DEVELOPMENT OF DIGITAL IMAGE PROCESSING FOR MAPPING GEOLOGICAL FEATURES RELATED TO LATERITIC Ni DEPOSITS

M. Stefouli

SUMMARY

The aim of the work has been to evaluate the applicability of the use of digital image data (Landsat TM, SPOT) along with ancillary data for the mapping of local scale geological features related to lateritic Ni deposits, using advanced image processing techniques.

Image processing techniques have been applied to remotely sensed data for : Removal of artifacts related to atmosphere. Rectification of the images. Reduction of the high inter-band correlation inherent to the reflected part of the spectrum through the decorrelation stretching of bands. Interpolation and co-registration of all data sets. Image integration. Spectral models based on ratio, I.HS. and PCA / DPCA of the images have been developed for the mapping of variations in ferric - iron and clay mineral content. Remotely sensed imagery have been interpreted in terms of geologic structures, lithology and mineralogical variations for the Vermion area of study.

Geologic features of specific interest to the Ni lateritic deposits have been mapped for the first time on the satellite imagery. Generally, the use of the remotely sensed images in geologic map updating to scales up to 1:25,000 lies in the fact, that various geologic and mainly structural features can be mapped quickly for large areas. The time which is needed to delineate the general structure of the area and to mark lithological / mineralogical features is minimum, relatively to that needed for the construction of a geological map and field mineralogical / lithological observation collection.

ΑΝΑΠΤΥΞΗ ΤΕΧΝΙΚΩΝ ΨΗΦΙΑΚΗΣ ΕΠΕΞΕΡΓΑΣΙΑΣ ΕΙΚΟΝΑΣ ΜΕ ΧΡΗΣΙΜΟΤΗΤΑ ΣΤΗΝ ΕΡΕΥΝΑ ΜΕΤΑΛΛΕΥΜΑΤΩΝ ΝΙΚΕΛΙΟΥ.

Μ. Στεφούλη

ΠΕΡΙΛΗΨΗ

Αντικειμενικός στόχος της εργασίας είναι η αξιολόγηση της χρησιμότητας των ψηφιακών δορυφορικών εικόνων (Landsat TM & SPOT) στην έρευνα λατεριτικών μεταλλευμάτων Νικελίου, μετά την ανάπτυξη εξειδικευμένων τεχνικών επεξεργασίας εικόνας.

Τεχνικές επεξεργασίας εικόνας έχουν εφαρμοσθεί στις δορυφορικές εικόνες για την ατμοσφαιρική και γεωμετρική διόρθωση τους, την μείωση του όγκου της πληροφορίας που περιέχεται στην ανακλώμενη περιοχή του φάσματος, και την ταυτόχρονη συσχέτιση των διαφορετικής διακριτικότητας εικόνων. Εξειδικευμένα φασματικά μοντέλα έχουν αναπτυχθεί, έτσι ώστε να διευκολυνθεί η χαρτογράφηση και ερμηνεία διαφοροποιήσεων του εδάφους και / ή των πετρωμάτων που συνδέονται με μεταβολές της περιεκτικότητας σε σιδηρούχα και αργιλικά υλικά. Όλες οι δορυφορικές εικόνες, της περιοχής μελέτης του Βερμίου έχουν ερμηνευτεί σε σχέση με τις γεωλογικές δομές και τις λιθολογικές ορυκτολογικές μεταβολές ενδιαφέροντος σε σχέση με την έρευνα Νικελίου.

Το αποτέλεσμα της μελέτης δείχνει ότι τα δεδομένα της τηλεπισκόπησης μπορούν να χρησιμοποιηθούν στην συμπλήρωση ή αναθεώρηση γεωλογικών / κοιτασματολογικών χαρτών κλίμακας έως 1 :25,000. Ο χρόνος που απαιτείται για την οριοθέτηση της γενικής δομής της περιοχής μελέτης και τον εντοπισμό θέσεων λιθολογικών / ορυκτολογικών διαφοροποιήσεων είναι ελάχιστος σε σχέση με αυτόν των χαρτογραφήσεων υπαίθρου. Γενικά από τις δορυφορικές εικόνες, έχουν χαρτογραφηθεί, για πρώτη φορά, στην περιοχή μελέτης του Βερμίου, γεωλογικά στοιχεία που συνδέονται άμεσα με λατεριτικά κοιτάσματα Νικελίου.

