Mineral mapping in the western Kunlun Mountains using Tiangong-1 hyperspectral imagery

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Abstract. The unmanned Chinese space module Tiangong-1 was launched in September 2011 with a hyperspectral sensor on board. The sensor combines high spatial and spectral resolution suitable for mineral mapping. In this study, Tiangong-1 hyperspectral data were employed for mineral mapping in the western Kunlun Mountains, an important metallogenic belt in China. A Spectral Hourglass Wizard method was applied to detect common minerals from the Tiangong-1 shortwave infrared data with reference to a set of spectral libraries. Spectral information on minerals, such as zoisite, mica, quartz, sodalite, dolomite, and actinolite, was extracted from the data. The resulting mineral interpretation maps were highly correlated with the reference geological maps and information from ASTER satellite imagery, suggesting that the hyperspectral data are suitable for mineral mapping.

1. Introduction

Data from spaceborne remote sensing systems have been applied for decades to geological prospecting and exploration along with requisite geologic and tectonic framework analyses. Airborne imaging spectrometry data and hyperspectral imagery (HSI) have been used by the geological community since the early 1980s, such that hyperspectral sensing has become a mature technology [1]. Riley and Hecker [2] used SEBASS to map unaltered and altered rocks in the Cuprite mining district of southwestern Nevada. Kruse et al. [1] compared the differences between airborne hyperspectral data and EO-1 Hyperion satellite data. Their mineral mapping results were based on the study of several sites with established ground truth and multi-year airborne hyperspectral data collection, demonstrating that HSI can effectively yield useful geological and mineralogical information.

The unmanned Chinese space module Tiangong-1 was launched in September of 2011, carrying an advanced hyperspectral imager on board. This imager is a new source of data for scientific research in China. It contains 65 visible-near infrared (VNIR) spectral bands ranging from 0.4 to 1.0μm, at approximately 10-nm spectral resolution, with 10-m spatial resolution, and 65 short-wave infrared (SWIR) spectral bands, ranging from 1 to 2.5μm at approximately 23-nm spectral resolution, and 20-m spatial resolution. This new imagery has the potential of providing adequate spectral bands and fine spatial resolutions for mineral mapping. This potential can be explored with conjuction with well-established imagers, such as the American ASTER sensor.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was launched aboard NASA’s Terra satellite in December 1999. ASTER contains three visible near infrared (0.4-1.0μm) spectral bands with 15-m spatial resolution, and six shortwave infrared (1.0-2.5μm) bands with
30-m spatial resolution and 5 thermal bands; the VNIR spectral region of the ASTER and Tiangong-1 data is especially useful for discriminating minerals exposed at gossans, such as goethite, hematite and jarosite [3]. The SWIR region, on the other hand, covers spectral features of hydroxyl-bearing minerals as well as C-O bearing minerals like phyllosilicate, sulfate, and carbonate, which are common in geological rock units and hydrothermal alteration assemblages [1, 4]. This spectral region provides diagnostic spectral features of many altered minerals such as biotite, sericite, illite, kaolinite, alunite, pyrophyllite, chlorite, calcite, epidote, and jarosite [5]. This study employed multispectral and hyperspectral remote sensing data and the VNIR and SWIR spectral features to identify general alteration zones, including propyllic and phyllic [5, 6].

2. Geology of study area
The 10 km by 15 km large study area is centered on coordinates 79°0'-79°30'E / 36°21'-36°42'N in the western Kunlun Mountains of Xinjiang Province, China. The Kunlun Mountains are known as the motherland of the mountains in China, traversing Xinjiang and Tibet and extending to Qinghai Province, with an average elevation of 5500 to 6000 meters. As an important metallogenic belt, the western Kunlun Mountains play a significant role in Chinese exploration. However, due to the high elevation, harsh weather, difficult access, and low population, it is challenging to carry out conventional geological exploration in this region. Hyperspectral remote sensing can be used as an alternative exploration technique to detect subtle spectral features of mineralization areas from space. The geology in the research area consists mainly of early Paleozoic ophiolitic mélange, Cambrian-Ordovician schist and quartz schist, Carboniferous carbonaceous slate and phyllite, and magma intrusive veins (figure 1).

3. Methodology
The 2.0-2.5μm SWIR spectral range covers the diagnostic spectral features of hydroxyl-bearing minerals, sulfates and carbonates that are common to many geologic units and hydrothermal alteration assemblages [1, 4]. Hence, the Tiangong-1 SWIR images were selected to map areas with high concentration of minerals. The Tiangong-1 hyperspectral data were acquired on July 13, 2012, as summer imagery have a higher signal-to-noise ratio (SNR) than the data collected in winter. The higher SNR of hyperspectral imagery facilitates extracting information of target minerals.

