# Active hyperspectral sensing (AHS) applications for mineral deposit exploration

# Приложение на активни хиперспектрални изследвания (AHS) при търсене на минерални находища

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## Introduction

Remote sensing and hyperspectral imaging, in particular, have been used in mineral exploration and other mining industry applications for decades (Sabine,1999, Frazer et al., 2006, Murphy et al., 2015, etc.). The hyperspectral imaging using satellites, drones, or on-ground imaging are the ways this of technology to benefit geological exploration, commonly by analysing the reflected light signal for mineral and alteration classification (Krupnik, Khan, 2019). The conventional hyperspectral cameras for remote sensing use sunlight as an illumination source, which restricts their application to sunny days and outdoors applications. For all other conditions, short-distance sensing (up to about one meter) using active illumination with halogen bulbs or LED arrays is possible. However, the screening of large surface areas irrespective of any light conditions is not available. Thus, high-quality geological mapping of outcrops is impossible for underground mining and challenging light conditions, such as in forests.

A new technology addressing this challenge called active hyperspectral sensing (AHS) has been developed recently (Kääriäinen, T. et al., 2019). This approach could be applied under any ambient light conditions and enables longer detection distances while can distinguish a huge number of minerals. The innovation of AHS application for mineral exploration (Fig. 1) is based on the utilization of supercontinuum (SC) light sources for sample surface illumination. Then, the reflected light is gathered and analyzed using an imaging system.

## Samples and methods of study

Twenty samples from both host-rocks alteration and ore mineral assemblages from Vlaykov Vruh, Tsar Assen porphyry-copper deposits and Radka, Elshitsa and Krassen high-sulphidation Cu-Au deposits from Panagyurishte ore district (Bogdanov,1987, Kouzmanov et al., 2009, Popov et al.,2012) have been tested using IRreflectance spectroscopy and X-ray diffraction (XRD) for mineral detection in VTT, Finland and Sofia University, respectively(Table. 1, Fig. 2). The reflectance measurements were carried out in the near- and mid-infrared (NIR & MIR) ranges using the NIRQuest (900-2100 nm, spectral resolution: 8 nm) and the ARCoptix (2000-5500 nm, spectral resolution: 2-14 nm) spectrometers, respectively. Single-point spectra were recorded by coupling a reflectance fiber optic probe bundle (NIR: low-OH $SiO_2$, Thorlabs RP23; MIR: chalcogenide glass, ArtPhotonics) to the spectrometer and using broadband blackbody sources (NIR: tungsten-halogen lamp, Thorlabs SLS201L/M; MIR: SiC globar, ARCoptix) to illuminate the sample. Reflectance spectra were also recorded using the SC source developed at VTT for the AHS system (1550 and 2000 nm), using a multimode low-OH $SiO_2$ and a reflective collimator (Thorlabs, RC08SMA-P01) for collecting the reflected light. For each rock, single-point reflectance spectra were recorded at 5 points, and a single measurement was taken using the SC source. Fig. 2 shows the reflectance spectra after smoothing by Savitzky-Golay using either a 25 (NIR) or 15 (MIR) point window, and standard normal variate (SNV).

## Results, discussion and conclusion

Alteration minerals from phyllic, argillic, propyllitic and K-silicate alteration zones associated with epithermal gold and porphyry-copper style of mineralization for validation of mineralogy were detected (Table. 1, Fig. 2). Spectral properties of phyllosilicate minerals such as kaolinite, montmorillonite, illite, clinochlore, celadonite were discussed by Clark (1999), Bishop et al., (2008). ASTER data have also been employed worldwide for mineral prospecting purposes (Di Tommaso, Rubinstein, 2007) including Panagyurishte ore region in Bulgaria (Bakardjiev, Popov, 2015). Meanwhile, the imaging spectroscopy of common silicate and non-silicate minerals of interest for geological applications have been recently reviewed by Krupnik and Khan (2019). Muscovite, illite, albite, K-feldspar, epidote, clinochlore, pyrite, chalcopyrite, magnetite, hematite, calcite, dolomite, anhydrite and jarosite have also been confirmed by reference XRD study. If we compare for example acquired reflectance spectra for epidote (Fig. 2b) it is evident that the 2000-2500 nm SWIR range is the most characteristic and reliable for alteration mineral assemblages detection and geological exploration applications.

Our preliminary results of reflectance spectra recorded with the SC for mineral detection study (Fig. 2) of the ore associated phyllic, argillic and propylytic alteration assemblages from epithermal gold and porphyry-copper style deposits reveal the advantages of AHS sensing for mineral detection and targeting as express new innovative technology and efficient tool for mineral prospecting. Ongoing work aims at extending the spectral coverage of the SC up to 2500 nm, enabling the identification of a wider range of important features for mineral identification.

