Application of High Altitude and Ground-based Spectroradiometry in the Monitoring of Hazardous Waste Derived from Sokolov Open-pit Mine

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Abstract

Mines (abandoned, still-active) are one of the most challenging environmental problems faced by government, communities and mining industry worldwide. Mineral spectroradiometry, both from airborne or spaceborne sensors and ground measurements, represents an alternative to conventional methods and offers and efficient way to characterize mines and assess the potential for AMD discharge (Acid Mine Drainage). High-altitude spectroradiometry (ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer satellite data) together with ground-based spectroradiometry (ASD Filedspec spectroradiometer) were applied in order to define the capability for identifying the locations of the most significant sources of AMD discharge at the Sokolov open-pit mine site.

Key words: Acid Mine Drainage (AMD), spectroradiometry, ASTER, mining waste, Sokolov open-pit mine

Introduction

The Sokolov basin, Oligocene to Miocene in age, extends over 8 – 9 km wide to 36 km long and the total area of the basin is about 200 km^2. It consists in 60 % volcanic ejecta resulting from faults and volcanic cones and 40 % sediments. It is bordered by a complex SW – NE fault system and is cut by NW – SE faults. The basin is limited to the North by the Lipniza fault system. Hydrothermal fluids have been circulating along the faults where silicification and sulphides can be found, responsible for Acid Mine Drainage. Lignite is found only in the western part of the basin and comprises of the three coal seams. The Josef coal seam represents the lower, just above the basement rocks. It is very rich in sulphide (up to 5%) and arsenic (60 – 70 ppm). The seam Anežka is more recent than the Josef seam and is developed only in the western part of the basin. The Josef and Anežka seams have been exploited in particular in the Medard open pit. The Antonin seam is currently exploited in the Jiří open pit and it contains up to 8 % sulphides together with arsenic. (Rojík et al, 1998, Rojík, 2003).

Mining for bituminous slates at the outcrop of lignite seams started in 1642 for the production of vitriol, alum and sulphuric acid and extraction of lignite for combustion began in 1793. From 1890, large-scale underground and surface mining operations eventually led to considerable environmental problems in the region (Murad and Rojík, 2003).

The collaboration between the CGS (as part of the project "Environmental mining impacts", 2007–2009, funded by the Ministry of the Environmemt) and BRGM (within its self-funded RTD projects) started in 2007 over the Sokolov lignite mine, focusing on mining impact assessment using high-altitude and ground based spectroradiometry. A first preliminary field reconnaissance was organized during the first two weeks of September 2007. In this first year, the collaborating team focused on:

- Field spectroradiometric campaign using the BRGM's ASD FieldSpec® 3 portable spectroradiometer, in natural illumination conditions;
- Laboraty spectroradiometric measurements of representative rock/mineral samples in artificial illumination conditions, using the same spectroradiometer;
- Very first image processing of available superspectral ASTER satellite imagery to identify locations of the most significant sources of acid mine drainage discharge (AMD).

Field reconnaissance

The area is largely affected by Acid Mine Drainage (AMD) due to the presence of sulphides: (a) In the brown coal itself: 5 to 8 % pyrite in the coal and (b) in the hydrothermal deposits along the faulting system that borders the basin and is affected by the exploitation. AMD affects the mine waters in the former exploited open pits. Low pH has been measured in the abandoned Lomnice pit (Fig. 3, pH =

2.2 at observation point SO 16 with the presence of Na-Jarosite). Several abandoned pits (Lomnice, Medard, Marie) present intensive AMD and low-pH waters, both on the pit slopes ("acid springs") and at the pit bottom ("acid lakes"). AMD also occurs locally on dumpsites. Despite the dumped material consisting mostly of Cypris clays, locally some AMD-generating material (coal and/or material from hydrothermal zones) has been dumped. "Acid springs" and/or "acid lakes" have been found in several places in the dumping areas during the field visit (Fig. 3, SO 5, SO 6, SO 7 and SO 28). It seems there could be an artificial "perched" water level inside the dump that could indicate the presence of an indurated "impervious" level.

