarchical classification scheme. The outcrops identified are then subdivided into rock types. The cover types identified can be symbol-coded to produce maps on a line printer or a hard-copy terminal; alternatively, they can be color-coded to generate maps in hard-copy form using either the CSFR or the EBIR at CCRS.

A5.1 SOFTWARE PACKAGE FOR LINE PRINTER MAPS

The software developed to map rock outcrops and rock types consists of several modules, most of which were coded in DEC-10 FORTRAN. All the necessary modules are listed in a file named ALLROK.CMD on the PDP-10 system. The load module of this package is called ALLROK.EXE which can be executed by the RUN command on the PDP-10. A sample run of the program is shown here followed by an explanation of the more salient features of this package.

The software package can process MSS data from all currently available Landsat CCT formats. These formats include CCRS-OLD, CCRS-JSC, CCRS-DICS, EROS-OLD, and EROS-NEW. The radiance levels present and the system corrections performed are different for the different formats.

The MSS data can be standardized prior to computing the threshold value of a pixel area during execution of the program. The various options available for standardizing the data include radiometric corrections, sun elevation corrections, compensating for differences in satellites 1, 2, and 3, and adjusting the video data obtained from any format CCT to 256 levels in all bands.

In mapping large regions, it may not be necessary to map or examine all pixels within the region. That is, the threshold values for comparison may be computed for only 1 in every N pixels and 1 in every M lines within the region. If this estimation procedure is satisfactory, the CPU time requirements to map rock outcrops would be reduced accordingly. This method of decimating the data within the area of interest was implemented as an option in this package.

In producing the maps on a line printer, it must be recognized that line printers introduce an aspect ratio error by printing ten characters to an inch horizontally and six characters to an inch vertically. For maintaining the geometric accuracy of the maps, the aspect ratio error introduced by line printers must be compensated. In addition, it is recalled that the Landsat pixel is rectangular, unless it is resampled to a square pixel. Recognizing the above, the line/pixel combination for processing must be carefully selected in producing geometrically correct maps. The line and pixel ratios suggested for the sample areas are 5 to 3 for geometrically corrected (square pixels) and 3 to 2 when no geomtric corrections are applied (rectangular pixels).

Mensuration data on cover types can be obtained automatically using this package. The counting process can be performed for the entire region or a subset of the mapping area. The shape of the subregion for counting can be any four-sided figure.

A5.1.1 Input

The main input to the package is Landsat data that must be read from a disc file. The disc on which the MSS data are located must be mounted before executing the program. Auxiliary parameters such as site locations, line/pixel combinations are input during execution in response to prompts by the software. Provisions were made throughout the interactive segment of the program allowing corrective actions to any erroneous input.

A5.1.2 Output

The output from the software is a symbol-coded map which may consist of upto three vertical strips. The map is written on disc files (one for each striP) for later retrieval. Each strip or file accommodates upto 120 symbols across the page on a line printer. These strips may be printed either on a line printer or on a hard-copy terminal. To accommodate printing on any hard-copy terminal, the width of the individual strips can be adjusted (max. 120) during the execution of the program.In addtion to the idividual strips, the files contain auxiliary information for identification of the map.

The pre-assigned names of the three disc files are ROCK1.MAP, ROCK2.MAP, AND ROCK3.MAP. The files may be printed on a line printer using the Q command with Fortran switch on the CCRS PDP-10 system.

When the mensuration option is selected, a temporary disc file with extension LPT is created. This file contains the mensuration data on cover types identified and auxiliary information for identification. This file may be printed on the line printer using the Q command.

A5.1.3 Sample Procedure

```
.RU ALLROK

MSS INPUT FILE NAME ?:U622AL
STRUCTURE ON WHICH FILE IS LOCATED ?:CHAG
LANDSAT FRAME NUMBER ?2015118431
DATE IMAGED ?22 JUNE 75
SITE NAME(2A5) ?COPPERMINE
SPECIFY THE AREA OF INTEREST -
1ST LINE,LAST LINE,LEFT PIX, RIGHT PIX -

170 386 150 479
FIRST LINE            :  170
LAST LINE             :  386
LEFTMOST PIXEL        :  150
RIGHTMOST PIXEL       :  479

       ARE THESE CORRECT (Y/N) ?Y
LINE & PIXEL DECIMATION FACTORS
 (N FOR 1 OUT OF N):5 3
LINE & PIXEL DECIM. FACTORS R :  5    3
ARE THESE CORRECT (Y/N)?Y
NAME OF RAD CORR LOOK UP TABLE ?LINCM5.622
WANT SUN EL CORRECTIONS (Y/N) ?Y
SUN EL. ANGLE IN DEGREES ?:46


WANT TO SEE THE CURRENT VALUES (Y/N) ?N
SATELLITE NUMBER (1/2/3) >2
4*  3.479226     ,
110,
43, 110, 330, 1, 110,
1, 1, 110, 4*0,
CLASSIFICATION PROC.(1/2/3/4) :1
1,

END OF EXECUTION
CPU TIME: 1.96  ELAPSED TIME: 1:47.88
EXIT

.Q ROCK1.MAP/FILE:FORTRAN
Total of 11 blocks in 1 file in LPT request

.
```

A5.2 SOFTWARE PACKAGE FOR COLOR-CODED MAPS

The software package written for producing color-coded maps is a modified version of ALLROK package (A5.1). This modified version is called MADROK. The major difference between the two packages is that MADROK creates a display compatible file (A6.1) containing the map. Hard-copy color products may be generated from this file by employing procedures similar to those used for enhanced images (A6.2).

MADROK consists of several modules, most of which were coded in DEC-10 FORTRAN. Some of the modules are, however, the same as in ALLROK. All the necessary modules to execute the MADROK package are listed in a file named MADROK.CMD. The load module of this package is called MADROK.EXE which can be executed by the RUN command on the PDP-10 system. A sample run of this program is shown followed by an explanation of the additional features of this package over ALLROK.

The assignment of colors to the cover types as well as the names of the cover types can be changed during execution. Selection of colors can be made from any of the 17 possible colors (including black and white) available in this package. If the user wishes, he may use the default parameters for color assignments and for the names of the cover types.

A color legend is written at the end of the file. The color legend consists of rectangles filled with colors assigned to the cover types. On the color map produced, the legend would appear across the width at the bottom of the map. The sequence in which the colors are written is identical to the sequence in which the class numbers are assigned to the cover types.

The map produced using the hierarchical classification scheme may be enlarged by repeating pixels during execution. Somewhat comparable enlargements may, however, be made from negative produced in the photographic process. It is cautioned that this kind of enlargements are only useful for display purposes rather than improving the mapping accuracy.

For comparison purposes, the Landsat image of the map area can be written on the same display compatible file as the map. The pre-assigned band combination for the blue, green, and red colors are Band 4, Band 5, and Band 7 respectively. The original image is written on the top half of the file and the map is written on the bottom half of the file.

A5.2.1 Input

The main input to the MADROK package is identical to that of ALLROK package; some of the auxiliary parameters required are different. All parameters are input during execution in response to prompts by the software.

A5.2.3 Output

The output from this package is a display compatible file called DSPLAY.MAP. This file is created on the disc which contains the MSS data.

A5.2.4 Sample Procedure

```
.RUN MADROK
MSS INPUT FILE NAME ?:U622AL
STRUCTURE ON WHICH FILE IS LOCATED ?:CHAG
LANDSAT FRAME NUMBER ?2015118431
DATE IMAGED ?22 JUNE 75
SITE NAME(2A5) ?COPPERMINE
SPECIFY THE AREA OF INTEREST -
1ST LINE,LAST LINE,LEFT PIX, RIGHT PIX -
150 385 150 500
FIRST LINE          :  150
LAST LINE           :  385
LEFTMOST PIXEL      :  150
RIGHTMOST PIXEL     :  500

       ARE THESE CORRECT (Y/N) ?Y
LINE & PIXEL DECIMATION FACTORS
 (N FOR 1 OUT OF N):1 1
LINE & PIXEL DECIM. FACTORS R :  1    1
ARE THESE CORRECT (Y/N)?Y
NAME OF RAD CORR LOOK UP TABLE ?DUMMY.DAT
WANT SUN EL CORRECTIONS (Y/N) ?Y
SUN EL. ANGLE IN DEGREES ?:46
```

```
WANT TO SEE THE CURRENT VALUES (Y/N) ?N
SATELLITE NUMBER (1/2/3) >2
4*  3.479226     ,
110,
CLASSIFICATION PROC.(1/2/3/4) :1
1,
MAGNIFICATION OF DISPLAY >1
SPLIT SCREEN DISPLAY(Y/N) >N
COLOR CODES ARE:
 BLACK      - 1; BLUE       - 2; GREEN      - 3; RED        - 4;
LIGHT BLUE- 5; PINK PURPL- 6; YELLOW     - 7; GREY       - 8;
BROWN      - 9; BLUISHGREY-10; ORANGE     -11; DARK BLUE -12;
DARK RED   -13; DARK GREEN-14; TARQUOISE -15; PURPLE     -16;
WHITE      -17;

END OF EXECUTION
CPU TIME: 15.93 ELAPSED TIME: 3:18.13
EXIT
```

A6.0 GENERATING ENHANCED IMAGES

Digitally enhanced Landsat data were used in this study for visual analysis of rock outcrops and rock types. The methodology of digital enhancements was described in Chapter 3. Software to perform some of these enhancements was developed for this project. Display compatible disc files containing the enhanced data were created by the software developed. These data files may be used in producing hard copy color products.

A6.1 DISPLAY COMPATIBLE DISC FILES OF ENHANCED DATA

The software package that creates display compatible disc files of enhanced data is called DSPLAY. Two different enhancement procedures can be performed by the DSPLAY package. The two procedures are the linear contrast stretch and the multiplication enhancement which is used in generating the simulated color infrared imagery. The enhanced data are written on an output file which is referred to here as the display compatible file.

The data can also be written on the display compatible files without performing any enhancements. However, in all the three cases the data are standardized prior to creating the output file.

The format of the display compatible file accommodates only three bands. Any three of the four bands in the MSS can be selected during the execution of the program. A grid (black lines) may be super-imposed on the enhanced image for ease of referencing. The grid size, in terms of lines and pixels, may be selected during the execution.

The input Landsat data may consist of the OLD format or the JSC format disc file. The data may be decimated when not interested in using all the original data. Alternatively, the enhanced data may be digitally enlarged to provide larger scales by repeating pixels and lines.

The display compatible file (output) is created on the same disc as the input. The disc which contains the input Landsat data must be mounted prior to running the program.

A6.1.1 Sample Procedure

```
.RUN DSPLAY ↲

MSS INPUT FILE NAME ?:U622AL ↲
STRUCTURE ON WHICH FILE IS LOCATED ?:CHAG ↲
LANDSAT FRAME NUMBER ?2015118431 ↲
DATE IMAGED ?22 JUNE 75 ↲
SITE NAME(2A5) ?COPPERMINE ↲
SPECIFY THE AREA OF INTEREST -
1ST LINE,LAST LINE,LEFT PIX, RIGHT PIX -

150 385 150 500 ↲
FIRST LINE          :  150
LAST LINE           :  385
LEFTMOST PIXEL      :  150
RIGHTMOST PIXEL     :  500

      ARE THESE CORRECT (Y/N) ?Y ↲
LINE & PIXEL DECIMATION FACTORS
 (N FOR 1 OUT OF N):1 1 ↲
LINE & PIXEL DECIM. FACTORS R :  1    1
ARE THESE CORRECT (Y/N)?Y ↲
NAME OF RAD CORR LOOK UP TABLE ?DUMMY.DAT ↲
WANT SUN EL CORRECTIONS (Y/N) ?Y ↲
SUN EL. ANGLE IN DEGREES ?:46 ↲
```

```
FORMAT OPTION - (0-JSC/CCRS;1-JSC/EROS;2-OLD/CCRS):2
SATELLITE NUMBER (1/2/3) >2
4*   3.479226      ,
SELECT ENHANCEMENT PROC. (1-LIN.STRECH; 2-MULTIPLY; 0-OTHERWISE)2
MSS BANDS(1-4) FOR BLUE,GREEN & RED GUNS >1 2 4
MULTIPLICATION FACTRORS FOR BL GR RED GUNS >1. .75 .5
WANT GRID ON DISPLAY (Y/N) ?:Y
GRID SELECTION LINES/PIXELS(ORIGINAL) :100 100
MAGNIFICATION OF DISPLAY >1
NAME OF DISPLAY COMPATIBLE FILE >MULTY.DSP

END OF EXECUTION
CPU TIME: 21.38 ELAPSED TIME: 6:38.40
EXIT
```

A6.2 OBTAINING HARD COPY COLOR PRODUCTS

Hard copy color products of the enhanced data may be obtained either on the CSFR or the EBIR. An input tape for the CSFR or the EBIR must be generated from the display compatible file containing the enhanced data.

The programs that must be used in creating the input tapes for the CSFR and the EBIR are DSPCSF and DSPEBR respectively. Both these programs are in the MICA package and documentation is available in the HELP files on the CCRS PDP-10 system.

A7.0 GEOMETRIC CORRECTIONS

Geomtrically corrected Landsat data that would fit the UTM grid are now available routinely from CCRS as a standard product called DICS CCT. However, when this project was initiated, the DICS CCT's were not availble. Consequently, geometric corrections and resampling of pixels was carried out for this project as mentioned in Section 3.5.1. Software used for these corrections is available in the CCRS MICA system and was developed by Dr.S. Shlien. The software and the execution procedures are explained here.

The pixel size on the DICS CCT's is 50 m by 50 m. However, if one chooses to select a different size, the procedures explained here would be useful.

A7.1 CORRECTION PROCEDURES

The geometric correction procedures are carried out in four different steps by four independent programs. The four steps are: (a) locating and digitizing Ground Control Points (GCP's), (b) obtaining the image coordinates of the digitized GCP's from a disc file containing the data, (c) generating a transformation to convert the image coordinates to the UTM coordinates and to resample the pixels using cubic convolution, and (d) apply transformation to the input Landsat data.

A7.1.1 Selection and Digitization of GCP's

GCP's for digitization were selected on the basis of the following criteria:

1. GCP's should be distributed uniformly throughout the area of interest to assure that any error is dispersed evenly throuout the area.
2. GCP's should be stable geographical or cultural features (eg. road intersections) to avoid any confusion in locating it precisely on the input Landsat data.
3. GCP's should be located in the vicinity of an easily identifiable feature such as a large or an unique shaped water body to insure that each GCP is uniquely identified.

Over twenty GCP's were selected on the 1:250,000 NTS maps (maps at larger scales do not exist for areas north of 60 degrees parallel) using the above criteria.

The selected GCP's were digitized on a Gradicon digitizer at CCRS using program GCPAQ. The output from this program is a file (with user specified name) containing the identification of the GCP's and their corresponding UTM coordinates.

A7.1.2 Determining the Image Coordinates of GCP's

The image coordinates (line and pixel numbers) of the digitized GCP's were obtained using program GCPMAD. These coordinates are added to the GCP file created in the previous step. This file containing the UTM and the image coordinates is latter used in generating the necessary transformation.

Program GCPMAD can compute the line and pixel coordinates of a specified GCP and then display a segment of the image with the GCP at the center. However, this can only be done when a transformation is available between the UTM coordinates and the image coordinates. Coordinates of atleast five to six GCP's must be avialble for generating the transformation.

About six of the digitized GCP's were located on the image using the Bendix MAD display system. Image coordinates for these GCP's were obtained manually using the cursor option of program GCPMAD. The coordinates of these GCP's are used in automatically locating the other GCP's.

In practice the procedure followed was iterative. The line and pixel numbers of the initial six GCP's were used in generating an approximate transformation. The automatic mode of the program was used in computing the coordinates of the remaining GCP's. If the GCP location was not computed accurately, corrections were made to the location using the cursor option. The transformation is regenerated after correctly identifying an additional four to five GCP's. This procedure was repeated until all the GCP's were precisely located.

The procedure can be sppeded up if the coordinates of the initial five to six GCP's are obtained precisely. Also, it is desirable to discard a GCP, atleast temporarily, if there is any doubt regarding it's true identification.

A7.1.3 Generating the Necessary Transformation

The necessary transformation to map the Landsat data on to the UTM grid was generated using program GCPTRN. The number of coefficients used was 5; and MSS mirror scan velocity correction was always applied when generating the final transformation. The GCP file, containing the UTM and image coordinates, was the input for generating the transformation.

The RMS error for the two sites on both the dates was less than 100 m. In our experience, it was found that using a large number of GCP's would not necessarily improve the accuracies achieved.

A7.1.4 Producing the Corrected Landsat Image

In producing the corrected Landsat image, the transformation generated in the previous step was applied to the input Landsat data. This is the final step and was performed by program SAMUTM to create a disc file of the image.

Pixel size of 50 m by 50 m was selected in this study. In addtion to being square pixels, this selection allows overlaying uniform grid lines on any display to match with the UTM grid lines. Selection of a larger size in meeting the above condition would sacrifice the available resolution; selection of smaller size would create data handling problems and also would mean striving for a resolution that is non-existent.

Producing the corrected image by applying the transformation was the most expensive step in terms of the CPU time. The actual time used depends upon the the size of the output image and the number of coeffcients in the transformation. In this study, program SAMUTM used approximately 3 sec per 1000 pixels to apply the transformation.