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Table 1. Mineral composition of samples from Vlaykov Vruh, Tsar Assen porphyry-copper deposits and Radka, Elshitsa and Krassen high-sulphidation Cu-Au deposits.

| | Mineral | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | **Quartz** | **Albite** | **Microcline** | **Muscovite** | **Illite** | **Goethite** | **Clinochlore** | **Kaolinite** | **Calcite** | **Dolomite** | **Pyrite** | **Jarosite** | **Anhydrite** | **Andradite** | **Gypsum** | **Plagioclase** | **K-Feldspar** | **Hematite** | **Magnetite** | **Chalcopyrit** | **Epidote** | **Chlorite** |
| KE 002 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 005 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 009 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 010 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 013 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 014 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 015 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KE 016 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| T 103 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T 104-1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T 105 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T 105-1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| VEL 028 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| EL 032 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| E 1106182 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| TZA 6/138 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| TZA 40/140 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| TZA 17/66 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| TZA 17/134 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |

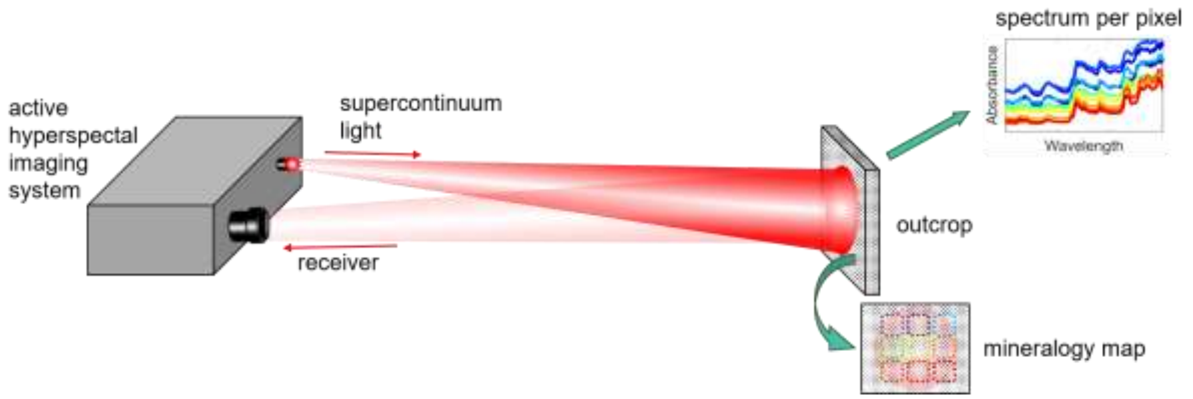

Figure 1. Scheme of active hyperspectral sensing (AHS).

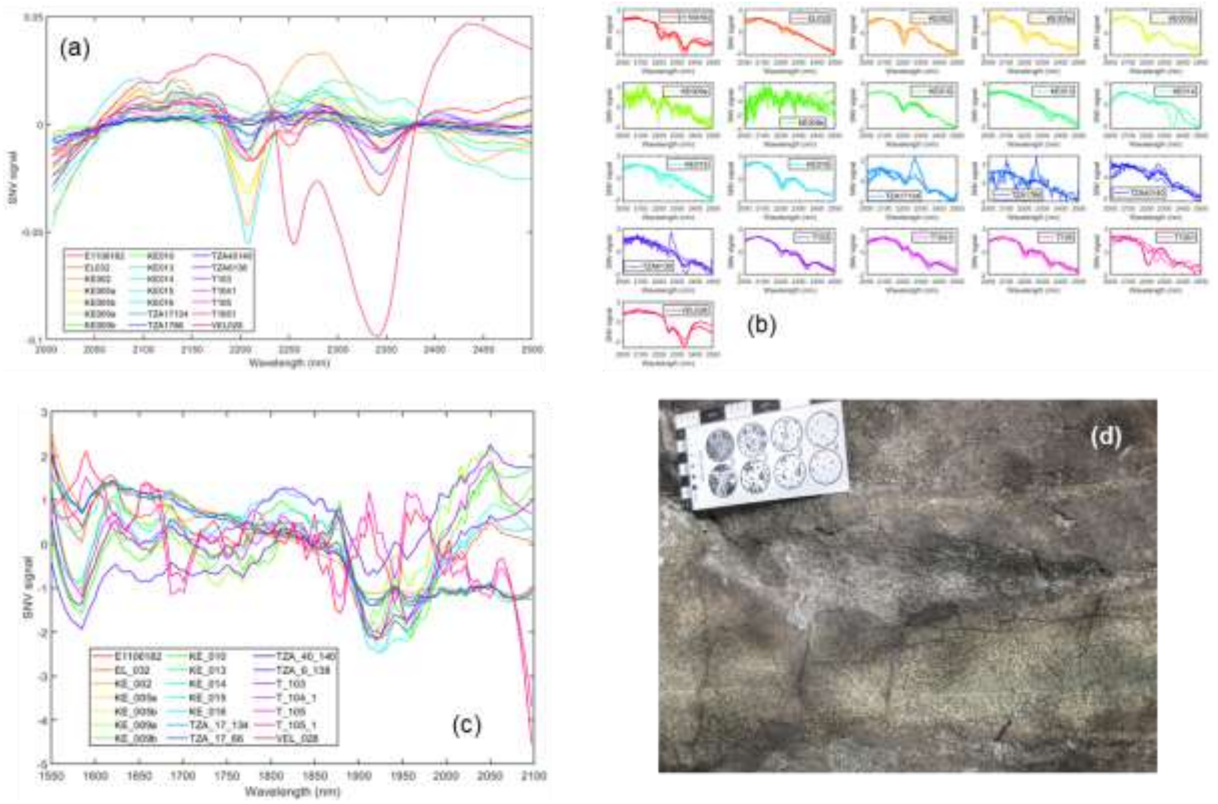

Figure 2. Reflectance spectra of samples from Panagyurishte ore region (a) Average reflectance spectra using the ARCoptix and a SiC globar source in the range 2000-2500 nm; b) individual reflectance spectra for each sample shown in (a); (c) NIR reflectance spectra acquired using the SC source in the range 1550-2100 nm; (d) chlorite, epidote, albite (propylitic) alteration assemblage (VEL 028).