MULTI- AND HYPERSPECTRAL SATELLITE SENSORS FOR MINERAL EXPLORATION, NEW APPLICATIONS TO THE SENTINEL-2 AND ENMAP MISSION.

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ABSTRACT

Imaging spectroscopy is a widely used tool in mineral exploration today where exploration companies offer the full service package to their clients: (data acquisition, preprocessing and product delivery). These exploration projects rely mainly on airborne imaging spectrometers such as Hymap, AISA or HySpex. This data is usually scarce and expensive and may not be available to academic research. The only operational spaceborne imaging spectrometer that covers the full spectral range from the visible to the shortwave infrared is Hyperion aboard EO-1, which has been providing data for over a decade now. New and advanced spaceborne imaging spectrometers such as the Environmental Mapping and analysis Program (EnMAP) will provide new data for research in the field of imaging spectroscopy for mineral exploration. This study presents a comparison of the mapping capabilities between the Hyperion and EnMAP sensors, on the basis of simulated EnMAP data. This is shown with an example from a porphyry copper complex in southern Namibia (Haib River). In addition to that results from multispectral sensors (Landsat-8 OLI, EO-1 ALI and simulated data from the next generation Sentinel-2) are shown to illustrate their potential to map the gossan-outcrops at the Haib River Complex using the Iron Feature Depth (IFD).

Keywords: EnMAP, Sentinel-2, EO-1, IFD, USGS MICA

INTRODUCTION

The use of airborne hyperspectral imaging spectrometers such asHymap[1] or HySpex[2] is a common approach in exploration campaigns today[3]. These airborne sensors combine a good signal-to-noise ratio and a good spectral and spatial resolution. However, the usage of these systems in large and remote areas involves high costs due to the difficult logistics that is involved in airborne hyperspectral campaigns. Therefore, the usage of multispectral imagers, such as the Operational Land Imager aboard Landsat-8 [4] and Sentinel-2[5] in combination with hyperspectral spaceborneinstruments such as Hyperion [6] andEnMAP[7], will increase in geological mapping and exploration campaigns to reduce airborne related costs to a minimum possible extent. This is due to the open data policy that accompanies these spaceborne missions as in case of the National Aeronautics and Space Administration's (NASA's) EO-1 satellite, or NASA's Landsat program. The future European Sentinel-2 and the future German EnMAP mission will supply data with a similar data usage policy to the geoscientific community worldwide. The here presented study, therefore, aims at illustrating synergetic effects in mineral exploration that emerge from the usage of these spacebornemultispectral and hyperspectral instruments. This is done for the Haib River porphyry copper deposit in the lower Orange River area, shown in Figure 1, which has been identified as one of the oldest porphyry copper deposits in the world ([8],[9])situated in the Namaqua Mobile Belt [10]. Early exploration work up until the work of Minnit[9] is advocating for a classical succession of hydrothermal alteration zones, which indicate a porphyry copper deposit [9]. Therefore, this area represents a unique test site for the demonstration of new remote sensing techniques for mineral mapping and exploration [11].