APPENDIX B: LISTINGS OF PROGRAMS DEVELOPED

CVALUE.CMD

```
CVALUE.FOR,VEGTXT.FOR,DISKRD.FOR,PRTNUM.FOR,HIST.FOR,CAMP.REL,REL:CCRSL.REL/L
```

```
C                              @@@@@@@@@@
C                              @ CVALUE @
C                              @@@@@@@@@@
C  CVALUE.FOR, DEC. 1978.
c  @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
c  @                        COPYRIGHT NOTICE                          @
c  .                        ----------------                          .
c  @ This program was written by P. Chagarlamudi of The Sibbald @
c  @ Group of Haskins & Sells Associates, 630-99 bank St.,Ottawa@
c  @          It may be used for any purposes of the Department of       @
c  @ Agriculture or of the Government of Canada.                 @
c  @          It may not be reproduced in any form without the       @
c  @ written consent of The Sibbald Group.                          @
c  @          Use by employees of the Government of Canada at the        @
c  @ Canada Centre for Remote Sensing is expressly permitted.       @
c  @          All reproductions of this program must include this        @
c  @ notice.                                                         @
c  @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C  CODE WRITTEN BY
C  PAK CHAGARLAMUDI,HASKINS & SELLS ASSOCIATES.
C  OTTAWA, ONTARIO
C -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
C  CVALUE CAN PRINT THE DIGITAL VALUES OR PRODUCE A HISTOGRAM
C  OF A SMALL PORTION OF LANDSAT DATA.
C  THE DATA MUST BE LOCATED ON A DISK FILE EITHER IN JSC OR OLD FORMAT
C  THE FOLLOWING OPTIONS EXIST IN THIS PROGRAM:
C  (A)TO DECIMATE THE DATA WHEN NOT INTERESTED IN USING ALL THE DATA.
C  (B) TO PRINT THE DIGITAL VALUES IN ALL THE BANDS
C  (C) CAN HANDLE EITHER JSC OR OLD FORMAT (CCRS OR EROS DATA).
C -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
C  THE VALUES OR THE HISTOGRAMS ARE WRITTEN ON FILE(S)(UPTO 3)
C  FOR LATER RETRIEVAL - STAT1.MAP,STAT2.MAP,STAT3.MAP.
C -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
C  ROUTINE CVALUE.FOR IS THE MAIN PROGRAM IN CVALUE PACKAGE.
C  ROUTINES REQUIRED BY CVALUE PACKAGE ARE LISTED IN CVALUE.CMD
C -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
C  VARIABLES:
C  GLOBAL:
C   IBANDS,IBUF,ICAL,IDAT,IDATE,IFID,IFILEM,
C   IFILER,IQSUN,IRTPIX,ISITE,ISTLIN,ISTR
C   JL,JP,LFTPIX,LINE,LN,LSTLIN,LU1,LU2,LU3
C   M,MBLK,MLINE,NB,NBLK,NBS,NC,NF,NFORM,NP,NPT,
C   SUNCOR,SUNELD
C
C###########################################################
      DOUBLE PRECISION FILEN,FILES(3)
      REAL BORDR (500,2),CORR(4)
      INTEGER IFILEM(2),IFILER(2),IDATE(2),IFID(2),ISITE(2)
      INTEGER IBUF(3648),IDAT(550,4),ICAL(4,6,64),IUPAK(2201)
      INTEGER ICOUNT(21),IBANDS(4),NBS(4)
      EQUIVALENCE (IFILER,FILEN)
      COMMON /IONA/IONA.KAKA
      COMMON /MSSD/ IBUF,IUPAK,CORR
      COMMON /CHAN/ IDAT
      COMMON /CAL/ ICAL
      COMMON /LOC/  ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE.ISTR,ISITE
      COMMON /OUT/  LU1,LU2,LU3,FILES
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
      DATA FILES /'STAT1.MAP','STAT2.MAP','STAT3.MAP'/
      DATA KAKA /'N'/
C
```

```
C  SET UP ROUTINE CAMP & STOP WHEN FAILED.
      CALL CAMP
      IF (IONA .NE. KAKA) STOP1000
C  INITIALIZE LOGICAL UNITS
      LU1=21
      LU2=22
      LU3=23
C  QUERRY THE USER RE. PARAMETERS.
      CALL VEGTXT
      SUNCOR=1.
      IF (IQSUN .NE. 0) SUNCOR=COSD(SUNELD)/COSD(37.)
C  GET THE FORMAT OPTION
105         WRITE (5,110)
110         FORMAT(1H ,'FORMAT OPTN. (0-JSC CCRS;1-JSC EROS;2-OLD CCRS)>',$)
      READ (5,510) NQ
      IF (NQ .LT. 0 .OR. NQ .GT. 2) GO TO 105
      NFORM = NQ
      IF (NFORM .NE. 2)GO TO 240
C  READ THE LOOKUP TABLE
      OPEN (UNIT=LU1,ACCESS='SEQIN',FILE=FILEN)
      READ (LU1,210)(((ICAL(I,J,K),K=1,64),J=1,6),I=1,4)
210         FORMAT(1X,32I4)
      CLOSE (UNIT=LU1)
C  WRITE SUPPORTING INFORMATION ON A FILE FOR LATER RETRIEVAL.
240         OPEN (UNIT=LU1,ACCESS='SEQOUT',FILE=FILES(1))
      WRITE (LU1,270) IFID,IDATE
270         FORMAT (1X,'FRAME IDENTIFICATION :',2A5,10X,' D
     *ATA ACQUIRED ON :',2A5,4X)
      WRITE (LU1,272) SUNELD,SUNCOR
272         FORMAT (1X,'SUN ELEVATION :',F4.0,10X,'SUN CORRECTION FACTOR :'
     *,F6.4,2X)
      WRITE (LU1,274) IFILER
274         FORMAT (1X,'MSS RADIOMETRIC CORRECTION TABLES FROM FILE :',2A5)
      WRITE (LU1,276)IFILEM
276         FORMAT (1X,'MSS DATA INPUT FILE : ',2A5,3X)
      WRITE (LU1,278)ISITE
278         FORMAT (1X,'SITE : ',2A5)
C  INITIALIZE THE DISK FILE
      IF (NFORM .EQ. 2)  CALL ODSKST
      IF (NFORM .NE. 2) CALL NDSKST
C  WE HAVE TO PROCESS "MLINE" LINES AND NP PIXELS FROM EACH LINE
      MLINE=(LSTLIN-ISTLIN+1) / JL
C@       TYPE*,MLINE,NP,NPT
C  WRITE PARAMETERS ON FILE FOR LATER RETRIEVAL
      WRITE (LU1,315)
      WRITE (LU1,320) ISTLIN,LSTLIN,LFTPIX,IRTPIX
315         FORMAT (1X,'STATS SHOWN WERE DERIVED FROM THE FOLLO
     *WING AREA :   ')
320         FORMAT (1X,10X,'LINES :',I4,' TO ',I4,' & PIXELS
     *:',I4,' TO ',I4,3X)
      WRITE (LU1,325)JL,JP
325         FORMAT (1X,'DECIM. FACT.- LINES :',I2,'; PIXELS :',I2)
C  SELECT OPTION AND THEN GO TO APPROPRIATE ROUTINE.
      WRITE (5,500)
500         FORMAT (1H ,'SELECT OPTN.(1-LIST VALS;2-HISTOGRAMS)>',$)
      READ (5,510) NQ
510         FORMAT (I)
      IF (NQ .EQ. 1) CALL PRTNUM
      IF (NQ .EQ. 2) CALL HIST
      RETURN
      END
```

```
C                                  @@@@@@@@@@@@@@
C                                  @ PRTNUM.FOR @
C                                  @@@@@@@@@@@@@@
C*****SUBROUTINE PRTNUM
C-  -   -   -   -   -   -   -   -   -   -   -   -   -
C  PRINTS NUMBERS FOR ALL THE BANDS
C  PART OF CVALUE PACKAGE
C  ALL VARIABLES ARE PASSED THROUGH COMMON AREAS.
C-  -   -   -   -   -   -   -   -   -   -   -   -   -
C  VARIABLES:
C  GLOBAL  : IDAT,LFTPIX,NB,MLINE
C  LOCAL   : NDUM1,NDUM2
C-  -   -   -   -   -   -   -   -   -   -   -   -   -
      SUBROUTINE PRTNUM
C#########################################################
      INTEGER IBANDS(4),NBS(4),IDAT(550,4),ICOUNT(21)
      INTEGER IFILEM(2),IFILER(2),IFID(2),IDATE(2),ISITE(2)
      REAL BORDR(500,2)
      DOUBLE PRECISION FILES(3)
      COMMON /CHAN/ IDAT
      COMMON /LOC/ ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON/IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/ NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
      COMMON /DESIR1/ IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /OUT/ LU1,LU2,LU3,FILES
C
      OPEN (UNIT=LU2,ACCESS='SEQOUT',FILE=FILES(2))
      OPEN (UNIT=LU3,ACCESS='SEQOUT',FILE=FILES(3))
      K=1
      WRITE(LU1,70)IFID,IDATE,K,ISITE
      K=2
      WRITE (LU2,70) IFID,IDATE,K,ISITE
  70        FORMAT (1H1,10X,2A5,' FRAME IMAGED ',2A5,10X,' PAGE ',I1
     *,5X,'SITE ',2A5)
      K=3
      WRITE (LU3,70) IFID,IDATE,K,ISITE
      NDUM1=LFTPIX+25*JP
      NDUM2=LFTPIX+50*JP
      WRITE (LU1,80) LFTPIX,JP
      WRITE (LU2,80) NDUM1,JP
      WRITE (LU3,80) NDUM2,JP
 80        FORMAT (1H ,//,' START PIXEL NUMBER =',I4,'  PIXEL DEC. F
     *ACTOR =',I2,//)
      DO 50 I=1,MLINE
C  GET THE REQUIRED PIXELS FROM THE CURRENT SCAN LINE.
      IF (NFORM .EQ. 2) CALL OSETLN
      IF (NFORM .NE. 2) CALL NSETLN
      WRITE (LU1,90)LINE
      WRITE (LU2,90)LINE
      WRITE (LU3,90)LINE
 90        FORMAT (1X,/,' LINE NUMBER =',I4,/)
      DO 110 J=1,NB
130        WRITE (LU3,120) J,(IDAT(K,J),K=51,75)
140        WRITE (LU2,120) J,(IDAT(K,J),K=26,50)
150        WRITE (LU1,120) J,(IDAT(K,J),K=1,25)
120        FORMAT (1H*,'BAND=',I1,2X,10I4,2X,10I4,2X,10I4)
110        CONTINUE
 50        CONTINUE
      RETURN
      END
```

```
C                                 @@@@@@@@@@@@
C                                 @ HIST.FOR @
C                                 @@@@@@@@@@@@
C-  -   -   -   -   -   -   -   -   -   -   -   -   -
C  ROUTINE HIST.FOR, DEC. 1978.
C  HIST PRODUCES A HISTOGRAM FOR DATA FROM A SPECIFIED AREA.
C  PAK CHAGARLAMUDI,HASKINS & SELLS ASSOCIATES,OTTAWA.
C  MODIFIED TO ACCEPT DATA FROM EITHER CCRS JSC,CCRS EROS,CCRS OLD
C  ORIGINAL CODE WRITTEN BY M.M. TAYLOR.
C  FORMAT DISK FILE DAT. EXTENDED TO ACCEPT 256 LEVELS AND 8 BIT DATA.
C  COMPATIBLE WITH OTHER ROUTINES OF THE VARIOUS ANALYSIS ROUTINES.
C  HISTOGRAMS ARE GENERATED FROM THE DATA OVER THE AREA SPECIFIED BY
C  LINES ISTLIN TO LSTLIN & PIXELS LFTPIX TO IRTPIX.
C  THE VALUES USED MAY BE RADIOMETRICALLY & LINEARLY CORRECTED BY THE
C  TABLE. SPECIFIED & MAY BE SUN CORRECTED TO THE STANDARD SUN ANGLE.
C  VALUES MAY BE 6,7, OR 8 BIT -USER SPECIFIIES.
C  MAX NUMBER OF LEVELS IN THE HISTOGRAM IS 256.
C  MIN & MAX VALUES FOR EACH BAND ARE GIVEN IF REQUESTED.
C  THE INCREMENT FOR THE LEVELS IS CALCULATED BY DIVIDING THE
C  MAX VALUE POSIBLE BY THE # OF LEVELS.  THIS MAY BE CHANGED LATER
C  TO ALLOW THE USER TO SPECIFY THE LEVELS IN EACH BAND SHOULD THIS
C  BECOME VALUABLE.
C  HISTOGRAMS ARE MADE FOR ALL 4 BANDS UNLESS YOU SAY OTHERWISE.
C  OUTPUT IS ON STAT1.MAP UNIT 21.
C  GET STAT1.MAP ON LPT USING FILE:FORTRAN SWITCH USING Q .
C-  -   -   -   -   -   -   -   -   -   -   -   -   -
        SUBROUTINE HIST
C#################################################################
        IMPLICIT INTEGER (A-Z)
        DOUBLE PRECISION FILES (3)
        REAL SUM,TEMP,BORDR(500,2)
        DIMENSION MULTY(4),ICOUNT (21),IDAT(550,4)
        DIMENSION BIT(4),BANDS(4),INC(4),HIST(4,256),MIN(4),MAX(4)
        COMMON /CHAN/IDAT
        COMMON /LOC/ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
        COMMON /OUT/LU1,LU2,LU3,FILES
        COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
        COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
        DATA STAR/'*'/
C
C        SET UP DEFAULT VALUES
        BAND = 4
        DO 100 I=1,4
        MAX(I)=0
        MIN(I)=256
        BANDS(I)=I+3
        MULTY(I)=1
 100        BIT(I)=8
        MINMAX = 1
        LEVS = 256
C
C        GIVE COMMAND LIST
        TYPE 110
 110        FORMAT(1H ,'USE THE FOLLOWING COMMAND LIST TO CHANGE DEFAULTS'/
     *             1H ,'BIT - # BITS IN RADIOMETRICALLY CORRECTED DATA'/
     *             1H ,'BAND - WHICH BANDS TO CREATE HISTOGRAMS FOR'/
     *             1H ,'NOMIN - MIN & MAX VALUES FOR THE BANDS WILL NOT ',
     *             'BE CALCULATED'/
     *             1H ,'LEVS - # OF LEVELS IN THE HISTOGRAMS'/
     *             1H ,'OK - DEFAULTS USED:BIT=8,BAND=ALL,MINMAX,LEVS=256'/
     *             1H ,'GO - START EXECUTION')
 112        ORDER = '    '
        TYPE 114,STAR
 114        FORMAT(1H ,A1)
```

```
      ACCEPT 113,ORDER
 113       FORMAT(A5)
C
      IF(ORDER.NE.'BAND ')GO TO 125
 115       TYPE 117
 117       FORMAT(1H ,'HISTOGRAMS SHOULD BE MADE FOR WHICH BANDS?')
      DO 118 I=1,4
 118       BANDS(I)=0
      BAND=0
      ACCEPT 119,(BANDS(I),I=1,4)
 119       FORMAT(4I)
      IF(BANDS(1).EQ.0)GO TO 115
      DO 120 I=1,4
      IF(BANDS(I).EQ.0)GO TO 121
      IF(BANDS(I).LT.4.OR.BANDS(I).GT.7)GO TO 115
 120       BAND = BAND+1
 121       TYPE 122,(BANDS(I),I=1,BAND)
 122       FORMAT(1H ,'HISTOGRAMS ARE TO BE MADE FOR BANDS',4(2X,I2))
      GO TO 112
C
 125       IF(ORDER.NE.'BIT  ')GO TO 140
 126       TYPE 127,(BANDS(I),I=1,BAND)
 127       FORMAT(1H ,'TYPE # OF SIGNIFICANT BITS IN DATA FOR ',
     *           'EACH BAND'/1H ,'BANDS ',4(2X,I2))
      ACCEPT 128,(BIT(I),I=1,4)
 128       FORMAT(4I)
      DO 130 I=1,BAND
      IF(BIT(I).LT.6.OR.BIT(I).GT.8)GO TO 126
      TYPE 129,BANDS(I),BIT(I)
 129       FORMAT(1H ,'VALUES IN BAND ',I2,' WILL BE ASSUMED TO BE ',
     *           I2,' BIT')
      IF (BIT (I) .EQ. 8) MULTY(I)=1
      IF (BIT (I) .EQ. 7) MULTY(I)=2
      IF (BIT (I) .EQ. 6) MULTY(I)=4
 130       CONTINUE
      GO TO 112
C
 140       IF(ORDER.NE.'NOMIN')GO TO 145
C      MINMAX=0 MEANS NO MIN/MAX VALUES WANTED
      MINMAX = 0
      GO TO 112
C
 145       IF(ORDER.NE.'LEVS ')GO TO 150
 146       TYPE 147
 147       FORMAT(1H ,'GIVE NEW # OF LEVELS FOR THE HISTOGRAMS(MAX 256)')
      ACCEPT 148,LEVS
 148       FORMAT(I4)
      IF(LEVS.LT.1.OR.LEVS.GT.256) GO TO 146
      GO TO 112
C
 150       IF(ORDER.EQ.'OK   ') GO TO 155
      IF(ORDER.EQ.'GO   ') GO TO 155
      GO TO 112
C
C      READY TO GO    EMPTY BUFFERS
 155       DO 160 I=1,4
      DO 160 J=1,256
 160       HIST(I,J) = 0
      DO 161 I=1,BAND
      INC(I)=2**BIT(I)/LEVS
      IF (INC(I) .LE. 0) INC(I)=1
C@     TYPE *,INC(I)
 161       CONTINUE
C     FOR EVERY LINE IN THE ARE DO*
```

```
      DO 300 I=1,MLINE
      IF (NFORM .EQ. 2) CALL OSETLN
      IF (NFORM .NE. 2) CALL NSETLN
C      FOR EVERY PIXEL IN THE LINE DO :
      DO 200 J=1,NP
C      FOR EVERY BAND SPECIFIED DO:
      DO 190 K=1,BAND
      KK=BANDS(K)-3
      MSS=(IDAT(J,KK)-1)/MULTY(K)+1
C      CHECK IF MIN OR MAX
      IF(MINMAX.EQ.0)GO TO 180
      IF(MSS.LT.MIN(K)) MIN(K)=MSS
      IF(MSS.GT.MAX(K)) MAX(K)=MSS
C      PUT INTO HISTOGRAM
  180      DO 170 NN=1,LEVS
      IF(MSS.GE.NN*INC(K)) GO TO 170
      HIST(K,NN) = HIST(K,NN)+1
      GO TO 190
  170      CONTINUE
  190      CONTINUE
  200      CONTINUE
  300      CONTINUE
C      NOW READY FOR PRINTING HISTOGRAMS
C      FOR EACH HISTOGRAM PRINT:
      DO 400 I=1,BAND
      WRITE(LU1,350)BANDS(I),BIT(I),INC(I)
  350      FORMAT(/1H0,'BAND',I2,' (',I2,' BIT VALUES IN INCREMENTS ',
     *            'OF ',I2,' )')
      WRITE(LU1,352) (HIST(I,J),J=1,LEVS)
  352      FORMAT(16(1H ,16I8/))
      WRITE(LU1,355)BANDS(I),MIN(I),MAX(I)
  355      FORMAT(1H ,'FOR BAND ',I2,' MINIMUM =',I4,',  MAXIMUM =',I4)
  400      CONTINUE
C
      WRITE (LU1,370)
  370      FORMAT (1H1,10X,'FOLLOWING ARE THE PERCENT DISTRIBUTIONS',/)
      DO 500 I=1,BAND
      SUM=0.
      DO 450 J=1,LEVS
  450      SUM=SUM+HIST(I,J)
      DO 480 J=1,LEVS
      TEMP=FLOAT(HIST(I,J))
  480      HIST(I,J)=IFIX(TEMP*100./SUM)
      WRITE(LU1,350)BANDS(I),BIT(I),INC(I)
      WRITE(LU1,352)(HIST(I,J),J=1,LEVS)
  500      CONTINUE
      RETURN
      END
```

