Alunite Characterization with Ultra-High Resolution SWIR

Lori Shelton Pieniazek
Spectral Evolution
lori.shelton@spectralevolution.com

SUMMARY

Alunite characteristics and composition are used as a good indicator of gold potential in an epithermal system. Alunite precipitates from fluid that is very acidic and oxidized in hypogene acidic epithermal systems and supergene environments. When Alunite occurs as an alteration of some other mineral, it is difficult to identify and distinguish by eye due to the crystals occurring at sizes too small to see, even with a hand lens. A clue to hypogene alunite is the association with pyrophyllite and occurrence with high temperature kaolinite. Pyrophyllite that occurs with alunite is very difficult to identify by eye as it almost never forms crystals big enough to visually see.

Field portable spectrometers have been widely used around the world to focus on the spectral shift in the composition of alunite from potassium rich (K-alunite) to sodium-rich (Na-alunite) to vector the mineralization. In recent years, spectral resolution of these instruments has increased due to demand by correlating data sets from other remote sensing technologies like hyperspectral imaging. This study focuses on the evolution of spectral resolution using ultra-high resolution to characterize K-alunite from Na-alunite and its association with pyrophyllite and high temperature kaolinite by identifying additional features not seen with lower resolution spectrometers, an application that could prove to be useful in the future for better understanding of mineralized zones.

Key words: visible near-infrared-shortwave-infrared spectroscopy, Vis-NIR-SWIR spectroscopy, hydrothermal alteration, epithermal gold deposits, mineral exploration

INTRODUCTION

In recent years, the mining industry has developed new techniques and procedures for data acquisition in the exploration phase of ore deposits. An important part of this new evolution throughout the mining industry is acquiring data on a higher quality control through remote sensing techniques. Airborne and hyperspectral surveys have produced newer technology with higher spectral resolution to give a better picture of mineral alterations leading ground truthing validation room for improvement and innovation. The use of short-wave infrared (SWIR) spectral techniques in the field is widely accepted as a general practice amongst mining companies, universities and research institutions around the world due to its instant data acquisition capabilities, lack of sample preparation needed and a well-studied return on investment in comparison on relying on other traditional mineral analysis techniques (e.g., Thompson et al., 1999,2009; Halley, 2010; Chang, 2012).

Spanning over a wide variety of mineral applications, access to a high spectral resolution field spectrometer is important as hyperspectral survey data continues to increase. It is well studied with standard spectral resolution (3nm - UV, 8nm – VIS, and 6nm- NIR) that important alteration minerals for mineralized zones show systematic changes in composition and peak height ratios due to changes in crystallinity (e.g..Hauff and Cocks,1992; Yang et al.,1998,2000, 2004, 2005, 2011). Fluid compositions and/or temperature assumptions can be made by the spectral features that occur throughout the full range (350-2500nm) that covers the ultraviolet, visible, and near-infrared regions. In the mining industry, SWIR is the accepted terminology to describe two parts of the near infrared regions sometimes mentioned as SWIR1 and SWIR2. This useful technology helps indicate directions toward fluid sources and/or potential sites of ore deposition which is well documented over the past few decades using standard resolution instruments such as the PIMA and TerraSpec (Hauff and Cocks, 1992). As hyperspectral survey technology inch closer to a 1.5nm resolution, the need for ultra-high resolution field spectrometers is increasing, although the applications haven't been full studied or understood yet.

An ultra-high resolution field spectrometer was introduced in 2017 with a spectral resolution of 1.5nm-UV,3.8nm-VIS and 3.0nm-NIR. This is nearly double the resolution obtained from instruments used in the past as standard protocol throughout the world. A field instrument with this capability truly allows the concept of being able to bring the lab

into the field. Current studies with ultra-high spectral resolution are starting to be published (Cardoso-Fernandes, 2021) but the need for more understanding on different types of deposits and mineral alterations will benefit the mining community. High temperature alteration minerals such as kaolinite and pyrophyllite show additional features throughout the full range spectrum that were not previously seen with standard resolution instruments. This led to the question of how this may positively affect the spectral shift in the composition of alunite from potassium rich (K-alunite) to sodium-rich (Na-alunite) to vector the mineralization by focusing on the 1480nm region and studying its subtle spectral shift towards 1495nm. In this study, the spectral resolution variation amongst 3 different devices on the same set of samples were investigated, focusing on the increase in spectral resolution for alunite, pyrophyllite and kaolinite mixture samples from different porphyry deposits in Peru and Philippines, Mongolia and a high sulfidation epithermal deposit in Indonesia.

