



EnMAP

Technical Report

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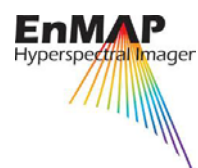


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Abstract

We describe EnMAP-like imaging spectroscopy data files to be used for mineral mapping with the EnMAPBOX software. It is simulated EnMAP satellite data, which is based on hyperspectral flight campaign data with the AVIRIS-NG and HyMap sensors. In preparation of the EnMAP satellite mission, an EnMAPBOX software package provides tools for visualization and scientific analysis of the data. Among many applications, the EnMAPBOX contains geological mapping tools (EnGeoMAP). Here we apply these tools to several representative test cases (Boesche, 2015; Boesche et al., 2016; Mielke et al., 2016). The test data comprise two study sites.

The first scene covers the Mountain Pass open pit mine - a carbonatite deposit in California, USA. It contains calcitic rock units and rare earth element (REE) bearing minerals of the bastnaesite group, also called fluorocarbonates (Olson et al., 1954). The REE concentrations at mountain pass are 9.2% on average, among the highest in the world (Brüning and Böhmer, 2011). The high concentration and the open pit activities make Mountain Pass an ideal test site to investigate the rare earth element distribution in the surface layer. The airborne image data were collected in 2014 by Jet Propulsion Laboratory (JPL), USA, with the AVIRIS-NG sensor and form the basis for EnMAP simulations (Segl et al., 2012; Thompson et al., 2015).

The second HyMap spectral image data covers part of the Miocene Cabo de Gata-Níjar volcanic field, in southeast Spain. It comprises a subset of (Chabrilat et al., 2016) covering the Rodalquilar and Lomilla Calderas, which host the economically relevant gold-silver, lead-zinc-silver-gold and alunite deposits. It is a hydrothermal alteration complex, representing the silicic alteration, the advanced argillic alteration zone, which grades into the argillic and propylitic zone (Arribas et al., 1995, 1989). The image data are part of the Cabo de Gata-Níjar HyMap imagery which was collected during the DLR HyEurope airborne campaign 2005 in the frame of the GFZ land degradation program (Chabrilat et al., 2016, 2005).

We use these datasets to simulate EnMAP-like images for classification and mapping using spectroscopic remote sensing techniques in the EnGeoMAP tools. The EnMAP end-to-end Simulation (EeteS) tool produced simulated EnMAP like data with a spatial sampling distance of 30 x 30 m and 242 spectral bands (Guanter et al., 2015; Segl et al., 2012).

Keywords: Hyperspectral Imagery, Imaging spectroscopy, Mineral Mapping, Rare Earth Elements, EnMAP, EnGeoMAP, simulated data, Rodalquilar, Mountain Pass

Related Work:

An overview of the EnMAP mission is provided in Guanter et al. (2015):

Guanter, L., Kaufmann, H., Segl, K., Foerster, S., Rogaß, C., Chabrilat, S., Küster, T., Hollstein, A., Rossner, G., Chlebek, C., Straif, C., Fischer, S., Schrader, S., Storch, T., Heiden, U., Mueller, A., Bachmann, M., Mühle, H., Müller, R., Habermeyer, M., Ohndorf, A., Hill, J., Buddenbaum, H., Hostert, P., van der Linden, S., Leitão, P., Rabe, A., Doerffer, R., Krasemann, H., Xi, H., Mauser, W., Hank, T., Locherer, M., Rast, M., Staenz, K., Sang, B. (2015): The EnMAP Spaceborne Imaging Spectroscopy Mission for Earth Observation. - Remote Sensing, 7, 7, p. 8830-8857, <http://doi.org/10.3390/rs70708830>.

Mineral mapping of hydrothermal occurrences using the EnGeoMAP Base algorithm is presented by Mielke et al. (2016):

Mielke, C.; Rogass, C.; Boesche, N.; Segl, K.; Altenberger, U. EnGeoMAP 2.0—Automated Hyperspectral Mineral Identification for the German EnMAP Space Mission. Remote Sens. 2016, 8, 127. <http://doi.org/10.3390/rs8020127>.

Rare Earth Element mapping using a first version of the EnGeoMAP REE algorithm is described by Boesche (2015):

Boesche, Nina K. 2015. Detection of Rare Earth Elements and Rare Earth Oxides with Hyperspectral Spectroscopy, Die Erkennung von Seltenerdelementen Und Seltenerdoxidien Mittels Hyperspektraler Spektroskopie. Dissertation, Germany: University of Postdam. URN: <http://urn:nbn:de:kobv:517-opus4-85363>.