INTRODUCTION

The aim of the task has been to evaluate the applicability of the use of digital image data (Landsat TM. SPOT) along with ancillary data for the mapping of local scale geological features related to lateritic Ni deposits, using advanced image processing techniques. The investigated area is a part of the western Vermion and consists of formations deposited on the eastern margin of the Pelagonian Zone and on the western Almopias border (Brunn, 1956; Photiades et. al.., 1998)

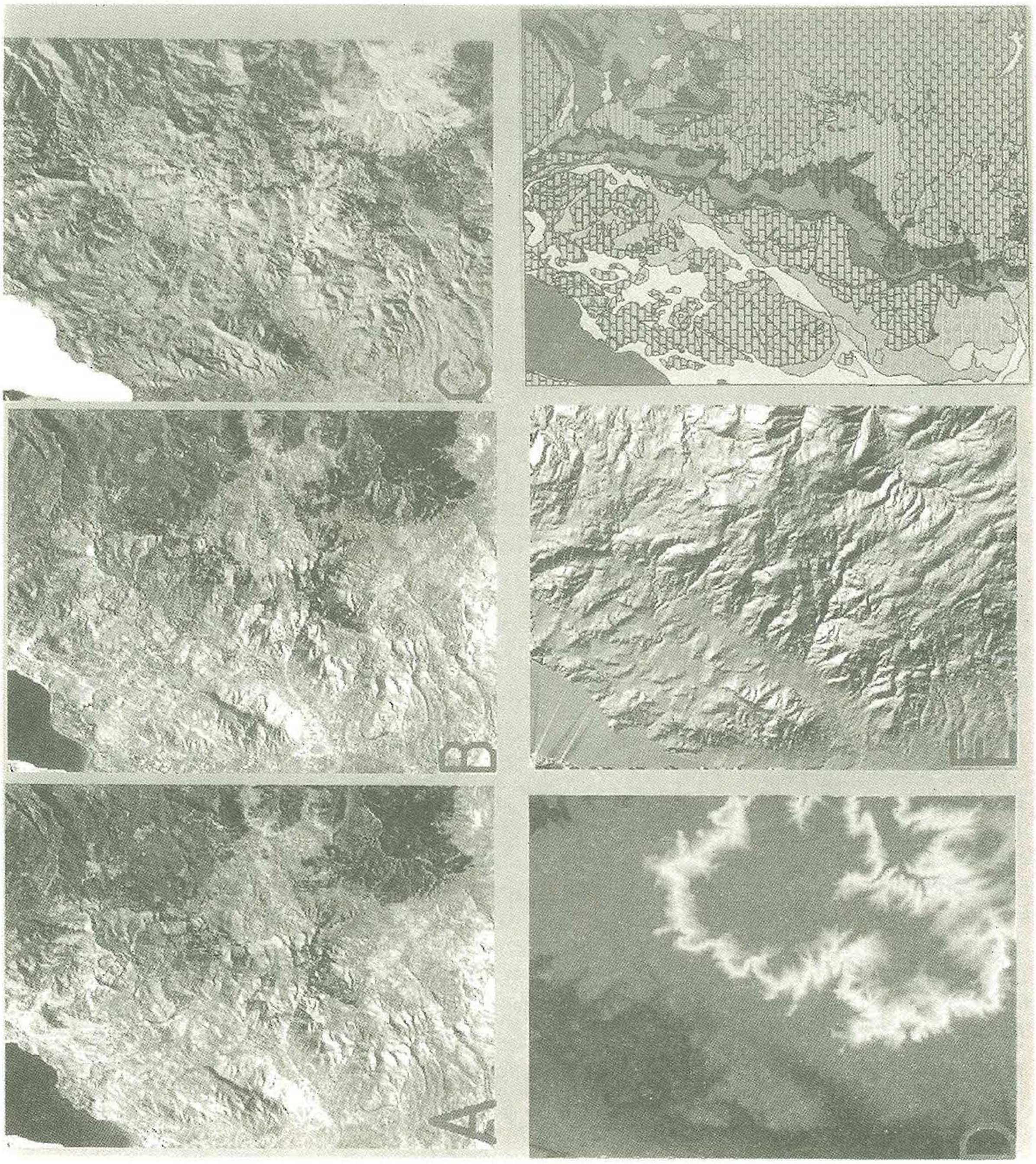
The use of Landsat and SPOT images in mineral exploration is well established. It is also quite certain that Landsat images are in routine use by many mining companies at their own expense, but access to the results obtained is difficult. Consequently the success or failure rates of actually using features identified by remote sensing techniques in exploration, especially for certain geotectonic environments is not well established. Also image processing for geologic research (exploration of Ni minerals) has not always employed to its potential, because most Image Processing systems are not designed for direct applications to geologic research and there is little communication between workers in geology and workers in image processing. One of the objectives of the present work is to attempt to fill the gap which exists between the various computerized procedures of Image Processing and the geologic interpretation techniques, specifically related to Ni mineral exploration.