SAMPLES

The samples used for this study were acquired from previous work published by Z.Chang,2012. These visually homogenous samples are from different deposits and prospects. Alunite samples used in the mentioned study mixed with kaolinite and pyrophyllite that have continuous 1480nm OH spectral absorption values ranging from 1480nm-1495nm. PR samples were chosen for comparison to ultra-high resolution and correlate to the Cocanes lithocap close to the Perol porphyry deposits in the Minas Conga district in Peru (Figure 7).

INSTRUMENTS

The instruments used in the previous study mentioned above (Z.Chang, 2012) are the PIMA and TerraSpec to obtain spectral measurements.. The main difference in these two instruments is that the PIMA covers 1300nm-2500nm whereas the TerraSpec is full range (350-2500nm) The evolution from these two instruments had convincing arguments as to why full range offers more information than that of the limited range of the PIMA. Most may recall the PIMA as it is one of the first field spectrometers used for mineral analysis, albeit not so portable. The newest innovation in spectral geology technology is the oreXpert ultra-high resolution spectrometer that boasts a 1.5nm spectral resolution in the UV up to a 3.0nm spectral resolution in the NIR and is one of the most portable units on the market.

MEASUREMENTS

Previous measurements were taken with the instruments mentioned above on the same set of samples in the same exact three spots (Z.Chang, 2012). The same argument of increased spectral resolution can be also made with the style of measurements. Data taken with the oreXpert ultra-high resolution spectrometer were acquired with a mini probe that has a 3mm field of view and a white reference quick clip accessory, allowing for better measurement control and less risk of spectral unmixing for some applications. The measurement time with the oreXpert can be set by users, mostly depending on the darkness of the sample. The measurement time of all sample sets was used at the default setting of 3 seconds - as technology has increased over the years, so has measurement time. A fresh white reference measurement was taken as new samples were introduced.

SPECTRAL DATA

To understand the implications of what ultra-high resolution does for important mineral alterations, there is still work to be done on what characteristics cause the additional features that are not seen with standard spectral resolution. In the case of alunite, as K-Alunite spectrally shifts from 1480nm closer to 1495nm into Na-Alunite, an additional shoulder (~1430-1445nm) appears as it inches towards the longer wavelengths (Figure 1). In the case of Kaolinite, there are two areas where ultra-high resolution affects the data. The strong absorption features at 1396nm and 1413nm now include an additional feature at 1405nm making that feature a triplet, instead of the very well understood doublet with standard resolution due to the OH stretch overtone. Features seen at 2166nm and 2209nm are now shared with an additional feature at 2193nm, due to the Al-OH bond plus OH stretch combinations (Figure 2), potentially being an important factor when studying temperature and alterations of Kaolinite. Pyrophyllite shows additional features with ultra-high resolution throughout the full range (350-2500nm). There are three additional strong OH absorption bands in the 1400nm region that cannot be seen with standard resolution. Ultra-high resolution allows for the 1346nm, 1404nm, and 1414nm OH overtone features to be seen. Additionally, the main Al-OH band at 2198nm benefits from ultra-high resolution with the introduction of a doublet at 2208nm. Finally, secondary OH

absorption bands close to 950nm and 1230nm are now introduced as doublets and triplets like the new features seen for the secondary Al-OH bands at 2090nm and 2320nm (Figure 3), potentially being a useful indicator for vectoring.