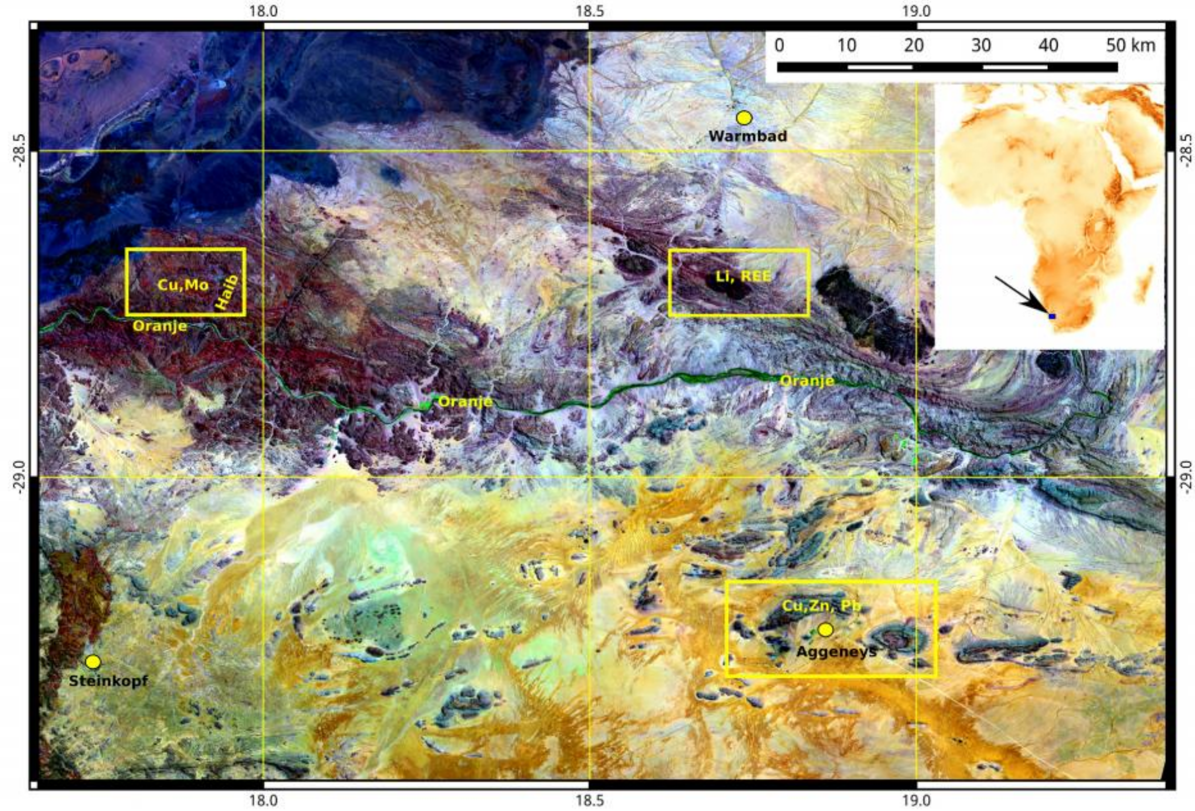

Figure 1: Landsat-8 OLI false color composite (OLI scene ID: LC81760802014026LGN00) (R: 2200 nm, G: 860 nm, B: 560 nm) showing the Orange River area with the three major mineral deposit sites in the border region of South Africa and Namibia. These are the Aggeneys lead-zinc deposit, the lithium pegmatites and rare earth element bearing site close to Tantalite Valley, south of Warmbad and the Haib River Complex with its copper deposit.

METHODS

For this study data was acquired from the EO-1 Hyperion and ALI sensors, as well as data from Landsat-8 OLI, shown in Figure 1. Airborne hyperspectral data (Hymap) from the Geological Survey of Namibia was used to simulate the future multispectral Sentinel-2 and the future hyperspectral EnMAP sensor using theEnMAP End-to-End simulation tool of Segl et al. [12]. This enables the demonstration of the full capacity of Sentinel-2 and EnMAP and facilitates algorithm development and validation prior to the launch of these sensors. Fieldwork was carried out for sample collection and field spectrometer measurements for verification purposes. In order to exploit the large spatial coverage of multispectral spaceborne instruments and the high spectral resolution and ability to characterize the surface mineralogy the Iron Feature Depth (IFD) [13] is used for mapping the spatial distribution of secondary iron bearing minerals such as goethite, hematite and jarosite. These minerals are essential in the process of exploration, where the occurrence of gossans may show zones of sulfide oxidation and metal leaching, which can be indicative for copper exploration [14] and material transport from mine waste sites [13]. Figure 2 shows that the IFD, which exploits the 900 nm iron absorption feature in a three-point band-depth fashion, is able to highlight the abundance of secondary iron bearing minerals. Even OLI is able to map the iron related absorption feature at 900 nm, due to its band layout, as shown in Figure 2.Hyperspectral spaceborne data in combination with the USGS Mineral Identification and Characterization Algorithm (MICA) was used [15] for mapping the mineral distribution of the alteration minerals from the hyperspectral spaceborne data, which complements the IFD analysis of the multispectral spaceborne systems.

