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Combined use of AISA, HyMap and ultraspectral image data for detection of environmental features, a case history from Elijärvi chromium mine, Finland

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ABSTRACT: The Remote Sensing Laboratory of the Geological Survey of Finland carried out two phase airborne imaging spectrometry campaign and one field spectrometry campaign in the area of Elijärvi chromium mine near to the town of Kemi in NW Finland. Hyperspectral remote sensing data were recorded by the imaging spectrometers AISA and HyMap. FieldSpecFR was run using a specifically constructed scanner mechanism for recording ultraspectral images (2151 channels) from the set of field samples.

AISA channels covered the VISNIR area and pixel size is about 1x1 m^2 from the altitude of 1100 m. AISA data was mainly used for calculating Weighted Difference Vegetation Index (WDVI). HyMap channels cover VNIR, SWIR1 and SWIR2 areas and pixel size was 5x5 m^2 from the flight altitude of 2000 m. HyMap data was used mainly to calculate the Red Edge Inflection Point maps and Minimum Noise Fraction maps. They were also used to detect the areal distribution of minerals. Reflectances of single and multiple samples (ultraspectral images) were used for training the classification of HyMap data. The ultraspectral images were obtained using the portable FieldSpec spectrometer in 'scanning mode' by a stepwise rotation mechanism.

The study resulted in mapping the distribution of weathering products of sulfides, some of which are contaminating the vegetated areas. Contamination of plants, mainly caused by mineral dust, could partly be mapped with the aid of changes in spectral symptoms of plants due to stressed vegetation.

1 REMOTE SENSING ON MINING ENVIRONMENTS

Mining environments have become as specific targets of environmental research and remediation due to new and/or forthcoming European legislative issues. In addition to classical geochemical field sampling based methods, remote sensing offers versatile tools and materials for the studies of mining environments. Further, imaging spectrometry can be used to assess both crucial mineral materials and vegetation stress possibly due to contaminating minerals. The purpose of this study is to enhance and classify remotely sensed imaging spectrometer data for finding possible areal extent of environmental impact of mining

2 ELIJÄRVI CHROMIUM MINE AND IT'S ENVIRONMENT

The Elijärvi chromite ore is hosted by an early Proterozoic mafic to ultramafic layered intrusion that separates the Archaean and Proterozoic rocks (Leinonen 1998, Kujanpää 1987, Kujanpää 1971). The formation is 15 km long and 50 - 2000 m thick. The economic ore is a 4.5 km long sequence of numerous separate ore bodies near the Kemi township. The mining area is indicated by the small dark rectangle in Fig. 1. In places, the ore layer is about 100 m thick. Chromite is the only mineral of economic importance. The ore also contains minor amounts minerals such as magnetite, ilmenite, hematite, rutile, pyrite, chalcopyrite and millerite. The ore consists of 65-70 % chromite, with gangue minerals such as talc, carbonates and serpentine. The Kemi chromite mine has remained productive since production commenced in 1968. It is operated by Avesta Polarit Ltd. At present the mine produces about 1 million tonnes of chromite ore per year. Concentration takes place at the mine. The concentrates, i.e. the upgraded lumpy ore and the metallurgical grade concentrate, are used as raw materials in ferrochrome production, which is about 260 000 tons per year. After 2003 there will be a gradual move of production to underground mining. (Arkimaa et al 2002).

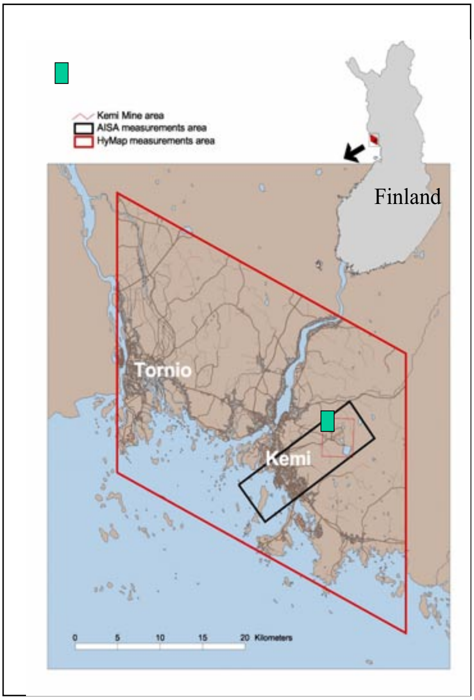

Figure 1. Location of the Elijärvi mining area near the Kemi town and the AISA and HyMap measurement areas.
(Base map © National Land Survey of Finland permission no 13/MYY/01)