The mixed samples from the previous study done by Z. Chang,2012 also show similar trends with an increase in spectral resolution. The Pyrophyllite-Alunite mixture samples (PR08-66) have an alunite spectral shift position of 1492nm indicating Na-Alunite and the typical pyrophyllite peak at 1389nm. Figure 4 shows the evolution of how spectral resolution can impact the basic spectral data that we observe starting from the PIMA data, increased to the TerraSpec data and finally the new ultra high resolution oreXpert data. The conclusions of the additional shoulder at ~1430nm are apparent in the Na-Alunite as well as the sharp increase in the pyrophyllite peak at 1392nm with the additional 1414nm feature from the increased resolution in the pyrophyllite. To test how efficient the spectral resolution increase would work with a triple mixture of alunite, kaolinite, and pyrophyllite – sample PR08-10 as measured and compared (Figure 5). The PIMA data seems to be very hard to un-mix all three minerals, as the resolution in the TerraSpec improved one can start to see the occurrence of all three minerals. The ultra-high resolution oreXpert shows in detail distinct features from all three minerals having absorptions in the same region. While this alunite is centred at 1483nm and is identified as the K-Alunite, features from Kaolinite and Pyrophyllite are apparent.
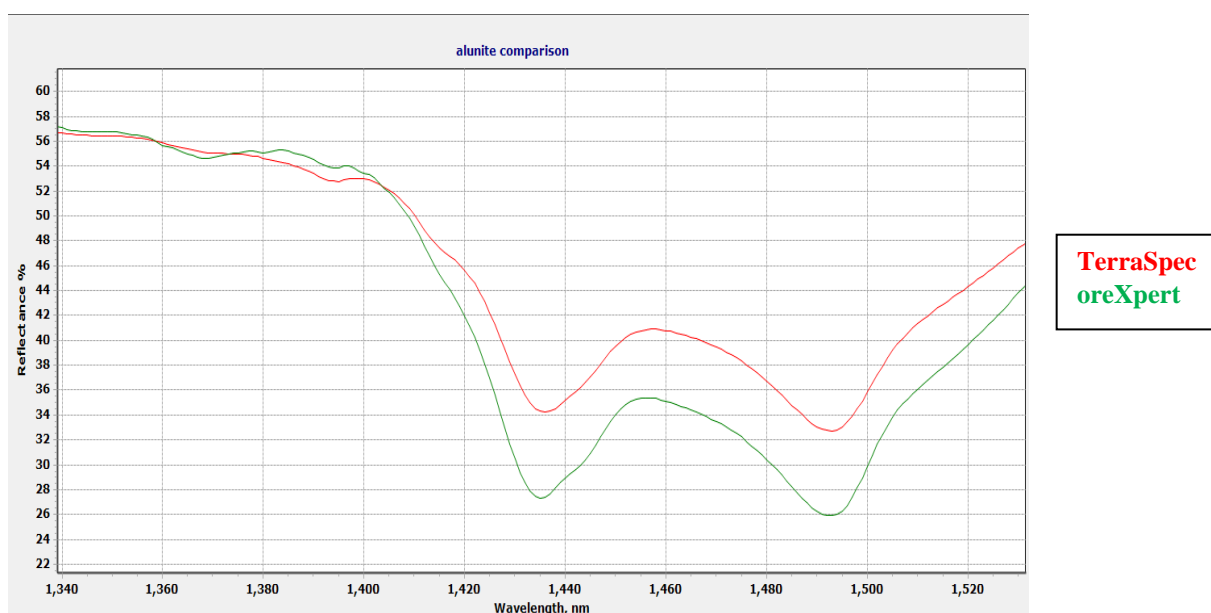

