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Evaluation of EnMAP hyperspectral satellite data for epithermal alteration mapping at Cuprite-Goldfield, southwestern Nevada, USA

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Abstract

The Environmental Mapping and Analysis Program (EnMAP) is a German hyperspectral satellite mission launched into orbit on April 1, 2022. The EnMAP records 246 hyperspectral channels in the 0.42-2.45 μm wavelength range, with a spatial resolution of 30 m. This wavelength range is useful for environmental and geological mapping. This study evaluates the application of the EnMAP data to the mapping of epithermal alteration systems at Cuprite and Goldfield in southwestern Nevada, USA. The Cuprite has served since 1980s as a test site of the U.S. National Aeronautics and Space Administration (NASA) for the evaluation of airborne and satellite remote sensing sensors. The surface reflectance Cuprite-Goldfield EnMAP scene analyzed in this study was recorded on April 9, 2023. The EnMAP data were analyzed using the spectral mixture analysis technique. The results obtained from the EnMAP moderate spatial resolution satellite hyperspectral data show accurate detection of the alteration zones in the Cuprite-Goldfield study area. The study indicates the potential of the EnMAP data for various geological and environmental applications.

Keywords: EnMAP, spaceborne, hyperspectral, mineral, Goldfield, Cuprite.

Avaliação de dados de satélite hiperespectral EnMAP para mapeamento de alterações epitérmicas em Cuprite-Goldfield, sudoeste de Nevada, EUA

RESUMO

O Programa de Mapeamento e Análise Ambiental (EnMAP) é uma missão de satélite hiperespectral alemã lançada em órbita em 1º de abril de 2022. O EnMAP registra 246 canais hiperespectrais na faixa de comprimento de onda de 0,42-2,45 μm, com resolução espacial de 30 m. Esta faixa de comprimento de onda é útil para mapeamento ambiental e geológico. Este estudo avalia a aplicação dos dados EnMAP ao mapeamento de sistemas de alteração epitérmica em Cuprite e Goldfield, no sudoeste de Nevada, EUA. O Cuprite serve desde 1980 como local de teste da Administração Nacional de Aeronáutica e Espaço (NASA) dos EUA para a avaliação de sensores de sensoriamento remoto aéreos e de satélite. A cena EnMAP de refletância de superfície Cuprite-Goldfield analisada neste estudo foi registrada em 9 de abril de 2023. Os dados EnMAP foram analisados usando a técnica de análise de mistura espectral. Os resultados obtidos a partir dos dados hiperespectrais do satélite EnMAP de resolução espacial moderada mostram uma detecção precisa das zonas de alteração na área de estudo Cuprite-Goldfield. O estudo indica o potencial dos dados EnMAP para diversas aplicações geológicas e ambientais.

Palavras-chave: EnMAP, espacial, hiperespectral, mineral, Goldfield, Cuprite.

1 Introduction

The Environmental Mapping and Analysis Program (EnMAP) is a German hyperspectral satellite mission that monitors and characterizes Earth's environment on a global scale (www.enmap.org). The EnMAP was launched into orbit on April 1, 2022. The EnMAP consists of visible and near infrared (VNIR, 0.42-1.0 µm) and short-wave infrared (SWIR, 0.9-2.45 µm) sensors that record 246 hyperspectral channels. The VNIR and SWIR sensors have spectral sampling intervals of about 6.5 nm and 10 nm, respectively. The spatial resolution of the EnMAP hyperspectral data is 30 m. The swath is 30 km with a field of view of 2.63° across track. The signal-to-noise ratio is reported to be approximately 400:1 in the VNIR and 170:1 in the SWIR (www.enmap.org).

The epithermal hydrothermal systems are associated with characteristic mineral alteration (e.g., Pirajno, 2009; Hedenquist and Arribas, 2022). A number of alteration minerals display distinct spectral features in the 0.4-2.5 µm wavelength region (Figure 1; Clark, 1999), that allows detection and mapping of these minerals from airborne and spaceborne hyperspectral imagery (Kruse, 2012). The use of airborne hyperspectral imagery to investigate epithermal alteration is reported in many studies (Bedini, 2017; van der Meer et al., 2012). Several studies have also evaluated the potential of satellite hyperspectral data for detection and mapping of hydrothermal alteration systems. Kruse and Boardman (2003) applied the NASA's Hyperion EO-1 hyperspectral imagery to the mapping of epithermal alteration systems. Pour et al. (2014) used the Hyperion EO-1 to prospect for gold in the Bau gold field, Sarawak, Malaysia. Bedini and Chen (2022) used satellite hyperspectral imagery acquired by the PRISMA satellite of the Italian Space Agency (ASI) to the investigation of hydrothermal alteration that occurs at Kap Simpson, in eastern Greenland.

