

ASTER VNIR & SWIR Band Enhancement for Lithological Mapping - A case study of the Azegour Area (Western High Atlas, Morocco)

Mouhssine WAHI^{1*}; Kamal TAJ-EDDINE¹; Nouredine LAFTOUHI²

1. DYBAGEO Laboratory, Department of Geology, Faculty of Sciences SEMLALIA - Cadi Ayyad University, Prince Moulay Abdellah Boulevard, P.O. Box 2390, 40 000 Marrakech, Morocco.
2. GEOHYD Laboratory, Department of Geology, Faculty of Sciences SEMLALIA - Cadi Ayyad University, P.O. Box 2390 Marrakech, Morocco.

* E-mail of the corresponding author: mouhssine.wahi@gmail.com

Abstract

The purpose of this study is to emphasize on the ASTER images effectiveness and capabilities in the field of lithological mapping. An ASTER image (L1b) covering the study area has been used. Visible, near-infrared and short wave infrared reflectance data (9 ASTER bands) have been processed and interpreted.

Preprocessing included geometric correction; crossTalk correction; orthorectification. Then the VNIR and SWIR bands have been normalized using the Flat Field Calibration method. Digital processing focused on image enhancement by applying principal component analysis (PCA) and a minimum noise fraction (MNF) transformation. This was achieved by using ENVI 4.7®.

Results showed that there are dissimilarities with the published geological map. Offset between lithological boundaries and the obtained results, textures and/or contrast detected inside homogeneously mapped layers have been observed. The existing geological map contains relevant lithological information, however these results provide a new layer of information that can be used to upgrade it. Thus the image enhancement of ASTER remote sensing data can be used as a powerful tool for lithological mapping.

Keywords: ASTER, Lithological Mapping, Band enhancement, Western High Atlas,

1. Introduction

A geological map is a representation of an outcropping pattern on the surface of the ground. This pattern may indicate bed rocks or the regolith (indicating the altered part of the bed rock and including the surface formations). A geological map contains information about the limits of the outcropping features, the rock units or the geologic strata. Geological maps can provide the basis for exploring the landmass in search of its resources.

The Time, accessibility and heterogeneity of the information which is added to the empirical means of extrapolation and interpolation used for mapping makes the usual mapping methods long, hard and expensive.

To mitigate these problems, the use of remote sensing data can constitute a considerable information source. Actually, geological features on the surface may be distinguishable in bedrock outcroppings, from air photographs (photogeological reconnaissance) and/or from satellite images. In fact, each sensor measures the physical properties of land surface with precise characteristics (spatial, spectral and radiometric resolutions, viewing angle, acquisition time...). The use of remote sensing data can provide digital and georeferenced information which can be used in geological mapping. Many earlier studies have suggested several methodologies for lithological discrimination and mapping of surface features by using multispectral or/and hyperspectral remote sensing. (Rencz, 1999).

This study aims to provide an overview of the use of remote sensing data more specifically ASTER images, in the field of geological mapping in the region of AZEGOUR (Occidental High Atlas, MOROCCO). This will be achieved mainly using digital processing, particularly, principal component analysis (PCA) and minimum noise fraction (MNF) in order to enhance the capability of lithological discrimination between different rock units in the study area.

2. General characteristics of the study area

2.1. Study area location

The study area is located on the Northern slope of the Western High Atlas, at 60km to the SSW of the city of Marrakech (Figure 1). The Western High Atlas rises from the Atlantic coast until the highest segment of the chain (High Atlas of Marrakech). It's the oldest massif of the High Atlas chain, constituted of Paleozoic and post Paleozoic formations. Its highest peak is Jbel Toubkal (4167 meters). Two orogenies have affected this area: The Hercynian orogeny marked by synschistose folds with an overall direction N-S and assigned to the post- viséan phase of regional deformation (Lagarde, 1987), and the Atlasic orogeny, less intense than the previous one,

which is dominated by deformations (folds and faults) with a direction E-W to NE-SW.

Since the work of Proust (1961), the Western block of the old massifs of the High-Atlas is defined as a Paleozoic field, located at the NW of the Tizi-N-Test accident. Various authors were interested in the geological investigation in this part of the High-Atlas. We quote: Moret (1931). Neltner(1938), Permingeat (1957), Schaer (1964). Ouanaimi (1989), Gasquet (1991), etc.

However the absence of detailed geological maps and the structural complexity of these lands make the determination of the stratigraphic sequences not very easy. The first results were the works of recognitions based on large-scale mapping where intrusions were represented on the map of Moret (1931), Neltner (1938), Dresch (1941), then resumed by Proust(1961), schauer (1962), Huvelin & Vilarid (1978), Froitzheim & Rauxel, (1987), Cornée (1989), Ouanaimi (1989) and Labriki (1996). This works led in particular to the localization of the intrusions. Except for some local descriptions, no detailed lithological and structural maps were undertaken.

