



**HAL**  
open science

# Hyperspectral Survey for Mantle Rock Surface Mineralogy Mapping of the Sumail / Maqsad Peridotitic Massif

P.C. Pinet, G. Ceuleneer

► **To cite this version:**

P.C. Pinet, G. Ceuleneer. Hyperspectral Survey for Mantle Rock Surface Mineralogy Mapping of the Sumail / Maqsad Peridotitic Massif. International Conference on Ophiolites and the Oceanic Lithosphere: Results of the Oman Drilling Project and Related Research, Prof. Sobhi Nasir (Chairman), Sultan Qaboos University and Organizing Committee, Jan 2020, Mascate, Oman. pp.190-92. hal-03100942

**HAL Id: hal-03100942**

**<https://hal.science/hal-03100942v1>**

Submitted on 6 Jan 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## **Hyperspectral Survey for Mantle Rock Surface Mineralogy Mapping of the Sumail / Maqсад Peridotitic Massif**

**Patrick C. Pinet<sup>1,2</sup> and Georges Ceuleneer<sup>3,4</sup>**

<sup>1</sup>Université de Toulouse, UPS-OMP, IRAP, Toulouse, France, <sup>2</sup>CNRS/CNES, IRAP, Toulouse, France, <sup>3</sup>Université de Toulouse, UPS-OMP, GET, Toulouse, France, <sup>4</sup>CNRS, GET, Toulouse, France.

### **Introduction**

The Sumail massif and the Maqсад oasis lie in a semi-arid region of Oman, bordered by sedimentary formations (limestones, sandstones, radiolarites,...). It exposes one of the largest outcrops on Earth of mantle-derived peridotite and rocks from the oceanic crust.

Beyond its intrinsic geologic interest, this area is quite appropriate for developing and testing hyperspectral remote sensing methods relevant to the study of planetary surfaces, particularly in the martian context. Oman ophiolite presents large outcrops of relatively homogenous lithologies, spanning a range of variations in mafic mineral assemblages (olivine, pyroxenes), in association with alteration products (carbonates, serpentines) that can be documented by imaging spectroscopy.

### **Hyperspectral geological mapping: data acquisition**

Several geological maps of the Northern Oman Mountains have been published over the last decades. Following the pioneering work of Glennie et al. [1] who mapped this area at a 1:500,000 scale, the BRGM (French Geological Survey) [2,3] and other companies, have produced more detailed maps, at a 1:100,000 and 1:50,000 scales. In the Sumail massif, Amri [4] produced a detailed non commercial map at a 1:40,000 scale that represented a significant improvement in the definition and mapping of the different lithological units making up the crustal section of the Sumail massif. This survey was located in the southeastern part of the Oman ophiolite, where a former mid-ocean ridge axis and the related mantle upwelling (the Maqсад “diapir” ) had been mapped through the study of high-temperature plastic deformation structures in mantle harzburgites and of the distribution of petrological features [5,6].

Hyperspectral coverage of the Sumail Massif has been acquired by the HyMap airborne imaging spectrometer [7]. The HyMap mosaic overlaps the regional geological cartography established by [4]. The data set covers an  $\sim 15 \times 60$  km<sup>2</sup> area with a pixel size of about 6 m acquired at 3500-4000 m flight elevation (i.e., 4 km wide swath). The solar elevation ranges from 35° to 45° while azimuth ranges between 150° and 220°. HyMap is a 128-channel instrument that collects data between 0.45 and 2.48  $\mu$ m with a spectral

resolution of 15-20 nm [8]. Spectral coverage is nearly continuous except for the 1.40 and 1.90  $\mu$ m bands that are saturated by atmospheric water vapor. HyMap data have been atmospherically corrected by the HyVista Corp. on the basis of atmosphere removal radiative transfer model [9] and the Empirical Flat Field Optimal Reflectance Transformation [10]. Geometry corrections and orthorectification are based on an Advanced Spaceborne Thermal Emission and Reflection Radiometer digital elevation model. A cross-track correction was also applied to obtain a spectrally homogeneous mosaic (each band is divided by a function which is representative of the reflectance evolution orthogonally to the trace axis).