During the last decade, the mine itself, the ferrochrome plant at Tornio and the counties of Kemi, Tornio and Keminmaa have carried out several environmental studies. A bioindication study has been made every five years. In these studies a red-stemmed feather moss (Pleurozium schreberi) has used as a test plant. Cr, Ni, Zn, Cd, Pb, V and As have been analyzed (the four last elements analyzed only from a part of the specimens). The specimens were collected from profiles trending in all cardinal and half-cardinal directions. The samples closest to the Tornio ferrochrome plant and the Kemi mine are 1.5 km from these, and the furthest are 70 km away.
The 1990 study showed that the occurrence of higher Cr contents extended 8 - 16 km from the Tornio ferrochrome plant, and 4 - 6 km from the Kemi mine. The corresponding distances for Ni content were 5 - 7 km and 4 - 6 km respectively. For Zn, the correlation between content and distance was not as clear. The 1995 study gave approximately similar results: the effect of the Tornio ferrochrome plant remained as large as in 1990, but the Cr and Ni contents were lower. The environmental effect of the Kemi mine on results was somewhat more limited than previously (Ekholm & Lepola 1991, Lepola & Määttä 1996).

The mine has also carried out studies on accumulation of dust in three sampling points located in the mine area and next to it. This study has shown that chromite dust (specific weight 4.5 g/cm3) accumulate almost in the same place as it has risen and that gangue minerals talc, chlorite, serpentine and tremolite, which are lighter minerals (specific weight < 3 g/cm3) are transported further by the wind (Bergström 1996).

The mine also makes a monthly examination of water quality in the drainage ditch taking water from the mine.

3 REMOTE SENSING AND OTHER SPECTROMETRY DATA.

An aerial survey of the test area using the hyperspectral **AISA** imaging spectrometer was made on 12th of September 1999 using 17 spectral channels. The used wavelength area covered about 450 - 870 nm, channel width varying in the range 7.3 - 7.6 nm. The measurement was conducted from an altitude of 1100 m resulting the terrain resolution of 1.1 m x 1.1 m. The survey area was about 5 km x 16 km in size (NW rectangle in Fig. 1). AISA on board radiance was geometrically and atmospherically corrected into ground reflectance.

The hyperspectral **HyMap** imaging spectrometer was used on 29th July 2000 in the following mode: 126 spectral channels were recorded on the wavelength range 400-2500 nm with bandwidths 12 - 16 nm. The HyMap measurement area covers about 1100 km^2 and includes the Kemi mine, the towns of Kemi and Tornio, and the ferrochrome plant at Tornio (large rhomboid in Fig. 1). The measurements cover about 40 km of the coast of Perämeri sea. The pixel resolution was 5.0 m and swath width 2.0 km. HyMap on board radiance was geometrically and atmospherically corrected into ground reflectance.

FieldSpecFR portable field spectrometer was used to measure several mineralogical and environmental field targets and specific samples. Reflectance spectra of most component minerals of ore and wall rocks, and especially, the environmentally relevant rock types such as sulfide bearing gabbros, and their weathering products. The common vegetation species within and outside the mining area were also measured.
FieldSpecFR was also used in specific ‘scanning mode’ by a programmable stepwise rotation mechanism (Fig. 2). The final scanned images were composed of 2151 FieldSpecFR 2 - 9 nm wide channels covering the wavelength range 400 - 2500 nm (Fig. 3). Therefore, because of high number of channels, the scanned images are here called as ‘ultraspectral images’.

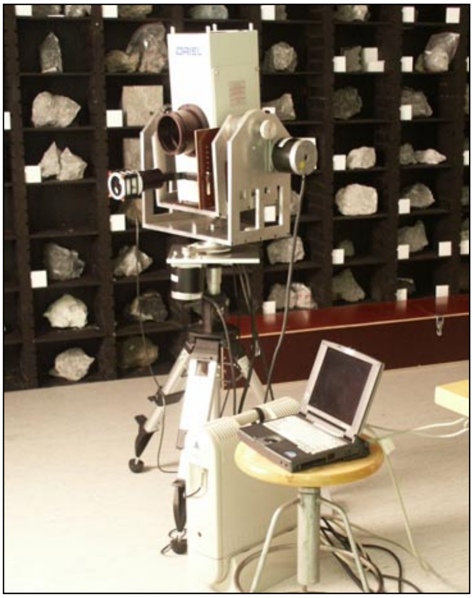

Figure 2. FieldSpecFR combined with Oriel 1000 W illuminator was used to 'scan' the shelf, which was loaded by rock and environmental samples. The white standard reflectors (6x6 cm) were placed near to the samples in order to ensure spectroradiometric corrections after possible instrumental drift.