MEANS USED TO ACHIEVE THE OBJECTIVES

The digital image processing system, which is operating at IGME, was mainly used to analyse the image data (UNIX LX system, 96 MB memory, 6 GB hard disk, CD, DAT 4 mm). The analysis has been carried out with the TNTmips Image Processing system.

The system has been effective in order to:
a) perform image processing tasks (image enhancement); b) test the applicability of various models specialized image processing tasks of interest to the Ni mining exploration; c) cover the needs for the system development, concerning the image processing and GIS tasks and data exchange; d) apply both raster and vector techniques; e) allow information from different sources to be combined ; f) provide flexible image processing facilities to enhance relevant image features; g) provide tools for image registration, geometric corrections; h) provide rapid quantification facilities to enable the accurate identification of regions on the basis of colour and intensity; i) provide automatic extrapolation from the ground truth data; and j) allow the storage and processing of both raster images and vector - map data, along with the application of modelling techniques. The cost to processing functions ratio is well justifiable to mining research work.

The satellite images that have been analyzed are mainly the Landsat TM and SPOT images. The image data used are shown in Figure 1. Also the processed within the GIS system digitized geologic and topographic (contour lines and drainage pattern) information of the 1:50,000 Pirgoi sheet have been also included in the analysis, Figure 1.



<<**FIGURE** 1. Display of the satellite, topographic and the existing geologic data used in the project. **A**: True colour composite of the Landsat TM image (Bands, 3:2:1 in R:G:B respectively). **B**: SPOT Panchromatic image. **C**: Image obtained from the multilinear regression process of ERS-SAR with the Landsat TM image **D**: Digital Elevation Model of Pirgoi sheet displayed with a colour palette. **E**: The shaded relief image produced from the analysis of the Digital Elevation Model **F**: Two dimensional representation of the processed in the GIS existing geologic map of Pirgoi sheet of 1:50,000 scale. Different geologic patterns have been created in order to display the coded into the database information. >>

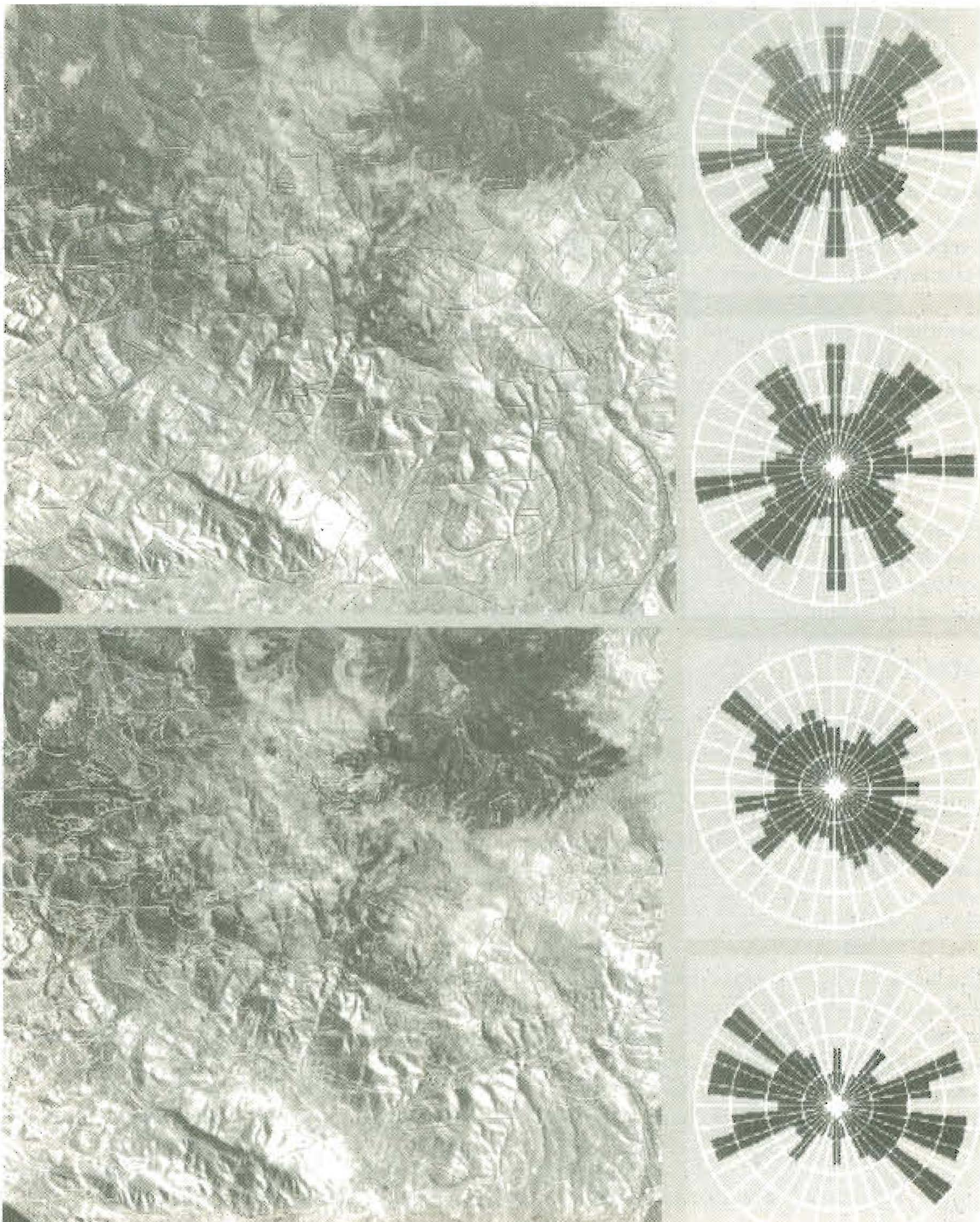
IMAGE ENHANCEMENT OF SPECTRAL FEATURES RELATED TO Ni.