2.2 Geological setting

2.2.1. The Paleozoic

The Paleozoic outcrop in two parts of the study area: First in the sector of Azegour the Lower Cambrian marked (Ki) on the geological map of Amizmiz at 1/100.000 scale (Figure2) is constituted of schist and of sandstone with dacitic and pyroclastic volcanic bands (tuff and breccia) which are intercalated between limestones. The middle Cambrian, marked (Km) is indicated mainly by schist, orthoquartzites and greywakes associated with trachytic lava and pyroclastic rocks, in some areas with limestones, pink silts and tuffs. Finally, the Ordovician marked (Or) rests with a local discordance over the middle Cambrien, with the absence of the upper Cambrien. It is represented by bioturbated, micaceous sandy schists and Quartzitic Sandstone bars at the top of the unit. Second, in the Erdouz sector, which is located in the South of the Midinet fault, the Lower Cambrian is constituted of volcano-detritic units with lava flows and volcanic conglomerate associated with silicified limestone with interstratified basic lava and tuffs. The middle Cambrian is indicated by mudstones, schistes, orthoquartzite and greywackes. The Ordovician is similar to the Azegour sector.

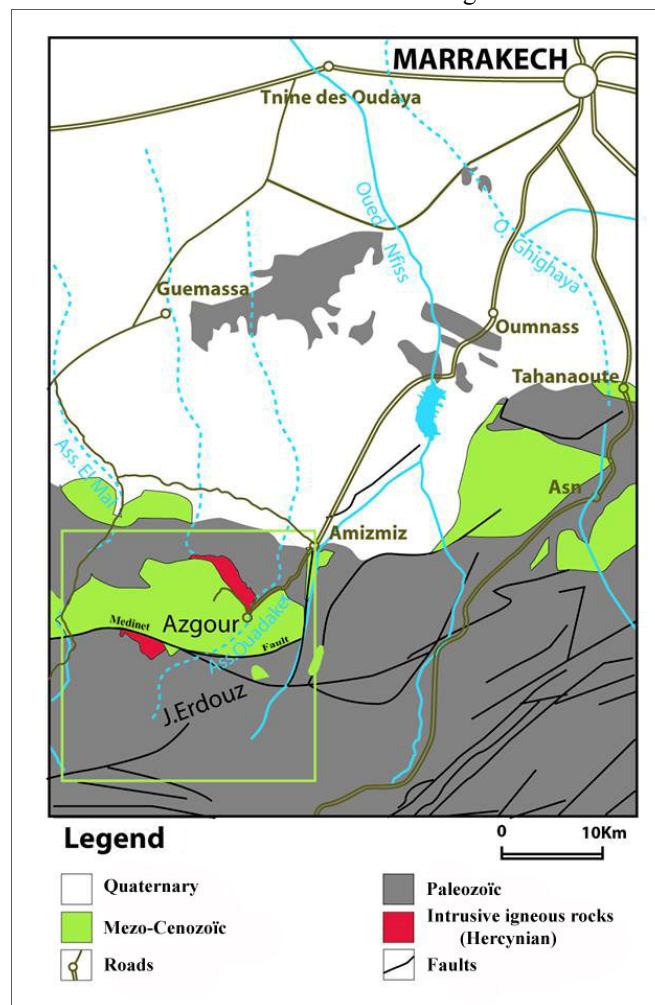


Figure 1. Simplified map of the study area location

Hercynian signature in the Western High Atlas is characterized by the presence of isoclinal folds with subméridien axis (El Archi, 1989 ; Jouhari, 2001). This area is characterized by the implementation of Hercynian granitoids (Azegour Granite) (Lagarde, 1987; El Amrani, 1985 ; Mrini, 1985). All authors agree about the fact that the intensity of Hercynian deformation (Namuro-Westphalian) and synschistose metamorphism increases around the granite massifs such as Azegour (Eddif, 2002), as it can also be concentrated in shear zones (Lagarde, 1987). Regional schistosity developed during the Hercynian phase is submeridian overall direction NE-SW with virgations and changes of directions around granitic intrusions (Schaer, 1964 ; Lagarde, 1987 ; Ait Ayad, 1987 ; El Archi, 1989 ; Badra, 1992 ; Jouhari, 2001 ; Eddif, 2002). The granite of Azegour (269 to 271 M.Y) (Mrini, 1985) is one of the most important granitic intrusions of the Western High-Atlas (ancient massif). Its pink color is one of the outstanding distinctions of this small massif. It is a grainy rock, composed mainly of quartz, orthoclase, plagioclases, small amounts of biotite and accidentally iron oxides (Zerhouni, 1988). Extending in a NW-SE direction, it outcrops over a 7.5 km length and a maximum width of 1.5 km. The small massif of Medinet located on the north side of the Erdouz sector is constituted of quartzitic tonalite-diorite (Gasquet, 1991).