ALLROK.CMD

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ALLROK.FOR,VEGTXT.FOR,DISKRD.FOR,WRTHD.FOR,CNTPIX.FOR,REL:CCRSL.REL/L
```

```
C                              @@@@@@@@@@@@
C                              @  ALLROK  @
C                              @@@@@@@@@@@@
C  ALLROK.FOR, JAN. 1979.
C  CODE WRITTEN BY
C  PAK CHAGARLAMUDI, UNIV. OF MANITOBA
C  OTTAWA, ONTARIO
C-    -    -    -    -    -    -    -    -    -
C  THIS SUIT OF PROGRAMS READS A DISK FILE OF A SMALL
C  PORTION OF LANDSAT DATA AND THEN IDENTIFIES POSSIBLE OUTCROPS.
C  THE FOLLOWING OPTIONS EXIST IN THIS PROGRAM:
C  (A)TO DECIMATE THE DATA WHEN NOT INTERESTED IN USING ALL THE DATA.
C  (B) TO CREATE THE LINE PRINTER MAP.
C  (C) TO COUNT PIXELS IN A SUBSET OF THE MAP FOR ALL THE CLASSES.
C  (D) CAN HANDLE EITHER JSC (CCRS OR EROS DATA) OR OLD FORMAT.
C  THE SYMBOLS FOR THE CLASSES ASSIGNED AND OTHER PERTINENT
C  THEMATIC MAPS ARE WRITTEN ON FILES (UPTO 3) FOR LATER RETRIEVAL.
C  THESE FILES MAY BE PRINTED EITHER ON THE LINE PRINTER OR
C  ON A TERMINAL.
C-    -    -    -    -    -    -    -    -    -
C  ROUTINE ALLROK.FOR IS THE MAIN PROGRAM IN ALLROK PACKAGE.
C  ROUTINES REQUIRED BY ALLROK PACKAGE ARE LISTED IN ALLROK.CMD
C-    -    -    -    -    -    -    -    -    -
C  VARIABLES:
C  GLOBAL:
C   AR,FEAT1,IBANDS,IBUF,ICAL,ICLS,IDAT,IDATE,IFID,IFILEM,
C   IFILER,IQSUN,IRTPIX,ISITE,ISTLIN,ISTR
C   JL,JP,LFTPIX,LINE,LN,LSTLIN,LU1,LU2,LU3
C   M,MBLK,MLINE,NB,NBLK,NBS,NC,NF,NFORM,NP,NPT,
C   RPS1,RPS2,SUNCOR,SUNELD,SYMBL
C################################################################
      DOUBLE PRECISION ICLS (21)
      DOUBLE PRECISION FILEN,FILES(3)
      REAL BORDR (500,2),CORR(4)
      INTEGER IFILEM(2),IFILER(2),IDATE(2),IFID(2),ISITE(2)
      INTEGER IBUF(3648),IDAT(550,4),ICAL(4,6,64),IUPAK(2201)
      INTEGER SYMBL(21),AR(550),IS5(21),IS7(21),ISR(21),ICOUNT(21)
      INTEGER KF(6),IBANDS(4),NBS(4),FEAT1(21)
      EQUIVALENCE (IFILER,FILEN)
      COMMON /MSSD/ IBUF,IUPAK,CORR
      COMMON /CHAN/ IDAT
      COMMON /CAL/ ICAL
      COMMON /LOC/  ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /OUT/  LU1,LU2,LU3,FILES
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
      COMMON /COUNT/ MTRL,MBLL
      DATA FILES /'ROCK1.MAP','ROCK2.MAP','ROCK3.MAP'/
C
C  INITIALIZE LOGICAL UNITS
      LU1=21
      LU2=22
      LU3=23
C  QUERRY THE USER RE. PARAMETERS.
      CALL VEGTXT
      SUNCOR=1.
      IF (IQSUN .NE. 0) SUNCOR=COSD(SUNELD)/COSD(37.)
C  CHANGE THE DEFAULT PARAMETERS IF REQUESTED
      CALL DSRROK
      IF (NFORM .NE. 2)GO TO 240
C  READ THE LOOKUP TABLE
```

```
      OPEN (UNIT=LU1,ACCESS='SEQIN',FILE=FILEN)
      READ (LU1,210)(((ICAL(I,J,K),K=1,64),J=1,6),I=1,4)
210      FORMAT(1X,32I4)
      CLOSE (UNIT=LU1)
C  WRITE SUPPORTING INFORMATION ON A FILE FOR LATER RETRIEVAL.
240      OPEN (UNIT=LU1,ACCESS='SEQOUT',FILE=FILES(1))
      WRITE (LU1,270) IFID,IDATE
270      FORMAT (1X,'FRAME IDENTIFICATION :',2A5,10X,' D
    *ATA ACQUIRED ON :',2A5,4X)
      WRITE (LU1,272) SUNELD,SUNCOR
272      FORMAT (1X,'SUN ELEVATION :',F4.0,10X,'SUN CORRECTION FACTOR :'
    *,F6.4,2X)
      WRITE (LU1,274) IFILER
274      FORMAT (1X,'MSS RADIOMETRIC CORRECTION TABLES FROM FILE :',2A5)
      WRITE (LU1,276)IFILEM
276      FORMAT (1X,'MSS DATA INPUT FILE : ',2A5,3X)
      WRITE (LU1,278) ISITE
278      FORMAT (1X,'SITE : ',2A5)
C  INITIALIZE THE DISK FILE
      IF (NFORM .EQ. 2)  CALL ODSKST
      IF (NFORM .NE. 2) CALL NDSKST
      TYPE *,LN
C  WE HAVE TO PROCESS "MLINE" LINES AND NP PIXELS FROM EACH LINE
      MLINE=(LSTLIN-ISTLIN+1) / JL
      NF=NP/LN
      IF (MOD(NP,LN) .GT. 0) NF=NF+1
C  ASSIGN APPROPRIATE STATEMENTS NUMBERS TO IGO TO WRITE FILE(S)
      IF (NF .EQ. 1) ASSIGN 470 TO IGO
      IF (NF .EQ. 2) ASSIGN 460 TO IGO
      IF (NF .EQ. 3) ASSIGN 450 TO IGO
      TYPE*,MLINE,NP,NPT,NF,LN
C  WRITE PARAMETERS ON FILE FOR LATER RETRIEVAL
      WRITE (LU1,292) NC
292      FORMAT (1X,'# OF CLASSES:',I2)
      WRITE (LU1,294) MLINE,NF,NC,LN
294      FORMAT (1X,4I)
      WRITE (LU1,285)
285      FORMAT (1X,'DETAILS OF CLASSIFICATION')
      WRITE (LU1,290)
290      FORMAT (1X,'CLASS #',4X,'NAME',9X,'BAND-5 BAND-7 FACTR SYMBOL')
      DO 300 I=1,NC
      WRITE (LU1,310) I,ICLS(I),IS5(I),IS7(I),ISR(I),SYMBL(I)
310      FORMAT (1X,2X,I2,5X,A10,3X,3I6,6X,A1,2X)
300      CONTINUE
      WRITE (LU1,315)
      WRITE (LU1,320) ISTLIN,LSTLIN,LFTPIX,IRTPIX
315      FORMAT (1X,'THE AREA SHOWN ON THE MAP HAS THE FOLLO
    *WING CO-ORDINATES :  ')
320      FORMAT (1X,10X,'LINES :',I4,' TO ',I4,' & PIXELS
    *:',I4,' TO ',I4,3X)
      WRITE (LU1,325)JL,JP
325      FORMAT (1X,'DECIM. FACT.- LINES :',I2,'; PIXELS :',I2)
C  WRITE OTHER INFORMATION ON FILE FOR LATER RETRIEVAL
      CALL WRTHD1
      DO 400 I=1,NF*2,2
      KF(I)=(I/2)*LN+1
      KF(I+1)=KF(I)+LN-1
400      CONTINUE
      TYPE *,NF,KF
      IF (NCOUNT .EQ. 1) CALL INICNT
      IF (NFRINT .EQ. 0) ASSIGN 410 TO IGO
C SELECT CLASS PROC.
490      WRITE (5,500)
500      FORMAT (1X,'CLASSIFICATION PROC.(1/2/3/4) :'$)
```

```
      READ (5,510) NQ
 510       FORMAT (I)
      TYPE *,NQ
      IF (NQ .LT. 1) GO TO 490
      IF (NQ .GT. 4 ) GO TO 490
      DO 410 I=1,MLINE
C  GET THE REQUIRED # OF PIXELS FROM THE CURRENT SCAN LINE
      IF (NFORM .EQ. 2) CALL OSETLN
      IF (NFORM .NE. 2) CALL NSETLN
C  DECIDE ON THE CLASS TO WHICH EACH DATA POINT BELONGS TO
      IF (NQ .EQ. 1) CALL CLROK1
      IF (NQ .EQ. 2) CALL CLROK1
      IF (NQ .EQ. 3) CALL CLROK1
      IF (NQ .EQ. 4) CALL CLROK1
C  ASSIGN SYMBOLS FOR ALL CLASSES TO PRINT ON LPT.
      IF (NPRINT .EQ. 1) CALL ALSYMB
C  WRITE THE CLASS SYMBOLS FOR THIS LINE ON A FILE
      GO TO IGO
 450       WRITE (LU3,420) LINE,(AR(K),K=KF(5),KF(6))
 460       WRITE (LU2,420) LINE,(AR(K),K=KF(3),KF(4))
 470       WRITE (LU1,420) LINE,(AR(K),K=KF(1),KF(2))
 420       FORMAT (1H*,I4,1X,110A1)
 410       CONTINUE
C  PRINT THE RESULTS FROM COUNTING
      IF (NCOUNT .EQ. 1) CALL PRICNT
C      PUT THE BOTTOM SET OF TIC MARKS
      CALL WRTHD2
      RETURN
      END
```

```
C
C                                    @@@@@@@@@@@@@@@
C                                    @ DSRROK.FOR @
C                                    @@@@@@@@@@@@@@@
C  ROUTINE DSRROK.FOR, JAN. 1979.
C-    -    -    -    -    -    -    -    -    -    -
C  CODE WRITTEN BY
C        PAK CHAGARLAMUDI
C        OTTAWA, ONTARIO
C-    -    -    -    -    -    -    -    -    -    -
C  ROUTINE DSRROK.FOR IS A PART OF "ALLROK" PACKAGE.
C  THIS ROUTINE DISPLAYS THE CURRENT CLASS NAMES, FACTOR
C  VALUES, AND SYMBOLS ASSIGNED TO CLASSES.
C  ALSO ALLOWS THE USER TO ALTER THE CONTENTS IF SO DESIRED.
C-    -    -    -    -    -    -    -    -    -    -
C  VARIABLES:
C  GLOBAL: FEAT1,ICLS,LN,NC,SYMBL
C  LOCAL : NQ
C-    -    -    -    -    -    -    -    -    -    -
      SUBROUTINE DSRROK
C#####################################################
      DOUBLE PRECISION ICLS (21)
      INTEGER IS5(21),IS7(21),ISR(21),ICOUNT(21)
      REAL BITS (2),BORDR(500,2)
      INTEGER SYMBL (21),AR(550)
C  COMMON AREAS
C
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /DEFF/  NC,LN,NPT,NP,MLINE,JL,JP,NF
C
      DATA IS5 /0,100,0,0,0,0,0,1550,0,55,0,0,0,0,0,0,0,0,0,0,0/
      DATA IS7 /20,0,0,2800,0,46,0,0,0,0,0,0,0,0,0
     *,0,0,0,0,0/
      DATA ISR /0,0,185,145,175,0,0,0,0
     *,0,0,0,0,0,0,0,0,0,0,0,0/
      DATA SYMBL /'.','C',' ','D','L','B','G','N','S','+',' ',' '
     *,' ',' ',' ',' ',' ',' ',' ',' ',' '/
      DATA ICLS /'WATER','CLOUD','VEGETATION','DOLOMITE.','SOIL/BLDRS'
     *,'BASALT','GRAN/FELS.','SAND','SANDSTONES','SNOW/ICE','
     *','          ','          ','          ','          ','
     *','          ','          ','          ','          '/
C  INITIALIZE NUMBER OF CLASSES AND BUFFER SIZE FOR EACH SECTION
C  AND THE IBP LEVEL,FORMAT,PRINT,COUNT OPTIONS.
      NQ=0
      IBP=1
      NC=10
      LN=110
      NFORM=2
      NPRINT=1
      NCOUNT=0
C  QUERRY THE USER IF HE WANTS TO SEE THE DEFAULT VALUES
C  IF THE USER DESIRES, DISPLAY 8 ALTER  WHEN REQUESTED
90      WRITE (5,95)
95        FORMAT (//)
      WRITE (5,100)
100       FORMAT (1X,'WANT TO SEE THE CURRENT VALUES (Y/N) ?',S)
      READ (5,110) NQ
110       FORMAT (A1)
      IF (NQ .NE. 'Y') GO TO 300
      WRITE (5,114) LN
114       FORMAT (1X,'CURRENT BUFFER SIZE FOR EACH SECTION OF MAP :',I3)
      IF (NFORM .EQ. 0) WRITE (5,510)
      IF (NFORM .EQ. 1) WRITE (5,520)
```

