

EXTRACTING OLIVINE-RICH PORTIONS OF ULTRAMAFIC ROCKS USING ASTER TIR DATA

O. B. Gurcay

MTA General Directorate, RS&GIS Department, 06520 Cankaya-Ankara, Turkey (gurbora@yahoo.com)

ISPRS Commission VII Symposium

KEY WORDS: Geology, Mapping, Extraction, Satellite, Multispectral, Optical, Thermal

ABSTRACT:

There are several studies for extracting ophiolitic rocks using thermal properties. The algorithms developed to discriminate olivine-rich rocks among ophiolite units, even altered to serpentinite.

Within this study, it was objected to recognize peridotite group rich in olivine minerals among ophiolitic rocks or *mélange*, and to map them with distinct boundaries. Besides, these results may point to the chromite occurrences related to dunite rocks as well.

These algorithms were applied to ophiolitic units around Cankiri region. Various rock types exist within the area and were mapped during previous studies. Target ophiolitic rocks have extensive outcrops in Eldivan Mountain. The ophiolitic rocks cover most of ophiolitic sequence around the study area.

The purpose is to discriminate olivine-rich portions of ultramafic lithologies with their thermal infrared properties. Olivine-rich ultramafic rocks have intense reflection near 10.58 and 11.92 micrometers and absorption around 8.86. Those can be identical for extracting dunite or olivine-rich units using ASTER data. Band ratio algorithms were developed by comparing olivine reference spectra with ASTER TIR bands 12, 13, and 14. Consequently, olivine-rich lithologies were clearly identified, and were checked during ground truth in 15 different locations. Petrographical determinations indicate that 13 of 15 samples are mostly serpentinitized but still contain olivine, less orthopyroxene and clinopyroxene as relicts. Additionally, target unit's boundaries were distinctly mapped among ophiolitic *mélange* within the area.

1. INTRODUCTION

Ophiolitic units include various types of lithologies such as peridotite, pyroxenite, gabbro, diabase, spilitic basalt, radiolarite, cherty limestone. In some cases, it can be easy to map with their composition and texture in the field. However, altered portions of ultramafic rocks are sometimes rather difficult to distinguish from each other. Various researches and algorithms concerning to the evaluation or identification of ultramafic rocks or related mineralizations have been conducted by using multispectral or hyperspectral satellite data analysis and reflectance or emittance portions of electromagnetic spectrum (Hunt and Wynn, 1979; Ninomiya, 2002, 2003; Chellaiah, 2003; Swayze et al, 2004; Rowan et al, 2004, 2005; Hook et al, 2005).

The aim of this study is to detect olivine-rich bodies of ultramafic rock units belong to ophiolite or *mélange* with multispectral thermal infrared portion of ASTER image data.

1.1 Thermal Spectral Properties of Ultramafic Rocks and Minerals

The spectral reflectance, absorption or emittance interactions of surface materials responding to the electromagnetic solar energy have been commonly used in remote sensing studies (Chabrilat et al., 2000; Ninomiya, 2002, 2003; Saldanha, 2004; Swayze et al., 2004; Hook et al., 2005; Rowan et al., 2005)

The reflection and absorption behaviors with respect to VNIR-SWIR and TIR wavelength of electromagnetic energy regions of common minerals constituting ultramafic rocks are given in figure 1A and 1B. The pyroxene group has typical reflection in

0.54 and 2.37 micrometers and has an absorption in 2.32 micrometers according to figure 1A. Mg-rich olivine mineral, forsterite, in VNIR-SWIR region has absorptions in 0.62 and 1.06 micrometers, and reflection in 0.58, 0.67 micrometers and the reflection increases to the longer wavelengths in SWIR region. The alteration product of those minerals, serpentine, has absorptions in 0.72, 1.39 and 2.36 micrometers and the characteristic reflection features in 0.51, 2.20 and 2.37 micrometers.

The electromagnetic energy is absorbed in 8.40, 10.09 and 10.73 micrometers, and reflected in 8.85, 10.41 and 10.89 micrometers when the one of clinopyroxene minerals, like augite, is observed. If the spectral properties of other orthopyroxene group mineral has examined, the hyperstene mineral has absorptions in 8.49, 9.89, 10.37 and 11.03 micrometers, and reflections in 8.22, 9.34, 10.19, 10.45 and 11.34 micrometers. Similarly, besides having unique absorptions in 8.86, 10.05 and 10.39 micrometers, and the olivine mineral has also the reflections in 9.84, 10.19 and 10.49 micrometers, then the reflection is getting decreased to the longer TIR wavelengths.