The EnGeoMAP tools and a manual by Boesche et al. (2016) is available at:

Boesche, N., Mielke, C., Rogass, C. (2016): EnGeoMAP - Tutorial for Application: Basic minerals and rare earth elements mapping, (EnMAP Technical Report), Potsdam: GFZ Data Services, 16 p. <http://doi.org/10.2312/enmap.2016.003>.

The full Cabo de Gata-Níjar HyMap imagery, associated simulated EnMAP imagery and soil data are described and available at (Chabrillat et al., 2016):

Chabrillat, S., Naumann, N., Escribano, P., Bachmann, M., Spengler, D., Holzwarth, S., Palacios-Orueta, A., and Oyonarte, C. (2016), Cabo de Gata-Níjar Natural Park 2003-2005 – A Multitemporal Hyperspectral Flight Campaign for EnMAP Science Preparatory Activities. EnMAP Flight Campaigns Technical Report, GFZ Data Services. <http://doi.org/10.2312/enmap.2016.004>.

1 Introduction

The Environmental Mapping and Analysis Program (EnMAP) is a German satellite imaging spectrometer mission that aims at monitoring and characterizing the Earth's environment on a global scale. EnMAP serves to measure and model key dynamic processes of the Earth's ecosystems by extracting geochemical, biochemical and biophysical parameters, which provide information on the status and evolution of various terrestrial and aquatic ecosystems. In the frame of the EnMAP preparatory phase, pre-flight campaigns including airborne and in-situ measurements in different environments and for several application fields are being conducted. The main purpose of these campaigns is to support the development of scientific applications for EnMAP. In addition, the acquired data are used by the EnMAP end-to-end simulation tool (EeteS) to test data pre-processing and calibration-validation methods. The campaign data are made freely available to the scientific community under a Creative Commons Attribution-ShareAlike 4.0 International License. An overview of all available data is provided in in the EnMAP Flight Campaigns Metadata Portal (<http://www.enmap.org/?q=flights>).

1.1 Testdata 1 Mountain Pass, USA

The Mountain Pass district is located to the north and south of the route 91, which connects Las Vegas and Barstow (figure 1). The Mountain Pass rock unit comprises pre-Cambrian metamorphic rocks (granitic gneisses, pegmatites, and migmatites; all with varying mafic constituents, Olson et al., 1954). To the north, it is bound to the Clark Mountain rock unit; to the west, it is cut by the Clark Mountain normal fault. The Mountain Pass metamorphic rocks were later intruded by carbonatitic magma. The carbonatites are the rare earth element (REE) rich end product of a shonkinite to syenite to granite differentiation in the magma chamber.

A rough estimation of the principal constituents in the carbonatites is: 60% carbonates, 20% barite, 10% REE fluorocarbonates, 10% quartz and other constituents (Olson et al., 1954). The occurrence of highest REE concentration is located to the North of the route 91 – the sulphide queen carbonate body (Olson et al., 1954). Its REE concentration values vary within the ore body, as the carbonatite veins are inhomogeneously distributed and of different width. Very high REE values are found close to the Sulphide Queen mineshaft. The Sulphide Queen Carbonate body is covered by a layer of gravels and alluvium, but the open pit mine of Mountain Pass reveals the ore body (Olson et al., 1954). Our simulation scene covers the open pit mine, whose east-side walls cut the ore zone. In addition, the rock processing areas and mine dumps are visible. The northern part of the image shows a small section of the metamorphic rocks of Clark Mountain. In the south the image shows small carbonate rock bodies, in which no REE rich dykes were found so far (Olson et al., 1954).