This study applies EnMAP hyperspectral remote sensing imagery to characterize the hydrothermal alteration at Cuprite-Goldfield area in southwestern Nevada, USA. A color composite of the EnMAP scene over the Cuprite-Goldfield study area is shown in Figure 2. In the study area occur extensive epithermal alteration of the quartz-alunite type (Ashley, 1974; Ashley and Abrams, 1980). This type of alteration is considered prospective for gold mineralization (e.g., Pirajno 2009; Hedenquist and Arribas, 2022). Gold has been mined at Goldfield, but no gold deposits have yet been found at Cuprite. This study has potential to evaluate the application of the EnMAP imagery for the localization and mapping of the mineral alteration assemblages and for geological applications in general. The results could also be useful to environmental studies employing EnMAP satellite hyperspectral imagery.

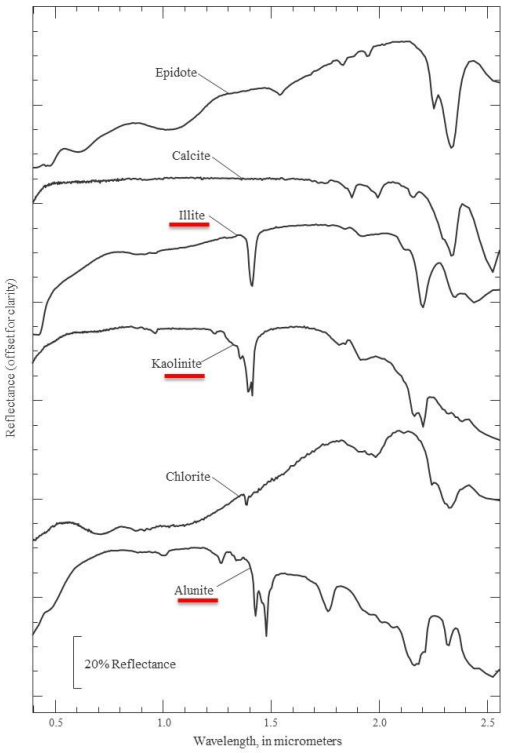

Figure 1. Reflectance spectra of several minerals, which are common in hydrothermal alteration systems (modified from Mars and Rowan, 2006). The red bars underline the alteration minerals targeted in this study to depict the alteration zones by the analysis of the EnMAP Cuprite-Goldfield image.

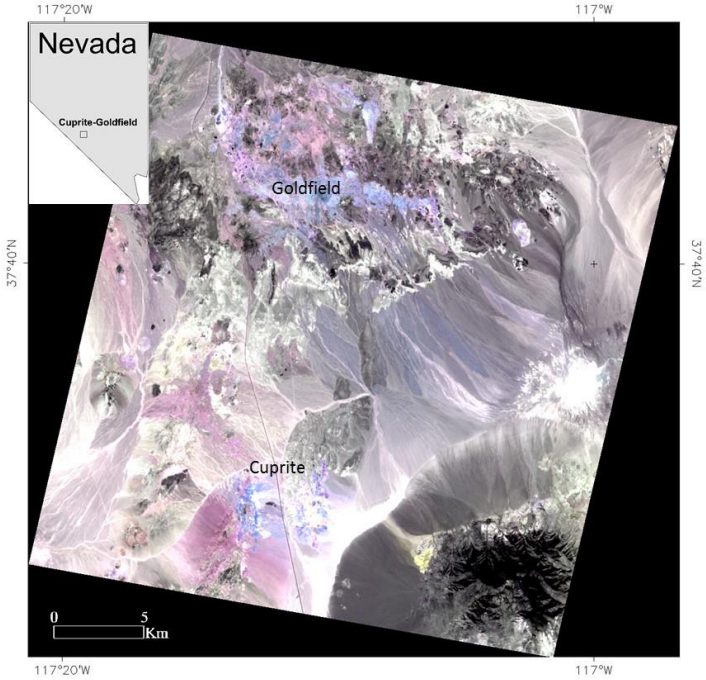

Figure 2. Color composite of the EnMAP hyperspectral image of the Cuprite-Goldfield area in southwestern Nevada, USA. EnMAP channels recording at 2.165 µm = red, 2.207 µm = green, 2.265 µm = blue.