```
      IF (NFORM .EQ. 2) WRITE (5,530)
510     FORMAT (1X,'ASSUMING JSC FORMAT - CCRS DATA')
520     FORMAT (1X,'ASSUMING JSC FORMAT - EROS DATA')
530     FORMAT (1X,'ASSUMING OLD FORMAT - CCRS DATA')
      IF (NPRINT .EQ. 0) WRITE (5,540)
      IF (NPRINT .EQ. 1) WRITE (5,550)
540     FORMAT (1X,'WILL NOT CREATE LINE PRINTER MAP')
550     FORMAT (1X,'WILL BE CREATING LINE PRINTER MAP')
      IF (NCOUNT .EQ. 0) WRITE (5,560)
      IF (NCOUNT .EQ. 1) WRITE (5,570)
560     FORMAT (1X,'WILL NOT COUNT PIXELS')
570     FORMAT (1X,'WILL BE COUNTING PIXELS')
      WRITE (5,120)
 120     FORMAT (1X,'THE FOLLOWING CLASSES ARE AVAILABLE NOW :',/,
     *1X,'CLASS #',4X,'NAME',9X,'BAND-5 BAND-7 FACTR SYMBOL',/)
      DO 130 I=1,NC
      WRITE (5,140) I,ICLS(I),IS5(I),IS7(I),ISR(I),SYMBL(I)
 140     FORMAT (1X,2X,I2,5X,A10,3X,I6,I6,I6,6X,A1)
 130     CONTINUE
C  IF THE USER DESIRES, CHANGE THE VALUES
      WRITE (5,132)
132     FORMAT (1X,'WANT TO CHANGE ANY OF THE VALUES (Y/N) ?',$)
      READ (5,110) NQ
      IF (NQ .NE. 'Y') GO TO 300
      WRITE (5,136) LN
136     FORMAT (1X,'OLD BUFF SIZE =',I3,'; NEW(MAX-110;0-KEEPS OLD) ??',$)
      READ (5,155) NQ
      IF (NQ .NE. 0) LN=NQ
      WRITE (5,580) NFORM
580     FORMAT (1X,'FORMAT OPTION =',I2,' NEW(0-JSC CCRS;1-JSC EROS
     *; 2-OLD CCRS):',$)
      READ (5,155) NQ
      NFORM=NQ
585     WRITE (5,590) NPRINT
590     FORMAT (1X,'PRINT OPTION =',I2,'NEW(1-TO CREATE MAP; 0-OTHER
     *WISE):',$)
      READ (5,155) NPRINT
      WRITE (5,600) NCOUNT
600     FORMAT (1X,'COUNT OPTION =',I2,'NEW(1-TO COUNT; 0 OTHERWISE):',$)
      READ (5,155) NCOUNT
 145     WRITE (5,150)
 150     FORMAT (1X,'CLASS # YOU WISH TO CHANGE ("0" FOR NONE) ?',$)
      READ (5,155) NQ
 155     FORMAT (I)
      IF (NQ .EQ. 0) GO TO 90
C  CHECK IF CLASS # IS AVAILABLE IN THE CURRENT BUFFER
      IF (NQ .LT. 0  .OR.  NQ .GT. NC) GO TO 310
      WRITE (5,160) NQ
 160     FORMAT (1X,'CLASS # :',I2)
      WRITE (5,170) ICLS (NQ)
 170     FORMAT (1X,'OLD NAME =',A10,' NEW ?',$)
      READ (5,180) ICLS (NQ)
 180     FORMAT (A10)
      WRITE (5,190) SYMBL(NQ)
 190     FORMAT (1X,'OLD SYMBOL =',A1,' NEW ?',$)
      READ (5,110) SYMBL(NQ)
      WRITE (5,200) IS5(NQ),IS7(NQ),ISR(NQ)
 200     FORMAT (1X,'OLD VALUES =',3I5,' NEW ?',$)
      READ (5,210) IS5(NQ),IS7(NQ),ISR(NQ)
 210     FORMAT (3I)
      GO TO 145
C  NORMAL RETURN
 300     RETURN
C  ERROR MESSAGE ;   STOP IF REQUIRED
```

```
310         WRITE (5,320) NQ,NC
320         FORMAT (1X,'WANTED TO CHANGE CLASS # :',I2,/,
   *1X,'# OF CLASSES ALLOWED AT PRESENT ARE :',I2,/
   *1X,'WANT TO EXIT (0)  OR  PROCEED (1) ?',$)
     READ (5,155) NQ
     IF (NQ .EQ. 1) GO TO 145
     STOP
     END
```

```
C                                  @@@@@@@@@@@@@@
C                                  @ CLROK1.FOR @
C                                  @@@@@@@@@@@@@@
C  ROUTINE CLROK1.FOR, JAN 1979
C-    -    -    -    -    -    -    -    -    -    -
C  CODE WRITTEN BY
C
C  PAK CHAGARLAMUDI,UNIV. OF MANITOBA.
C  OTTAWA, ONTARIO
C
C-    -    -    -    -    -    -    -    -    -    -
C  ROUTINE CLROK1.FOR IS A PART OF  ALLROK PACKAGE
C  THIS ROUTINE DECIDES ON THE CLASS TO WHICH EACH PIXEL
C  BELONGS TO AND THEN ASSIGNS THE NUMBER FOR THAT CLASS
C  NOTE: ALL PARAMETERS ARE PASSED THROUGH COMMON AREAS.
C  SEE COMMON AREAS FOR DETAILS.
C
C-    -    -    -    -    -    -    -    -    -    -
C  VARIABLES:
C  GLOBAL: AR,FEAT1,IDAT,NFORM,NP,RPS1,RPS2,SUNCOR,SYMBL
C  LOCAL : ISRT
C
C-    -    -    -    -    -    -    -    -    -    -
      SUBROUTINE CLROK1
C#############################################################
      DOUBLE PRECISION ICLS (21)
      INTEGER AR(550),SYMBL(21),IDAT(550,4),IS5(21),IS7(21),ISR(21)
      INTEGER ICOUNT (21)
      REAL BORDR(500,2)
C  COMMON AREAS
      COMMON /CHAN/ IDAT
      COMMON /DESIR/  ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DEFF/  NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /LOC/ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /COUNT/MTRL,MBLL
C
C  CHECK IF COUNTING IS REQUIRED, IF NOT AVOID COUNTING.
      ASSIGN 500 TO KOKO
      IF (NCOUNT .EQ. 0) ASSIGN 90 TO KOKO
      IF (LINE .LT. MTRL .OR. LINE .GT. MBLL) ASSIGN 90 TO KOKO
      KJ=(LINE-MTRL)/JL +1
      NSPXL=IFIX(BORDR(KJ,1)+0.5)
      NLPXL=IFIX(BORDR(KJ,2)+0.5)
C##      TYPE *,KJ,LINE,NSPXL,NLPXL
C  CLASSIFY EACH PIXEL IN THIS LINE
      DO 90 I=1,NP
C  CHECK FOR WATER
      IF (IDAT(I,4) .LT. IS7(1) ) GO TO 100
C  CHECK FOR CLOUD
      IF (IDAT(I,2) .GT. IS5(2) ) GO TO 200
C  CHECK FOR SNOW/ICE
      IF (IDAT (I,1) .GT. IS5(10) ) GO TO 220
C  CHECK FOR VEGETATION
      IS=IDAT(I,4)*100/IDAT(I,2)
      IF (IS .GT. ISR(3)) GO TO 250
      GO TO 260
C  MUST BE WATER.
100      NOW=1
      GO TO 300
C  BELONGS TO CLOUD
200      NOW=2
      GO TO 300
C  BELOGS TO SNOW ICE
220      NOW=10
      GO TO 300
```

```
C  BELONGS TO VEGETATION
 250        NOW=3
        GO TO 300
C  MAY BE OUTCROP. WE WANT TO EXAMINE THIS PIXEL FURTHER.
C  SPLIT THIS INTO TWO GROUPS
 260        IN=IDAT(I,3)*IDAT(I,4)
        IF (IN .GT. IS7(4) ) GO TO 700
        GO TO 265
C  MAY BE SAND OR DOLOMITE
 700        IM=IDAT(I,1)*IDAT(I,2)
        IF (IM .GT. IS5(8) ) GO TO 270
C  MUST BE DOLOMITE
        GO TO 670
C
 265        IF (IS .GE. ISR(4) ) GO TO 600
C  BELONGS TO GROUP1 (CLASS 8 8 9)
C  CHECK IF IT IS SAND
        IF (IM .GT. IS5(8) ) GO TO 270
C  MUST BE CLASS 9 - SST
        NOW=9
        GO TO 300
C  MUST BE CLASS 8 - SAND
 270        NOW=8
        GO TO 300
C
C  BELONGS TO GROUP 2
 600        IF (IN .GT. IS7(4) ) GO TO 670
        IF (IS .GE. ISR(5) ) GO TO 680
C  CHECK IF IT BELONGS TO CLASS 6 - BASALT
        IF (IDAT(I,3) .LE. IS7(6) ) GO TO 690
C  BELONGS TO CLASS 7 - GRANITES/FELSITE
        NOW=7
        GO TO 300
C  BELONGS TO CLASS 4 - DOLOMITES
 670        NOW=4
        GO TO 300
C  BELONGS TO CLASS 5 - SOIL/BOULDERY
 680        NOW=5
        GO TO 300
C  BELONGS TO CLASS 6 - BASALT
 690        NOW=6
        GO TO 300
 300        AR(I)=NOW
        GO TO KOKO
 500        KJ=LFTPIX+(I-1)*JP
        IF (KJ .LT. NSPXL .OR. KJ .GT. NLPXL) GO TO 90
        ICOUNT (NOW)=ICOUNT(NOW)+1
 90         CONTINUE
        RETURN
        END
```

```
C*******SUBROUTINE ALSYMB
```

```
C                                   @@@@@@@@@@@@@
C                                   @ WRTHD.FOR @
C                                   @@@@@@@@@@@@@
C  CONTAINS WRTHD1,WRTHD2. JULY 1978.
C*******SUBROUTINE WRTHD1
C-    -    -    -    -    -    -    -    -    -    -
C  WRITES ANNOTATION ON FILES FOR PRINTING.
C-    -    -    -    -    -    -    -    -    -    -
C  VARIABLES:
C  GLOBAL: FILES,IDATE,IFID,ISITE,JP,LFTPIX,LN
C  LOCAL : IP INTEGER SIZE=11, CONTAINS PIXEL NUMS. FOR TIC MARKS.
C  SEE THE COMMON AREAS.
C-    -    -    -    -    -    -    -    -    -    -
      SUBROUTINE WRTHD1
C#################################################################
      DOUBLE PRECISION IDUM (11),FILES(3)
      INTEGER IP(11),IFILEM(2),IFILER(2),IDATE(2),IFID(2),ISITE(2)
      COMMON /LOC/ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /OUT/LU1,LU2,LU3,FILES
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
C
      OPEN(UNIT=LU2,ACCESS='SEQOUT',FILE=FILES(2))
      OPEN(UNIT=LU3,ACCESS='SEQOUT',FILE=FILES(3))
      K = 0
      LU =LU1
 2       K=K+1
        WRITE(LU,500)IFID,IDATE,K,ISITE
 500     FORMAT(1H1,10X,2A5,' FRAME IMAGED ',2A5,10X,'PAGE ',I1
     *,5X,'SITE ',2A5)
      WRITE(LU,501)
 501     FORMAT(1X,'LINE',11X,'PIXEL')
      II = LN/10
      DO 10 I=1,II
      IDUM(I)='!+++++++++'
 10     IP(I) = LFTPIX + (I-1)*10*JP + LN*(K-1)*JP
      WRITE(LU,502)(IP(I),I=1,II)
 502     FORMAT (1X,11(I6,4X))
      WRITE(LU,503)(IDUM(I),I=1,II)
 503     FORMAT(1X,5X,11A10)
      GO TO (20,30,40)K
 20     LU = LU2
      GO TO 2
 30     LU = LU3
      GO TO 2
 40     RETURN
      END
```

```
C-   -   -   -   -   -   -   -   -   -   -
C  VARIABLES:
C  GLOBAL : IDATE,IFID,ISITE
C  LOCAL : IP
C  PLEASE SEE THE COMMON AREAS.
C-   -   -   -   -   -   -   -   -   -   -
        SUBROUTINE WRTHD2
C################################################################
        DOUBLE PRECISION IDUM (11),FILES(3)
        INTEGER IP(11),IFILEM(2),IFILER(2),IFID(2),IDATE(2),ISITE(2)
        COMMON /OUT/LU1,LU2,LU3,FILES
        COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
        COMMON /LOC/ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
        COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
        K = 0
        LU =LU1
  2         K=K+1
 500        FORMAT(1X,10X,2A5,' FRAME IMAGED ',2A5,10X,'PAGE ',I1
     *,5X,'SITE ',2A5)
 501        FORMAT(1X,'LINE',11X,'PIXEL')
 502        FORMAT (1X,11(I6,4X))
        II=LN/10
        DO 10 I=1,II
        IDUM(I)='!+++++++++'
  10        IP(I)=LFTPIX+(I-1)*10*JP+LN*(K-1)*JP
        WRITE(LU,503)(IDUM(I),I=1,II)
 503        FORMAT(1X,5X,11A10)
        WRITE (LU,502) (IP(I),I=1,II)
        WRITE (LU,501)
        WRITE (LU,500)IFID.IDATE,K,ISITE
        GO TO (20,30,40)K
  20        LU = LU2
        GO TO 2
  30        LU = LU3
        GO TO 2
  40        RETURN
        END
```

```
C                                   @@@@@@@@@@@@@@
C                                   @ VEGTXT.FOR @
C                                   @@@@@@@@@@@@@@
C  ROUTINE VEGTXT.FOR, JULY 1978.
C  QUERRIES THE USER & GETS THE PARM.
C
C  PAK CHAGARLAMUDI,HASKINS & SELLS ASSOCIATES.
C  OTTAWA, ONTARIO
C
C  VARIABLES:
C  GLOBAL:IBANDS,IDATE,IFID,IFILEM,IFILER,IQSUN
C          IRTPIX,ISITE,ISTLIN,ISTR
C          JL,JP
C          LFTPIX,LINE,LN,LSTLIN
C          M,MBLK,MLINE
C          NB,NBLK,NBS,NC,NF,NP,NPT
C          SUNCOR,SUNELD,SYMBL
C  LOCAL   NQ
C
      SUBROUTINE VEGTXT
      INTEGER IFILEM(2),IFILER(2),IFID(2),IDATE(2),ISITE(2)
      INTEGER IBANDS (4),NBS(4)
      COMMON /LOC/ ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /IDENT/ IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/ NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
C
      DATA NB  /4/
      DATA IBANDS  /4,5,6,7/
C  REQUEST MSS FILE NAME & THE STRUCTURE
 10        WRITE (5,20)
 20        FORMAT (1X,'MSS INPUT FILE NAME ?:',$)
      READ (5,30)IFILEM
 30        FORMAT (2A5)
      WRITE (5,40)
 40        FORMAT (1X,'STRUCTURE ON WHICH FILE IS LOCATED ?:',$)
      READ (5,30)ISTR
C  CHECK FOR THE PRESENCE OF THE FILE ON THE STRUCTURE
      CALL CHECK (IFILEM,IER,0,0,ISTR)
      IF (IER .EQ. 0) GO TO 60
      WRITE (5,50) IFILEM,ISTR
 50        FORMAT (1X,'FILE ',2A5,' NOT FOUND ON ',A5)
      GO TO 10
C  REQUEST FRAME # AND DATE IMMAGED
 60        WRITE (5,110)
110        FORMAT (1X,'LANDSAT FRAME NUMBER ?',$)
      READ (5,30) IFID
      WRITE(5,130)
130        FORMAT (1X,'DATE IMAGED ?',$)
      READ (5,30) IDATE
C  GET SITE NAME
      WRITE (5,132)
132        FORMAT (1X,'SITE NAME(2A5) ?',$)
      READ (5,30) ISITE
C  GET SPECIFICATIONS OF THE AREA OF INTEREST
180        WRITE (5,140)
140        FORMAT (1X,'SPECIFY THE AREA OF INTEREST -',/,
     *1X,'1ST LINE,LAST LINE,LEFT PIX, RIGHT PIX -',/)
      READ (5,150) ISTLIN,LSTLIN,LFTPIX,IRTPIX
150        FORMAT (4I)
C  CHECK COORDINATES WITH THE USER TO MAKE SURE THEY ARE OK
      WRITE (5,160) ISTLIN,LSTLIN,LFTPIX,IRTPIX
160        FORMAT (1X,'FIRST LINE          :',I5,/,
     *1X,'LAST LINE           :',I5,/,
```

```
     *1X,'LEFTMOST PIXEL        :',I5,/,
     *1X,'RIGHTMOST PIXEL       :',I5,//,
     *1X,'        ARE THESE CORRECT (Y/N) ?',$)
        READ (5,170) NQ
 170        FORMAT (A1)
        IF (NQ .NE. 'Y') GO TO 180
C  QUERRY USER RE LINE & PIXEL DECIMATION FACTOR
 190        WRITE (5,195)
 195        FORMAT (1X,'LINE & PIXEL DECIMATION FACTORS',/,'  (N F
     1OR 1 OUT OF N):',$)
        READ (5,200) JL,JP
 200        FORMAT (2I)
        IF (JL .LT.1) JL=1
        IF (JP .LT. 1) JP=1
        WRITE (5,210) JL,JP
 210        FORMAT (1X,'LINE & PIXEL DECIM. FACTORS R :',I3,2X,I3,/,' A
     1RE THESE CORRECT (Y/N)?',$)
        READ (5,170) NQ
        IF (NQ .NE. 'Y') GO TO 190
C  CHECK IF # OF PIXELS ARE < 550.
        NPT =IRTPIX-LFTPIX+1
        NP=NPT/JP
        IF (NP .LE. 550) GO TO 215
        NQ=JP*550
        WRITE (5,175)NPT,JP,NQ
 175        FORMAT(1X,'TOTAL # OF PIX:',I5,'MAX. ALLOWED:550*',I3,'=',I5)
        GO TO 190
C  QUERRY LOOK UP TABLE NAME (INTEGER 6 BIT)
 215        WRITE (5,220)
 220        FORMAT (1X,'NAME OF RAD CORR LOOK UP TABLE ?',$)
        READ (5,30) IFILER
C  QUERRY USER RE SUN EL CORRECTIONS
        WRITE (5,230)
 230        FORMAT (1X,'WANT SUN EL CORRECTIONS (Y/N) ?',$)
        READ (5,170) NQ
        SUNELD=0
        IQSUN=0
        IF (NQ .NE. 'Y') RETURN
C  REQUEST SUN EL. ANGLE.
        IQSUN=1
        WRITE (5,240)
 240        FORMAT (1X,'SUN EL. ANGLE IN DEGREES ?:',$)
        READ (5,250) SUNELD
 250        FORMAT (F)
        RETURN
        END
```