2.2.2. The Meso-Cenozoic

The Meso-Cenozoic is represented, in the area of Azegour by the cretaceous-Eocene units. This unit rests in discordance over the Paleozoic base and the granite of Azegour. These formations vary in age from Jurassic superior to the middle Eocene. The facies of Portlandian marked (Jc) on the geological map of Amizmiz outcrop exclusively in the western part of this unit formed of yellow marl and gypsum with red clays and sandstones. Néocomian (Lower Cretaceous) (N2-3) rests in discordance over the Portlandian in the East and over the Paleozoic base and the granite in the rest of the area. It outcrops along the entire unit, and is formed by red clays, sandstones and conglomerates. The Barrémien-Albien (n4-6) rests directly over this formation. It is a yellowish unit constituted of marls, calcareous sandstone, sandy marls and sands. The Cenomanian (C1) is formed by an alternation of limestone, green marls, red clays and red sandstones. The Turonian (C2) is presented in the form of a white-beige carbonate bands forming an escarpment which arises well in the landscape and which is used as a perfect cartographic reference. The Senonian marked (C3-6) is represented by an alternation of red sandstone, limestone, green marls, red clays and gypsum. Finally, the Middle Eocene (e4) constitutes the summit of the Meso-Cenozoic series in the sector. It rests in angular discordance over the Senonian. It is formed of beige limestone with concentrations of flint and marine fauna (Nautiloïdes), marly limestone and white marls.

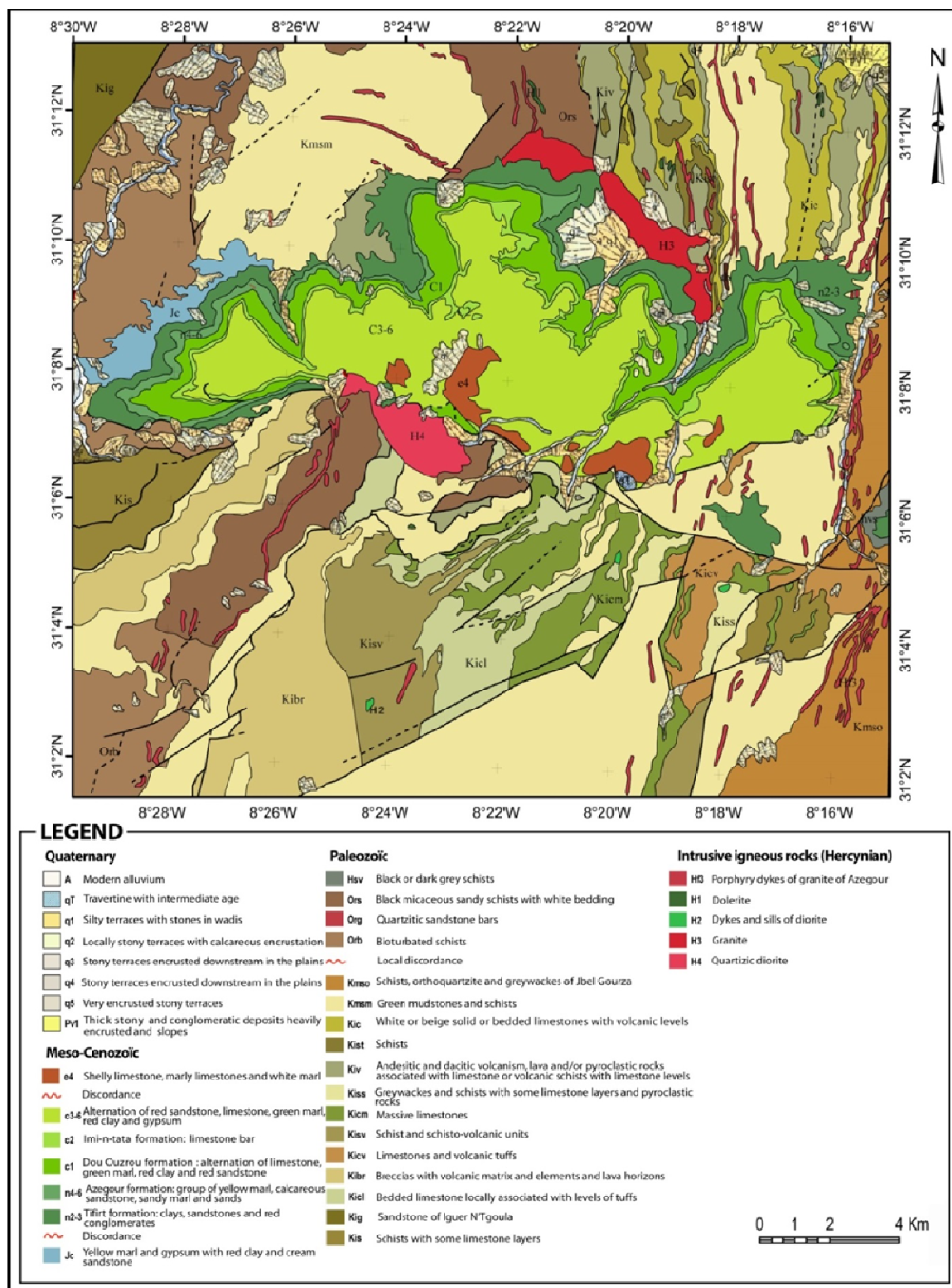


Figure 2. Geological map of the study area, subset digitized from the geological map of Amizmiz at 1/100 000 scale Labriki (1996)

3. Remote sensing data analysis and interpretation

3.1. Data set

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a research facility instrument launched on NASA's Terra (originally called EOS AM-1) spacecraft in December 1999 (Yamaguchi and Naito, 2003). The ASTER instrument has three spectral bands in the visible and near-infrared (VNIR) with 15m spatial resolution, six bands in the short-wave-infrared (SWIR) with 30m spatial resolution, and five bands in the thermal infrared (TIR) with 90m spatial resolution (NASA ASTER, 2004) (Figure3).