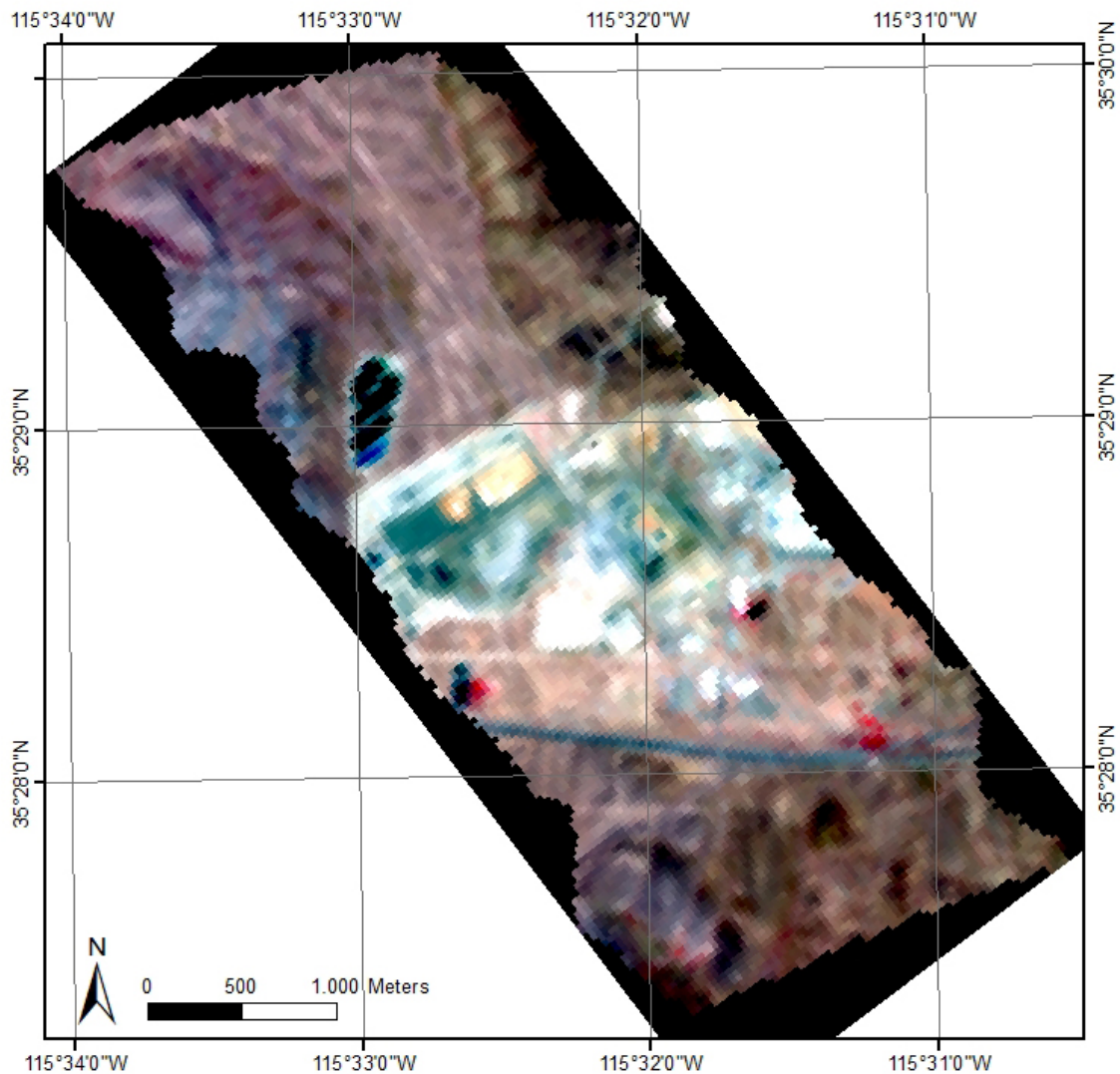


Figure 1: Mountain pass spectral EnMAP image (R: 863 nm, G: 652 nm, B: 548 nm). It was simulated based on Aviris NG data (from 2014).

1.2 Testdata 2 Rodalquilar, Spain

The caldera of Rodalquilar, situated 24 km to the East of Almeria in south-eastern Spain, is one of three calderas in the Miocene Cabo de Gata-Níjar volcanic field (Arribas et al., 1989; Chabrilat et al., 2016). The other two calderas are the not mineralized Los Frailes Caldera and the Lomilla Caldera (Cunningham et al., 1990; Rytuba et al., 1990). The Lomilla Caldera is superimposed on the older Rodalquilar Caldera. Both are host to the economically relevant gold-silver, lead-zinc-silver-gold and alunite deposits (Cunningham et al., 1990; Rytuba et al., 1990). Massive vuggy silica dominates the innermost zone, highlighting the acidic conditions during the time of ore formation (Arribas et al., 1989). The following advanced argillic alteration zone is dominated by quartz and alunite/ jarosite \pm pyrophyllite (Arribas et al., 1995). This zone grades into an outer argillic zone with quartz, kaolinite and illite (Arribas et al., 1995). The outermost zone is the propylitic zone, which is largely covered by vegetation.