```
C                                  @@@@@@@@@@@@@@
C                                  @ DISKRD.FOR @
C                                  @@@@@@@@@@@@@@
C  CONTAINS NDSKRD.FOR & ODSKRD.FOR. JULY 1978.
C
C  PAK CHAGARLAMUDI, OTTAWA, ONT.
C  CONTAINS NDSKST & ENTRY POINT NSETLN.
C  NDSKST OPENS THE DISK FILE & SETS PARAMETERS UP FOR GETTING THE
C  DATA LATER BY NSETLN.
C  NSETLN READS THE DATA STARTING @ BLOCK NBLK AND UNPACKS THE DATA.
C  IN THE BEGINNING INCREMENTS LINE # AND THE BLOCK #.
C
C  THE PIXEL NUMBER NOTATION IN THIS ROUTINE CORRESPONDS TO
C  THAT OF THE MICA PACKAGE. AS A RESULT, THE FIRST N PIXEL LOCATIONS
C  CONTAIN ZEROS, WHERE N VARIES WITH THE LATITUDE (EG. N IS APPROX.
C  100 AT 53 DEG N.). THE ZERO FILL WAS DUE TO THE EARTH ROTATION
C  CORRECTIONS ON THE CCRS GENERATED JSC FORMAT TAPES.
C
C  VARIABLES:
C  GLOBAL:
C          IBANDS,IBUF,ICAL,ICLS,IDAT,IDATE,IFID,IFILEM,IFILER
C          IQSUN,IRTPIX,ISITE,ISTLIN,ISTR
C          JL,JP
C          LFTPIX,LINE,LN,LSTLIN
C          M,MBLK,MLINE,NB,NBLK,NBS,NC,NF,NP,NPT
C          SUNCOR,SUNELD,SYMBL
C  LOCAL: IBC,IDUM,IEOF,IER
C
      SUBROUTINE NDSKST
      INTEGER IBUF(3648),IBANDS(4),NBS(4),IDAT(550,4)
      INTEGER IFILEM(2),IFILER(2),IFID(2),IDATE(2),ISITE(2)
      INTEGER IUPAK (2201),ICOUNT(21)
      REAL BORDR(500,2),CORR(4)
C
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /LOC/ ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
      COMMON /DESIR1/ IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /MSSD/IBUF,IUPAK,CORR
      COMMON /CHAN/ IDAT
C  INITIALIZE THE MSS DISK FILE
      CALL INITT (IFILEM,1,IER,0,0,ISTR)
      IF (IER .EQ. 0) GO TO 20
      WRITE (5,10) IFILEM,ISTR
 10        FORMAT (1X,'COULD NOT OPEN FILE ',2A5,' ON ',A5)
C  ERROR RETURN
      STOP
C  SET STARTING BLOCK # FOR READING(1 REC=29 BLOCKS FOR HEADER)
 20        NBLK=(ISTLIN-JL-1)*29+3
      MBLK=JL*29
      LINE=ISTLIN-JL
C  SET UP THE # OF BYTES TO BE SKIPPED FOR EACH BAND
      NBS(1)=LFTPIX-1+180
      NBS(2)=NBS(1)+3780-176
      NBS(3)=NBS(2)+3604
      NBS(4)=NBS(3)+3604
C  GET THE CORRECTION FACTORS FOR ALL THE BANDS
      CALL REDUCE
      RETURN

C
      ENTRY NSETLN
C  INCREMENT THE LINE # & THE BLOCK #
```

```
      LINE=LINE+JL
      NBLK=NBLK+MBLK
      CALL GET (1,NBLK,2648,IBUF,IEOF,IER)
      IF (IER .NE. 0) WRITE (5,50) LINE
50        FORMAT (1X,'ERROR IN LINE:',I5)
      IF (IEOF .NE. 0) WRITE (5,60) LINE
60        FORMAT (1X,'END OF FILE OCCURED AT LINE ',I4)
C  UNPACK DATA & THEN APPLY CORRECTIONS.
      DO 70 I=1,NB
      IBC=I
      CALL BYTUPC (8,NPT,IBUF,NBS(IBC),IUPAK(1),IER)
      IF (IER .NE. 0) TYPE 50,LINE
      KK=1
      DO 70 K=1,NPT,JP
      IDAT (KK,IBC)=IFIX(FLOAT(IUPAK(K))*CORR(IBC)+0.5)
      KK=KK+1
70        CONTINUE
      RETURN
      END
```

```
C   ODSKRD.FOR,JULY 1978.
C
C   PAK CHAGARLAMUDI, OTTAWA,ONT.
C   CONTAINS ODSKST & ENTRY POINT OSETLN.
C   ODSKST OPENS THE DISK FILE & SETS PARAMETERS UP FOR GETTING THE
C   DATA LATER BY OSETLN.
C   OSETLN READS THE DATA STARTING @ BLOCK NBLK AND UNPACKS THE DATA.
C   IN THE BEGINNING INCREMENTS LINE # AND THE BLOCK #.
C
C   VARIABLES:
C   GLOBAL:
C            IBANDS,IBUF,ICAL,ICLS,IDAT,IDATE,IFID,IFILEM,IFILER
C            IQSUN,IRTPIX,ISITE,ISTLIN,ISTR,IUPAK
C            JL,JP
C            LFTPIX,LINE,LN,LSTLIN
C            M,MBLK,MLINE,NB,NBLK,NBS,NC,NF,NP,NPT
C            SUNCOR.SUNELD,SYMBL
C   LOCAL: IBC,IEOF,IER
C
      SUBROUTINE ODSKST
      REAL CORR(4),BORDR(500,2)
      INTEGER IBUF(3648),ICOUNT(21),IBANDS(4),NBS(4),IDAT(550,4)
      INTEGER IFILEM(2),IFILER(2),IFID(2),IDATE(2),ISITE(2)
      INTEGER IUPAK (2201),ICAL (4,6,64)
C
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /LOC/ ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /CAL/ICAL
      COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
      COMMON/DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /MSSD/IBUF,IUPAK,CORR
      COMMON /CHAN/ IDAT
C   INITIALIZE THE MSS DISK FILE
      CALL INITT (IFILEM,1,IER,0,0,ISTR)
      IF (IER .EQ. 0) GO TO 20
      WRITE (5,10) IFILEM,ISTR
 10       FORMAT (1X,'COULD NOT OPEN FILE ',2A5,' ON ',A5)
C   ERROR RETURN
      STOP
C   SET STARTING BLOCK # FOR READING(1 REC=19 BLOCKS FOR HEADER)
 20       NBLK=(ISTLIN-JL)*19+1
      MBLK=JL*19
      LINE=ISTLIN-JL
C   SET UP THE # OF BYTES TO BE SKIPPED FOR EACH BAND
      DO 30 J=1,NB
      NBS(J)=(IBANDS(J)-4)*3612+(IBANDS(J)-4)*2+LFTPIX-1+6
 30       CONTINUE
C   GET CORRECTION FACTORS
      CALL REDUCE
      RETURN

C
      ENTRY OSETLN
C   INCREMENT THE LINE # & THE BLOCK #
      LINE=LINE+JL
      NBLK=NBLK+MBLK
      CALL GET (1,NBLK,2432,IBUF,IEOF,IER)
      IF (IER .NE. 0) WRITE (5,50) LINE
 50       FORMAT (1X,'ERROR IN LINE:',I5)
      IF (IEOF .NE. 0) WRITE (5,60) LINE
 60       FORMAT (1X,'END OF FILE OCCURED AT LINE ',I4)
      M=MOD(IBUF(1),64)
      DO 70 I=1,NB
```

```
      IBC=1
      CALL BYTUPC (6,NPT,IBUF,NBS(IBC),IUPAK(1),IER)
      IF (IER .NE. 0) TYPE 50,LINE
      KK=1
      DO 70 K=1,NPT,JP
      IDAT(KK,IBC)=ICAL(IBC,M,IUPAK(K)+1)
      IDAT(KK,IBC)=IFIX(FLOAT(IDAT(KK,IBC))*CORR(IBC)+0.5)
      KK=KK+1
70        CONTINUE
      RETURN
      END
```

```
        SUBROUTINE REDUCE
        REAL ERTS1(4),ERTS3(4),CORR(4),BORDR(500,2)
        INTEGER ICOUNT (21),IBUF(3648),IUPAK(2201)
        COMMON/DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
        COMMON /MSSD/IBUF,IUPAK,CORR
C
        DATA ERTS1/1.028,0.8500,0.8295,0.8261/
        DATA ERTS3 /0.9346,1.1364,0.8163,0.9/
C  GET THE SATELLITE NUMBER
 90         WRITE (5,100)
 100        FORMAT (1X,'SATELLITE NUMBER (1/2/3) >',$)
        READ (5,110) LSAT
 110        FORMAT (I)
        IF (LSAT .LE. 0 .OR. LSAT .GT. 3) GO TO 90
C  COMPUTE CORRECTION FACTORS TO STANDARDIZE AMONG SATELLITES
C  AND DIFFERENT SUNELEVATIONS.
C  ALSO CONVERT 6 BIT DATA OF BAND7 TO 8BIT DATA IN THE
C  CASE OF EROS DATA.
C
        DO 120 I=1,4
        CORR(I)=SUNCOR
 120        CONTINUE
        IF (LSAT .EQ. 1) GO TO 130
        IF (LSAT .EQ. 3) GO TO 140
        GO TO 150
C  LANDSAT 1 DATA
 130        DO 135 I=1,4
        CORR(I)=CORR(I)/ERTS1(I)
 135        CONTINUE
        GO TO 150
C  LANDSAT 3 DATA
 140        DO 145 I=1,4
        CORR(I)=CORR(I)/ERTS3(I)
 145        CONTINUE
C
 150        IF (NFORM .NE. 1) GO TO 160
C  EROS DATA
        DO 155 I=1,3
        CORR(I)=CORR(I)*2.0
 155        CONTINUE
        CORR(4)=CORR(4)*4.0
C
 160        IF (NFORM .NE. 2) GO TO 170
C  CCRS OLD FORMAT DATA
        DO 165 I=1,4
        CORR(I)=CORR(I)*4.0
 165        CONTINUE
C
 170        CONTINUE
        TYPE *,CORR
        RETURN
        END
```

```
C                                   @@@@@@@@@@@@@@
C                                   @ CNTPIX.FOR @
C                                   @@@@@@@@@@@@@@
C  CONTAINS INICNT & ENTRY PRICNT
C  ROUTINE INICNT.FOR,JULY 1978.
C  CODE WRITTEN BY
C  PAK CHAGARLAMUDI,HASKINS & SELLS ASSOCIATES.
C  HASKINS & SELLS ASSOCIATES
C
C  INICNT:
C  CALCULATES THE STARTING & END PIXEL NUMBERS FOR ALL THE LINES
C  WITHIN THEE SITE AND STORES THEM IN ARRAY BORDR(I,J) FOR USE.
C  ENTRY PRICNT:
C  PRINTS THE PIXEL COUNTS ON THE LPT.
C
      SUBROUTINE INICNT
      INTEGER AR(550),IS5(21),IS7(21),ISR(21),ICOUNT(21),SYMBL(21)
      INTEGER IFILEM(2),IFILER(2),IDATE(2),IFID(2),ISITE(2)
      REAL BORDR(500,2)
      DOUBLE PRECISION ICLS(21)
      COMMON /LOC/ ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /DESIR/ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /COUNT/MTRL,MBLL
      INTEGER YES
      DATA YES /'Y'/
 90      WRITE (5,100)
 100     FORMAT (1X,'PLEASE PROVIDE ACTUAL SITE COORDINATES (LINE & PIXEL
     *#''S) FOR COUNTING   PURPOSE - SEPARATE #''S BY SPACE',/,
     *' TOP LEFT: LINE & PIXEL ; TOP RIGHT: LINE & PIXEL ; BOTTOM LEFT
     *: LINE & PIXEL ; BOTTOM RIGHT: LINE & PIXEL',//)
      READ (5,110) MTLL,MTLP,MTRL,MTRP,MBLL,MBLP,MBRL,MBRP
 110     FORMAT (8I)
      WRITE (5,120) MTLL,MTLP,MTRL,MTRP,MBLL,MBLP,MBRL,MBRP
 120     FORMAT (1X,'LINE & PIXEL #''S FOR   TOP   LEFT   :',2I6,/
     *' LINE & PIXEL #''S FOR   TOP  RIGHT :',2I6,/
     *' LINE & PIXEL #''S FOR BOTTOM  LEFT :',2I6,/
     *' LINE & PIXEL #''S FOR BOTTOM RIGHT :',2I6,//
     *' ARE THESE CORRECT (Y/N) ??',$)
      READ (5,130) NOYES
 130     FORMAT (A1)
      IF (NOYES .NE. YES) GO TO 90
C  CALCULATE SCAN LINE GRADIENT FOR THE SITE
      IDUK=MTLL-MTRL
      IF (IDUK .GT.0) GO TO 140
      SNGRDT=0.
      GO TO 145
 140     SNGRDT=FLOAT (MTRP - MTLP) / FLOAT (IDUK)
 145     IDUK=MBLL-MBRL
      IF (IDUK .GT. 0) GO TO 150
      SNGRDB=0.
      GO TO 155
 150     SNGRDB=FLOAT (MBRP - MBLP) / FLOAT (IDUK)
C  CALCULATE PIXEL GRADIENT FOR THE SITE
 155     IDUK=MBLL-MTLL
      IF (IDUK .GT. 0) GO TO 160
      PXGRDL=0.
      GO TO 165
 160     PXGRDL=FLOAT(MBLP - MTLP) / FLOAT(IDUK)
 165     IDUK=MBRL-MTRL
      IF (IDUK .GT.0) GO TO 170
      PXGRDR=0.
```

```
        GO TO 175
 170        PXGRDR=FLOAT(MBRP - MTRP) / FLOAT(IDUK)
C  CHANGE THE GRADIENTS AS PER LINE & PIXEL INTERVAL.
 175        SNGRDT=SNGRDT*FLOAT(JP)
        SNGRDB=SNGRDB*FLOAT(JP)
        PXGRDL=PXGRDL*FLOAT(JL)
        PXGRDR=PXGRDR*FLOAT(JL)
C  BUILD UP THE START & END PIXEL NUMBERS FOR ALL SCAN LINES
C  IN THE SITE.
C ASSIGN LEFT & RIGHT PIXEL TO 1ST & LAST WHEN GRADS ARE ZERO.
        IF (SNGRDT. GT. 0.  .AND. PXGRDL .GT. 0.) GO TO 195
        DO 180 I=1,MLINE
        BORDR(I,1)=FLOAT(LFTPIX)
        BORDR(I,2)=FLOAT(IRTPIX)
 180        CONTINUE
        GO TO 218
C  STARTING PIXEL
C  INITIALIZE FOR TOP RIGHT LINE (MTRL)
 195        KK=1
        BORDR(KK,1)=FLOAT(MTRP)
C  TOP PORTION
        DO 200 I=MTRL+1,MTLL-1,JL
        KK=KK+1
        BORDR(KK,1)=BORDR(KK-1,1) - SNGRDT
 200        CONTINUE
C  INITIALIZE FOR TOP LEFT LINE (MTLL)
        KK=KK+1
        BORDR(KK,1)=FLOAT (MTLP)
        DO 205 I=MTLL+1,MBLL-1,JL
        KK=KK+1
        BORDR(KK,1)=BORDR(KK-1,1)+PXGRDL
 205        CONTINUE
C  INITIALIZE LOWER LEFT LINE (MBLL)
        KK=KK+1
        BORDR(KK,1)=FLOAT(MBLP)
C  ENDING PIXELS
C  INITIALIZE FOR TOP RIGHT LINE (MTRL)
        KK=1
        BORDR(KK,2)=FLOAT(MTRP)
C  RIGHT PORTION
        DO 210 I=MTRL+1,MBRL-1,JL
        KK=KK+1
        BORDR(KK,2)=BORDR(KK-1,2)+PXGRDR
 210        CONTINUE
C  INITIALIZE FOR BOTTOM RIGHT LINE
        KK=KK+1
        BORDR(KK,2)=FLOAT(MBRP)
C  BOTTOM PORTION
        DO 215 I=MBRL+1,MBLL,JL
        KK=KK+1
        BORDR(KK,2)=BORDR(KK-1,2)-SNGRDB
 215        CONTINUE
C  INITIALIZE ALL THE COUNTERS (ONLY ONCE)
 218        DO 220 J=1,21
        ICOUNT (J)=0
 220        CONTINUE
C  THIS FINISHES THE 1ST SECTION OF THE PROGRAM
        RETURN
C
C  ENTRY PRICNT
C
        ENTRY PRICNT
C  THIS SECTION PRINTS THE RESULTS ON LINE PRINTER (UNIT=3)
 390        CONTINUE
```