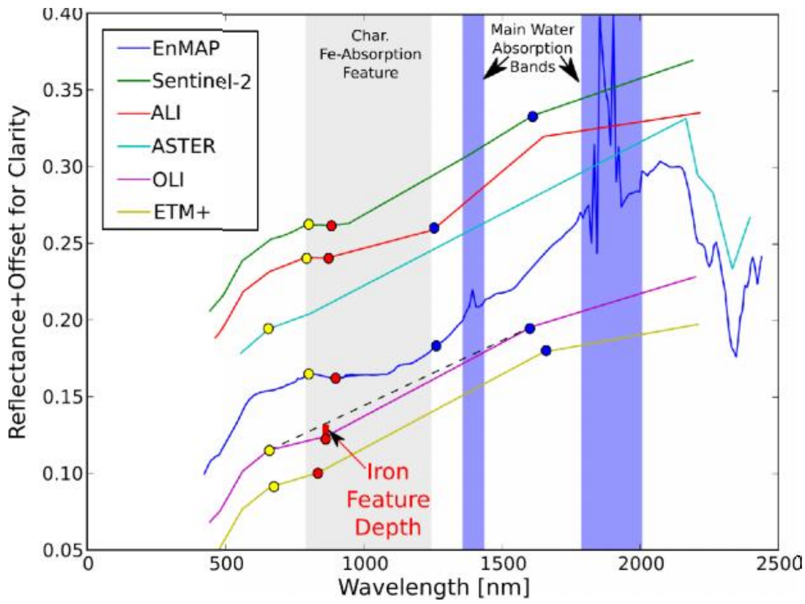

Figure 2: Definition of the Iron Feature Depth for selected multispectral sensors (hyperspectral EnMAP data for reference) to illustrate the capacity of the IFD for mapping the iron absorption feature in a spectrum from the Haib River Complex.

RESULTS

Figure 3 shows IFD results from the Haib River Complex calculated from simulated Sentinel-2 data, from data takes of EO-1 ALI and from Landsat-8 OLI.The data coverage differs between the three sensors due to a different swath width especially if the narrow coverage of ALI is considered. Therefore, the gossan occurrence the northwest outside the main mineralized zone is not shown on the ALI data due to a lack of ALI data coverage in this region. Sentinel-2 and OLI do however highlight this gossan occurrence, although the IFD values of OLI are much lower in this region than in the corresponding Sentinel-2 data. This is due to the different band layout and spectral coverage of the two multispectral spaceborne sensors, illustrated in Figure 2. The differences in the spatial pattern of the IFD in the main mineralized zone can be also explained by the differences in the band layout of the three sensors. Sentinel-2 and ALI are better equipped to map the 900 nm iron absorption feature, because of the number, position and bandwidth of their red, near-infrared and shortwave infrared 1 channels in comparison to Landsat-8 OLI.

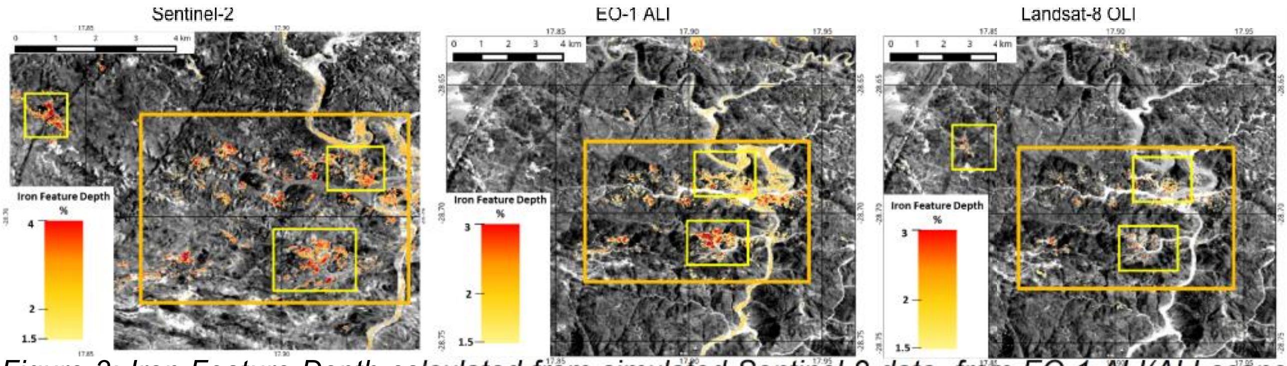

Figure 3: Iron Feature Depth calculated from simulated Sentinel-2 data, from EO-1 ALI(ALI scene IDs: EO1A1760802013267110K,EO1A1760802014013110PF) and from Landsat-8 OLI, (OLI scene ID: LC81760802014026LGN00) overlain over the Landsat-8 OLI near-infrared channel. Yellow boxes outline the occurrences of gossans, whilst the orange box outlines the main mineralized zone of the deposit.