Spectroradiometric measurements

Two types of spectroradiometric measurements can be performed using the BRGM's ASD Fieldspec 3 spectroradiometer: (a) Field measurement in natural illumination conditions; this requires a sunny clear sky with low humidity to avoid noisy spectra, in particular in the Short Wave Infrared (SWIR) range, the most interesting for AMD-generating mineral discrimination; (b) laboratory measurement in artificial illumination conditions, using a specific probe: this type of measurement requires a physical contact between the target and the probe and is hence limited to the measurement of very small areas, however, it avoids the signal perturbation by water absorption bands.

Due to the very bad weather condition that prevailed over central Europe during the first two weeks of September 2007, only about 15 field spectra have been collected in a single locality, around the so-called Bohemian Geo Park, representative of the different type of clays and rocks encountered there. The spectra were noisy in the SWIR 2 range (over 2350 nm in particular) due to humidity remaining in the air after rainy weeks. Moreover, samples were collected in the field at several places for spectral measurements in the laboratory using the contact probe in artificial illumination. The CGS performed X-ray powder diffraction (XRD) analysis to supplement the mineralogical description of those samples.

Systematic spectra measurements in artificial illumination conditions have been carried out on the collection of representative samples of all the facies encountered in the Sokolov basin or stratigraphically equivalent (provided by Dr. Rojík, Sokolovská Uhelná a.s.). A total of seventy different facies representative of the Sokolov Basin material and its surroundings have been measured this way.

The spectral libraries built from the field spectra (Geo Park) and from the laboratory spectra of the basin stratigraphic column material have been resampled to the ASTER spectral resolution to enable further processing and classification of the ASTER images.

Data processing

Spectroscopic AMD approaches are based on the mapping of minerals that occur at the surface of waste-rock piles and their surroundings, focusing on minerals that serve as indicators of sub-aerial oxidation of pyrite ("hot spots") and the subsequent formation of AMD/ARD. Those processes lead to the accumulation of Fe minerals, wherein centers of such low-pH forming minerals as copiapite and jarosite ($pH< 3$) are surrounded successively by goethite and hematite, the minerals marking progressive increases in pH.

The general approach of mineral spectral-feature mapping involves the following steps: characterization of the spectral absorption features, comparison to ground truth (spectral library, field samplings) and further data analysis. Therefore the first step consists in building the spectral libraries for representative samples of jarosite, goethite, hematite and clay mineral groups comprising the field spectra, laboratory spectra and selected mineral spectra from the USGS (http://speclab.cr.usgs.gov) and JPL libraries (http://asterweb.jpl.nasa.gov).

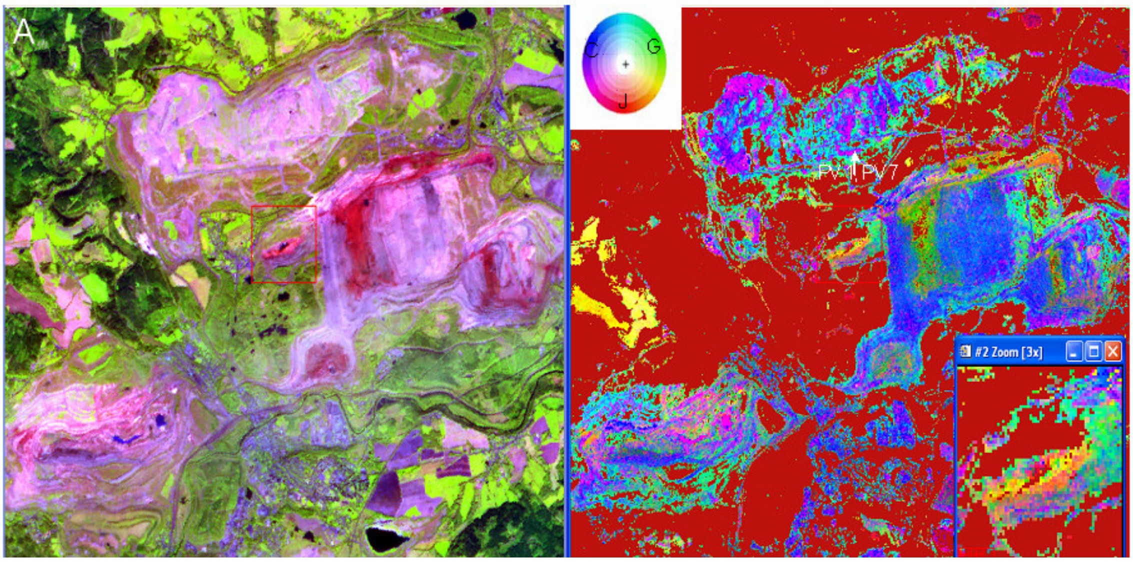
Two ASTER satellite acquired images,12/9/2004 and 28/10/2005, respectively were utilized to create spectral mineral maps. Various hyperspectral image processing algorithms can be used for mineral mapping. Three spectral mineral mapping techniques, "Spectral Angle Mapper" (SAM), "Linear Spectral Unmixing" (LSU) and "Match filtering" (MF), were employed to create mineral abundance maps over the study area.