Figure 1. Plot of Alunite Spectra at 1400nm region: TerraSpec vs oreXpert ultra-high resolution data. The oreXpert shows an additional shoulder at ~1440nm.
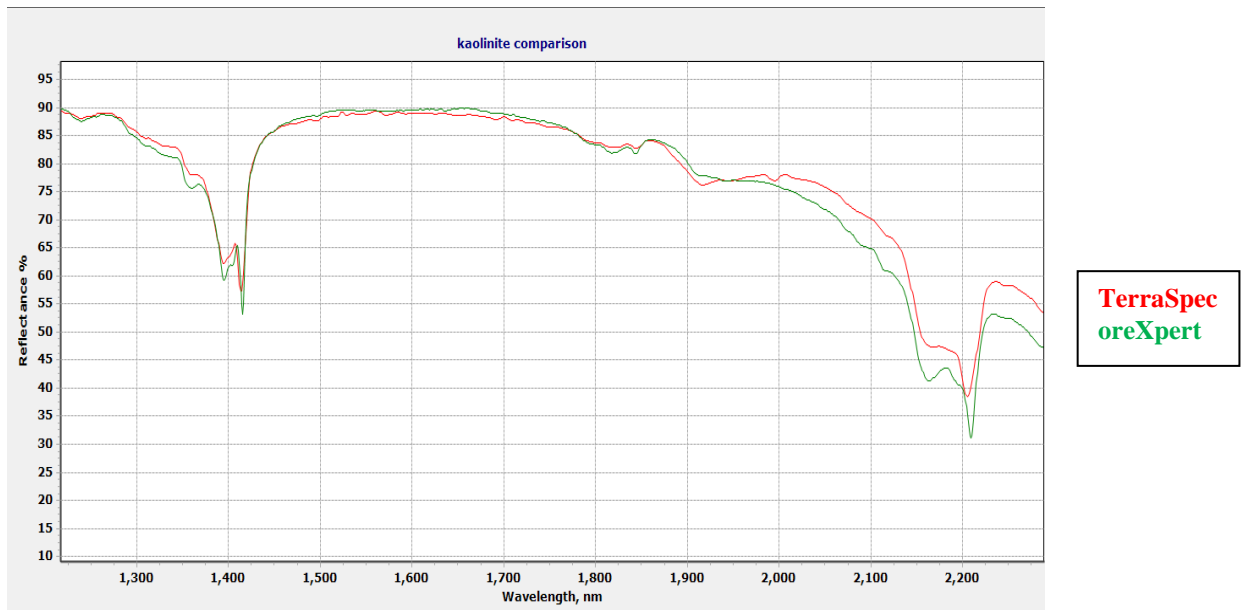
Figure 2. Plot of Kaolinite Spectra from 1400nm-2500nm regions: TerraSpec vs oreXpert ultra-high resolution data. oreXpert shows additional features in the 1400nm OH region and Al-OH 2200nm region.
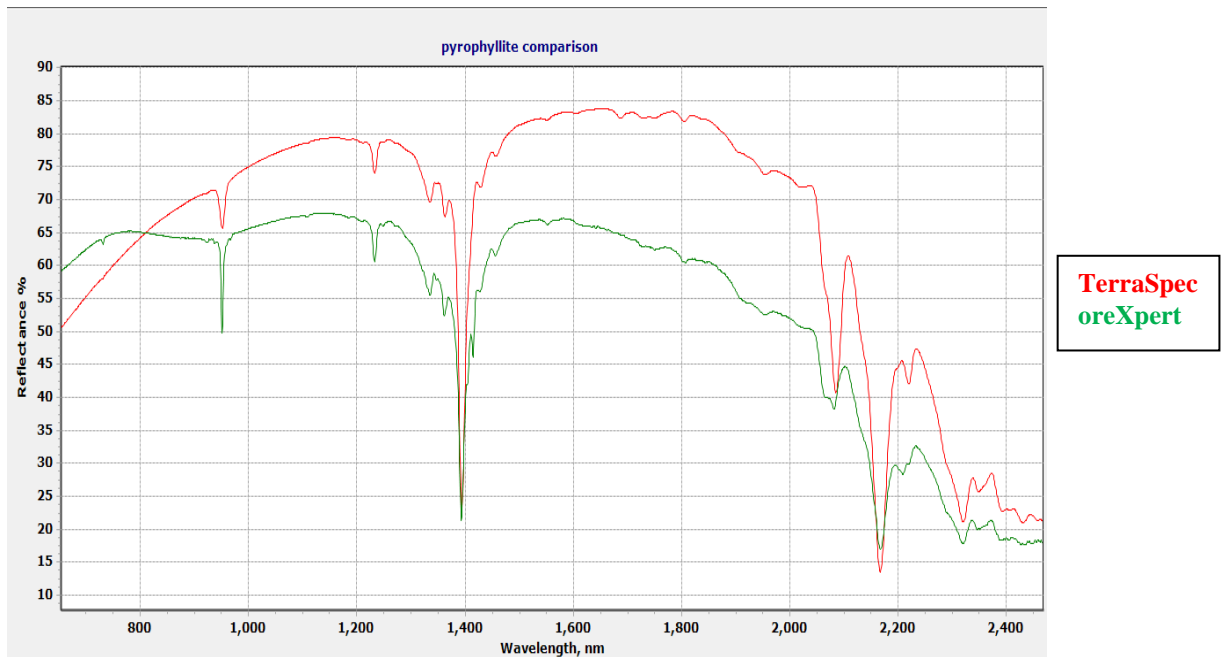