Ophiolitic sequences in connection with plate movements and ocean spreading are worlwide pheuomena during Alpine orogeny. The association of weathered ophiolitic sequences, nickel laterites and bauxites, therefore should appear as a world-wide type of ore deposits. Serpentinized ultrabasic rocks represent the exposed primary parent rocks in the Vermion area. They consist of homogeneous hartzburgite exhibiting different textural types. The majority of the Ni-Fe ores is bedded upon deeply serpentinized ultramafic rocks representing the predominant parent rocks. More precisely the ophiolitic rocks of Vermion cover a zone of 40 km long and of several hundrends to some decades of meters wide. They consist of serpentinized tectonites, of hartzburgitic and dunitic composition, with high concentrations of chromite, dismembered and deformed, due to the fracturing tectonism and mylonitization. The Fe-Ni mineral deposits of Vermion, occur, mainly in its western slope and their strartigraphic positions is equivalent to that of the mineral occurences in Euboea, in Ieropigi (near Kastoria) and in Albania, more to the north. They always lie over peridotites and are transgressively, overlaid by carbonate rocks of "middle" cretaceous age or they are covered by Miocene mollasic conglomerates, (Photiades et. al., 1998).

Remote sensing strategy depends on lithologically determined variations of clay minerals, secondary silica, magnesite, and ferric minerals in lateritic soils, and to a lesser extend on the more resistant primary silicates such as chlorite, talc, and serpentines. An extensive review of the spectral characteristics of indicative minerals gave an impression of the possibilities for discrimination among hydroxylated silicates and aluminosilicates, carbonates, and sulphates in the SWIR. Unfortunately, none of the unique intricacies can be spectrally resolved by TM band 7. All that is possible is the empirical use of the differences between the reflectance high (1550 to 1750 nm, TM band 5) and lows due to hydroxylated silicates in TM band 7. The absorption feature in carbonates is also too close to the edge of band 7 band pass to have any noticeable effect on radiance.

APPLICATION OF IMAGE ENHANCEMENT TECHNIQUES

Two basic approaches can be distinguished in image processing. The first approach maximizes image information content and quality, so that the analyst can directly use it for interpetation. The second approach stresses techniques involving computerized classifications (interpretations). Image enancement belongs to the first approach and it has as a purpose the best representation of the initial scene. The main problem that was faced, is the plethora of techniques which are available for image enhancement, from which a few had to be selected. Models were developed to build the Image Interpreter functions to suit the Ni exploration application. Additionally specialized processing has been carried out in Outokumpu Mining Oy (Aarnisalo ,1998) for the spectral enhancement of Landsat TM image of Pirgoi Sheet Figure 2.



<<**FIGURE** 2. Three dimensional representations of the spectrally enhanced Landsat TM image by two different models. The lithologic units have been overlayed on top of the DEM to compare the results. Different coloured patterns have been used to distinguish the lithological types stored in the database. Also a three dimensional image has been created by overlaying on the DEM a standard colour composite of bands 4,5,3.>>

Two types of digital analysis were initially performed on the LANDSAT TM data:
1. determination of band and band-ratio combinations after modeling through DPCA the Fe, OH and greenness components of the data that provide optimum discrimination for geologic mapping, and
2. determination of the TM reflectance characteristics of the major units interpreted on the images.

The selected techniques that have been applied and the results obtained are described in Table 1.