Discussion

Spectroradiometric measurements: *Iron oxy-hydroxides* - In accordance with other studies, iron oxy-hydroxides showed diagnostic absorption before 1.000 µm, in this particular case at the wavelength of 0.8 µm. This absorption feature was found to be more visible on the hematite group minerals, on the other hand, the goethite minerals showed a more distinctive reflection feature at the 0.661 wavelength. *Jarosite mineral group* - Jarosite, as other sulfates, has the same diagnostic features as iron oxy-hydroxides, and in addition, shows an absorption feature before 2.2 µm, in this particular case in 2.167 µm. *Clay minerals* - Clays are the most common minerals at the open pit mine site, and thus are found in different geological materials as a part of the intimate mixture. They have the most distinctive absorption feature near to 2.2 µm. Our study confirmed that finding as the clay absorption feature was found at 2.209 µm.

Spectral mineral mapping: **"Linear spectral unmixing" (LSU) method** allows determining relative abundance of materials depicted in multispectral/hyperspectral imagery based on the materials' spectral characteristics. The reflectance at each pixel of the image is assumed to be a linear combination of the reflectance of each material (or endmember) present within the pixel. Spectral unmixing results are highly dependent on the input endmembers; in this particular case the spectral reflectance curves obtained from the representative mineral samples of Sokolovská open pit mine were used as input endmembers.

Figure 1 *Results of classification employing LSU concept (j = jarosite, g = goethite, c = clay minerals), no data" values assigned as dark orange-red color.*



"Spectral Angle Mapper" (SAM) compares reference spectra from the spectral library to each image pixel spectrum, it determines the similarity between a reference spectrum and image spectrum by calculating the "spectral angle" between them both. An angular threshold value is then chosen so that only pixels with smaller angles to the reference spectra will be mapped (Fig. 2). In this case the reference spectra were the field spectra measured at Geopark (SW of the site area).

Attempted mapping of potential water contamination

Image spectra corresponding to various water types were collected (surface water, turbid water, contaminated water at Geopark and contaminated water (red waters) at Medar pit. A classification algorithm was applied to the Visible and Near infrared bands of the ASTER image (below 1µm). The result, presented in figure 3, clearly shows turbid waters in former open pits (south and south east of Sokolov, contaminated waters in several pits west of Sokolov, including Medard pit and south of Habartov. Highly contaminated water is found south of Hor Pochlovice. However, contaminated-like waters are also indicated outside of the mining area.