Hyperspectral spaceborne data from EO-1 Hyperion and from simulated EnMAP data complements the analysis from the multispectral spaceborne sensors by showing the spatial distribution of minerals that highlight zone of alteration mineralogy. These zones are outlined by yellow and blue boxes in Figure 4, where typical alteration minerals such as alunite, kaolinite and montmorillonite have been detected via the USGS MICA analysis [15]. The spatial co-occurrence between the clay mineral anomaly in the blue boxes and the westernmost IFD area suggests a mineralogical exploration anomaly that needs to be evaluated by further exploration work in the field.

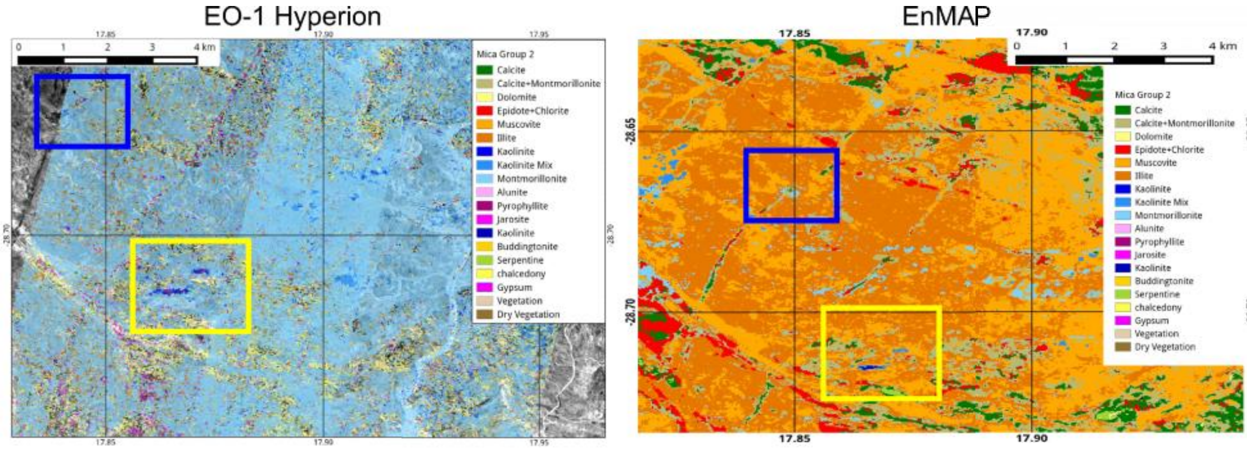

Figure 4: USGS MICA group 2 analysis results highlighting alteration zones within the Haib River Complex (yellow boxes). Analysis were carried out on EO-1 Hyperion data (Hyperion scene IDs: EO1H1760802013267110K,EO1H1760802014013110PF). Please note that the clay mineral occurrence in the Hyperion data and in the simulated EnMAP data (blue boxes)spatially coincides with the IFD anomaly in Figure 3 on the Sentinel-2 and OLI data on the westernmost dike structure.

CONCLUSIONS

This study showed that a combined, complementary use of multi- and hyperspectral spaceborne data yields high potential for mineral exploration. The spatial occurrence of gossans can be mapped from multispectral spaceborne data using the IFD [13] as shown in Figure 3. Hyperspectral spaceborne data is then able to further highlight zones of alteration mineralogy, if analyzed with expert systems, such as the USGS MICA [15]. This combination of potential gossan anomalies and alteration mineralogy then yields important target zones for further exploration work, which may include high spatial resolution hyperspectral airborne data takes and zones for further field investigation. This can then help to locate the zones of potential sulfide oxidation (zones of high secondary iron mineral abundance and hence zones with a strong positive IFD) and supergene copper enrichment [14]. Figure 3 also shows that next generation multispectral spaceborne sensors such as ESA's Sentinel-2 show a more detailed picture of potential gossan anomalies than state of the art sensors such as Landsat-8 OLI, due to their band layout and higher spectral resolution in the near-infrared. The differences in the MICA analysis between the simulated EnMAP data and Hyperion are due to the generally lower, unfavorable signal-to-noise ratio of Hyperion if compared to the high signal-to-noise ratio of EnMAP. However both sensors show the two elliptical alteration mineral anomalies outlined in the yellow boxes of Figure 4. This shows that a combination of next generation multispectral sensors, such as the Sentinel-2 for gossan detection via the IFD and next generation hyperspectral sensors, such as EnMAP for identification of alteration mineralogy and mapping will likely reduce costs in future exploration campaigns by further focusing expensive airborne hyperspectral campaigns and field work on potential target areas that have been highlighted and interpreted as mineralogical exploration anomalies of interest.

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