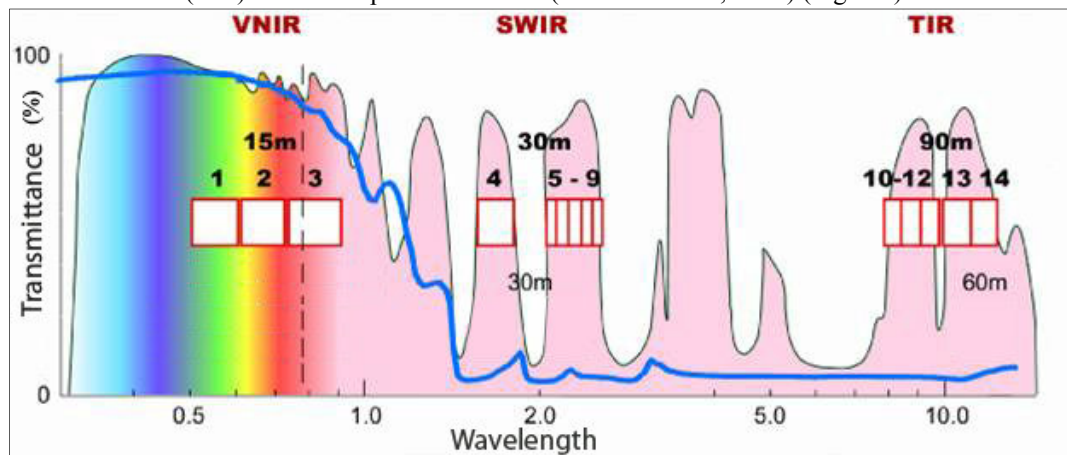


Figure 3. Location of the 14 ASTER spectral bands in the atmospheric transmission spectrum

An advantage of ASTER data is the unique combination of wide spectral coverage and high spatial resolution. It has a particular interest to remote sensing in the field of geology because it provides a relatively wide spectral range and good spatial resolution. Because of this advantage, ASTER simulation and data have been used increasingly for geological mapping (Gad & Kusky, 2007). Another advantage of ASTER data is that the band number 3 in the visible and near-infrared (VNIR) sensor has an additional backward telescope (named 3B) that allows the collection of stereoscopic images at a 15 m spatial resolution. This stereoscopic ability makes ASTER ideal for geological and geomorphological interpretation (NASA ASTER, 2004).

3.2. ASTER processing and Analysis

3.2.1. Methodology

An ASTER image (AST_L1B_003_06132001113036_HDF) that covers the whole region of Azegour was used in this study. A subset from the original ASTER scene has been processed and analyzed (Figure 4).

Preprocessing was achieved using ENVI 4.7® and carried out geometric correction to the geological map of AMIZMIZ at 1:100.000 scale (Projection: Lambert Conformal Conic; Spheroid: Clarke 1880; Datum: Merchich). Crosstalk effect on the SWIR bands have been corrected manually using "ERSDAC crosstalk 3". The image was then resampled so that all VNIR and SWIR bands have the same size of pixels (15 x 15 m). Then an orthorectification via Aster GDEM (Global Digital Elevation Model) has been performed to remove pixels distortions related to the relief. Finally, ASTER VNIR and SWIR bands have been normalized using the "Flat Field Calibration" method.

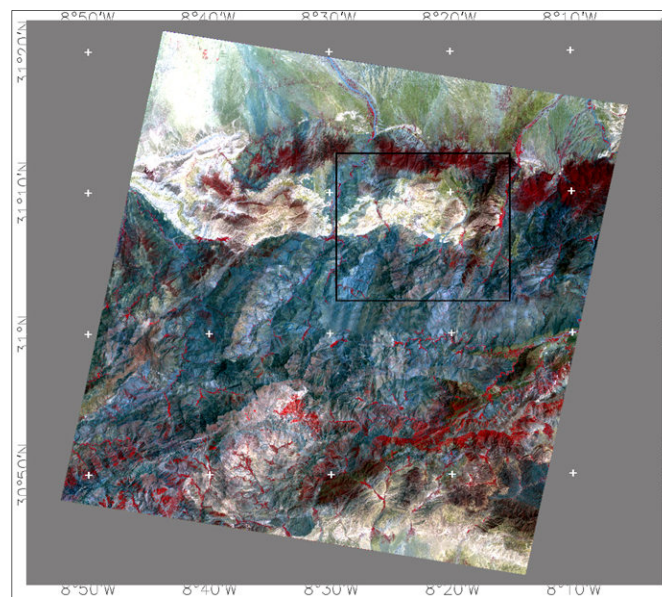


Figure 4. Study area location on the ASTER scene

As a first step, several False Color Composites (FCC) of ASTER band combinations were established and evaluated using visual interpretation. This, revealed that FCC 831 in RGB (Figure 5) is the finest FCC generated, which shows a good discrimination between the different lithological unites and the vegetation that covers the northern part of the image (in green). In this FCC, we can see a good contrast between the Meso-Cenozoic formations with light colors and the Paleozoic formations with dark colors. We can also distinguish the granitic intrusion of Azegour (H3) with neat limits which makes its mapping easier. The Midinet diorite (H4) doesn't appear well in this image but can be recognized by its wrinkled morphology. Indeed, each false color composition contains an important volume of information including geological, topographic and roughness information. Thus, the geological information is more difficult to extract from initial ASTER bands than from enhanced bands.