Reflection and absorption properties of common ultramafic minerals in VNIR, SWIR and TIR regions are given in Figure 1.

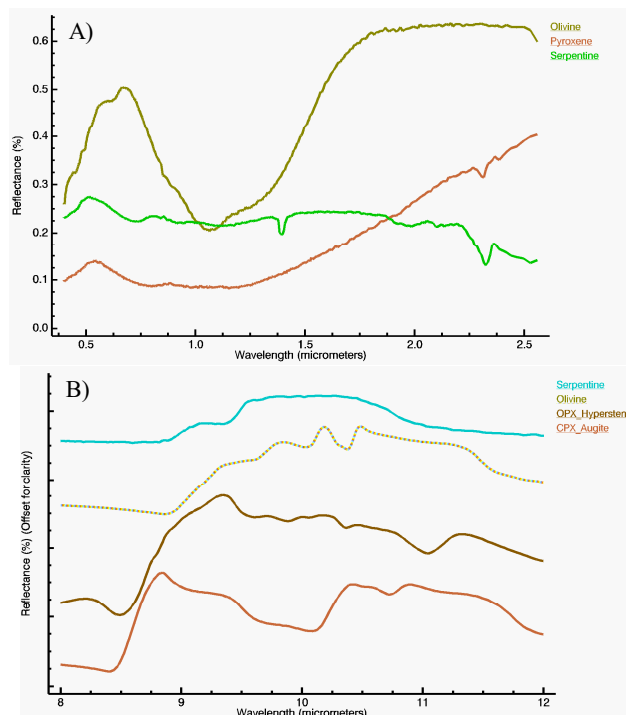


Figure 1. VNIR-SWIR (A) and TIR (B) spectral characteristics of common minerals exist in ultramafic rocks.

The common rock units in ophiolite sequence can be mafic or ultramafic. When the electromagnetic energy interactions with those rock types were compared (figure 2), the absorptions in 8.63, 10.16 and 11.05 for diabase, 9.21 and 10.25 for gabbro, and 8.86, 9.57, 10.33 and 11.81 micrometer wavelengths for olivine-peridotite (dunite) are noticeable. On the contrary, the distinct reflections in wavelengths are 8.56, 9.10, 9.80 and 11.15 for diabase, 8.77, 10.07 and 10.47 for gabbro, and 9.52, 10.17, 10.58 and 11.92 micrometers for olivine-peridotite rocks.

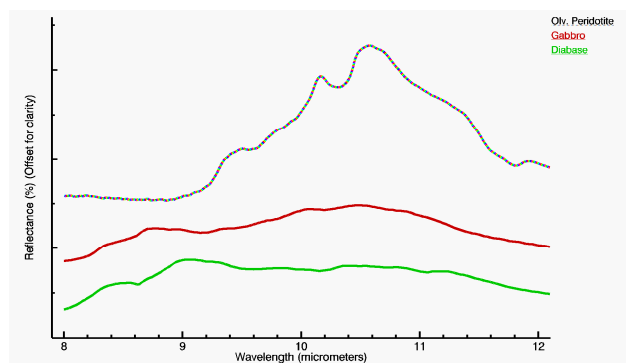


Figure 2. The spectral responses of abundant mafic and ultramafic rock types exist in ophiolite.

1.2 Study Area

Study area is located within the latitudes of 40°20' - 40°45'N and the longitudes of 33°10' - 33°35'E in the northern part of Central Anatolia (Figure 3). There have been conducted various studies covering the area concentrated mainly on regional and local geological features, tectonics and kinematics, paleogeographic evolution etc. (Hakyemez et al, 1986; Türkecan et al, 1991, Koçyiğit et al, 1995; Seyitoğlu et al, 1997; Sümer, 1997; Gökalp, 1999, Kaymakçı et al, 2003a, b).