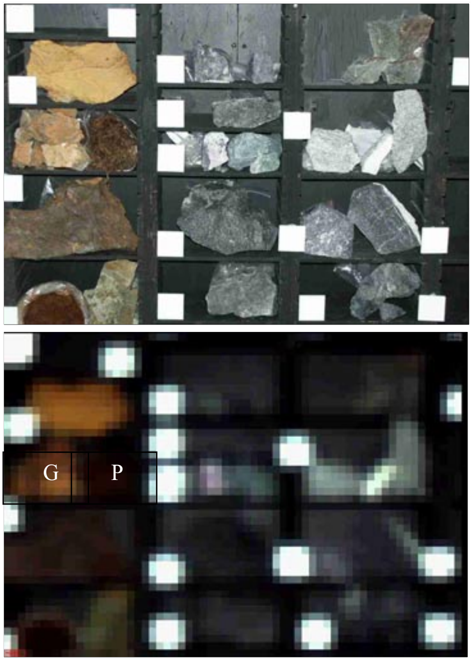

Figure 3. Photograph of the shelf loaded by significant samples (upper frame) and the RGB-bands of the ultraspectral FieldSpecFR-image from the same target. G and P indicate locations of weathered gabbro and peat pixels respectively.

A set samples of the main ore types, minerals and environmental samples were placed in the black shelf, which has minimal reflectance on the wavelength range 400 – 2500 nm. Four laser pointers were used to follow the progress of scanning. Scanning was performed from a distance of 1.3 meters from the samples using the Oriel 1000 W tungsten-halogen lamp illuminator with a voltage stabilizer.

4 ASSESMENT OF ENVIRONMENTAL FEATURES

4.1 *Training data*

The use of FieldSpecFR scanned images can be regarded as a link between the spectrometric field samples and the remote sensed imaging spectrometer data. Fig. 3 shows a photograph of the sample shelf loaded with some samples from the Elijärvi mining area.

The reflectance spectra of the weathered surface of sulphide bearing gabbro (G in Fig. 3 and in Fig. 4) are similar to reflectance of peat (P in Figs. 3 and 4), which has been contaminated by that weathering product. This observation suggests that such contamination can be detected in vegetated areas from remotely sensed imaging spectrometry data using models actually measured from rocks. The ultraspectral images are useful tools to compare numerous reflectance spectra and to evaluate their variability as well as to simulate the hyperspectral remote sensing data.

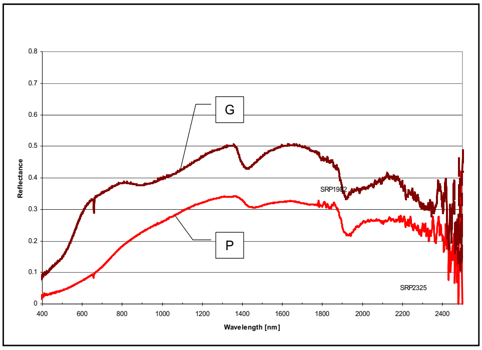

Figure 4. Contents of pixels G and P from the ultraspectral FieldSpecFR-image in Fig. 3: reflectance spectra of weathered surface of sulfide bearing gabbro and peat contaminated by that weathering product.

4.2 *Interpretation of AISA data*

The weighted difference vegetation index WDVI was calculated as a difference between near-infra channel 13 (780.7 nm) and red channel 10 (671.3 nm) weighted by the soil factor (calculated as a ratio between near-infra and red for uncovered soil, Fig. 5). Width of the area interpreted corresponds to 8 kilometers.

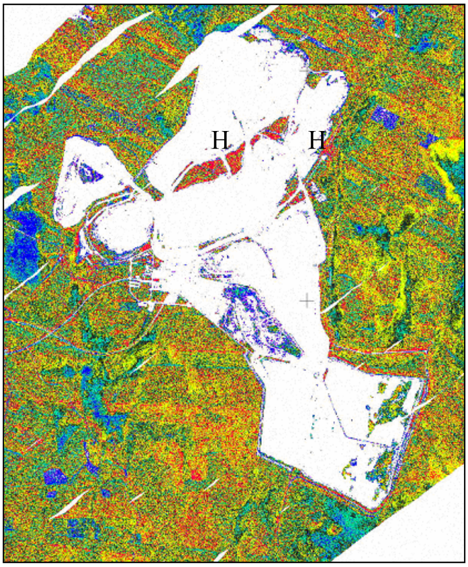

Figure 5. Weighted difference vegetation index (WDVI) calculated from AISA radiances for the vicinities of the Elijärvi mine.. The closed white area indicates the non-vegetated mineral cover in the mining area

The deciduous trees in the middle of the mining area and along it’s eastern side got high WDVI values (indicated by ‘H’s in Fig. 5). All the following image-processing tools are defined and explained in ENVI User’s Guide (2000).