### **Processing for spectral mapping of lithological units and mineralogical variations**

The mosaic has been used to map distinct lithological units and highlight specific lithologies [e.g., 11,12,13,14,15,16]. Both the mantle (essentially harzburgitic) and the crustal sections (essentially gabbroic) of the massif have been surveyed.

Various approaches have been implemented to process the data, involving spectral ratios and colored composition techniques (RGB), spectral unmixing and non-linear deconvolution (MGM: Modified Gaussian Model), giving access to a number of new geologic results that cannot be all depicted here. Instead, the choice is made to highlight a few examples and to refer the reader to the publications mentioned above, with a particular emphasis on the MGM outputs [16].

Of note is the fact that within the HyMap mosaic, the strength of the absorption features has a large range of values, going from spectra with very shallow to deep absorption features similar to those observed on laboratory data. The featureless spectra are found mainly in wadi (i.e., dry valleys) and oases and on recent sedimentary deposits and the related pixels are thus discarded.

The resulting mineralogical mapping is presented in Figure 1 with the detection of the main lithological units. Cyan pixels, associated with an olivine-orthopyroxene mixture, are dominant on the western part of the mosaic where mantle harzburgites have been mapped. Trending north-east southwest, a stripe of blue pixels is found in the mantle unit. It is indicative of variations in the olivine/orthopyroxenes

ratio in the harzburgite unit (see further in the text and Figure 2). Field observations confirm that this blue stripe is depleted in orthopyroxenes relative to the average harzburgites of the mosaic [14]. Red pixels, associated with clinopyroxene-rich lithologies (essentially gabbros), are reported mainly on the eastern part of the mosaic mapped as the crustal section of the Sumail massif.

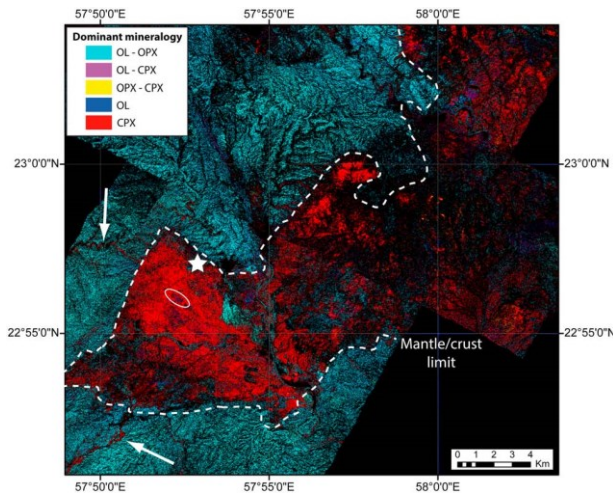


Figure 1(from [16]). Map of dominant mineralogy. Two distinct units are clearly mapped: The red pixels are rocks that are dominated by clinopyroxene (including pyroxenites and gabbros (crustal section), while the cyan pixels are dominated by olivine and orthopyroxene, i.e., harzburgite and dunite (see also Fig. 2) (mantle section). The dashed line represents the limit between the crustal and the mantle sections and matches the limits as defined using the geological map. The white star indicates the southern outcrop discussed further in the text. The white arrows point out gabbros originating from outcrops of the crustal section and transported downslope along wadi. OL-CPX, OPX-CPX, and OL detections can also be found within the studied area but only in outcrops with small spatial extents. The white ellipse corresponds to local wehrlite-rich patches.

This approach is also able to detect subtle geological features. For instance, the sinuous red strings (white arrows on Fig. 1) in the mantle harzburgites enhance the contours of those wadi that are filled with gabbro blocks transported from the crustal section located uphill in this area. Purple pixels, associated with the occurrence of olivine and clinopyroxene minerals, are found in the crustal section. They correspond to wehrlite-rich outcrops (e.g., see white ellipse). The mantle/crust boundary is correctly delineated and is successfully propagated outward the geological map of [4].