Analysis of ASTER data for lithological discrimination is based on the relation between the spectral absorptance or emittance and the mineral composition of rock units under investigation (Assiri & al, 2008). Each false color composition contains an important volume of information including geological, topographic and roughness information. Thus, the geological information is more difficult to extract from initial ASTER bands than from a processed image (Gomez and al. 2005). We applied further processing proven to be efficient in lithological discrimination. The main digital image processing techniques performed during this study are: Principal component analysis (PCA) and Minimum noise fraction transformation MNF. The following paragraphs describe in detail the selected results of these techniques:

The Principal Component Analysis (PCA) is a well-known method for lithological and alteration mapping. PCA is a multivariate statistical technique that selects uncorrelated linear combinations (Eigenvector loadings) of variables in such a way that each component successively extracts linear combination and has a smaller variance. It consists of finding a new set of orthogonal axes that have their origin at the data mean and that are rotated so that the data variance is maximized (Pour & Hashim, 2011). The number of output PCA bands is the same as the input spectral bands. The first PCA band contains the largest percentage of data variance and the second PCA band contains the second largest data variance, and so on; the last PCA bands appear noisy because they contain very little variance, much of which is due to the noise in the original spectral data (Pour & Hashim, 2011). A standard PCA transformation was performed with a calculation of the covariance matrix of the nine bands of the VNIR and SWIR. Analysis of the PCA outputs showed that only the first 6 PCA bands contain useful information for our study.

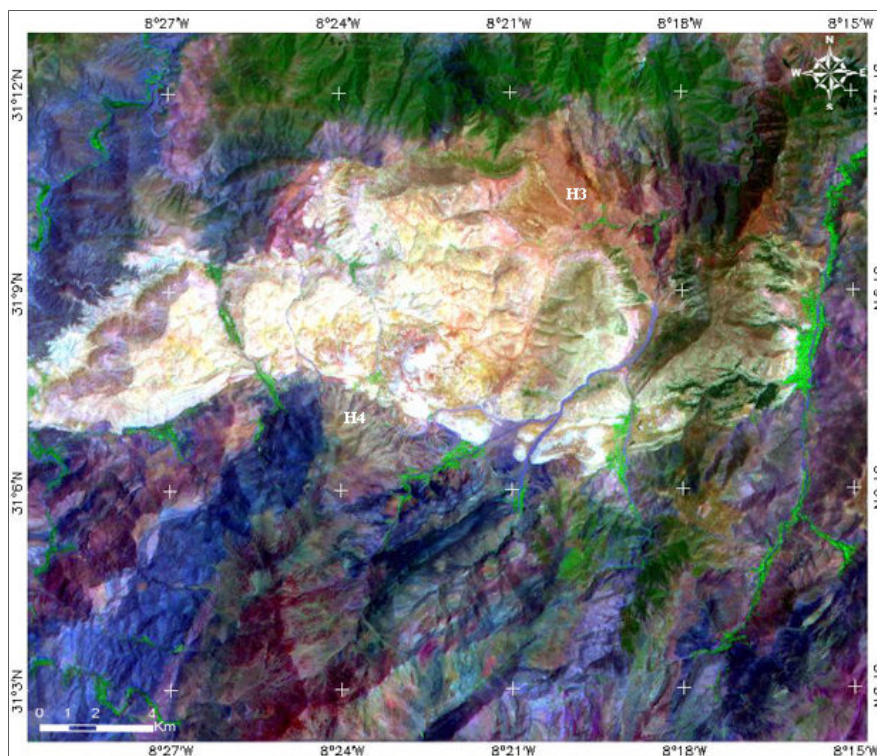


Figure 5. False Color Composites RGB 831

The Minimum Noise Fraction (MNF) transformation is a method similar to principal component analysis (PCA). It is used to determine the inherent dimensionality of image data, segregate noise in the data, and reduce the computational requirements for subsequent processing (Green et al., 1988; Boardman et al., 1995; Pour & Hashim, 2011). MNF is used as a preparatory transformation to condense most of the essential components into a few spectral bands and to order those bands from the most interesting to the least interesting (Altinbas et al. 2004). MNF transformation was applied to the nine bands of the VNIR and SWIR of ASTER image. The resulting images of the MNF transformation show a steady decrease in image quality to the last MNF components (Chen, 2000). The results show that MNF8 and MNF9 have no useful information due to the large amount of noise contained in these components. Therefore, we excluded these two images.

3.2.2. Results

Various color composite images generated from each analysis, have been compared to the published geological map (AMIZMIZ 1/100.000). We selected one derived composite Image from each processing which shows the best discrimination between the different lithological units. The RGBs (PC6; PC4; PC3) and (MNF8; MNF5; MNF4) have been selected and evaluated through visual interpretation. All of these derived images give more or less the same result with some differences that can be used to give a complete interpretation.