Most of the 25 top-ranked band-ratio combinations provide no more discrimination than does the PCC image. The five top-ranked band-ratio combinations, which involve the TM band 5/4 ratio and the 7/5 ratio, do enable discrimination of some rock units that are not easiliy discriminated on either the PCC image or the BCC image. The colour assignements for the band ratios used in the band-ratio colour composite (BRC) image were chosen to provide maximum discrimination of lithologic units (especially the marker limestone horizon and the serpentinized zones).

Alternative colour assignements for the band ratios do provide better discrimination of the other rock units, but these alternate colour assignments make discrimination of the serpentinites very difficult because the human eye is less sensitive to shades of blue and green than to shades of red. Figure 2 shows representations of the enhanced Landsat TM image. These color composites of the components that are related to the surface variations of Fe / OH and greenness have proved very effective in interpreting the various types of lithologies that are related to the Ni laterites.

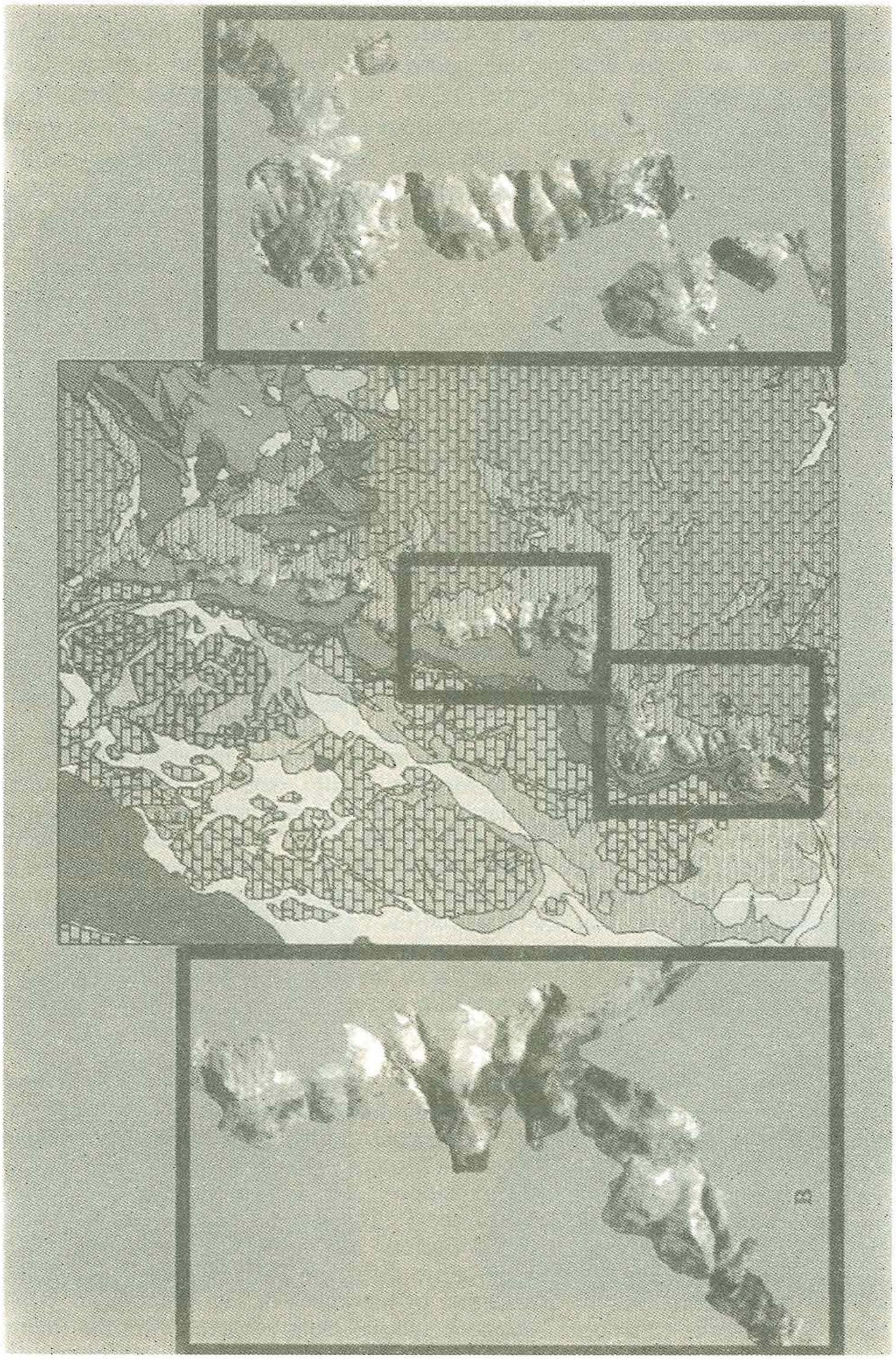
Visual qualitative comparisons between the published 1:50,000 scale geologic maps and the TM data have been performed, rather than quantitative analyses (applying statistical analysis to a digitized geologic maps and the TM data), because the information depicted on the general purpose maps proved to be too coarse to be related to the satellite image interpretations.