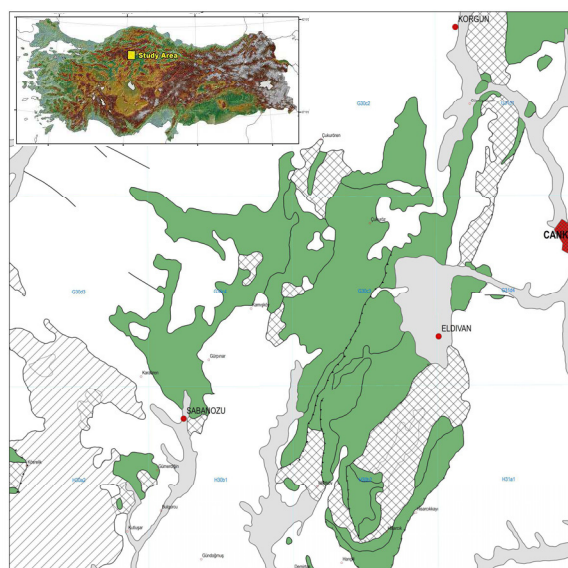


Figure 3. Location and simplified geological map of study area. The green (dark) colour in geological map represents ophiolitic lithologies.

Study area is located at İzmir-Ankara-Erzincan suture zone occurred as a northern branch of Neo-Tethys Ocean and started to activate in Liassic-Late Cretaceous and continued up to Early Lutetian presented by many authors (Akyürek et al, 1979, 1980, 1981; Şengör and Yılmaz, 1981; Görür et al, 1984; Hakyemez et al, 1986). Settlement time of ophiolite, which is a cause of closure of micro-continents (Şengör and Yılmaz, 1981; Görür et al, 1984; Hakyemez et al, 1986; Kaymakçı et al, 2003a, b), is recorded as Cenomanian-Turonian age (Akyürek et al, 1979, 1980, 1981). Tertiary shallow platform sedimentary sequence existed (Sengor and Yılmaz, 1981; Görür et al, 1984; Hakyemez et al, 1986; Seyitoğlu et al, 1997) after Middle Lutetian subsequent to closure of Neo-Tetis Ocean in Early Lutetian (Hakyemez et al, 1986). The geological units and stratigraphy are simplified concerning to the objective lithologies of this study (Figure 3 and Figure 4).

2. IMAGE ANALYSES, RESULTS AND DISCUSSION

Well known ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) level 3A01 ortho image data which was corrected to remove the geographic distortion caused by altitudes is used in order to identify olivine-rich ultramafic rocks. ASTER has spatial resolution of 15 meter for 3 VNIR (Visible-near infrared, 0.556 to 0.807 micrometers) bands, 30 meter for 6 SWIR (Short-wave infrared, 1.656 to 2.400 micrometers) bands and 90 meter for 5 TIR (Thermal infrared, 8.291 to 11.318 micrometers) bands, and radiometric resolution of 8 bit, and 12 bit for VNIR-SWIR and TIR respectively.

AST3A10207260852290603310610, AST3A10507270844 010603311228 and AST3A10404100850300702020025 images were used in the image analyses. The study area was cut after mosaicking those three images. During VNIR-SWIR band ratio image preparation, the masked image was used for better results.

Results obtained from VNIR, SWIR and TIR are frequently efficient to extract information regarding to alteration mineral or lithological mapping from target area (Ninomiya, 2002; Yamaguchi and Naito, 2003; San et al., 2004; Rowan et al.,

2004). Herein this study, thermal reflectance properties of ultramafic rocks rich in olivine minerals will be estimated.