Figure 6 (A & B) shows respectively the overlaying vector lines resulting from the digitization of the existing geological map on top of the MNF-derived composite Image (MNF8; MNF5; MNF4) and the PCA-derived composite Image (PC6; PC4; PC3). In these images, we can recognize most of the lithological units presented in the published geological map (Figure 2). Yet, it is clear that there are some units that appear poorly discriminated mostly because of their outcropping size or because of the existence of vegetation especially in the northern part of the study area. However, the generated images showed that there are dissimilarities with the digitized vector lines, which enabled us to suggest many improvements to the existing geological map. These dissimilarities are repeated in most of the composite images and reveal neat lithological boundaries of various lithological units and several faults.

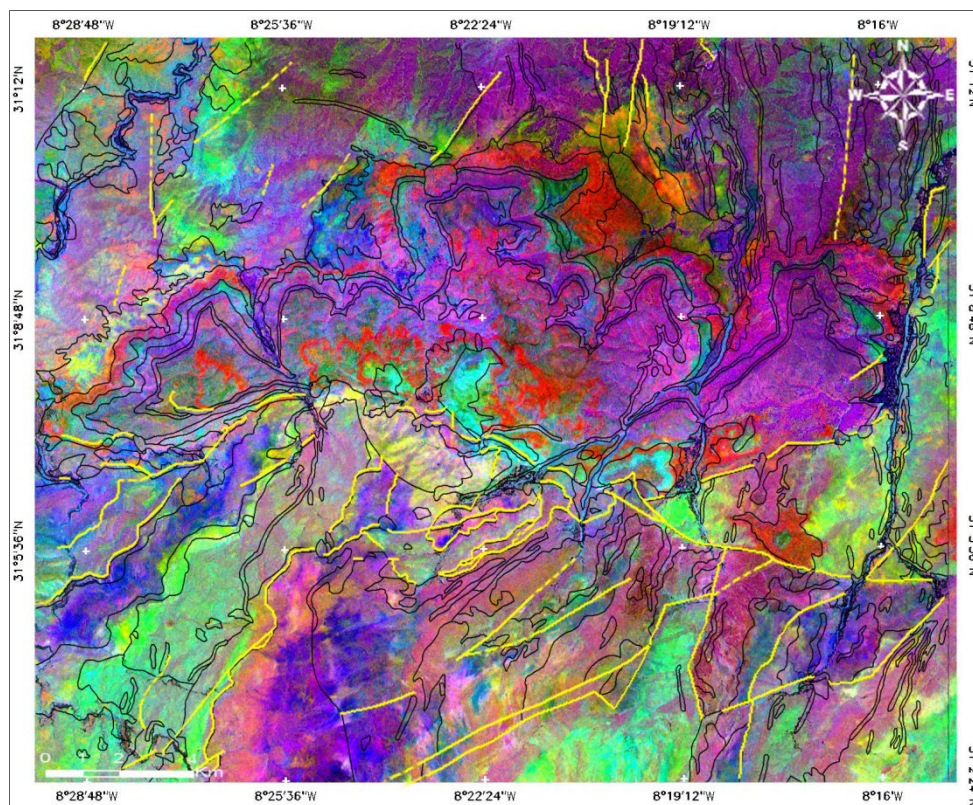


Figure 6-A. MNF-derived image (RGB: MNF8; MNF5; MNF4) with overlaid geological vector layers (faults in yellow and Lithological boundary in black)