Using ENVI software, information extraction was carried out with the Spectral Hourglass Wizard (SHW) for hyperspectral data mineral mapping, as follows:

- Transform the HSI data from digital numbers (DNs) into apparent reflectance with atmospheric correction;
- Apply the Minimum Noise Fraction (MNF) transform to the data to reduce data dimension;
- Apply the Pixel Purity Index (PPI) method to locate pure pixels;
- Extract end-member spectrum;
- Use spectral matching methods, such as Binary Encoding, Spectral Angle Mapper, and Spectral Feature Fitting, to identify the end-member spectrum; and
- Compare the mineral mapping results obtained from HSI data with the corresponding geological map to evaluate the Tiangong-1 HSI data employed.

Remote sensing data acquisition is impacted by atmospheric effects of the radiated energy and its spectral distribution [7]. Atmospheric correction can effectively eliminate the radiation errors caused by atmospheric scattering and ground scattering [8]. Two atmospheric correction approaches provided in the ENVI software were used in this study, including FLAASH and quick atmospheric correction (QUAC). The FLAASH approach is based on the atmospheric correction model of MODTRAN and requires acquisition time, location, elevation, and an aerosol model for the atmospheric correction of the remote sensing data [9]. The QUAC approach automatically collects spectral information of objects from the imagery to gain experience for hyperspectral data and multispectral data for quick atmospheric correction. The FLAASH approach can effectively remove the impact of aerosol
scattering and vapor and calibrate the ‘proximity effect’ between target pixels and their neighbors based on pixel-level correction. The two approaches can reach similar correction accuracies. In this study, the QUAC method was selected. The green spectral curve and the red spectral curve in figure 2 show the spectral curves of snow from USGS spectral library and the Tiangong-1 data after atmospheric correction, respectively. The similarities between the two spectral curves indicate that atmospheric effects were removed by the QUAC approach and correct spectra of objects obtained.

4. Mineral mapping
Using the mineral mapping methods described above, the Tiangong-1 hyperspectral data were used to map the main altered and unaltered minerals in the research area, such as quartz, kaolinite, dolomite, mica, alunite, and sodalite. The end-member spectra were matched with the spectral library. Figure 3 shows a good match of the spectral curves from the Tiangong-1 hyperspectral data and the spectral library data for four minerals, including epidote, actinolite, quartz, and chlorite.

Nine main minerals were mapped from the Tiangong-1 hyperspectral imagery, including zoisite, mica, quartz, alunite, cummingtontie, sodalite, dolomite, anorthite, and actinolite (figure 4). In the dunite/pyrozenite intrusive zone, the main mapped minerals are zoisite, quartz, anorthite, actinolite and dolomite; in the doleritic veins, the mapped minerals include actinolite, anorthite, quartz, cummingtontie, and sodalite. The spatial distribution of the minerals tends to match the outcrops of the main rocks in the research area well.

![Figure 1](image.jpg)

**Figure 1.** Location of the study area (red outline) and corresponding geological map (insert), displayed against the background of ASTER imagery. (ASTER data courtesy of NASA)
A band ratio technique is used to effectively extract information on different minerals from remote sensing imagery by enhancing the spectral signature differences [4]. This technique is widely used to extract mineral and lithology information in the analysis of multispectral remote sensing data [3, 6]. ASTER is well-known source of remote sensing data among geologists for mapping minerals. In this study, the band ratio technique was applied to the ASTER data to extract several common alteration minerals. The resulting Al-OH, ferric and carbonate alteration distributions are shown in figure 5.
**Figure 4.** Mineral mapping results based on Tiangong-1 hyperspectral image analysis.

**Figure 5.** Alteration mapping results based on ASTER (left: Al-OH, center: ferric, right: carbonate).

**Figure 6.** Carbonate mapping results from Tiangong-1 (left) and ASTER data (right).
A comparison between the carbonate mineral mapping results of Tiangong-1 and ASTER data shows a fairly high degree of commonality. Since ASTER data have been proved successful in mapping minerals [3, 6, 10, 11], we assume that the mineral mapping results from Tiangong-1 hyperspectral imagery are relatively accurate. Furthermore, a comparison between the mineral mapping results from Tiangong-1 hyperspectral imagery (figure 4) and the mineral/lithological information in the geological map (figure 1), along with the alteration information from the ASTER data (figure 6), shows that the Spectral Hourglass Wizard software is suitable to map minerals using Tiangong-1 data. Tiangong-1 data are also useful for extracting the characteristic spectra of minerals and for identifying individual altered and un-altered minerals (figure 4).

5. Conclusion

In this study, spectra of nine main minerals represented in the research area are extracted from Tiangong-1 hyperspectral data, including zoisite, mica, quartz, alunite, cummingstonite, sodalite, dolomite, anorthite, and actinolite. The experimental mapping results indicate that the Tiangong-1 hyperspectral data can be used to accurately map the main minerals and offer useful mineral alteration information. Due to the lack of field mineral spectra, the mineral mapping results were not fully verified and mapping errors have not been effectively removed. Moreover, it is difficult to separate minerals of similar spectral composition, for instance, calcite and dolomite, by means of Tiangong-1 hyperspectral image analysis.

6. References

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