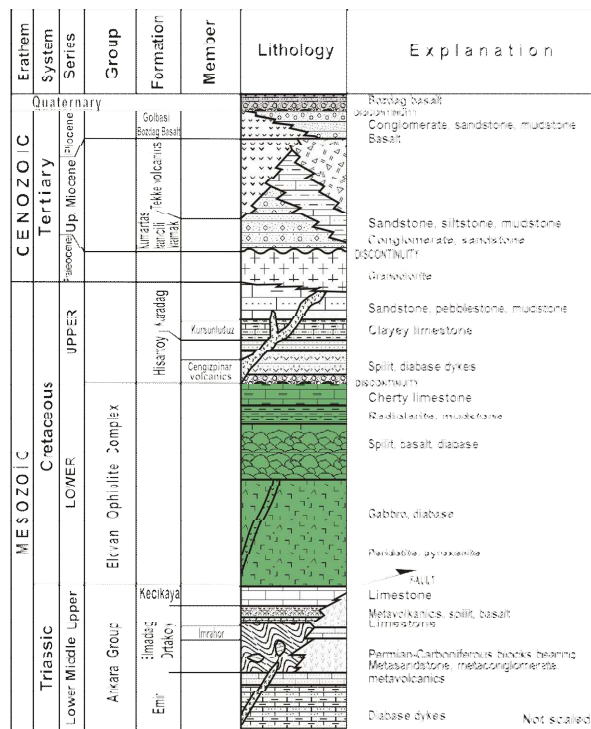


Figure 4. Simplified stratigraphic section of the study area. Lower Cretaceous Eldivan ophiolite, which is given in green (dark) color, overlays Triassic basement units, and overlaid by Tertiary sedimentary sequences.

2.1 VNIR-SWIR Band Ratio

According to the spectral properties of mafic minerals given in figure 1A, characteristic wavelengths can be correlated with ASTER VNIR and SWIR bands.

There are higher reflection responses in ASTER bands 2, 5 and 8, absorption in bands 1, 3 and 6 for olivine mineral while only a broad absorption in band 3 and a reflection in band 1 can be noticeable for pyroxene minerals in the SWIR region of electromagnetic spectrum. Serpentine, the alteration product of those minerals, has also distinguishing absorptions in bands 2, 7 and 8 and reflection in bands 3 and 6. The band ratios, 2/3, 2/3*1/3 for olivine mineral and 6/8 and 6/7 for serpentine mineral were developed.

2.2 TIR Band Algorithms

The pyroxenes exhibit visible reflections in ASTER bands 11 and 12 according to the given figure 1B. Despite, olivine mineral has higher reflection in band 13 and lower in bands 10, 11 and 12. While showing similarities, the olivine mineral is higher in bands 12 and 14 compared to the alteration product of olivine and pyroxenes, serpentine.

As the olivine-peridotite or dunite, composed of mainly olivine and additionally pyroxenes and less silica, is compared with ASTER bands in figure 5, band 13 is highly reflected while the bands 11, 12 has absorption and 14 is relatively low reflected. The absorption properties of ASTER bands 11 and 14 for

olivine display similarities to quartz mineral. However, the difference between those two spectra is noticeable in bands 12 and 13. This difference was also recorded as a result of a change in silicate content within the igneous rocks varies from felsic through mafic to ultramafic by some researchers (Ninomiya and Matsunaga, 1997, 2002, 2003; Hook et al, 2005).

While the higher reflection in band 13 for dunite and neighbouring bands 12 and 14 are taking under consideration in figure 5, the band ratios of 12/13 and 14/13 is achieved. To use opposite band ratios instead of usual ones is the cause of the energy emitted from the surface materials in thermal region. The higher reflection in the spectrum corresponds to the low emissivity. Since above ratios, $(12 \cdot 14) / (13^2)$ is obtained.

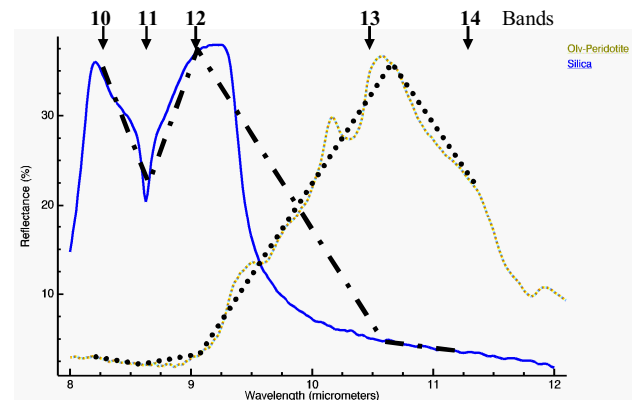


Figure 5. The spectral pattern comparison of olivine-peridotite (dunite) and quartz with corresponding ASTER bands

The formula, $(14/13) / (13/12)^3$, is developed by considering the ratio 14/13 for olivine and pyroxene mineral with comparing to the ratio 13/12 for silicate content. The exponential parameter (herein 3) is a number that is used for decreasing the effect of silica content within the rocks. The number used here, 3, is chosen for giving the best result.