Figure 2 *SAM classification results on ASTER image.*

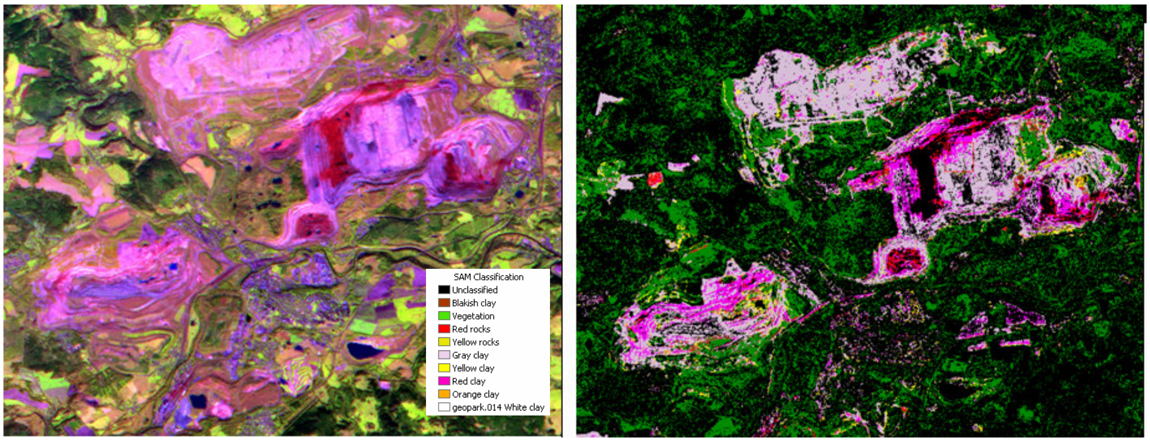
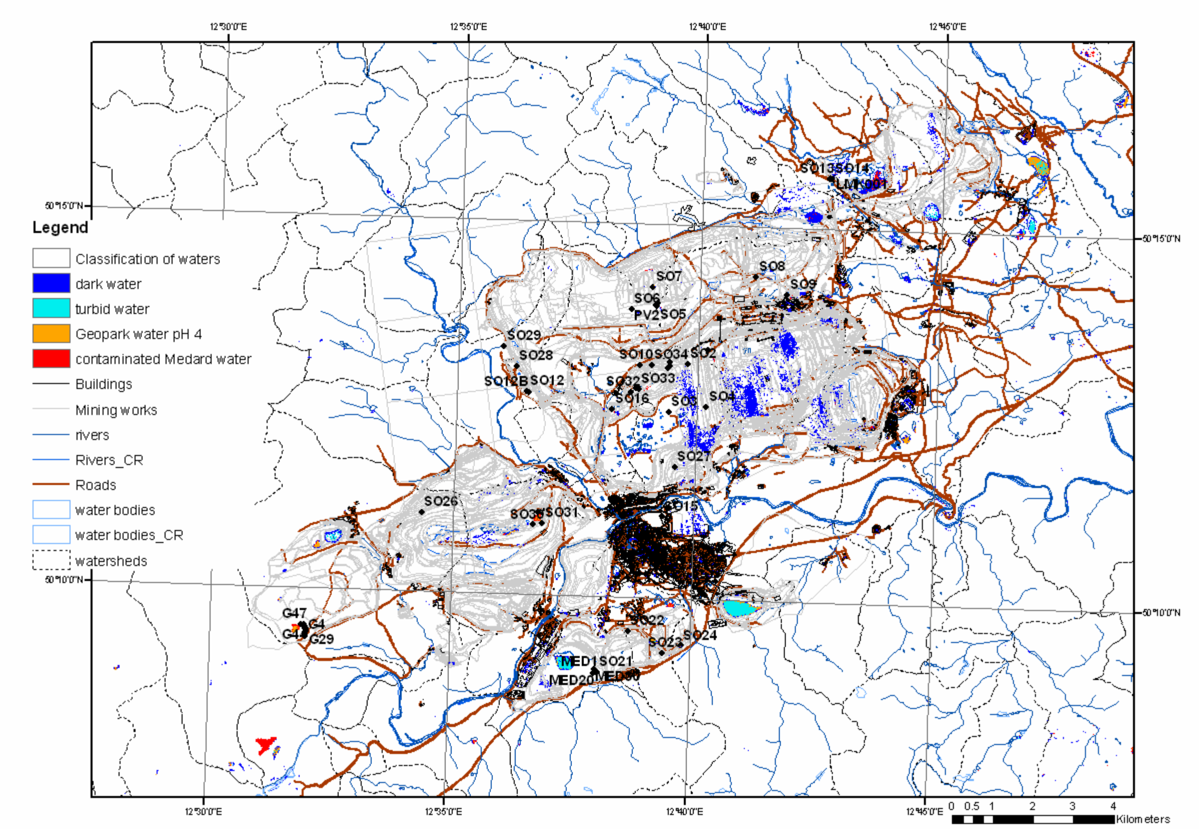


Figure 3 *Attempt of classification of potential water contamination from ASTER imagery.*



Conclusions

Initial results of comparing the mineral maps derived from ASTER imagery to field samples confirmed with XRD analyses demonstrated the ability of spectral remote sensing to the mapping of mineral species such as secondary iron minerals. Image processing identified jarosite as a part of the mixture material in accordance with conducted XRD analyses.

References

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