```
C  WRITE IDENTIFICATION INFORMATION ON LINE PRINTER
      WRITE (3,400) ISITE(1),ISITE(2)
 400      FORMAT (1X,25X,2A5,/,26X,'**********',///)
      WRITE (3,410)IFID
 410      FORMAT (1X,10X,'FRAME ID : ',2A5)
      WRITE (3,420)IDATE
 420      FORMAT (1X,10X,'DATE IMAGED : ',2A5)
      WRITE (3,422) IFILEM,IFILER
 422      FORMAT (1X,10X,' MSS DATA FILE : ',2A5,/,11X,'LOOK UP TABL
     *E : ',2A5)
      WRITE (3,423) SUNCOR
 423      FORMAT (1X,10X,'SUN EL. CORR. FACTOR : ',F7.4)
      WRITE (3,425) IBP
 425      FORMAT (1X,10X,'I B P  LEVEL :',I2,/)
      WRITE (3,430)
 430      FORMAT (1X,10X,'LINE PRINTER MAP COORDINATES:',/)
      WRITE (3,440) ISTLIN,LSTLIN
 440      FORMAT (1X,12X,'FIRST LINE :'I4,/,1X,12X,'LAST LINE :',I4)
      WRITE (3,450) LFTPIX,IRTPIX
 450      FORMAT (1X,12X,'START PIXEL :',I4,/,1X,12X,'LAST PIXEL :',I4,/)
      WRITE (3,460)
 460      FORMAT (1X,10X,'ACTUAL SITE COORDINATES :',/)
      WRITE (3,470) MTLL,MTLP
 470      FORMAT (1X,12X,'LINE & PIXEL FOR TOP LEFT :',I4,4X,I4)
      WRITE (3,480) MTRL,MTRP
 480      FORMAT (1X,12X,'LINE & PIXEL FOR TOP RIGHT :',I4,4X,I4)
      WRITE (3,490) MBLL,MBLP
 490      FORMAT (1X,12X,'LINE & PIXEL FOR BOTTOM LEFT :',I4,4X,I4)
      WRITE (3,500) MBRL,MBRP
 500      FORMAT (1X,12X,'LINE & PIXEL FOR BOTTOM RIGHT :',I4,4X,I4)
      WRITE (3,510)
 510      FORMAT (//,1X,10X,'PIXEL COUNTS IN THE SITE :',/)
      WRITE (3,700)
 700      FORMAT (1X,5X,'CLASS # CLASS - NAME  PIXELS',/)
      DO 710 I=1,NC
      WRITE (3,720) I,ICLS(I),ICOUNT(I)
 720      FORMAT (1X,5X,I3,2X,A10,4X,I6)
 710      CONTINUE
      WRITE (3,590)
 590      FORMAT (1X,30X,'***********')
C      PRINTING RESULTS IS COMPLETED, RETURN.
      RETURN
      END
```

MADROK.CMD

```
MADROK.FOR,VEGTXT.FOR,DISKRD.FOR,DSPFL.FOR,CNTPIX.FOR,REL:CCRSL.REL/L
```

```
C                               @@@@@@@@@@@@
C                               @  MADROK  @
C                               @@@@@@@@@@@@
C  MADROK.FOR, FEB. 1979.
C  CODE WRITTEN BY
C  PAK CHACARLAMUDI, UNIV. OF MANITOBA
C  OTTAWA, ONTARIO
C-  -  -  -  -  -  -  -  -  -  -  -
C  THIS SUIT OF PROGRAMS READS A DISK FILE OF A SMALL
C  PORTION OF LANDSAT DATA AND THEN IDENTIFIES POSSIBLE OUTCROPS.
C  THE FOLLOWING OPTIONS EXIST IN THIS PROGRAM:
C  (A)TO DECIMATE THE DATA WHEN NOT INTERESTED IN USING ALL THE DATA.
C  (B) TO GENERATE A DISPLAY COMPATIBLE FILE.
C  (C) TO COUNT PIXELS IN A SUBSET OF THE MAP FOR ALL THE CLASSES.
C  (D) CAN HANDLE EITHER JSC (CCRS OR EROS DATA) OR OLD FORMAT.
C  THE OUTPUT CLASSES ARE REPRESENTED AS DIFFERENT COLORS AND
C  THEN WRITTEN ON A DISPLAY COMPATIBLE FILE (DSPLAY.MAP).
C  OTHER PERTINENT INFORMATION IS WRITTEN ON A FILE (ROCK1.MAP)
C  FOR LATER RETRIEVAL.
C  THE DISPLAY COMPATIBLE FILE CAN BE DISPLAYED ON THE MAD USING
C  PROGRAM DSPCIO; CSFR TAPE CAN BE CREATED USING
C  DSPCSF; EBIR TAPE USING DSPEBR.
C-  -  -  -  -  -  -  -  -  -  -  -
C  ROUTINE MADROK.FOR IS THE MAIN PROGRAM IN MADROK PACKAGE.
C  ROUTINES REQUIRED BY MADROK PACKAGE ARE LISTED IN MADROK.CMD
C-  -  -  -  -  -  -  -  -  -  -  -
C  VARIABLES:
C  GLOBAL:
C   AR,FEAT1,IBANDS,IBUF,ICAL,ICLS,IDAT,IDATE,IFID,IFILEM,
C   IFILER,IQSUN,IRTPIX,ISITE,ISTLIN,ISTR
C   JL,JP,LFTPIX,LINE,LN,LSTLIN,LU1,LU2,LU3
C   M,MBLK,MLINE,NB,NBLK,NBS,NC,NF,NFORM,NP,NPT,
C   RPS1,RPS2,SUNCOR,SUNELD,SYMBL
C###################################################################
      DOUBLE PRECISION ICLS (21),CNAME(21)
      DOUBLE PRECISION FILEN,FILES(3)
      REAL BORDR (500,2),CORR(4)
      INTEGER IFILEM(2),IFILER(2),IDATE(2),IFID(2),ISITE(2)
      INTEGER IBUF(3648),IDAT(550,4),ICAL(4,6,64),IUPAK(2201)
      INTEGER SYMBL(21),AR(550),IS5(21),IS7(21),ISR(21),ICOUNT(21)
      INTEGER KF(6),IBANDS(4),NBS(4),ICOLOR(21)
      EQUIVALENCE (IFILER,FILEN)
      COMMON /MSSD/ IBUF,IUPAK,CORR
      COMMON /CHAN/ IDAT
      COMMON /CAL/ ICAL
      COMMON /LOC/  ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
      COMMON /OUT/  LU1,LU2,LU3,FILES
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DEFR/NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
      COMMON /COUNT/ MTRL,MBLL
      COMMON /COLOR/ ICOLOR,CNAME,LTBLK,LBBLK,MAG
      DATA FILES /'ROCK1.MAP','ROCK2.MAP','ROCK3.MAP'/
C
C  INITIALIZE LOGICAL UNITS
      LU1=21
      LU2=22
      LU3=23
C  QUERRY THE USER RE. PARAMETERS.
      CALL VEGTXT
      SUNCOR=1.
      IF (IQSUN .NE. 0) SUNCOR=COSD(SUNELD)/COSD(37.)
```

```
C  CHANGE THE DEFAULT PARAMETERS IF REQUESTED
         CALL DSRROK
         IF (NFORM .NE. 2)GO TO 240
C  READ THE LOOKUP TABLE
         OPEN (UNIT=LU1,ACCESS='SEQIN',FILE=FILEN)
         READ (LU1,210)(((ICAL(I,J,K),K=1,64),J=1,6),I=1,4)
 210        FORMAT(1X,32I4)
         CLOSE (UNIT=LU1)
C  WRITE SUPPORTING INFORMATION ON A FILE FOR LATER RETRIEVAL.
 240        OPEN (UNIT=LU1,ACCESS='SEQOUT',FILE=FILES(1))
         WRITE (LU1,270) IFID,IDATE
 270        FORMAT (1X,'FRAME IDENTIFICATION :',2A5,10X,' D
     *ATA ACQUIRED ON :',2A5,4X)
         WRITE (LU1,272) SUNELD,SUNCOR
 272        FORMAT (1X,'SUN ELEVATION :',F4.0,10X,'SUN CORRECTION FACTOR :'
     *,F6.4,2X)
         WRITE (LU1,274) IFILER
 274        FORMAT (1X,'MSS RADIOMETRIC CORRECTION TABLES FROM FILE :',2A5)
         WRITE (LU1,276)IFILEM
 276        FORMAT (1X,'MSS DATA INPUT FILE : ',2A5,3X)
         WRITE (LU1,278) ISITE
 278        FORMAT (1X,'SITE : ',2A5)
C  INITIALIZE THE DISK FILE
         IF (NFORM .EQ. 2)  CALL ODSKST
         IF (NFORM .NE. 2) CALL NDSKST
         TYPE *,LN
C  WE HAVE TO PROCESS "MLINE" LINES AND NP PIXELS FROM EACH LINE
         MLINE=(LSTLIN-ISTLIN+1) / JL
C  WRITE PARAMETERS ON FILE FOR LATER RETRIEVAL
         WRITE (LU1,292) NC
 292        FORMAT (1X,'# OF CLASSES:',I2)
         WRITE (LU1,294) MLINE,NP,NC,LN
 294        FORMAT (1X,4I)
         WRITE (LU1,285)
 285        FORMAT (1X,'DETAILS OF CLASSIFICATION')
         WRITE (LU1,290)
 290        FORMAT (1X,'CLASS #',4X,'NAME',9X,'BAND-5 BAND-7 FACTR COLOR')
         DO 300 I=1,NC
         WRITE (LU1,310) I,ICLS(I),IS5(I),IS7(I),ISR(I),CNAME(SYMBL(I))
 310        FORMAT (1X,2X,I2,5X,A10,3X,3I6,6X,A10,2X)
 300        CONTINUE
         WRITE (LU1,315)
         WRITE (LU1,320) ISTLIN,LSTLIN,LFTPIX,IRTPIX
 315        FORMAT (1X,'THE AREA SHOWN ON THE MAP HAS THE FOLLO
     *WING CO-ORDINATES :  ')
 320        FORMAT (1X,10X,'LINES :',I4,' TO ',I4,' & PIXELS
     *:',I4,' TO ',I4,3X)
         WRITE (LU1,325)JL,JP
 325        FORMAT (1X,'DECIM. FACT.- LINES :',I2,'; PIXELS :',I2)
         IF (NCOUNT .EQ. 1) CALL INICNT
C SELECT CLASS PROC.
 490        WRITE (5,500)
 500        FORMAT (1X,'CLASSIFICATION PROC.(1/2/3/4) :'$)
         READ (5,510) NQ
 510        FORMAT (I)
         TYPE *,NQ
         IF (NQ .LT. 1) GO TO 490
         IF (NQ .GT. 4 ) GO TO 490
C
         WRITE (5,520)
 520        FORMAT (1X,'MAGNIFICATION OF DISPLAY >',$)
         READ (5,510) MAG
         WRITE (5,530)
 530        FORMAT (1X,'SPLIT SCREEN DISPLAY(Y/N) >',$)
```

```
      READ (5,540) SPLIT
 540       FORMAT(A1)
C  OPEN CHANNEL FOR DISPLAY COMPATIBLE FILE
      CALL INITT2 ('DSPLAY.MAP',2,IER,0,0,ISTR)
      LTBLK=16
      LBBLK=766
      CALL COLNAM
      DO 410 I=1,MLINE
C  GET THE REQUIRED # OF PIXELS FROM THE CURRENT SCAN LINE
      IF (NFORM .EQ. 2) CALL OSETLN
      IF (NFORM .NE. 2) CALL NSETLN
C  DECIDE ON THE CLASS TO WHICH EACH DATA POINT BELONGS TO
      IF (NQ .EQ. 1) CALL CLROK1
      IF (NQ .EQ. 2) CALL CLROK1
      IF (NQ .EQ. 3) CALL CLROK1
      IF (NQ .EQ. 4) CALL CLROK1
C  ASSIGN COLORS FOR THE DISPLAY TO EACH OF THE CLASSES.
      IF (NPRINT .EQ. 0) GO TO 410
      IF (SPLIT .EQ. 'Y') CALL DSPFL1
      IF (SPLIT .NE. 'Y' ) CALL DSPFL2
 410       CONTINUE
C  PRINT THE RESULTS FROM COUNTING
      IF (NCOUNT .EQ. 1) CALL PRICNT
C  WRITE THE COLOR CODE
      CALL COLCOD
C  CLOSE THE CHANNEL OF THE DISPLAY COMPATIBLE FILE
      CALL CLOSEE (2)
      RETURN
      END
```

```
C                                  @@@@@@@@@@@@@@
C                                  @ DSRROK.FOR @
C                                  @@@@@@@@@@@@@@
C  ROUTINE DSRROK.FOR, JAN. 1979.
C  CODE WRITTEN BY
C         PAK CHAGARLAMUDI
C         OTTAWA, ONTARIO
C-  -  -  -  -  -  -  -  -  -  -  -  -
C  ROUTINE DSRROK.FOR IS A PART OF "MADROK" PACKAGE.
C  THIS ROUTINE DISPLAYS THE CURRENT CLASS NAMES, FACTOR
C  VALUES, AND COLORS ASSIGNED TO CLASSES.
C  ALSO ALLOWS THE USER TO ALTER THE CONTENTS IF SO DESIRED.
C-  -  -  -  -  -  -  -  -  -  -  -  -
C  VARIABLES:
C  GLOBAL: FEAT1,ICLS,LN,NC,SYMBL
C  LOCAL : NQ
C-  -  -  -  -  -  -  -  -  -  -  -  -
        SUBROUTINE DSRROK
C###############################################################
        DOUBLE PRECISION ICLS (21),CNAME(21)
        INTEGER IS5(21),IS7(21),ISR(21),ICOUNT(21)
        REAL BITS (2),BORDR(500,2)
        INTEGER SYMBL (21),AR(550),ICOLOR(21)
C  COMMON AREAS
C
        COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
        COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
        COMMON /DEFF/  NC,LN,NPT,NP,MLINE,JL,JP,NF
        COMMON /COLOR/ICOLOR,CNAME,LTBLK,LBBLK,MAG
C
        DATA IS5 /0,100,0,0,0,0,0,1550,0,55,0,0,0,0,0,0,0,0,0,0,0/
        DATA IS7 /20,0,0,2800,0,46,0,0,0,0,0,0,0,0,0,0
     *,0,0,0,0,0/
        DATA ISR /0,0,185,145,175,0,0,0,0
     *,0,0,0,0,0,0,0,0,0,0,0,0/
        DATA SYMBL /12,13,4,3,7,3,3,7,3,17,1,1,1,1,1,1,1,1,1,1,1/
        DATA ICLS /'WATER','CLOUD','VEGETATION','DOLOMITES','SOIL/BLDRS'
     *,'BASALT','GRAN/FELS.','SAND','SANDSTONES','SNOW/ICE','
     *,'         ','         ','         ','         ','         ','
     *,'         ','         ','         ','         ','         '/
C  INITIALIZE NUMBER OF CLASSES AND BUFFER SIZE FOR EACH SECTION
C  AND THE IBP LEVEL,FORMAT,PRINT,COUNT OPTIONS.
        NQ=0
        IBP=1
        NC=10
        LN=110
        NFORM=2
        NPRINT=1
        NCOUNT=0
C  QUERRY THE USER IF HE WANTS TO SEE THE DEFAULT VALUES
C  IF THE USER DESIRES, DISPLAY & ALTER  WHEN REQUESTED
 90       WRITE (5,95)
 95        FORMAT (//)
        WRITE (5,100)
 100        FORMAT (1X,'WANT TO SEE THE CURRENT VALUES (Y/N) ?',$)
        READ (5,110) NQ
 110        FORMAT (A1)
        IF (NQ .NE. 'Y') GO TO 300
        IF (NFORM .EQ. 0) WRITE (5,510)
        IF (NFORM .EQ. 1) WRITE (5,520)
        IF (NFORM .EQ. 2) WRITE (5,530)
510       FORMAT (1X,'ASSUMING JSC FORMAT - CCRS DATA')
520       FORMAT (1X,'ASSUMING JSC FORMAT - EROS DATA')
```

```
 530        FORMAT (1X,'ASSUMING OLD FORMAT - CCRS DATA')
        IF (NPRINT .EQ. 0) WRITE (5,540)
        IF (NPRINT .EQ. 1) WRITE (5,550)
 540        FORMAT (1X,'WILL NOT CREATE LINE PRINTER MAP')
 550        FORMAT (1X,'WILL BE CREATING LINE PRINTER MAP')
        IF (NCOUNT .EQ. 0) WRITE (5,560)
        IF (NCOUNT .EQ. 1) WRITE (5,570)
 560        FORMAT (1X,'WILL NOT COUNT PIXELS')
 570        FORMAT (1X,'WILL BE COUNTING PIXELS')
        WRITE (5,120)
 120        FORMAT (1X,'THE FOLLOWING CLASSES ARE AVAILABLE NOW :',/,
     *1X,'CLASS #',4X,'NAME',9X,'BAND-5 BAND-7 FACTR COLOR',/)
        DO 130 I=1,NC
        WRITE (5,140) I,ICLS(I),IS5(I),IS7(I),ISR(I)
     *,CNAME(SYMBL(I)),SYMBL(I)
 140        FORMAT (1X,2X,I2,5X,A10,3X,I6,I6,I6,6X,A10,'-',I2)
 130        CONTINUE
C  IF THE USER DESIRES, CHANGE THE VALUES
        WRITE (5,132)
 132        FORMAT (1X,'WANT TO CHANGE ANY OF THE VALUES (Y/N) ?',$)
        READ (5,110) NQ
        IF (NQ .NE. 'Y') GO TO 300
        WRITE (5,580) NFORM
 580        FORMAT (1X,'FORMAT OPTION =',I2,' NEW(0-JSC CCRS;1-JSC EROS
     *; 2-OLD CCRS):',$)
        READ (5,155) NQ
        NFORM=NQ
 585        WRITE (5,590) NPRINT
 590        FORMAT (1X,'PRINT OPTION =',I2,'NEW(1-TO CREATE MAP; 0-OTHER
     *WISE):',$)
        READ (5,155) NPRINT
        WRITE (5,600) NCOUNT
 600        FORMAT (1X,'COUNT OPTION =',I2,'NEW(1-TO COUNT; 0 OTHERWISE):',$)
        READ (5,155) NCOUNT
        CALL COLNAM
 145        WRITE (5,150)
 150        FORMAT (1X,'CLASS # YOU WISH TO CHANGE ("0" FOR NONE) ?',$)
        READ (5,155) NQ
 155        FORMAT (I)
        IF (NQ .EQ. 0) GO TO 90
C  CHECK IF CLASS # IS AVAILABLE IN THE CURRENT BUFFER
        IF (NQ .LT. 0  .OR.  NQ .GT. NC) GO TO 310
        CALL COLNAM
        WRITE (5,160) NQ
 160        FORMAT (1X,'CLASS # :',I2)
        WRITE (5,170) ICLS (NQ)
 170        FORMAT (1X,'OLD NAME =',A10,' NEW ?',$)
        READ (5,180) ICLS (NQ)
 180        FORMAT (A10)
        WRITE (5,190) SYMBL(NQ)
 190        FORMAT (1X,'OLD COLOR =',I2,' NEW ?',$)
        READ (5,155) SYMBL(NQ)
        WRITE (5,200) IS5(NQ),IS7(NQ),ISR(NQ)
 200        FORMAT (1X,'OLD VALUES =',3I5,' NEW ?',$)
        READ (5,210) IS5(NQ),IS7(NQ),ISR(NQ)
 210        FORMAT (3I)
        GO TO 145
C  NORMAL RETURN
 300        RETURN
C  ERROR MESSAGE ;   STOP IF REQUIRED
 310        WRITE (5,320) NQ,NC
 320        FORMAT (1X,'WANTED TO CHANGE CLASS # :',I2,/,
     *1X,'# OF CLASSES ALLOWED AT PRESENT ARE :',I2,/
     *1X,'WANT TO EXIT (0)  OR  PROCEED (1) ?',$)
```