2. Methods

The study area is located in southwestern Nevada. In the study area occur two major epithermal alteration centers, Cuprite and Goldfield (Figure 1). Cuprite has been used as a test site by NASA and other U.S. institutions to evaluate airborne and spaceborne remote sensing data (e.g., Swayze et al., 2014). Below it is given a brief description of the geology and hydrothermal alteration characteristics at Cuprite and Goldfield.

Well-exposed hydrothermal alteration zones occur at Cuprite (Ashley and Abrams, 1980) on both sides of U.S. Highway 95. Swayze et al. (2014) provide a comprehensive overview of the geology and epithermal alteration at Cuprite. To the west of Highway 95, the altered rocks consist of Cambrian meta-sedimentary formations, Tertiary conglomerates, and alkaline intrusive rocks comprising quartz latites and syeno-monzonites. On the eastern side of Highway 95, the altered rocks primarily consist of Tertiary rhyolitic ashflow, conglomerates, and basalt (Swayze et al., 2014). Ashley and Abrams (1980) distinguished various altered rock units, including silicified, opalized, and argillized formations. The highest degree of alteration is observed in the silicified rocks, characterized by the presence of quartz, chalcedony, and minor amounts of alunite and kaolinite. The opalized alteration zone contains opal along with varying quantities of alunite and kaolinite. Additionally, the argillized areas, located within the opalized rock units or at the periphery of the altered regions, contain minerals such as kaolinite, illite, and opal (Ashley and Abrams, 1980).

The Goldfield epithermal gold deposits are situated within a volcanic caldera, as detailed by Ashley (1974). The volcanic rocks at Goldfield are of the late Oligocene and early Miocene. They consist of andesites, rhyolite flows and tuffs, rhyodacites, and quartz latites (Ashley, 1974). The Goldfield contains a typical quartz-alunite type epithermal gold deposit. The Goldfield area has extensive hydrothermal alteration visible on the surface. The gold mineralization occurs within silicified zones, specifically within the advanced argillic alteration zone, at multiple locations along the west and north sides of a hypothesized ring-fracture system (Ashley, 1974). Key minerals within the epithermal alteration assemblage at Goldfield, displaying distinctive spectral features in the visible to shortwave infrared range, include alunite, kaolinite, illite, and iron hydroxides (e.g., Kruse, 2012).

The Cuprite-Goldfield EnMAP scene analyzed in this study was recorded on April 9, 2023. The EnMAP data were received by the German Airspace Center (DLR) in L2A that corresponds to georeferenced and atmospherically corrected hyperspectral imagery. The EnMAP data were analyzed using the spectral mixture analysis technique. The endmembers were collected from the image using the ‘‘hourglass” procedure (Kruse et al. 2003; Kruse et al., 2006; Boardman and Kruse, 2011). This processing scheme is based on convex and affine geometry to select the purest pixel spectra in an image by using the Pixel Purity Index (PPI) method (e.g., Boardman et al., 1995). The ‘‘hourglass” processing scheme consists of noise suppression and dimensionality reduction using the Minimum Noise Fraction (MNF) transformation, determination of endmembers using the Pixel Purity Index method (Boardman et al., 1995), extraction of the reference spectra using n-dimensional scatter plotting, identification of the reference spectra using spectral library comparisons. The image-derived reference spectra were used as input to the spectral mixture analysis algorithm.

The minerals alunite, kaolinite, and illite were considered useful to depict the epithermal systems in the study area. The sulphate mineral alunite has Al-OH absorption features that allow its detection and mapping from close-range spectroscopy, airborne and spaceborne imaging spectrometry data (Figure 1; Bishop and Murad, 2005). The presence of alunite is indicative of the advanced argillic alteration zone in the epithermal alteration systems (e.g., Pirajno 2009). The reflectance spectrum of the clay mineral kaolinite also displays Al-OH absorption features

at around 2.16–2.2 μm (Figure 1). Kaolinite is characteristic for the argillic alteration zone of epithermal gold deposits (e.g., Pirajno, 2009).

3. Results and discussion

The results of the EnMAP image analysis for the main alteration minerals are shown in Figure 3. The EnMAP data produced an accurate map of the alteration zones in the Cuprite-Goldfield study area. This alteration map is based on the detection of the key alteration minerals alunite, kaolinite and illite. EnMAP distinguished large areas of alunite that is characteristic for the quartz-alunite type epithermal alteration that occurs in the Cuprite-Goldfield study area. The outer parts of the alteration zones of the epithermal systems are usually dominated from the spectral response of illite or muscovite.