2.3 Results and Discussions

The VNIR-SWIR band ratios developed to extract the ultramafic units have mostly not efficient, except serpentine band ratio 6/8. On the contrary, the better results were attained with thermal infrared (TIR) region for detection of lithology like olivine-peridotite occurrences.

The results of VNIR-SWIR band ratios, 2/3 for olivine and 6/8 for serpentine minerals are given in Figure 6. Besides the matching localities for olivine resultant image, it is also possible to observe the areas unmatched. The serpentine band ratio 6/8 (or even 6/7) can mostly be correlated with the serpentinized ultramafic rock units. Besides the results of the olivine band ratio 2/3 correlating well with the ophiolite formations inside, it has widely wrong results outside the ophiolitic formation boundaries.

The olivine rich ultramafic rock, olivine-peridotite or dunite was noticeably extracted within the ophiolitic melange formation given in simplified geological map (figure 3, 7A, 7B) with distinct boundaries by using the spectral properties of target ultramafic rocks. Additionally, the ground truth studies were conducted to 15 localities of matched or unmatched with either analyses results or geological map units. 13 of 15 collected

samples concerning to TIR image results are mostly serpentinized but still contain olivine, less orthopyroxene and/or clinopyroxene as relicts determined by the petrographical studies. Additionally, target unit's boundaries were distinctly mapped among ophiolitic mélangé within the area.

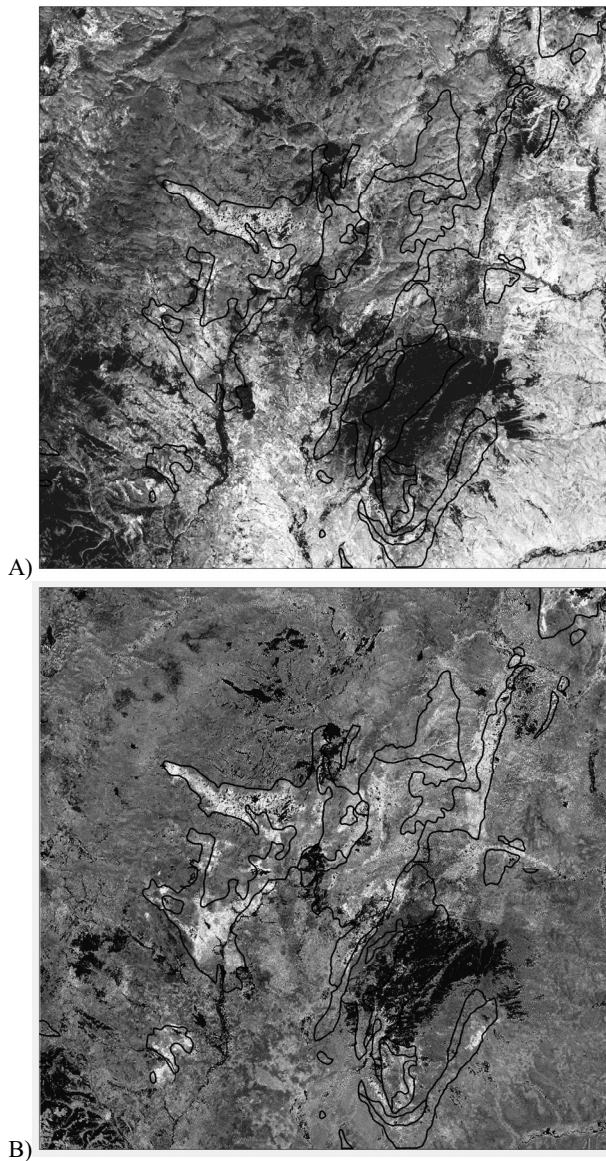


Figure 6. The results of (A) 2/3 and (B) 6/8 band ratio algorithms generated from ASTER SWIR bands.

The both results of TIR band algorithms are similar to each other in terms of lithological boundaries. On the other hand, the topographical effects are mostly observed as removed in the results obtained with the formula $(12 \cdot 14) / (13^2)$, given in figure 7A. Besides, the effect of vegetation on both results is interestingly noticeable. It can be possible to detect olivine rich ultramafic units as well in the central parts of the Eldivan ophiolitic mélangé, at SE of Eldivan Mountain, in the locations of sparse vegetation areas of the pinery. (Figure 3, 7A).

