Alteration Hydrothermal Stage Division and its Application in Geological Prospecting Using CASI-SASI Airborne Hyperspectral Data: Taken the Baixianishan Area in Liuyuan Town of Gansu Province as an Example

Yu Sun*, Yingjun Zhao, Kai Qin, Feng Tian and Chengkai Pei
Beijing Research Institute of Uranium Geology, National Key Laboratory of Remote Sensing Information and Image Analysis Technology, Beijing 100029, China

*Corresponding author e-mail: sunyutectonics@163.com

Abstract. The division of the hydrothermal period based on alteration minerals extracted from airborne hyperspectral data has been rarely researched. This work processed CASI-SASI airborne hyperspectral data, and optimized reference spectra from image endmembers based on the expert knowledge in the Baixianishan area. The mixed tuned matched filtering method was utilized to map alteration minerals, and the distribution of limonite, short-wavelength sericite, middle-wavelength sericite and long-wavelength sericite was obtained. Distribution patterns of limonite and three sericite subclasses were analyzed, and three hydrothermal stages were divided. It is considered that the second hydrothermal activity is closely related to the gold deposit. It is proposed that prospecting factors of the Baixianishan gold deposit are NEE-trending fault structure, the vein-like distribution of limonite and short-wavelength sericite. Based on the discuss above, a favorable prospecting section is found in the south of the Xiaobaishan area. It is indicated that the CASI-SASI airborne hyperspectral data can quickly and accurately provide more effective remote sensing criteria at the regional scale for both basic geological survey and mineral resources exploration, which has a wide application prospect in the geological field.

1. Introduction
Hyperspectral remote sensing has became a research focus in recent years [1]. With the characteristics of "double-high", airborne hyperspectral remote sensing has technical advantages of both a high spectral resolution and a high spatial resolution. It can identify objects which cannot be distinguished in wide-band remote sensing, and also can accurately locate and obtain objects attributes such as longitude, latitude and area. So, it plays an important role in natural resources survey [2-4]. The predecessors have done lots of work on the extraction and application of alteration minerals using hyperspectral data [5-7], but studies on the classification of hydrothermal stage from altered minerals have been less reported. Thus, the further delving of geological intension of alteration minerals is affected. In this work, CASI-SASI airborne hyperspectral data were utilized to furtherly divide sericite minerals, and distribution patterns of the limonite and three subclasses of sericite were analyzed. The division of hydrothermal stages of alteration minerals was discussed, and a favorable prospecting section was newly discovered.
by applying the established gold ore prospecting factors, and the geological intension of CASI-SASI airborne hyperspectral data was tapped deeply.

2. Materials and methods

2.1. Geological setting

The Baixianishan area is about 55km northwest of Liuyuan Town which is administrated by Dunhuang City of Gansu Province. The outcropped geological bodies are dominated by acidic intrusive rocks, while the Dundunshan formation of Upper Devonian (D$_{3}dn$) exposes locally in the southeast. Acidic intrusive rocks include the porphyritic granite of the first period in the Middle Variscan (πγ$^{42a}$), the monzogranite of the second period in the Middle Variscan (ηγ$^{42b}$). The quartz diorite of the first period in the Early Variscan (δ$^{41c}$o), as well as the monzogranite of the first period in the Indosinian (ηγ$^{51a}$), are locally developed. The veins in this area are well developed, including quartz veins (q), granite veins (γ) and diabase veins (βμ). The faults develops well, and trends of which are mainly NE-trending, as well as some are NW-trending. The quartz vein type gold deposit named Baixianishan is controlled by the NE-trending fault and quartz veins, with strong sericitization and limonitization.

2.2. Data source

The utilized airborne hyperspectral data in this study were acquired by the CASI-SASI measurement system produced by the ITRES Company of Canada. The main technical parameters of the CASI-SASI airborne hyperspectral measurement system are shown in Table 1. Four strips of hyperspectral data can fully cover the study area, and of which the imaging date was July 6th, 2011. The spatial resolution of CASI was 1 m and that of SASI was 2 m, at the relative flight altitude of 2000 m. During the flight period, the weather was clear and windless. The calibrated black and white targets were laid on the leveling ground, and spectra of them were collected synchronously by the ASD spectrometer when the aircraft passed through the roof.