Alunite is associated with kaolinite zones in the alteration centers at Cuprite and Goldfield. Illite is widespread in the area also due to surface weathering of the lithological units. In addition to the Cuprite and Goldfield, another alteration center is detected in the northwestern edge of the EnMAP image. The alteration patterns detected by the EnMAP data analysis are very well correlated with the alteration maps of the Cuprite and Goldfield. The reader is referred to the schematic alteration maps produced by Ashley and Abrams (1980) and Ashley (1974).

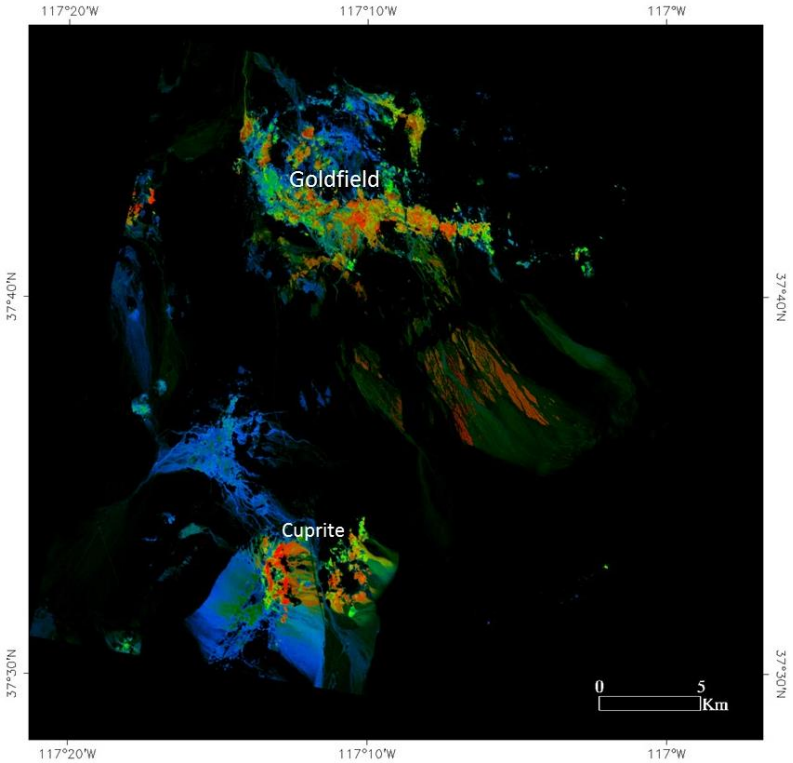

Figure 3. Color composite of the fractions for alunite (red), kaolinite (green), and illite (blue) produced from the analysis of EnMAP Cuprite-Goldfield image.

At Cuprite it is also characteristic the presence of a zone noted from the spectral response of the NH_4-feldspar mineral buddingtonite (e.g., Swayze et al., 2014). Buddingtonite can be formed by the alteration of primary feldspar when hydrothermal fluids incorporate ammonium from buried plant matter (Hallam and Eugster, 1976). This zone was first discovered by airborne imaging spectrometry (Goetz and Srivastava, 1985). The buddingtonite has N-H absorption at

around 2.12 μm (Figure 4; Swayze et al., 2014). Bedini and Chen (2020) detected buddingtonite at Cuprite using PRISMA satellite hyperspectral data. The spectral features of buddingtonite do also occur in the EnMAP pixel spectra, allowing the detection of the areas where this particular NH_4-feldspar mineral occurs (Figure 5). Accurate detection of the occurrence of a particular mineral such as buddingtonite from spaceborne hyperspectral imagery using the PRISMA data (Bedini and Chen, 2020) and EnMAP data shows a major advancement in the satellite hyperspectral imaging technology in terms of the signal-to-noise ratio.

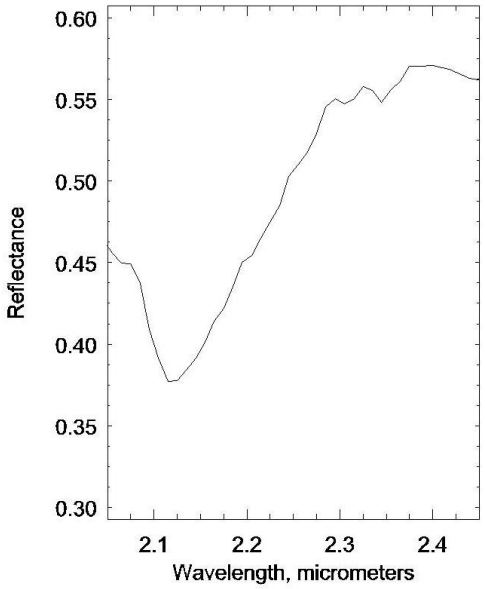

Figure 4. Reflectance spectrum of the ammonium feldspar buddingtonite from the USGS spectral library (Clark, 1999). Note the characteristic N-H absorption at around 2.12 μm.