While correlating the simplified geological map of the region with the analyses results, it can be easily recognized that the olivine-peridotite portions of ultramafic units are displayed as bright pixels either inside or outside the boundaries of ophiolitic

melange. Ground truth surveys show that those out-boundary results are also matched with the peridotite units. It is concluded that to improve the geological map details while working with ultramafic lithologies, the band algorithms concerning to the olivine-peridotite (figure 7A, 7B) can be helpful.

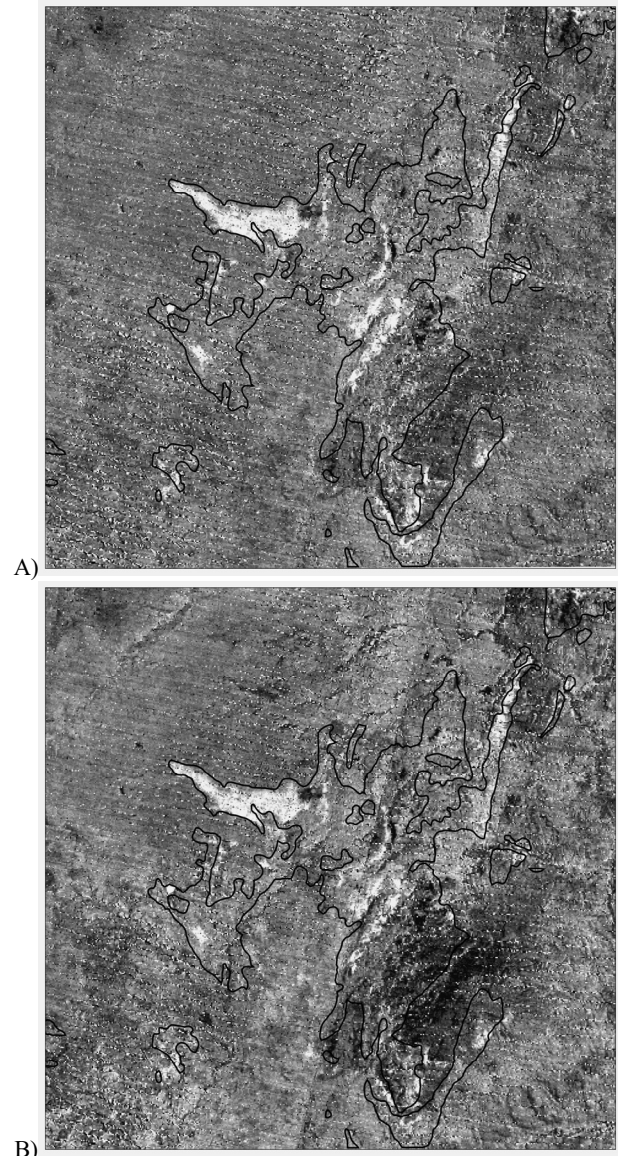


Figure 7. The olivine-peridotite (dunite) band algorithms developed using spectral characteristics of ultramafic rocks. Band algorithm results: (A) $(12 \cdot 14) / (13^2)$ and (B) $(14/13) / (13/12)^3$.

In case of mapping the lithologies related to ultramafic units, the spatial resolution sometimes limits the detail of studies. The band ratio 6/8 could be used in matched areas to correlate boundaries of ultramafic units.

3. SUMMARY AND CONCLUSION

The olivine-rich ultramafic unit, especially olivine-peridotite or dunite and those boundaries was clearly discriminated and mapped within the ophiolitic lithologies.

Among the band ratios introduced by using spectral characteristics of the mafic minerals, olivine, pyroxene, serpentine group, the ratio 6/8 can be used in such cases.

The thermal band algorithms, $(12*14) / (13^2)$ and $(14/13) / (13/12)^3$ were developed by considering the spectral responses of mafic minerals exist in constituting rock units compared with ASTER TIR bands. These algorithms are highly effective to distinguish the olivine-rich ultramafic portions in the region of ophiolitic rocks. It is also capable of mapping those lithologies in a certain boundaries.

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