The mineral deposit sites near Rodalquilar are shown in figure 2. Here gold has been mined mainly at the Cinto and Consulta Mines. To the southeast of Consulta are large mine waste piles, which also include material from the denver plant near Consulta. Los Tollos has been used as a major alunite mine in the region.

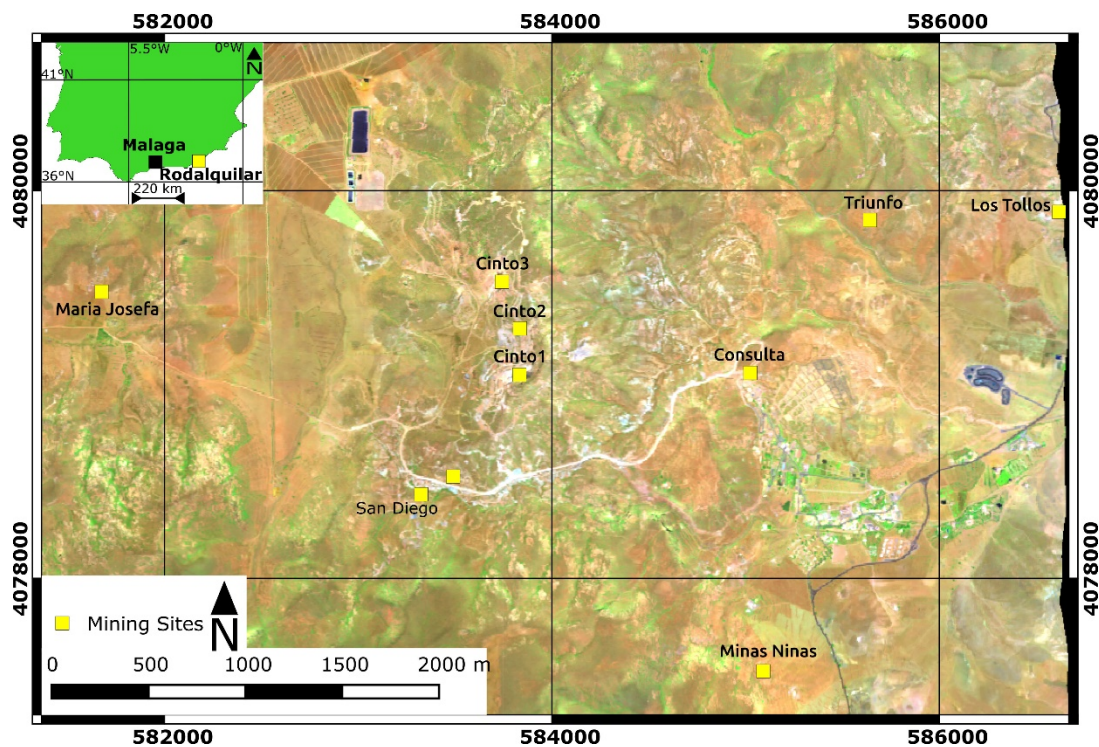


Figure 2: Composite map of the main part of the Rodalquilar caldera, based on HyMap data from 2005 (R: 2225 nm, G: 911 nm, B: 556 nm), with the locations of the former mining sites in the greater Rodalquilar area. After Mielke et al. 2016.

The mining at Rodalquilar started at 1880 and continued until 1966. A total amount of 6 t of gold and minor, lead and zinc ore was extracted (Arribas et al., 1989). New exploration activity was sparked in the 1980's including three years of mining activity (Arribas et al., 1995, p. 19). This exploration activity included the appreciation of the large lateral and vertical extent of the hydrothermal alteration zones at the Rodalquilar deposits (Arribas et al., 1995). The alteration zones at Rodalquilar consist of an inner silicic alteration zone that grade into an outer advanced argillic alteration zone, which is followed by an argillic alteration (Arribas et al., 1995).