Figure 3. Plot of Pyrophyllite Spectra, full range 350-2500nm: TerraSpec vs oreXpert ultra-high resolution data. oreXpert shows additional features throughout the full range.
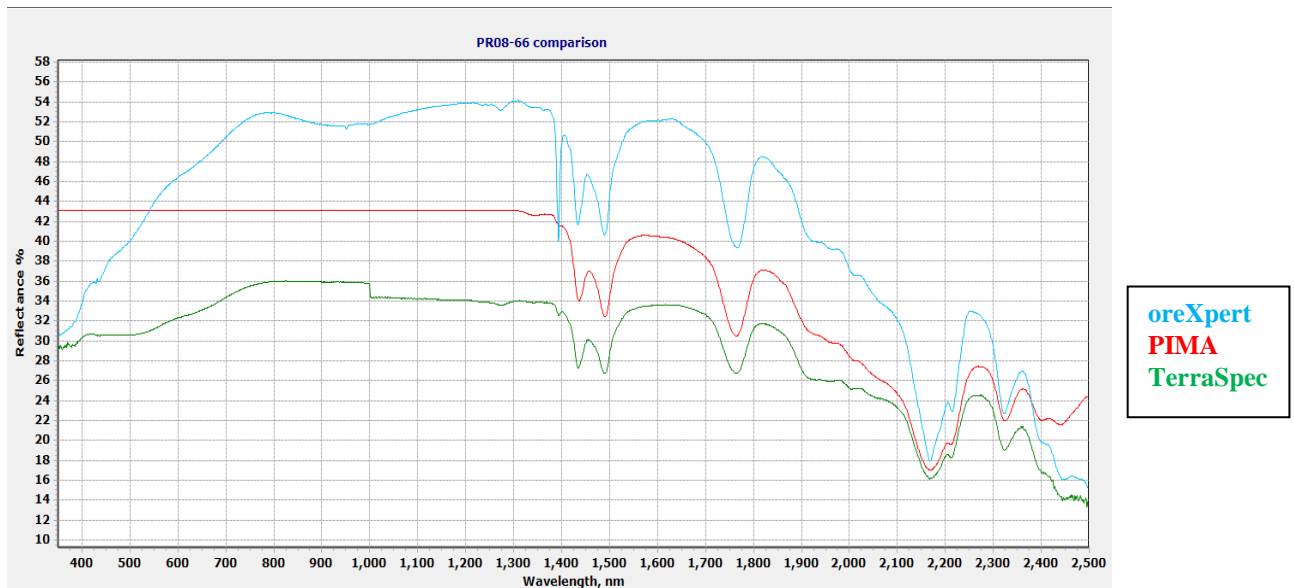
Figure 4. Plot of mixture sample PR08-66 with alunite and pyrophyllite: PIMA, TerraSpec and oreXpert ultra-high resolution data comparison. oreXpert ultra high resolution shows additional shoulder of Na-Alunite and additional pyrophyllite features throughout the spectrum.
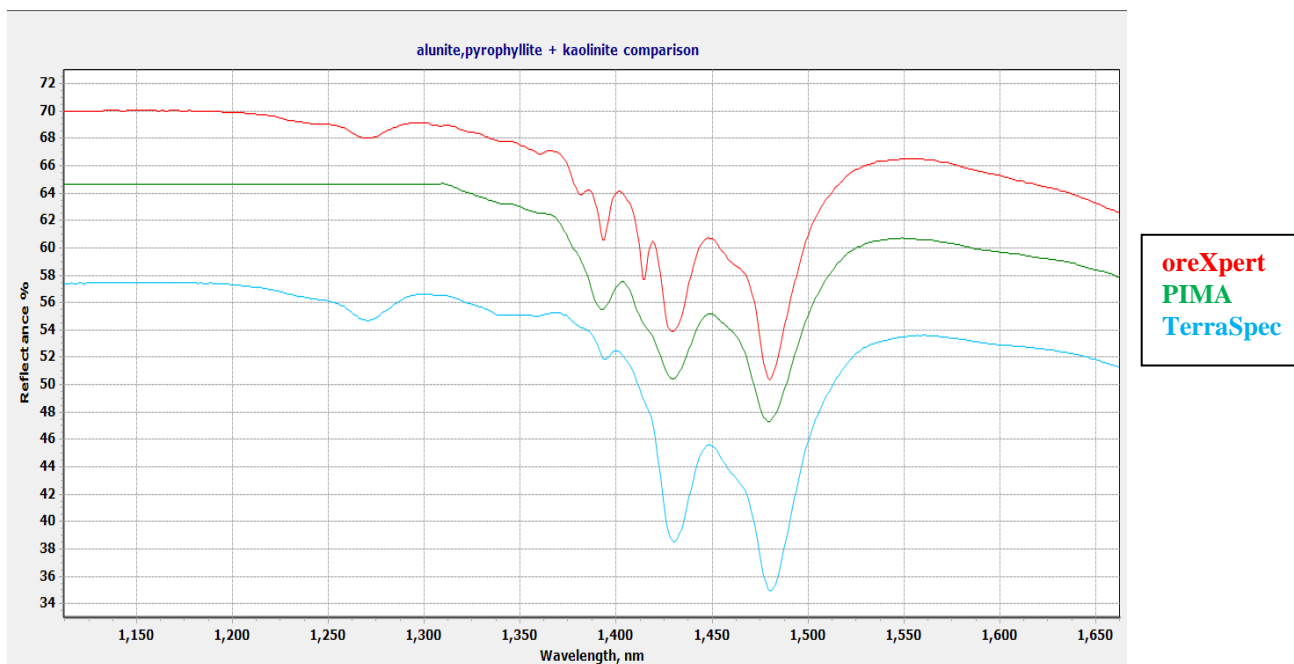

Figure 5. Plot of triple mixture sample PR08-10 including alunite, kaolinite, and pyrophyllite: PIMA, TerraSpec and oreXpert ultra-high resolution data comparison. oreXpert ultra high resolution shows typical K-Alunite position at 1483nm, increase in resolution leading to easily identifying kaolinite and pyrophyllite in the 1400nm region.

DISCUSSION

As we try and navigate the ever-changing advances in technology, understanding the relationship to ultra-high resolution and how it positively affects mineral vectoring is important. Over the past few decades, advances in spectral resolution for field spectrometers has increased and led to new developments and understanding of mineral systems and ore deposits. Hydrothermal and epithermal gold deposits remain a hot topic amongst spectral geologists and exploration companies looking to combine hyperspectral and ground truthing methods. As ultra-high spectral resolution is introduced into the mining community, more research is needed to correlate the advancements in additional spectral features to a better understanding of economic ore deposits.

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