```
      READ (5,155) NQ
      IF (NQ .EQ. 1) GO TO 145
      STOP
      END
C
C                         @@@@@@@@@@@@@@@
C                         @ CLROK1.FOR @
C                         @@@@@@@@@@@@@@@
C  ROUTINE CLROK1.FOR, JAN. 1979.
C-  -  -  -  -  -  -  -  -  -  -  -
C  CODE WRITTEN BY
C  PAK CHAGARLAMUDI,UNIV. OF MANITOBA.
C  OTTAWA, ONTARIO
C-  -  -  -  -  -  -  -  -  -  -  -
C  ROUTINE CLROK1.FOR IS A PART OF  MADROK PACKAGE
C  THIS ROUTINE DECIDES ON THE CLASS TO WHICH EACH PIXEL
C  BELONGS TO AND THEN ASSIGNS THE NUMBER FOR THAT CLASS
C  NOTE: ALL PARAMETERS ARE PASSED THROUGH COMMON AREAS.
C  SEE COMMON AREAS FOR DETAILS.
C-  -  -  -  -  -  -  -  -  -  -  -
C  VARIABLES:
C  GLOBAL: AR,FEAT1,IDAT,NFORM,NP,RPS1,RPS2,SUNCOR,SYMBL
C  LOCAL : ISRT
C-  -  -  -  -  -  -  -  -  -  -  -
      SUBROUTINE CLROK1
C###########################################################
      DOUBLE PRECISION ICLS (21)
      INTEGER AR(550),SYMBL(21),IDAT(550,4),IS5(21),IS7(21),ISR(21)
      INTEGER ICOUNT (21)
      REAL BORDR(500,2)
C  COMMON AREAS
      COMMON /CHAN/ IDAT
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DEFF/  NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
      COMMON /LOC/ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /COUNT/MTRL,MBLL
C
C  CHECK IF COUNTING IS REQUIRED, IF NOT AVOID COUNTING.
      ASSIGN 500 TO KOKO
      IF (NCOUNT .EQ. 0) ASSIGN 90 TO KOKO
      IF (LINE .LT. MTRL .OR. LINE .GT. MBLL) ASSIGN 90 TO KOKO
      KJ=(LINE-MTRL)/JL +1
      NSPXL=IFIX(BORDR(KJ,1)+0.5)
      NLPXL=IFIX(BORDR(KJ,2)+0.5)
C##        TYPE *,KJ,LINE,NSPXL,NLPXL
C  CLASSIFY EACH PIXEL IN THIS LINE
      DO 90 I=1,NP
C  CHECK FOR WATER
      IF (IDAT(I,4) .LT. IS7(1) ) GO TO 100
C  CHECK FOR CLOUD
      IF (IDAT(I,2) .GT. IS5(2) ) GO TO 200
C  CHECK FOR SNOW/ICE
      IF (IDAT (I,1) .GT. IS5(10) ) GO TO 220
C  CHECK FOR VEGETATION
      IS=IDAT(I,4)*100/IDAT(I,2)
      IF (IS .GT. ISR(3)) GO TO 250
      GO TO 260
C  MUST BE WATER.
100      NOW=1
      GO TO 300
C  BELONGS TO CLOUD
200      NOW=2
      GO TO 300
```

```
C  BELOGS TO SNOW ICE
 220          NOW=10
        GO TO 300
C  BELONGS TO VEGETATION
 250          NOW=3
        GO TO 300
C  MAY BE OUTCROP. WE WANT TO EXAMINE THIS PIXEL FURTHER.
C  SPLIT THIS INTO TWO GROUPS
 260          IN=IDAT(I,3)*IDAT(I,4)
        IF (IN .GT. IS7(4) ) GO TO 700
        GO TO 265
C  MAY BE SAND OR DOLOMITE
 700          IM=IDAT(I,1)*IDAT(I,2)
        IF (IM .GT. IS5(8) ) GO TO 270
C  MUST BE DOLOMITE
        GO TO 670
C
 265          IF (IS .GE. ISR(4) ) GO TO 600
C  BELONGS TO GROUP1 (CLASS 8 8 9)
C  CHECK IF IT IS SAND
        IF (IM .GT. IS5(8) ) GO TO 270
C  MUST BE CLASS 9 - SST
        NOW=9
        GO TO 300
C  MUST BE CLASS 8 - SAND
 270          NOW=8
        GO TO 300
C
C  BELONGS TO GROUP 2
 600          IF (IN .GT. IS7(4) ) GO TO 670
        IF (IS .GE. ISR(5) ) GO TO 680
C  CHECK IF IT BELONGS TO CLASS 6 - BASALT
        IF (IDAT(I,3) .LE. IS7(6) ) GO TO 690
C  BELONGS TO CLASS 7 - GRANITES/FELSITE
        NOW=7
        GO TO 300
C  BELONGS TO CLASS 4 - DOLOMITES
 670          NOW=4
        GO TO 300
C  BELONGS TO CLASS 5 - SOIL/BOULDERY
 680          NOW=5
        GO TO 300
C  BELONGS TO CLASS 6 - BASALT
 690          NOW=6
        GO TO 300
 300          AR(I)=NOW
        GO TO KOKO
 500          KJ=LFTPIX+(I-1)*JP
        IF (KJ .LT. NSPXL .OR. KJ .GT. NLPXL) GO TO 90
        ICOUNT (NOW)=ICOUNT(NOW)+1
  90          CONTINUE
        RETURN
        END
```

```
C******SUBROUTINE ALSYMB
C-   -   -   -   -   -   -   -   -   -   -   -
C  ASSIGNS COLORS FOR THE DISPLAY
C-   -   -   -   -   -   -   -   -   -   -   -
C  VARIABLES:
C  GLOBAL: AR,NP,SYMBL
C
C-   -   -   -   -   -   -   -   -   -   -   -
      SUBROUTINE ALSYMB
C#####################################################
      DOUBLE PRECISION ICLS(21)
      INTEGER SYMBL(21),AR(550),IS5(21),IS7(21),ISR(21)
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
C  ASSIGN SYMBOLS
      DO 10 I=1,NP
      AR (I)=SYMBL(AR(I))
 10      CONTINUE
      RETURN
      END
```

```
C                              @@@@@@@@@@
C                              @ COLNAM @
C                              @@@@@@@@@@
C-    -    -    -    -    -    -    -    -    -    -    -
C*****SUBROUTINE COLNAM
C  PAK CHAGARLAMUDI,OTTAWA,ONT., JUNE 1978.
C-    -    -    -    -    -    -    -    -    -    -    -
C  PART IF MADROK PACKAGE.
C  INITIALIZES THE COLOR CODE & DISPLAYS THE NAMES & CODE NUMBERS.
C  THE MIX FOR THE COLORS WAS OBTAINED FROM DR. S. SHLIEN.
C-    -    -    -    -    -    -    -    -    -    -    -
      SUBROUTINE COLNAM
C###########################################################
      DIMENSION ICOLOR(21)
      DOUBLE PRECISION CNAME (21)
      COMMON /COLOR/ ICOLOR,CNAME,LTBLK,LBBLK,MAG
      DATA CNAME/'BLACK','BLUE','GREEN','RED','LIGHT BLUE',
     *'PINK PURPL','YELLOW','GREY','BROWN','BLUISHGREY',
     *'ORANGE','DARK BLUE','DARK RED','DARK GREEN','TARQUOISE',
     *'PURPLE','WHITE',' ',' ',' ',' '/
C  COLOR CODE
C
C  BLACK
      ICOLOR(1)="0
C  BLUE
      ICOLOR(2)="550000550000
C  GREEN
      ICOLOR(3)="005500005500
C  RED
      ICOLOR(4)="000055000055
C  LIGHT BLUE
      ICOLOR(5)="777700777700
C  PINK PURPLE
      ICOLOR(6)="770077770077
C  YELLOW
      ICOLOR(7)="007777007777
C  GRAY
      ICOLOR(8)="404040404040
C  BROWN
      ICOLOR(9)="202030202030
C  BLUISH GRAY
      ICOLOR(10)="355500355500
C  ORANGE
      ICOLOR(11)="004565004565
C  DARK BLUE
      ICOLOR(12)="250000250000
C  DARK RED
      ICOLOR(13)="000025000025
C  DARK GREEN
      ICOLOR(14)="002500002500
C  TARQUOISE
      ICOLOR(15)="252500252500
C  PURPLE
      ICOLOR(16)="250025250025
C  WHITE
      ICOLOR (17)="555555555555
C  DISPLAY THE NAMES & NUMS.
      WRITE (5,50)
 50        FORMAT (1X,'COLOR CODES ARE:')
      WRITE (5,100) (CNAME(I),I,I=1,17)
 100 FORMAT (1X,4(1X,A10,'-',I2,';'))
      RETURN
      END
```

```
C                                @@@@@@@@@@
C                                @ DSPFL1 @
C                                @@@@@@@@@@
C-    -     -     -     -     -     -     -     -     -     -
C*******SUBROUTINE DSPFL1
C  CODE WRITTEN BY P. CHAGARLAMUDI
C  UNIV. OF MANITOBA, WINNIPEG, MAN.
C  FEB. 1979.
C-    -     -     -     -     -     -     -     -     -     -
C  CREATES & WRITES A DISPLAY COMPATIBLE FILE OF
C  A THEMATIC MAP.
C  SPLIT SCREEN VERSION.
C-    -     -     -     -     -     -     -     -     -     -
        SUBROUTINE DSPFL1
C##########################################################
        DOUBLE PRECISION ICLS (21),CNAME (21)
        INTEGER SYMBL (21),AR(550),IS5(21),IS7(21),ISR(21),IDAT(550,4)
        INTEGER IPXL (6), JUMP (279),ICOLOR(21)
        COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
        COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
        COMMON /COLOR/ ICOLOR,CNAME,LTBLK,LBBLK,MAG
        COMMON /CHAN/ IDAT
C
C  LOAD THE  THEMATIC MAP ON THE TOP HALF
C
C  CREATE THE BUFFER AS  PER MAG. SPECS.
        IWRD=0
        IBIT=35
        DO 20 I=1,NP
        DO 20 J=1,MAG
        IBIT=IBIT+18
        IF (IBIT .LT. 36) GO TO 30
        IWRD=IWRD+1
        IBIT=0
  30        CALL OFLD ( IBIT,18,JUMP(IWRD),ICOLOR(SYMBL(AR(I))))
  20        CONTINUE
C        TYPE *,((AR(I),SYMBL(AR(I)),ICOLOR(SYMBL(AR(I))),JUMP(I
C    *)),I=1,250,75)
C
C  WRITE THE LINE AS PER MAG. SPECS.
        DO 40 I=1,MAG
        CALL PUT (2,LTBLK,279,JUMP(1),IER)
        LTBLK=LTBLK+3
  40        CONTINUE
C
C  LOAD THE ORIGINAL IMAGE ON THE BOTTOM HALF
C
C  CREATE THE BUFFER AS PER MAG
        IWRD=0
        IBIT=35
        DO 100 I=1,NP
        IPXL(1)=IDAT(I,1)/2
        IPXL(2)=IDAT(I,2)/2
        IPXL(3)=IDAT(I,4)/2
        DO 120 J=1,3
        IF (IPXL(J) .GT. 63) IPXL(J)=63
        IPXL(J+3)=IPXL(J)
 120        CONTINUE
        CALL BYTPAC (6,6,IPXL(1),IPX,IER)
        DO 150 J=1,MAG
        IBIT=IBIT + 18
        IF (IBIT .LT. 36) GO TO 200
        IWRD=IWRD+1
```

```
        IBIT=0
  200         CALL OFLD (IBIT,18,JUMP(IWRD),IPX)
  150         CONTINUE
  100         CONTINUE
C        TYPE *,((AR(I),SYMBL(AR(I)),ICOLOR(SYMBL(AR(I))),JUMP(I
C    *)),I=1,250,75)
C  WRITE THE LINE AS PER MAG. SPECS.
        DO 250 I=1,MAG
        CALL PUT (2,LBBLK,279,JUMP(1),IER)
        LBBLK=LBBLK+3
 250          CONTINUE
        RETURN
        END
```

```
C                                          @@@@@@@@@@
C                                          @ DSPFL2 @
C                                          @@@@@@@@@@
C-     -     -     -     -     -     -     -     -     -     -     -
C******SUBROUTINE DSPFL2
C  WRITES A DISPLAY COMPATIBLE FILE OF THE THEMATIC MAP.
C-     -     -     -     -     -     -     -     -     -     -     -
      SUBROUTINE DSPFL2
C##############################################################
      INTEGER IPXL(3),JUMP(279),ICOLOR(21)
      DOUBLE PRECISION ICLS(21),CNAME(21)
      INTEGER SYMBL(21),AR(550),IS5(21),IS7(21),ISR(21),IDAT(550,4)
C
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DEFF/NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /COLOR/ICOLOR,CNAME,LTBLK,LBBLK,MAG
      COMMON /CHAN/IDAT
C
C  LOAD THE THEMATIC MAP.
C
C  CREATE THE BUFFER AS PER MAG. SPECS.
      IWRD=0
      IBIT=35
      DO 100 I=1,NP
      DO 100 J=1,MAG
      IBIT=IBIT+18
      IF (IBIT .LT. 36) GO TO 150
      IWRD=IWRD+1
      IBIT=0
 150      CALL OFLD (IBIT,18,JUMP(IWRD),ICOLOR(SYMBL(AR(I))))
 100      CONTINUE
C      TYPE *,((AR(I),SYMBL(AR(I)),ICOLOR(SYMBL(AR(I))),JUMP(I
C    *)),I=1,250,75)
C  WRITE THE LINE AS PER MAG. SPECS.
      DO 200 I=1,MAG
      CALL PUT(2,LTBLK,279,JUMP(1),IER)
      LTBLK=LTBLK+3
 200      CONTINUE
      RETURN
      END
```

```
C
C                                         @@@@@@@@@@
C                                         @ COLCOD @
C                                         @@@@@@@@@@
C-     -     -     -     -     -     -     -     -     -     -     -
C*******SUBROUTINE COLCOD
C-     -     -     -     -     -     -     -     -     -     -     -
C  ROUTINE COLCODE WRITES COLOR CODE AT THE BOTTOM OF THE SCREEN.
C  THE COLOR CODE IS WRITTEN ONLY FOR THE CLASSES(COLORS) IN USE AND
C  WILL BE IN SEQUENTIAL ORDER.
C-     -     -     -     -     -     -     -     -     -     -     -
C  PAK CHAGARLAMUDI, APRIL, 1979.
C-     -     -     -     -     -     -     -     -     -     -     -
      SUBROUTINE COLCOD
C#########################################################################
      INTEGER ICOLOR(21)
      DOUBLE PRECISION ICLS(21),CNAME(21)
      INTEGER SYMBL(21),AR(550),IS5(21),IS7(21),ISR(21)
C
      COMMON /DESIR/ ICLS,IS5,IS7,ISR,SYMBL,AR
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /COLOR/ ICOLOR,CNAME,LTBLK,LBBLK,MAG
C
C  THE WIDTH OF THE CODE IS SAME AS THE TOT # OF PIXEL WIDTH.
C  THIS IS SPLIT BETWEEN THE NC CLASSES
C
      K=NP/NC
      DO 100 I=1,NC
      K1=K*(I-1)+1
      K2=K1+K
      DO 100 J=K1,K2
      AR(J)=I
 100      CONTINUE
C
C  THE COLOR CODE IS WRITTEN ON 5*MAG LINES
C  WRITE THE COLOR CODE
      NEW=LTBLK
      IF (LBBLK .GT. NEW ) NEW=LBBLK
      IF (NEW .GT. 1485) NEW=1485
      LTBLK=NEW
      DO 150 I=1,5*MAG
      CALL DSPFL2
 150      CONTINUE
      RETURN
      END
```

DSPLAY.CMD