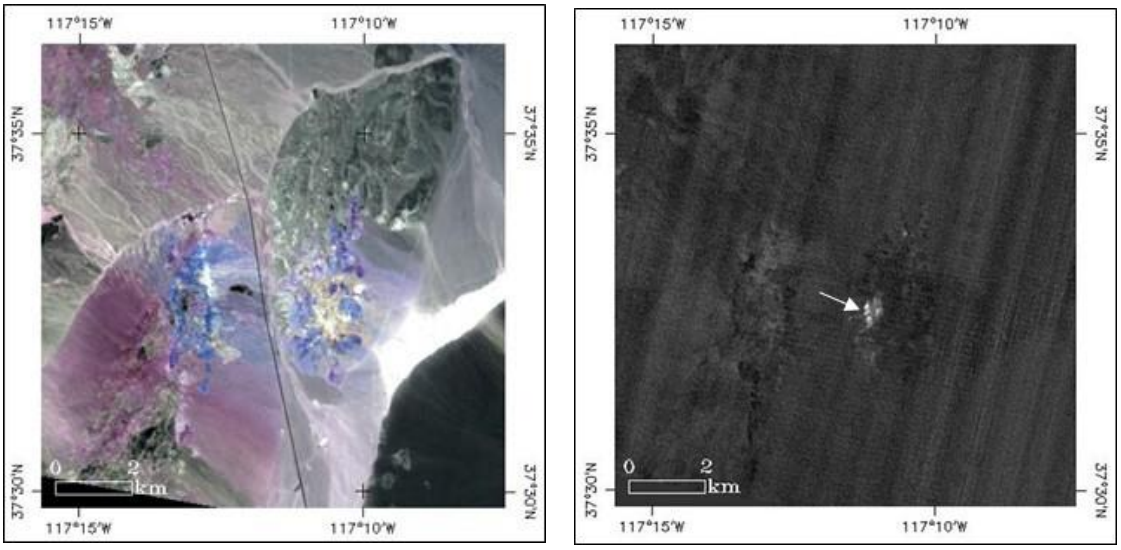

Figure 5. (a) subset of the EnMAP image at the Cuprite area. (b) detection of buddingtonite zones at Cuprite from the EnMAP image analysis. The buddingtonite zone indicated by the white arrow. A detailed discussion on the occurrence and location of buddingtonite at Cuprite can be found in Swayze et al. (2014).

4. Conclusions

This study evaluated the application of the EnMAP hyperspectral imagery to the detection and mapping of epithermal alteration zones at Cuprite and Goldfield in southwestern Nevada. Cuprite exhibits well-exposed epithermal alteration zones. However, no gold deposits have yet been found. Goldfield is characterized by extensive hydrothermal alteration within a volcanic caldera, with significant silicified zones that host gold mineralization. Especially Cuprite has been subject to extensive geological investigations. Cuprite has been utilized as a test site for remote sensing data evaluation. The EnMAP accurately detected the hydrothermal alteration systems. The mapping results produced form the EnMAP image analysis compare well with schematic alteration maps available for the Cuprite and Goldfield (Ashley and Abrams, 1980; Ashley, 1974).

The EnMAP data open new possibilities for various applications in geological and environmental studies. The moderate spatial resolution will limit its application for detailed investigations. In a typical remote sensing exploration program, the alteration zones detected by the moderate 30 m spatial resolution satellite hyperspectral data, will be followed by analysis of airborne hyperspectral data with higher spatial resolution (Bedini 2017; van der Meer et al., 2012) and field mapping. There are plans for other satellite hyperspectral missions from NASA and the European Space Agency (ESA), in both cases with moderate spatial resolution, and in the same wavelength range as EnMAP and PRISMA. An important development for the spaceborne hyperspectral imaging technology would be the increase of the spatial resolution to 5-10 m, without deteriorating the signal-to-noise ratio of the data, and maintaining an image swath of at least 30 km. In addition, the availability of thermal infrared satellite multispectral or hyperspectral data of at least 30 m nominal spatial resolution will be very contributive to geological and environmental applications.