Table 1. Main technical parameters of the CASI-SASI airborne hyperspectral measurement system

| Sensor name | CASI-1500 | SASI-600 |
|-------------|-----------|----------|
| Spectral range | 380nm-1050nm | 950nm-2450nm |
| Bands number | Programmable, up to 288 | 100 |
| Spectral resolution | up to 2.3nm | 15nm |
| Field of view (FOV) | 40° across-track | 40° across-track |
| Instantaneous field of view (IFOV) | 0.028° along-track | 0.07° along-track |
| Peak signal to noise ratio (S/N) | better than 1100 | better than 1100 |
| Digitization level | 14 bit | 14 bit |

2.3. Methods

2.3.1. Data preprocessing. Firstly, the systematic radiometric correction and the systematic geometric correction were carried out after raw CASI-SASI hyperspectral data were acquired, to obtain the hyperspectral data with clear physical meaning and geographical coordinates. Secondly, four strips of CASI and SASI hyperspectral data were merged respectively, and then were clipped according to the study area range to gain the CASI and SASI data for atmospheric correction. Thirdly, hyperspectral data were clipped through removing bands affected by water-vapor near 1400nm and 1900nm. Fourthly, the empirical linear regression equation was established based on measured spectra of ground calibrated black-white targets and image points in the hyperspectral data. Then, the regression parameters were obtained and applied. Finally, the CASI-SASI reflectance data for mineral mapping were achieved.

2.3.2. Band combination. According to the central wavelength position of each band of the hyperspectral data, three bands of 691nm, 538nm and 443nm were selected as RGB bands to produce a
true-color image of the study area. The visual effect of the image is good, and tones of different objects are real and natural, with obvious differences in spatial textures.

2.3.3. Reference spectra selecting. The CASI-SASI airborne hyperspectral data cover the electromagnetic wave range of 400nm-2500nm. In that range, common hydrothermal alteration minerals have obvious spectral absorption characteristics, which are mainly caused by the electron transition in the visible–near infrared (VNIR) range and the molecular vibration in the short-wave infrared (SWIR) range [8-9]. In this work, alteration minerals in the gold deposit were selected as the study target. The limonite mineral was extracted from the CASI data, and sericite minerals were extracted from the SASI data.

Spectral hourglass processing flow in the ENVI software was utilized to process the CASI and SASI hyperspectral reflectance data separately, including minimum noise fraction (MNF) transform, dimension compression, pixel purity index (PPI) calculation, N-dimensional visualizer analysis, and dozens of image endmember spectra were obtained. Spectral characteristics of image endmembers were analyzed one by one based on the expert knowledge of mineral spectroscopy, integrated the overall spectral shape and the local absorption position. Endmember spectra which similar to typical minerals spectra in the USGS spectral library were selected as reference spectra for mineral mapping, including the limonite and the sericite.

The spectral characteristics of the limonite reference spectrum are as follow:
(1) The reflectance continuously increases in ranges of 400nm - 760nm and 950nm – 1050nm, and the slope of reflectance slows down after 610nm; (2) There is a reflectance peak near 760nm and a broad absorption peak near 930nm.

The spectral characteristics of reference sericite spectrum are as follow:
(1) The reflectance decreases continuously in the range of 2135nm - 2195nm, while increases continuously in the range of 2225nm - 2285nm. (2) There is a dominant characteristic absorption peak in the range of 2195nm - 2210nm, while a secondary characteristic absorption peak near 2345nm. (3) There is a reflectance shoulder near 2285nm, and the reflectance value is the highest in the range of 60nm on both sides.

Furtherly, the sericites were subdivided into three subclasses according to the absorption peak position at the range of 2195nm - 2210nm, together with the spectral shape on both sides. The sericite subclasses were short-wavelength sericite (the dominant absorption peak at 2195nm), middle-wavelength sericite (the dominant absorption peak at 2210nm), and long-wavelength sericite (the dominant absorption peak at 2225nm).

2.3.4. Mineral mapping. Based on the analysis above, the mixed tuned matched filtering method was used to calculate the similarity between the image spectrum and the reference spectrum of each pixel. An appropriate threshold was setted for cutting from the high-value side, based on values of the similarity score and the reliability score [10]. Each mineral was given a color to distinguish, and was superimposed on the true color image according to the location of geographical coordinates. Finally, distribution map of the limonite and sericite subclasses minerals in the study area was achieved.

3. Results
As shown in Figer 1, distribution regions of the limonite and sericite subclasses are quite different, which are closely related to the geological structure, hydrothermal activity and artificial influence.
Figure 1. Distribution map of the limonite and sericites alterations in the Baixianishan area

The distribution pattern of the limonite can be classified into three types: (1) Plaque-like distribution pattern, which is closely related to the porphyritic granite of the first period in the Middle Variscan, and implies the regional alteration in the rock mass. The limonite of this type locates in the west of the Baixianishan area; (2) Vein-like distribution pattern, which is obviously controlled by faults. The limonite of this type locates in the east of the Baixianishan area; (3) Rectangle-like distribution pattern, which develops on the ore heap formed by mining development, and is not formed naturally. The limonite of this type locates in the southeast of the Baixianishan area and the north of the Xiaobaishan area.