The alteration of the primary igneous minerals (mostly serpentinization of olivine) and the desert varnish are potential sources of ambiguities and may generate false detections. In spite of this, it appears that mineral assemblages including olivine and pyroxenes are correctly detected and largely agree with field observation. Moreover, it has led to the detection of two outcrops presenting clinopyroxene-rich cumulates (interlayered clinopyroxenites and wehrlites) whose occurrence was previously undocumented [15].

Field checks allowed us to demonstrate that both areas are exceptionally rich in clinopyroxene and are composed of interlayered clinopyroxenitic and wehrlitic ultramafic cumulates.

The first area lies at the base of the crustal section in the southern part of the massif, outside the area mapped by [4] (Fig. 1, white star). This outcrop is a 150 m wide clinopyroxene-rich band extending for more than 1 km in a SW direction. Higher up, this crustal section is essentially composed of layered gabbros extending to the top of the outcrop. The Moho is faulted in this area, resulting in local tilting of the magmatic layering, but its regional attitude is almost horizontal, as in the whole Sumail massif.

The second area is found in the mantle section in the north. This northern outcrop shows up quite conspicuously due to the contrast between the spectral signature of the host mantle harzburgites and that of clinopyroxene-rich lithologies. In the field, this spectral variation corresponds to the alternation of outcrops with layers of olivine clinopyroxenites, clinopyroxene-rich wehrlites, olivine websterites on the one hand, and with clinopyroxene-poor cumulates (dunites and clinopyroxene-poor wehrlites) on the other hand, with a thinner layering composed of bands a few tens of meters in thickness. Our field survey has shown that even smaller scale (typically meters) alternations of clinopyroxene-rich and clinopyroxene-poor layers also exist but are not resolved by our airborne data. It appears that the relationships between the lithologic succession and the topographic surface are quite complicated in this northern outcrop.

Another result worth to be highlighted here is the ability of the MGM procedure to give access within the mantle section to the spatial variations of the relative proportion of both Ol and Opx minerals through the determination of the  $OL/(OL+OPX)$  ratio, based on the Gaussian band depth estimates (Fig. 2 below) [14]. In particular, focusing on the red rectangle, it reveals that there exists an organized spatial pattern in association with the Muqbariah shear zone, oriented NNO-SSE and indicative of petrological variations corresponding to more intense melt percolation processes witnessed by the occurrence of dunites.

# International Conference on Ophiolites and the Oceanic Lithosphere: Results of the Oman Drilling Project and Related Research

12-14th January, 2020, Sultan Qaboos University, Muscat, Sultanate of Oman

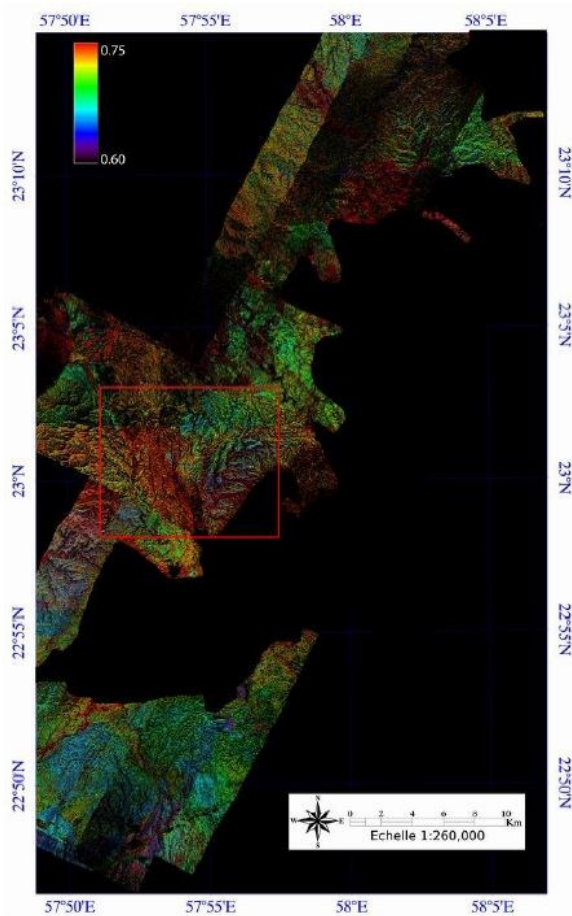


Figure 2 (from [14]) Mapping of the OL/(OL+OPX) spatial distribution across the mantle section. Color coding ranges from dark purple (0.60) to red (0.75).