5 Acknowledgment

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6 References

Ashley, R.P. and Abrams, M.J., 1980. Alteration mapping using multispectral images, Cuprite mining district, Esmeralda County, Nevada: U.S. Geological Survey Open File Report 80-367, 17 p.

Ashley, R. P. (1974). Goldfield mining district. Nevada Bureau of Mines and Geology Report, 19, 49-66.

Bedini, E. and Chen, J., 2022. Prospection for economic mineralization using PRISMA satellite hyperspectral remote sensing imagery: an example from central East Greenland. Journal of Hyperspectral Remote Sensing 12(3), pp.124-130.

Bedini, E. and Chen, J., 2020. Application of PRISMA satellite hyperspectral imagery to mineral alteration mapping at Cuprite, Nevada, USA. Journal of Hyperspectral Remote Sensing 10(2), 87-94.

Bedini, E., 2017. The use of hyperspectral remote sensing for mineral exploration: A review. Journal of Hyperspectral Remote Sensing, 7(4), 189-211.

Bishop, J.L. and Murad, E., 2005. The visible and infrared spectral properties of jarosite and alunite. American Mineralogist 90, 1100–1107.

Boardman, J.W. and Kruse, F.A., 2011. Analysis of imaging spectrometer data using N-dimensional geometry and a mixture-tuned matched filtering approach. IEEE Trans. Geosci. Remote Sens. 49, 4138–4152.

Boardman, J.W., Kruse F.A., Green R.O., 1995. Mapping target signatures via partial unmixing of AVIRIS data, in Summaries, Fifth JPL Airborne Earth Science Workshop, Jet Propulsion Laboratory Publ. 95-1, 1, 23-26.

Clark, R.N. Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy, in: A. Rencz (Ed.), Manual of Remote Sensing vol. 3. Wiley and Sons Inc., New York, pp. 3-58, 1999.

Goetz, A.F.H. and Srivastava V., 1985. Mineralogical mapping in the Cuprite mining district, Nevada. Proceedings of the Airborne Imaging Spectrometer Data Analysis Workshop. JPL Publication, Pasadena.

Hallam, M., and Eugster, H.P., 1976. Ammonium silicate stability relations. Contributions to Mineral Petrology 57, 227–244.

Hedenquist, J.W. and Arribas, A., 2022. Exploration Implications of Multiple Formation Environments of Advanced Argillic Minerals. Economic Geology, 117, 609-643.

Kruse, F.A., 2012. Mapping surface mineralogy using imaging spectrometry. Geomorphology, 137, 41-56.

Kruse, F.A., Perry, S.L., Caballero, A., 2006. District-level mineral survey using airborne hyperspectral data, Los Menucos, Argentina. Annals of Geophysics 49, 83–92.

Kruse, F.A, Boardman, J.W., Huntington, J.F., 2003. Comparison of airborne hyperspectral data and EO-1 Hyperion for mineral mapping. IEEE Transactions on Geoscience and Remote Sensing 41, 1388–1400.

Mars, J.C. and Rowan, L.C., 2006. Regional mapping of phyllic-and argillic-altered rocks in the Zagros magmatic arc, Iran, using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data and logical operator algorithms. Geosphere, 2(3), pp.161-186.

Pirajno, F., 2009. Hydrothermal Processes and Mineral Systems. Springer/Geological Survey of Western Australia, Dordrecht.

Pour, A.B., Hashim, M., Marghany, M., 2014. Exploration of gold mineralization in a tropical region using Earth Observing-1 (EO1) and JERS-1 SAR data: a case study from Bau gold field, Sarawak, Malaysia. Arabian Journal of Geosciences, 7, pp. 2393-2406.

Swayze, G.A., Clark, R.N., Goetz, A.F.H., Livo, K.E., Breit, G.N., Kruse, F.A., Sutley, S.J., Snee, L.W., Lowers, H.A., Post, J.L., 2014. Mapping Advanced Argillic Alteration at Cuprite, Nevada, Using Imaging Spectroscopy. Economic Geology 109, 1179-1221.

van der Meer, F.D., van der Werff, H.M., van Ruitenbeek, F.J., Hecker, C.A., Bakker, W.H., Noomen, M.F., van Der Meijde, M., Carranza, E.J.M., De Smeth, J.B., Woldai, T., 2012. Multi-and hyperspectral geologic remote sensing: A review. International Journal of Applied Earth Observation and Geoinformation, 14, 112-128.