2 Data Acquisition

The Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG) is a NASA Earth Science airborne sensor developed by Jet Propulsion Laboratory (JPL), USA (AVIRIS-Next Generation,). Its spectral range spans 350 to 2510 nm, with an average bandwidth of ca. 5 nm. It is mounted on a DHC-c, an aircraft flying at an altitude of 15 to 18 kft (4.6 to 5.5 km) (AVIRIS-Next Generation). The case study image was acquired on 21-June-2014 at around 1700h UTC (1000h local time). The flight altitude was ca. 13,000 feet above ground level, with the aircraft heading NW-SE. The ground sampling distance is 3.7 meters in X- and Y-direction. In July 2015, the image was further processed, georeferenced and reflectance retrieved (Thompson et al., 2015).

The Rodalquilar data were acquired with the HyMap imaging spectrometer during the GFZ/DLR Hy-Europe 2005 campaign over the Cabo de Gata-Níjar Natural Park (Chabrilat et al., 2016). Its spectral range is between 450 and 2500 nm with a bandwidth of 12-17 nm. The presented image data was collected on 15-June-2005, covering volcanic rocks, open pit mine residuals, dunes and salines. Six N-S oriented flight strips were acquired with a ground sampling distance of 5 m in X- and Y-direction (Chabrilat et al., 2014, 2005). The image was further processed, georeferenced and reflectance retrieved by Richter et al. (Richter et al., 2007).

2.1 Testdata 1: Mountain Pass, USA

EnMAP simulated image

Date: June 21, 2014

Samples: 83

Lines: 204

Bands: 242

Wavelengths: 423 – 2439 nm

2.2 Testdata 2: Rodalquilar, Spain

EnMAP simulated image

Date: June 15, 2005

Samples: 135

Lines: 226

Bands: 232

Wavelengths: 440 – 2446 nm

2.3 List of available datasets

Filename	UR coordinates		LL coordinates		Inter-leave	Projec-tion	Pixel Size
	Lat	Lon	Lat	Lon			
EnMAP-Moun-tain_Pass	35.50	-115.56	35.44	-115.50	bsq	UTM WGS 84 - Zone 11 N	3.7 m
EnMAP_rodal-quilar_subset	36.89	-2.07	36.83	-2.03	bsq	UTM WGS 84 - Zone 30 N	5 m

3 Data Processing

3.1 Airborne imaging spectroscopy data

The AVIRIS-NG Mountain Pass data processing includes three main steps: 1) radiometric corrections 2) orthorectification and 3) a “Level 2” correction for atmospheric effects. The latter consists of the estimation of anisotropic surface and on the ATmospheric REMoval (ATREM) algorithm (Gao and Goetz, 1990; Thompson et al., 2015). Moreover, enhanced water vapor estimation is performed using a linearized full-spectrum fit that accounts for vapor, liquid, and ice phases of water absorptions (Gao and Goetz, 1990; Thompson et al., 2015).

The raw airborne Cabo de Gata-Níjar hyperspectral data from the HyMap imaging spectrometer (Cocks et al., 1998) were system corrected to at-sensor-radiance based on calibration coefficients obtained during laboratory calibration by HyVista. The subsequent geometric and atmospheric correction of the data sets were performed using the program routines ORTHO (Schläpfer and Richter, 2002) and ATCOR4 (Schläpfer and Richter, 2002), including topographic correction for different terrain illumination using a DEM with 10 x 10 m resolution (Richter, 2010). A spatial subset was extracted which covers the Rodalquilar Caldera.

3.2 Simulated EnMAP data

The simulation of EnMAP from both reflectance mosaics was carried out with the EnMAP end-to-end Simulation software EeteS (Segl et al., 2012). EeteS simulates the entire image data acquisition, calibration and processing chain from spatially and spectrally oversampled data to intermediate Level-1a raw data and to the final EnMAP products, such as Level-1b, Level-1c and Level-2a data. The data acquisition consists of a sequential processing chain represented by four independent modules, namely the atmospheric, spatial, spectral, and radiometric modules. They are coupled with a backward simulation branch consisting of calibration modules, such as non-linearity, dark current, and absolute radiometric calibration, and a series of pre-processing modules, such as radiometric calibration, co-registration, orthorectification, and atmospheric correction. This process facilitates close to real world application utilizing the simulated EnMAP data, as for example with EnGeoMAP.

4 File Description

4.1 File Format

Band Sequential Image File [*.bsq] and file header [*.hdr]

4.2 Data content and structure

Image files are described in the header file by the following attributes:

ENVI description, samples, lines, bands, header offset, file type, data type, interleave, sensor type, byte order, (x start), map info, default bands, wavelength units, band names, wavelength, and fwhm (full width half maximum).

5 Dataset Contact

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6 Acknowledgements

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