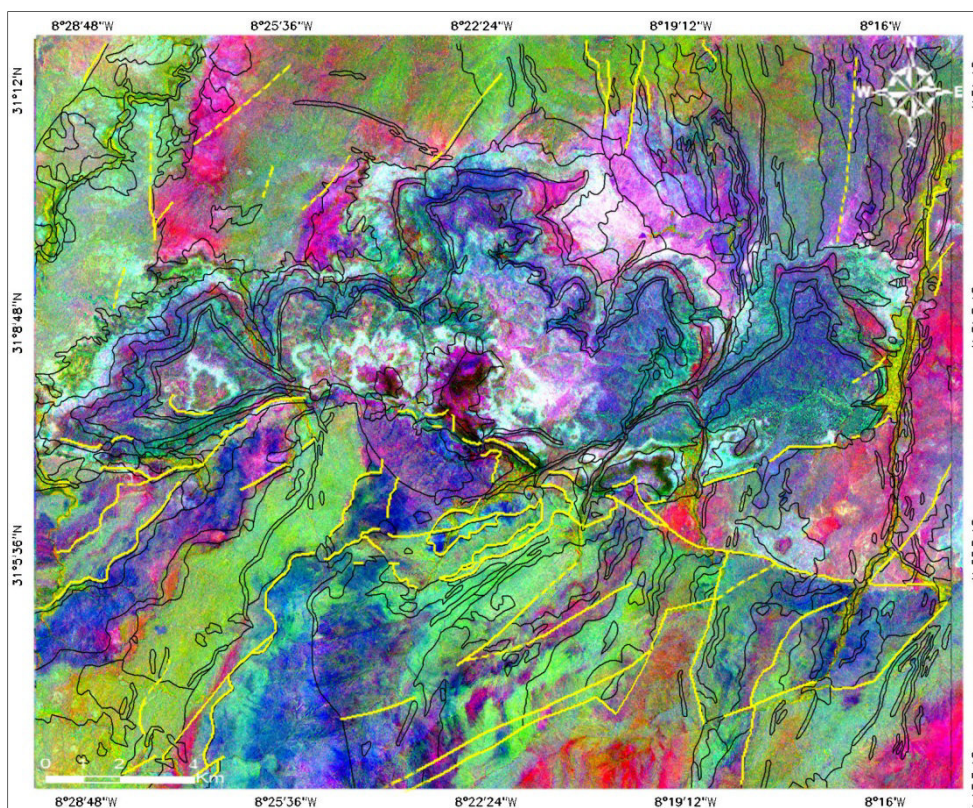


Figure 6-B. PCA-derived image (RGB: PC6; PC4; PC3) with overlaid geological vector layers
To highlight these dissimilarities, and for a better interpretation, we generated subsets of the sectors where we

observed changes vis-à-vis the published geology. The next step was to perform PCA and MNF transformations on these areas and evaluate the results to conclude whether it is a confirmed rectification to make or not. Offset between lithological boundaries and the image processing results and textures or contrast detected inside homogeneously mapped formations provide a new layer of information that can be used by geologists to upgrade the map (Gomez and al. 2005). For example, the Middle Eocene (e4), which constitutes the summit of the Mesozoic series in the study area, appearing in yellow tint in the PCA- derived image, appears to be eroded and covered in some areas with quaternary deposits most of which can probably indicate the (q2) formations that have been poorly mapped in the geological map in this sector (Figure 7). Figure 8 shows another example of Offset between lithological boundaries and the image processing results. In this MNF-derived image we can see that the width of the small diorite massif of Medinet on its South-Est limit seems to be larger than what have been mapped on the existing geological map. The same remark can be done for the Azegour granite especially on the North-West part.

Several unmapped formations on the published geological map have been noticed on the derived images. Figure 9 present an example of contrast distinguished inside homogeneous formation. We noticed that inside the (n2-3) formation a new contrast appears to be a lithological unit that hasn't been mapped. It's a contrast that is repetitive in most of the PCA and MNF derived images. This small unit has the same spectral response of the (n4-6) called Azegour formation on the geological map (Figure2).

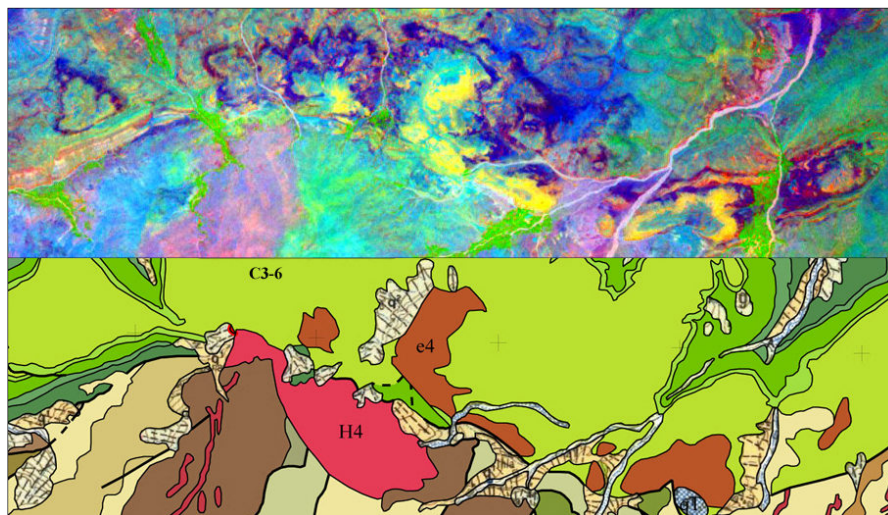


Figure 7. PCA-derived image (RGB: PC2, PC5, PC3) compared to the geological map of Amizmiz

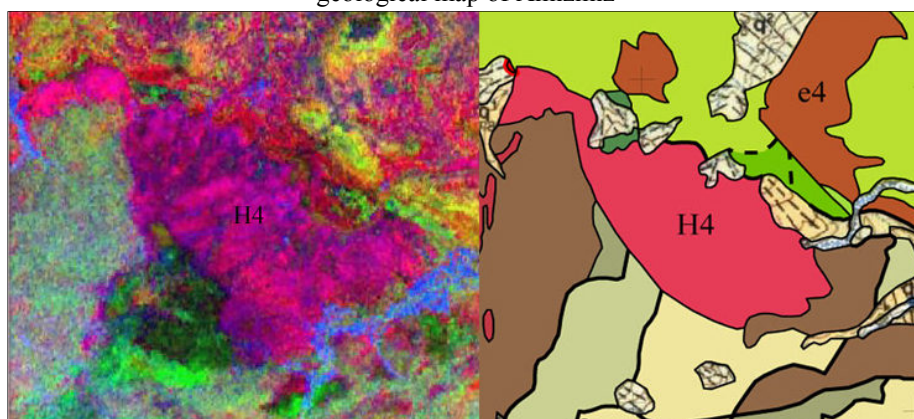


Figure 8. MNF-derived image (RGB: MNF4, MNF6, MNF5) compared to the geological map of Amizmiz