IMAGE MERGING

As it has been already noted, the resolution of satellite images is different from each other while they are recording in different part of VIS /IR parts of the spectrum. Because these two sensor types give different information about the same target , they are complementary data sets. If the two images are correctly combined, the resultant image will convey more useful than either image alone.

The methods for merging satellite data are still experimental., while the following methods have been tested: a) Co-displaying in a Viewer; b) RGB to IHS transforms; c) Principal components transform; d) Multiplicative; e) Multilinear regression

The technique applied in the present work, uses the RGB to IHS transforms. In this technique, an RGB (red, green, blue) color composite of bands (or band derivatives) such as ratios is transformed into intensity, hue, saturation color space. The intensity component is replaced by the high resolution image, and the scene is reverse transformed. This technique integrally merges the two data types. Using the IHS family, two options exist:
Intensity - rescales the gray scale image to the numerical range of intensity (I) and then substitutes it for I.
Saturation - rescales the gray scale image to the numerical range of saturation (S) and then substitutes it for S, Figure 3.



<<**FIGURE 3**. The characteristic Upper Cretaceous limestone horizon (K8-9.k) has been selected from the lithologies of the 1:50,000 scale geologic map pf Pirgoi sheet. The boundary of this horizon has been used to extract the corresponding part of the enhanced through data merging modelling techniques, satellite image. The satellite image subset has been plotted on top of the 1:50,000 scale vector format map Two enlarged subset images (A& B) have been plotted on the two sides of the geologic map.>>

DIMENSIONAL REPRESENTATIONS

Digitized topographic maps have been used to create a Digital Elevation Model (DEM). Regional structural features are shown very well on the shaded relief maps created from the DEM, Figure Draping of enhanced satellite images over the D.E.M. has resulted as a very useful technique for interpreting structural and litho-stratigraphic features more effectively. Figure 2 shows the result of the Landsat TM (bands 4,5,3) over the D.E.M. of the Pirgoi area of study. Also it shows different three-dimensional representations of the spectrally enhanced images. Interpretation of the lithological types in relation to the morphological relief can be carried out more effectively than the two dimensional images.

IMAGE INTERPRETATION

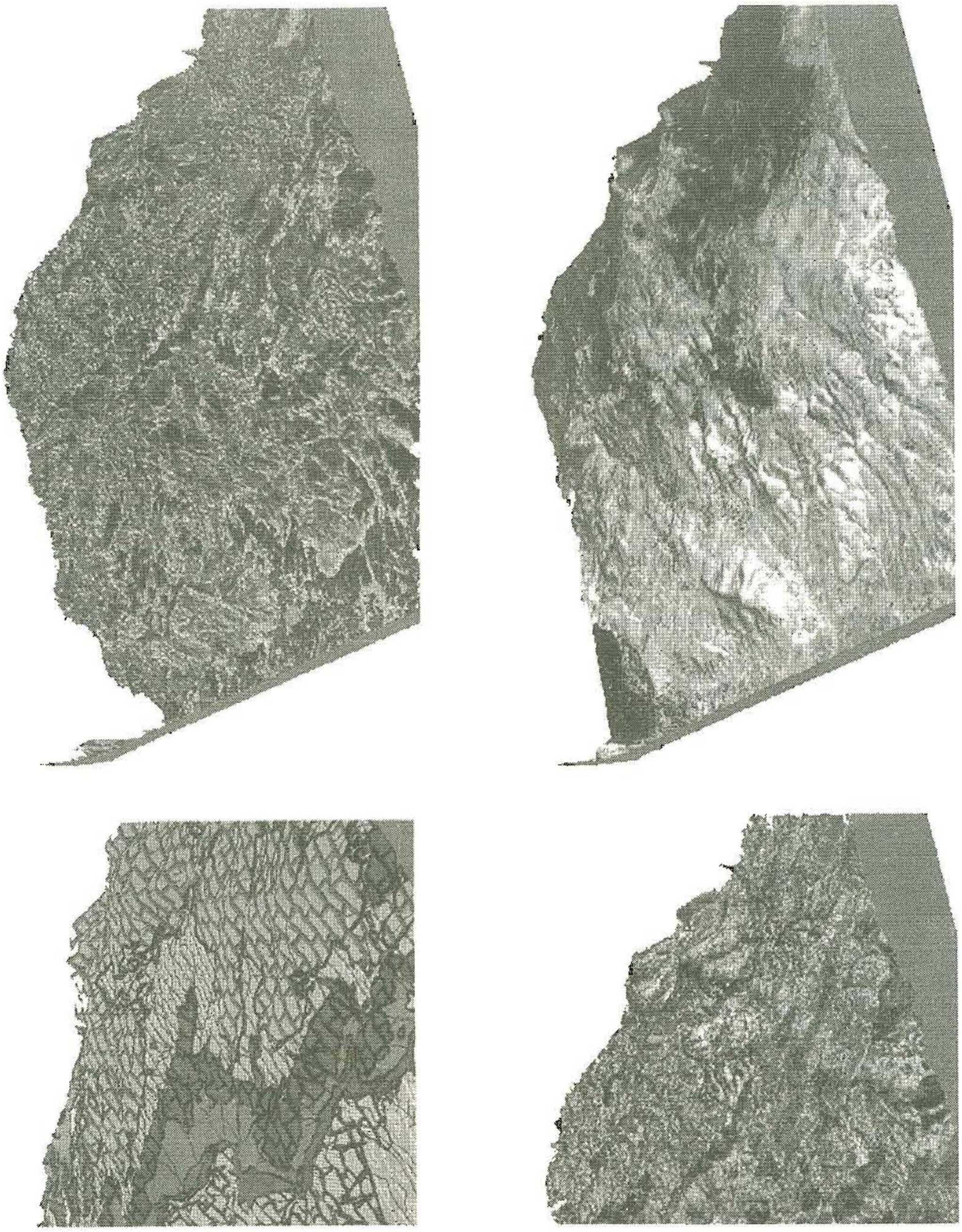
All processed images have been interpreted in terms of the geologic structures, lithology and mineralogical variations for the pilot project area of Vermion. The interpretation has been verified with the 1:50,000 scale geologic map. Distinctive patterns of lineaments in certain prominent directions can be easily interpreted on the enhanced satellite images of the pilot project areas, Figure 4