```
DSPLAY.FOR,VEGTXT.FOR,DISKRD.FOR,REL:CCRSL.REL/L
```

```
C                                @@@@@@@@@@@@
C                                @  DSPLAY  @
C                                @@@@@@@@@@@@
C   DSPLAY.FOR, JAN. 1980.
C   VERSION 80.1.1
C-  -   -   -   -   -   -   -   -   -   -   -   -
C   CODE WRITTEN BY
C   PAK CHAGARLAMUDI
C   OTTAWA, ONTARIO
C - -   -   -   -   -   -   -   -   -   -   -   -   -   -
C   THIS SUIT OF PROGRAMS READS A DISK FILE OF A SMALL
C   PORTION OF LANDSAT DATA AND THEN CREATES A DISPLAY COMPATIBLE FILE.
C   THE FOLLOWING OPTIONS EXIST IN THIS PROGRAM:
C   (A)TO DECIMATE THE DATA WHEN NOT INTERESTED IN USING ALL THE DATA.
C   (B) TO GENERATE THE DISPLAY FILE AT ANY MAGNIFICATION.
C   (C) CAN HANDLE EITHER JSC (CCRS OR EROS DATA) OR OLD FORMAT.
C   THE DISPLAY COMPATIBLE FILE CAN BE DISPLAYED ON THE MAD USING
C   PROGRAM DSPCIO ; A CSFR TAPE CAN BE CREATED USING DSPCSF
C   ; OR AN EBIR TAPE USING DSPEBR IN THE MICA PACKAGE.
C-  -   -   -   -   -   -   -   -   -   -   -   -
C   ROUTINE DSPLAY.FOR IS THE MAIN PROGRAM IN DSPLAY PACKAGE.
C   ROUTINES REQUIRED BY DSPLAY PACKAGE ARE LISTED IN DSPLAY.CMD
C-  -   -   -   -   -   -   -   -   -   -   -
C   VARIABLES:
C   CLOBAL:
C    AR,FEAT1,IBANDS,IBUF,ICAL,ICLS,IDAT,IDATE,IFID,IFILEM,
C    IFILER,IQSUN,IRTPIX,ISITE,ISTLIN,ISTR
C    JL,JP,LFTPIX,LINE,LN,LSTLIN,LU1,LU2,LU3
C    M,MBLK,MLINE,NB,NBLK,NBS,NC,NF,NFORM,NP,NPT,
C    RPS1,RPS2,SUNCOR,SUNELD,SYMBL
C
C###########################################################
        DOUBLE PRECISION FILEN
        REAL BORDR (500,2),CORR(4)
        INTEGER NAME(2),NBGR(3)
        INTEGER IFILEM(2),IFILER(2),IDATE(2),IFID(2),ISITE(2)
        INTEGER IBUF(3648),IDAT(550,4),ICAL(4,6,64),IUPAK(2201),ICOUNT(21)
        INTEGER KF(6),IBANDS(4),NBS(4)
        EQUIVALENCE (IFILER,FILEN)
        COMMON /MSSD/ IBUF,IUPAK,CORR
        COMMON /CHAN/ IDAT
        COMMON /CAL/ ICAL
        COMMON /LOC/  ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
        COMMON /IDENT/IFILEM,IFILER,IFID,IDATE,ISTR,ISITE
        COMMON /DESIR1/IBP,NFORM,NCOUNT,NPRINT,SUNCOR,BORDR,ICOUNT,LSAT
        COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
        COMMON /DEFR/NB,IBANDS,IQSUN,SUNELD,NBLK,MBLK,NBS
        COMMON /COUNT/ MTRL,MBLL
        COMMON /COLOR/ NBGR,CNAME,LTBLK,LBBLK,MAG
        COMMON /GRID/ GRID,NLGRID,NPGRID
C
C   QUERRY THE USER RE. PARAMETERS.
        CALL VEGTXT
        SUNCOR=1.
        IF (IQSUN .NE. 0) SUNCOR=COSD(SUNELD)/COSD(37.)
 600         WRITE (5,610)
 610         FORMAT (1X,'FORMAT OPTION - (0-JSC/CC
     1RS;1-JSC/EROS;2-OLD/CCRS):',$)
        READ (5,620) NFORM
 620         FORMAT (I)
        IF (NFORM .GT. 2 .OR. NFORM .LT. 0) GO TO 600
        IF (NFORM .NE. 2)GO TO 240
C   READ THE LOOKUP TABLE
        LU1=21
```

```
      OPEN (UNIT=LU1,ACCESS='SEQIN',FILE=FILEN)
      READ (LU1,210)(((ICAL(I,J,K),K=1,64),J=1,6),I=1,4)
210       FORMAT(1X,32I4)
      CLOSE (UNIT=LU1)
C  WRITE SUPPORTING INFORMATION ON AN LPT FILE
      LU1=3
240         WRITE (LU1,270) IFID,IDATE
270         FORMAT (1X,'FRAME IDENTIFICATION :',2A5,10X,' D
     *ATA ACQUIRED ON :',2A5,4X)
      WRITE (LU1,272) SUNELD,SUNCOR
272         FORMAT (1X,'SUN ELEVATION :',F4.0,10X,'SUN CORRECTION FACTOR :'
     *,F6.4,2X)
      WRITE (LU1,274) IFILER
274         FORMAT (1X,'MSS RADIOMETRIC CORRECTION TABLES FROM FILE :',2A5)
      WRITE (LU1,276)IFILEM,ISTR
276         FORMAT (1X,'MSS DATA INPUT FILE : ',2A5,3X,'STRUCTRE:',A5)
      WRITE (LU1,278) ISITE
278         FORMAT (1X,'SITE : ',2A5)
C  INITIALIZE THE DISK FILE
      IF (NFORM .EQ. 2)  CALL ODSKST
      IF (NFORM .NE. 2) CALL NDSKST
C  WE HAVE TO PROCESS "MLINE" LINES AND NP PIXELS FROM EACH LINE
      MLINE=(LSTLIN-ISTLIN+1) / JL
C  WRITE PARAMETERS ON FILE FOR LATER RETRIEVAL
      WRITE (LU1,315)
      WRITE (LU1,320) ISTLIN,LSTLIN,LFTPIX,IRTPIX
315         FORMAT (1X,'THE AREA SHOWN ON THE DISPLAY FILE HAS THE FOLLO
     *WING CO-ORDINATES :  ')
320         FORMAT (1X,10X,'LINES :',I4,' TO ',I4,' & PIXELS
     *:',I4,' TO ',I4,3X)
      WRITE (LU1,325)JL,JP
325         FORMAT (1X,'DECIM. FACT.- LINES :',I2,'; PIXELS :',I2)
C
      WRITE (5,505)
505         FORMAT (1X,'SELECT ENHANCEMENT PROC. (1-LIN.STRECH; 2-MULTIPLY
     1; 0-OTHERWISE)',$)
      READ (5,620) NQ
C  SET THE THREE COLOR GUNS RESPECTIVELY TO BAND 4,5 & 7.
      NBGR(1)=1
      NBGR(2)=2
      NBGR(3)=4
      IF (NQ .EQ. 1) CALL NHAN1
      IF (NQ .EQ. 2) CALL NHAN2
      WRITE (5,511)
511         FORMAT (1X,'WANT GRID ON DISPLAY (Y/N) ?:',$)
      READ (5,512) GRID
512         FORMAT (A1)
      IF (GRID .NE. 'Y') GO TO 516
      WRITE (5,513)
513         FORMAT (1X,'GRID SELECTION LINES/PIXELS(ORIGINAL) :',$)
      READ (5,514) NLGRID,NPGRID
514         FORMAT (2I)
      WRITE (LU1,515) NLGRID,NPGRID
515         FORMAT (1X,'GRID PLACED AT EVERY LINES - PIXELS :',2I5)
516         WRITE (5,520)
520         FORMAT (1X,'MAGNIFICATION OF DISPLAY >',$)
      READ (5,620) MAG
      WRITE (5,530)
530         FORMAT (1X,'NAME OF DISPLAY COMPATIBLE FILE >',$)
      READ (5,540) NAME
540         FORMAT (2A5)
      WRITE (LU1,550)NAME,MAG
550         FORMAT (1X,'DISPLAY FILE NAME :',2A5,5X,'MAG :',I2)
      WRITE (3,560) NBGR
```

```
 560        FORMAT (1X,'MSS BANDS SELECTED FOR BLUE,GREEN & RED :',3I2)
C  OPEN CHANNEL FOR DISPLAY COMPATIBLE FILE
      CALL INITT2 (NAME,2,IER,0,0,ISTR)
      LBBLK=1
      DO 410 I=1,MLINE
C  GET THE REQUIRED # OF PIXELS FROM THE CURRENT SCAN LINE
      IF (NFORM .EQ. 2) CALL OSETLN
      IF (NFORM .NE. 2) CALL NSETLN
C  PERFORM THE ENHANCEMENTS IF REQUIRED
      IF (NQ .EQ. 1) CALL NHAN11
      IF (NQ .EQ. 2) CALL NHAN21
C  WRITE THE LINE OF DATA ON DISPLAY COMPATIBLE FILE
      CALL DSPFL3
 410        CONTINUE
C  CLOSE THE CHANNEL OF THE DISPLAY COMPATIBLE FILE
      CALL CLOSEE (2)
      RETURN
      END
```

```
C
C                           @@@@@@@@@@
C                           @ DSPFL3 @
C                           @@@@@@@@@@
C****SUBROUTINE DSPFL3
C-  -   -   -   -   -   -   -   -   -   -
C  CODE WRITTEN BY P. CHAGARLAMUDI
C  JAN. 1980.
C-  -   -   -   -   -   -   -   -   -   -
C  PART OF DSPLAY PACKAGE
C  WRITES A LINE OF DATA ON DISPLAY COMPATIBLE FILE
C  ALSO PUTS THE SELECTED GRID ON THE FILE.
C-  -   -   -   -   -   -   -   -   -   -
C  ROUTINES REQUIRED BYTPAC,OFLD,PUT - ALL FROM CCRSL
C  VARIABLES PASSED THROUGH COMMON AREAS
C-  -   -   -   -   -   -   -   -   -   -
      SUBROUTINE DSPFL3
C################################################
      INTEGER IPXL (6),NBCR(3), JUMP (279),IDAT(550,4)
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /COLOR/ NBGR,CNAME,LTBLK,LBBLK,MAG
      COMMON /CHAN/ IDAT
      COMMON /LOC/ ISTLIN,LSTLIN,LFTPIX,IRTPIX,LINE,M
      COMMON /GRID/ GRID,NLGRID,NPGRID
C  PLACE THE GRID IF REQUIRED
      IF (GRID .NE. 'Y') GO TO 245
C  PLACE THE GRID AS PER SPECS
C  CHECK IF THE LINE IS A GRID LINE
      REM=MOD(LINE,NLGRID)
      IF (REM .NE. 0) GO TO 220
C      TYPE *,LINE,LINE,LINE
      DO 210 K=1,550
      DO 210 KK=1,3
      IDAT(K,NBGR(KK))=0
 210        CONTINUE
      GO TO 245
 220        REM=MOD(LFTPIX-1,NPGRID)
      REM=(NPGRID-REM)/JP
      DO 230 K=REM,550,NPGRID/JP
      DO 230 KK=1,3
      IDAT(K,NBGR(KK))=0
 230        CONTINUE
C
C
C  LOAD THE ORIGINAL IMAGE.
C  CREATE THE BUFFER AS PER MAG
 245        IWRD=0
      IBIT=35
      DO 100 I=1,NP
      IPXL(1)=IDAT(I,NBGR(1))
      IPXL(2)=IDAT(I,NBGR(2))
      IPXL(3)=IDAT(I,NBGR(3))
      DO 120 J=1,3
      IF (IPXL(J) .GT. 63) IPXL(J)=63
      IPXL(J+3)=IPXL(J)
 120        CONTINUE
      CALL BYTPAC (6,6,IPXL(1),IPX,IER)
      DO 150 J=1,MAG
      IBIT=IBIT + 18
      IF (IBIT .LT. 36) GO TO 200
      IWRD=IWRD+1
      IBIT=0
```

```
  200          CALL OFLD (IBIT,18,JUMP(IWRD),IPX)
  150          CONTINUE
  100          CONTINUE
C  WRITE THE LINE AS PER MAG. SPECS.
           DO 250 I=1,MAG
         CALL PUT (2,LBBLK,279,JUMP(1),IER)
         LBBLK=LBBLK+3
  250          CONTINUE
         RETURN
         END
```

```
C
C                                   @@@@@@@@@@
C                                   @ ENHANC@
                                    @@@@@@@@@@
C*****SUBROUTINE NHAN1
C-    -    -    -    -    -    -    -    -    -
C  THIS ROUTINE PERFORMS LINEAR CONTRAST STRETCH
C-    -    -    -    -    -    -    -    -    -
C  PAK CHAGARLAMUDI, JAN. 1980.
C-    -    -    -    -    -    -    -    -    -
C  PART OF DSPLAY PACKAGE
C  ROUTINES REQUIRED - NONE
C  ALL VARIABLES ARE PASSED THROUGH COMMON AREAS
C-    -    -    -    -    -    -    -    -    -
      SUBROUTINE NHAN1
C#################################################
      INTEGER MIN(3),MAX(3),NBGR(3),IDAT(550,4)
      DIMENSION FACTR(3)
      COMMON /CHAN/ IDAT
      COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
      COMMON /COLOR/ NBGR,CNAME,LTBLK,LBBLK,MAG
C
      WRITE (3,5)
    5     FORMAT (1X,'*** LINEAR STRETCH ENHANCEMENT ***')
      WRITE (5,10)
   10     FORMAT (1X,'MSS BANDS(1-4) FOR BLUE,GREEN & RED GUNS >',$)
      READ (5,20) NBGR
   20     FORMAT (3I)
CC      WRITE (3,30)NBGR
   30     FORMAT (1X,'MSS BANDS FOR BLUE,GREEN & RED GUNS WERE :',3I2)
C
      NMAX=255
      DO 40 I=1,3
      WRITE (5,50) NBGR(I)
   50     FORMAT (1X,'MIN. & MAX. FOR BAND ',I1,' >',$)
      READ (5,60) MIN(I),MAX(I)
   60     FORMAT (2I)
      FACTR(I)=NMAX/(MAX(I)-MIN(I))
      WRITE (3,70) NBGR(I),MIN(I),MAX(I)
   70     FORMAT (1X,'MIN. & MAX. FOR BAND ',I1,' WERE :',2I4)
   40     CONTINUE
      RETURN
C-    -    -    -    -    -    -    -    -    -
C*****ENTRY NHAN11
C-    -    -    -    -    -    -    -    -    -
      ENTRY NHAN11
C#################################################
C  PERFORM LINEAR CONTRAST STRETCH
      DO 100 I=1,3
      K=NBGR(I)
      DO 100 J=1,NP
      IDAT(J,K)=(IDAT(J,K)-MIN(I))*FACTR(I)
  100     CONTINUE
      RETURN
      END
```

```
C*****SUBROUTINE NHAN2
C-   -    -    -    -    -    -    -    -    -
C  THIS ROUTINE PERFORMS STANDARD ENHANCEMENT IE. MULTIPLICATION OF
C  BAND VALUES.
C-   -    -    -    -    -    -    -    -    -
C            PAK CHAGARLAMUDI
C-   -    -    -    -    -    -    -    -    -
C  PART OF DSPLAY PACKAGE
C  ROUTINE REQUIRED NONE
C  ALL VARIABLES PASSED THROUGH COMMON AREAS
C-   -    -    -    -    -    -    -    -    -
        SUBROUTINE NHAN2
C################################################
        DIMENSION FACTR(3)
        INTEGER NBGR(3),IDAT(550,4)
        COMMON /CHAN/IDAT
        COMMON /DEFF/ NC,LN,NPT,NP,MLINE,JL,JP,NF
        COMMON /COLOR/ NBGR,CNAME,LTBLK,LBBLK,MAG
C
        WRITE (3,5)
    5       FORMAT (1X,'*** MULTIPLICATION ENHANCEMENT ***')
        WRITE (5,10)
   10       FORMAT (1X,'MSS BANDS(1-4) FOR BLUE,GREEN & RED GUNS >',$)
        READ (5,20) NBGR
   20       FORMAT (3I)
CC        WRITE (3,30) NBGR
  30       FORMAT (1X,'MSS BANDS FOR BLUE,GREEN & RED GUNS WERE :',3I2)
        WRITE (5,40)
  40       FORMAT (1X,'MULTIPLICATION FACTRORS FOR BL GR RED GUNS >',$)
        READ (5,50)FACTR
  50        FORMAT (3F)
        WRITE (3,60) FACTR
  60        FORMAT (1X,'MULTIPLICATION FACTORS FOR BLUE,GREEN & RED GUNS WERE :
     1',3(F6.3,','))
        RETURN
C*****ENTRY NHAN21
        ENTRY NHAN21
C################################################
C  PERFORM STANDARD ENHANCEMENT FOR A LINE
        DO 100 I=1,3
        K=NBGR(I)
        DO 100 J=1,NP
        IDAT (J,K)=IDAT(J,K)*FACTR(I)
  100       CONTINUE
        RETURN
        END
```

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