4.3 *Interpretation of HyMap-data*

The shifts in the red-edge region between 670 nm – 780 nm have been found to indicate stresses in vegetation (Curtiss et al. 1991). The wavelengths of the red-edge inflection point (REIP) were calculated applying the method of Guyot and Baret (1988) for HyMap wavelengths using the formula:

$$LREIP = L(707.8) + L(753.4 - 707.8) \times (((R(783.5) - R(676.9))/2 - R(707.8))/(R(753.4) - R(707.8)))$$

where L is wavelength [nm] and R radiance value [W/steradian m2] of HyMap data.

The resulting REIP wavelength values of deciduous trees in the middle of the mine show a slight shift to longer wavelengths, a so-called "red shift" (Fig. 6). Width of the area interpreted in the following figures corresponds to 8 kilometers.

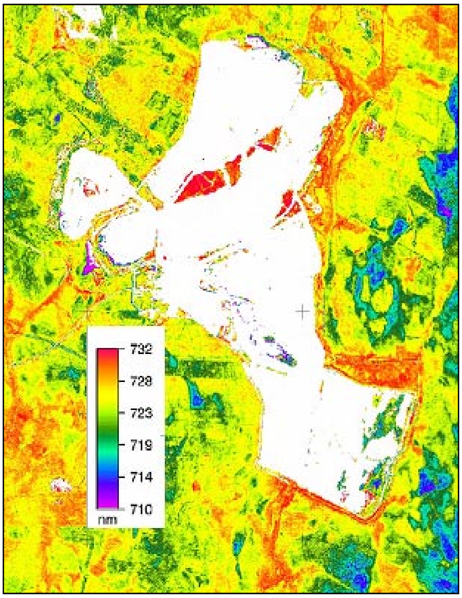

Figure 6. The image of the wavelengths corresponding to the red edge inflection point (REIP) in the surroundings of the vicinities of the Elijärvi mine.

The best resolution for different vegetation types in MNF-transformation were achieved using a mask - which excludes the non-vegetated areas - tailored from the vegetation index. The wavelengths of water absorption peaks near 1.4 mm and 1.7 mm were omitted from the transformation.

The resulting MNF-components 8 and 10 formed a zone around the mine. The width of the zone varies from ten to some hundred meters being at its widest on the eastern side of the mine (Fig. 7).

A possible cause for this can be vegetation stress symptoms but also the atmospheric scattering of radiation from the mineral material and/or dust particles in the air. Moreover, the dust accumulated on the ground and on vegetation could cause this phenomenon, too. The main wind directions to NW support this inference.

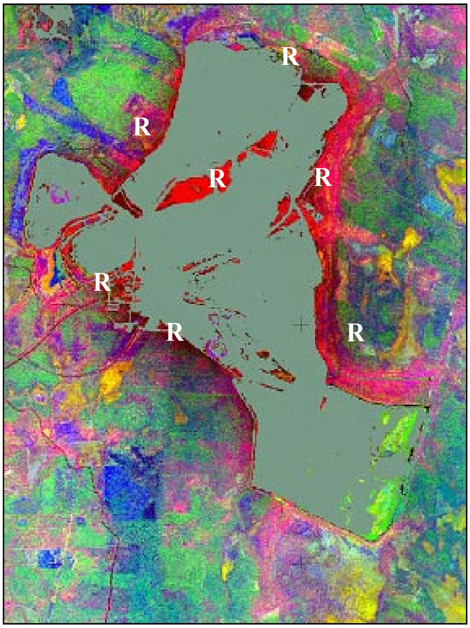

Figure 7. MNF-transformation of HyMap data (components 3, 8 and 10) made for vegetation in the surroundings of the Elijärvi mine.

This MNF-combination seems to summarize the areal extent of vegetation stress due to mineral dust and other stress inducing factors. The areas of main vegetation stress are indicated by the dark rim (R in Fig. 7) around and inside the mine.

A Spectral Angle Mapping (SAM) classification of the weathering products ('rusty' surfaces) of sulfide bearing rock was also carried out. The results (Fig. 8) also map the areal distribution of peat/humus, which may contain rust on the surface.

Figure 8. Spectral Angle Mapping of a weathered sulfide bearing rock surface characterized in Fig. 4. The black areas indicate targets similar to the model. Roads are added to this drawing in order to clarify the locations of the modeled features.

5 CONCLUSION

The ultraspectral images are useful tools to compare numerous reflectance spectra of significant environmental and mineral samples and to assess their variability. The FieldSpecFR portable spectrometer needs a high-energy lamp to illuminate the set of samples from a distance. Vegetation stress can best be mapped from AISA and HyMap data by ENVI enhancement tools such as vegetation indices and Minimum Noise Fraction transformation. In the case of natural rough surfaces with plenty of shadows the SAM classifier was the best tool to map environmentally meaningful mineral assemblages and their weathering products.

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