The distribution pattern of the short-wavelength sericite can be classified into two types: (1) Vein-like distribution pattern, which is controlled by fault structures, and reflects a local hydrothermal activity closely related to faults. The short-wavelength sericite of this type locates in the east of the Baixianishan area and the southwest of the Xiaobaishan area; (2) Plaque-like distribution pattern, which irregularly develops in rock bodies of the quartz diorite of the first period in Early Variscan and the monzogranite of the second period in the Middle Variscan, and implies a hydrothermal activity closely related to acid intrusive rocks. The short-wavelength sericite of this type locates in the northwest and south of the Xiaoheishan area.

The distribution pattern of the middle-wavelength sericite is vein-like, showing a number of small veins distributed as polylines, and only develops in the northwest corner and in the south of the Xiaoheishan area. The middle-wavelength sericite veins are intermittently exposed, and are NWW-trending. They cut through the NEE-trending structures, and the mechanical property of which is mainly tensile. It is different from the main NEE-trending structures with a compresso-shear property, and reflects a later hydrothermal activity in the study area.

The distribution pattern of the long-wavelength sericite can be classified into two types: (1) Plaque-like distribution pattern, which develops in the Variscan rock bodies, and locates in the Baixianishan area and the south of the Xiaoheishan area; (2) Strip-like distribution pattern, of which the overall trend is consistent with the trend of fault structures, and locates in the Xiaoheishan area and the Xiaobaishan area.
4. Discussion
Based on the analysis above, it is considered that three sericite subclasses can be delineated elaborately according to the absorption peak position. However, each alteration mineral does not undergo only a single hydrothermal stage, but is the superposition result of multi-stage hydrothermal. Hydrothermal activities in the study area can be divided into three stages after the comprehensive analysis of distribution patterns of the limonite and sericite subclasses.

The first stage is in the period of the formation of acidic intrusive rocks in the Middle Variscan. The distribution pattern of alteration minerals is plaque-like. The alteration mineral is mainly the long-wavelength sericite, as well as the short-wavelength sericite and the limonite. The second stage is in and after the period of the formation of NEE-trending faults, which is later than the Mid-Variscan, with lots of quartz veins formed. The distribution pattern of alteration minerals is vein-like. Alteration minerals are mainly the short-wavelength sericite and the limonite, as well as the long-wavelength sericite. The third stage is in the period of the formation of the NWW-trending structure, which is later than the second stage. The distribution pattern of alteration minerals is vein-like. The alteration mineral is mainly the middle-wavelength sericite. Among these three stages, the second stage is considered as the metallogenic stage, which is closely related to the gold mineralization.

The Baixinishan gold deposit is located at the intersection of the NE-trending and NEE-trending faults. There develops the limonite and the short-wavelength sericite with a vein-like distribution, which reflects an alteration hydrothermal activity closely related to gold mineralization. The metallogenic essential factors of the Baixianishan gold deposit are NE-trending fault structure, a superimposed vein-like distribution of the limonite and the short-wavelength sericite. According to the prospecting model based on metallogenic essential factors, a similar section has been found in the southwest of the Xiaobaishan area. There are superimposed limonite and short-wavelength sericite with vein-like distribution on the NEE-trending fault, which are significant indicators for gold prospecting.

5. Conclusions
(1) Fine division of the sericite was conducted based on the absorption peak position at the range of 2195nm - 2210nm. There are three sericite subclasses: short-wavelength sericite (the main absorption peak at 2195nm), middle-wavelength sericite (the main absorption peak at 2210nm), and long-wavelength sericite (the main absorption peak at 2225nm). The distribution of the limonite and three kinds of sericite minerals were obtained in the Baixianishan area using CASI-SASI airborne hyperspectral data.

(2) The alteration minerals extracted by CASI-SAIS hyperspectral data do not undergo only a single hydrothermal stage, but are the superposition result of multi-stage hydrothermal activities. According to the distribution patterns of limonite and sericite subclasses minerals, hydrothermal activities in the Baixianishan area are divided into three stages, of which the second stage is closely related to the gold mineralization.

(3) It is concluded that the metallogenic essential factors of the Baixianishan gold deposit are NE-trending fault structure, superimposed vein-like distribution of the limonite and the short-wavelength sericite. A similar section has been found in the southwest of the Xiaobaishan area. There are superimposed limonite and short-wavelength sericite with vein-like distribution on the NE-trending fault, which are significant indicators for gold prospecting.

(4) The CASI-SASI airborne hyperspectral data can quickly and accurately obtain the distribution of the limonite and sericite subclasses at regional scale, thus can provide more effective remote sensing criteria for basic geological survey and mineral resources exploration. Therefore, it has broad prospects in the geological field.

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