## Conclusions:

This study has shown that visible and near-infrared reflectance data acquired by imaging spectroscopy are of great help in detecting lithologies that may be overlooked during the geological mapping of large areas (~1000 km<sup>2</sup>) due to their resemblance to other, more common, rock types. As an example, this airborne hyperspectral survey of the Maqсад area has allowed us to establish the presence of clinopyroxene-rich ultramafic cumulates — an occurrence which has not been previously documented, nor expected, in this essentially gabbroic environment. These ultramafic cumulates are distributed in off-axis positions on both sides of the Maqсад paleoridge axis. This fact has important implications for the petrological evolution of melts produced in and around a mantle diapir rising beneath mid-ocean spreading centers.

With the consideration of some limits on the detection thresholds, these results set confidence on the operational use of the Modified Gaussian Model (MGM) with large hyperspectral data sets, for establishing detailed lithological/mineralogical

mappings intended to explore the petrology and mode of emplacement of magmatic units. This also demonstrates that one can reliably make use of the proposed MGM-based mapping procedure for revealing and highlighting large-scale variations in pyroxene and olivine ratios from hyperspectral imaging observations acquired under natural conditions. This is of particular interest for orbital imaging spectroscopy used in space exploration for the planetary crusts characterization.

## Acknowledgments:

The results synthesized here arise from several studies relying on contributions from I. Amri, H. Al Azri, H. Clenet, S. Chabrilat, J.P. Combes, Y. Daydou, E. Harris, P. Launeau, C. Rosemberg, R. Roy who are duly acknowledged.

## References:

- [1] Glennie, K.W. et al. (1974), Koninklijk Nederlands Geologisch Mijnbouwkundig Genootschap 31, 423.
- [2] Rabu D. et al. (1986), Geological map of Nakhil, Sheet NF 40-3E, Scale 1:100,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals.
- [3] Villey, M., J. et al. (1986), Geological map of Fanjah, Sheet NF 40-3F, Scale 1:100,000, Directorate General of Minerals, Oman Ministry of Petroleum and Minerals.
- [4] Amri, I. (1995), Ph.D.thesis, 199p., Toulouse University, France.
- [5] Ceuleneer, G. et al. (1988), Tectonophysics, 151, 1–26.
- [6] Ceuleneer, G. (1991), ed. by T. J. Peters, pp. 149–175, Kluwer Academic Press, Dordrecht, the Netherlands.
- [7] Pinet, P.C. et al. (2003), IUGG XXXIII General Assembly, International Union of Geodesy and Geophysics, Sapporo, Japan.
- [8] Cocks, T. et al. (1998), in 1st EARSEL Workshop on Imaging Spectroscopy, European Association of Remote Sensing Laboratories, Zurich.
- [9] Gao et al. (1993), Remote Sens. Environ., 44, 165–178.
- [10] Boardman, J.W. (1998), Summaries of the 7<sup>th</sup> JPL Airborne Earth Science Workshop 1, 53.
- [11] Combe, J.-P. et al. (2006), *G<sup>3</sup>*, 7, Q08001.
- [12] Pinet, P. C., et al. (2006), in LPSC 37<sup>th</sup>, # 1346.
- [13] Roy, R. et al. (2009), *G<sup>3</sup>*, 10, Q02004, doi:10.1029/2008GC002154.
- [14] Clenet, H. (2009), Ph.D. thesis, 362 pp., Toulouse University.
- [15] Clenet, H. et al. (2010), *Lithos*, 114, 265–281, doi:10.1016/j.lithos.2009.09.002.
- [16] Clenet, H., et al. (2013), *J. Geophys. Res. Planets*, 118, doi:10.1002/jgre.20112.