Structural features

A distinctive system of lineaments of NNW-SSE and E-W directions have been mapped in the central part of the study area, which is the most important part from the point of view of Ni occurences. Figure 4. The most prominent of the features of the map are the nearly NNE / SSW running major lineament zone. The zone is cut along approximately E-W running faults. These are partly shown as faults, thrust faults or lithological boundaries on the geologic maps. However, their extension over greater distances is indicated after the interpretation of satellite imagery, while they have been mapped to different locations. For example, a fault has been interpreted on the central part of the satellite image with the following characteristics : length ~ 6 km, direction ~158 deg. This fault line corresponds partly to the fault shown on the geologic map, but just for half its length (~ 3 km) and in a different direction (~ 168 deg). This specific fault seems to be of some importance, as it causes displacement of the Upper Cretaceous series of rocks to a more easterly direction. Similarly, one of the major fault lines (4.4 km length), of a general NE (63 deg) direction, that is located on the target area of Profitis Elias, it is shown only for its half length (~2.07 km) on the geologic map. Major lineaments of length more than 6 - 7 km of NE and NW directions have been interpreted all over the area of study, while they are not shown on the map. This is of importance, as they are controlling the location of litho-stratigraphic units that are related to the Fe -Ni occurences. Minor lineaments have been also mapped and they seem to play a role as far as the displacement of the continuity of the lateritic horizon is concerned. Finally, the mapping of fault traces and especially those of the thrust faults that has been achieved through the interpretation of satellite images is of some importance to the current project, as it is related to the occurrence of Fe / Ni deposits.

Litho-stratigraphic mapping

Distinctive lithological / mineralogical variations can be also interpreted on the images. The characteristic Upper Cretaceous limestones that overlay the laterites for the Metallion area are shown on the satellite image and their boundary has been traced. This limestone horizon is extended to the North, even though it is cut by numerous faults. The characteristic emplacement of these units is indicated on the satellite imagery. If the interpretation is extended to the North then the rest of the nappes are found in regular succession Figures 2 and 3. This very regular succession of the structural units implies a distinctive emplacement from Easterly directions. Generally, the outline of the lithological boundaries shown on the 1:50,000 scale map coincide to the traces interpreted on the satellite images at only certain places. Relocation of the traces of the lithological boundaries and especially those of the rocks of Upper Cretaceous age has been achieved after the interpretation of satellite imagery. For example a variety of different colors that correspond to different lithologies are evident in Figure 3. In this case, the light gray blue color corresponds to the rudist bearing Cretaceous limestones, while the dark brown colors correspond to the flysch and the transitional beds or debris flows (Photiades et. al. , 1998) Rock type alterations that are probably related to the variation of the amount of Al_2O_3, SiO_2 (MnO & Cr_2O_3) have been indicated on the satellite image for the Metallion area. Their placement forms a zone of a general N-NW/S-SE (28 deg) direction. Rocks of the ophiolitic sequence can be recognized in the study area and easily discriminated from the limestone terrain. The location of laterites is indicated by their characteristic coloring and the limestone horizon that overlays them.