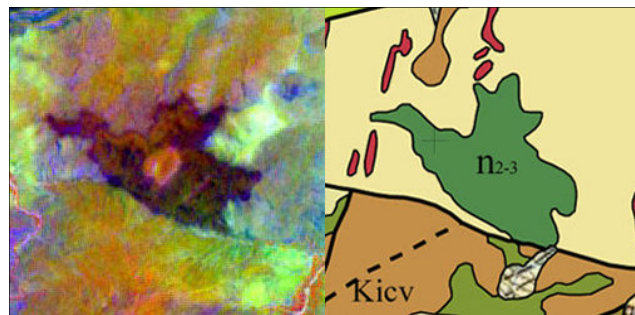


Figure 9. MNF-derived image (RGB: MNF4, MNF2, MNF5) compared to the geological map of Amizmiz

Figure 10 shows an example where we can see at the same time very well mapped formation in the geological map (Figure 2) which matches up perfectly with the derived images and the parts that can be upgraded using the remotely sensed data. In this PCA-derived image we can see offset between lithological boundaries and the published geology (contour lines digitized from the existing map). This also concerns some faults which we can see directly in the derived images and which we can confirm using convolution and morphology filters. We observed variabilities inside some lithological units that have been mapped as homogeneous. For example, green mudstones and schist (Kmsm) can be decomposed in at least two different layers with their own spectral response (labeled 1, 2). The same thing can be observed for the formation of Jbel Gourza (Kms0) where we can also see two different layers: the first presents the same spectral response in the (Kmsm) labeled 1 and a new one (labeled 3). This internal variability may have several origins: differences in lithologies, at the level of alteration or in surface roughness (Gomez and al. 2005).

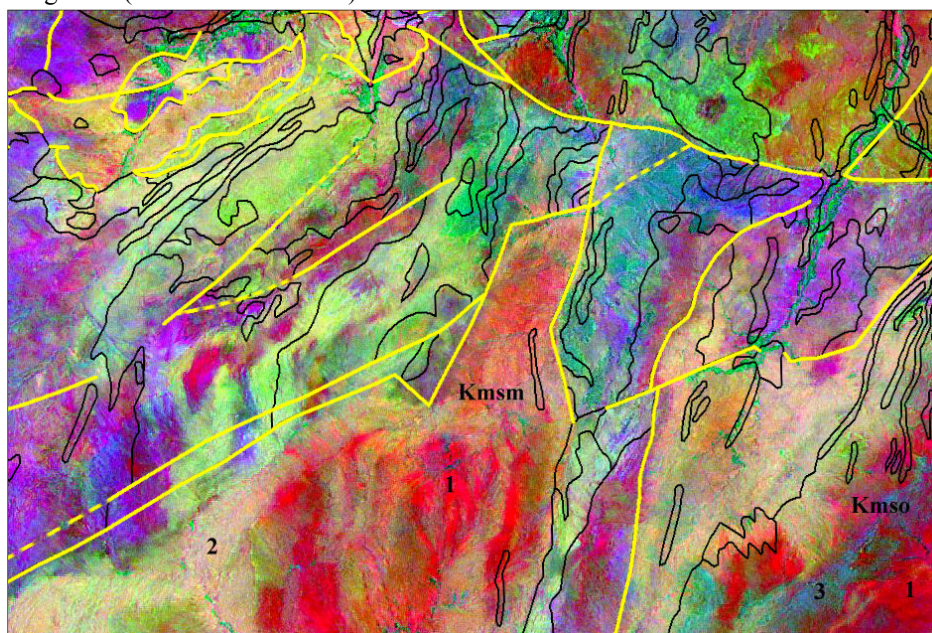


Figure 10. PCA-derived image (RGB: PC2, PC4, PC6)

4. Discussion and Conclusion

In this study, the visible, near-infrared (VNIR) and short wave infrared (SWIR) ASTER data have been used for lithological mapping. We used a published geological map as a reference to interpret the results.

Pre-processing included geometric correction, crossTalk correction and orthorectification. The VNIR and SWIR bands have been normalized using the Flat Field Calibration method. Processing focused on image enhancement by applying digital processing proven to be efficient for lithological mapping, Principal component analysis (PCA) and Minimum noise fraction transformation MNF are the main digital image processing techniques performed during this study using ENVI 4.7®.

Results showed that there are dissimilarities with the published geological map of Amizmiz at 1/100.000 scale. Offset between the digitized geological vector lines and the image processing results, textures and contrast have been detected inside homogeneously mapped formations in many sectors on the study area. Besides, it is

important to note that many lithological formations such as the porphyry dykes haven't been discriminated using remotely sensed data. This is generally due to the spatial resolution of the ASTER data. The existing geological map contains relevant lithological information. However, these results provide a new layer of information that can be used to upgrade it.

ASTER remote sensing dataset have been used widely as a powerful tool for geological mapping. It provides a georeferenced set of information about the reflectance of the rocks that can be used by the geologist to constrain and point out the extent of the lithological formations and to discriminate surficial formations that field geology cannot simply differentiate.

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