<<**FIGURE 4**. Landsat TM band 4 image overlayed by the lithologic boundaries (yellow lines) and the tectonic features (orange lines) as they have been digitized from the 1:50,000 scale geologic map (Vermio area of study / Pirgoi sheet. Landsat TM band 4 image, overlayed by the lineaments interpreted on the satellite image. The results of the statistical analysis have been plotted as rose diagrams. More lineaments have been mapped on the satellite images than those shown on the geologic map.>>

SUMMARY OF RESULTS

The traces of geologic features have been mapped more accurately on the satellite images than on the geologic maps. The ratio of the number of the features mapped on the satellite images to the geologic maps is 4 to 1 respectively. This stresses the fact that the information of satellite images can contribute to a more detailed geologic mapping to larger scales up to 1 :25,000.

Generally, the mapping of structural and stratigraphic features can be made quickly and quite accurately for comparatively large areas. Geologic maps could be updated. Finally, features related to Ni lateritic occurences have been interpreted on the satellite images, while they are not shown on the general purpose geologic maps. In the present study more structural features are depicted on the satellite images than the general 1:50,000 scale geologic maps. The time which is needed to delineate the general structure of the area and to compile the map of satellite image features of the area is minimum relatively to that needed for the construction of a geologic map. However, results also demonstrate both the need for, and the potential of, using systems designed to critically sample the narrowest mineral absorption features, significantly augmenting the ability to identify mineral assemblages and to map lithologic units.

REFERENCES

M Stefouli / I.G.M.E., 1997 Image processing / Pattern recognition. Satellite and other data acquisition, quality evaluation and image processing. Unpublished, preliminary report IGME July 1997

J. Aarnisalo 1998 Personal communication on spectral enhancement of Landsat TM images.

Photiades A., Skourtsis – Coroneou V, Grigoris P, 1998

The stratigraphic and paleogeographic evolution of the Eastern Pelagonian margin during the late Jurassic-Cretaceous interval (Western Vermion Mountain – western Macedonia, Greece). Bulletin of the Geological Society of Greece Vol. XXXII/1, pp71-77, 1998 (Proceedings of the 8th International Congress, Patras, May 1998).

Geological map of Greece : Pirgoi Sheet Scale 1:50,000. The geologic mapping has been carried out by Professor J. H. Brunn of the Orsay University, France. Published by IGME 1982.

TABLE 1 . SPECTRAL ENHANCEMENT TECHNIQUES

Enhancement technique	Description	Results
Band Combination	Analysis applied : Computing of 7*7 variance covariance matrix. Ranking in order the determinants for each 3*3 submatix. Application of statistical analysis. Testing.	The best three - band combinations include TM bands 1,3 (or 4) and 5 (or 7), Figures1,4 and 7. Natural color components and RGB: 7,5,4 or RGB:7,4,2 proved also effective for interpretation of geologic features.
Ratioing	Computation of various ratios using the methods of: DN=a(Dnils/DNjls)+b Dnijn=K(arctanDNijk/Dnijl) CC* after model development Masking techniques.	Relative interepretation of the location of broad categories of limonitic / non-liminitic rocks, clay-rich / clay-poor rocks and vegetation has been achieved.
HIS image	Application of HIS transformations, so as to merge band ratio images with other image data, (i.e. 5, 5/7, 2/3 as HIS). Transformations of RGB three band triplets to HIS through the use of models.	Multiband image enhancement and shadow supression is indicated. The interpretation of lithologies is facilitated
Principal Component Analysis	Data from N bands are combined additively, after weighting by the eigenvectors associated with each principal component and bands, to produce a decorrelated spread on N orthogonal principal component axes. Stretching has been applied, so as the data to fill the N-dimensional space much more fully.	Subtle diffrences among lithologies are more strongly contrasted in a greater variety of hues. Local structural complexities at sharp lithological contacts and in exposed finely banded units are enhanced.
Directed Principal Component (DPCA)	Direct principal component analysis at specific input band ratio images. Input ratios have been selected on the basis of information regarding the component of interest (Fe /OH/ greenness).	The vegetation signal is effectively decorrelated from the signal, thereby unmixing the effects of vegetation and pedogenic iron oxides and clay minerals.