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Pegmatite remote sensing extraction and metallogenic prediction in Azubai area, Xinjiang

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Abstract: Remote sensing technique plays an important role in geological prospecting in Altay because of the remote location and steep terrain with mountains. Pegmatite has important implications for metallogenic prospecting as most of rare metals occurs in it. Pegmatite information from optical and radar images was extracted, and the spatial distribution and scale of pegmatite were generalized in Azubai, Altay. Three mining targets, that is, Halon-Azubai, Kuermutu-Tuyibaguo and Zhuolute-Akuoyige, were delineated based on the analysis of pegmatite information, structure interpretation and other geological data.
Key words: pegmatite; remote sensing; information extraction; metallogenic prediction

1 Introduction

Azubai is a very important part of Altay metallogenic belt in central Asia and is famous for its non-ferrous metal and rare metals [1−2]. With extremely abundant in mineral resources, it achieved much attention from China and other countries. Its remote location, sparse population, steep terrain, difficult traffic, short duration of frost-free period and limited period of geological working make remote sensing technology play an important role in mineral resource prospecting and exploration in this area [3−4]. The rare metals are the dominant minerals of Altay and nearby area, which have wide distribution and rich variety. According to available statistics, about ten thousand pegmatite veins have the characteristic of mineralization. And there are one superlarge ore deposits, three large ore deposits, and twenty seven medium-size and small-size ore deposits [5−6]. In Altay, pegmatite has important implications for metallogenic prospecting because most of rare metals occurs in it [6−10]. So, pegmatite information extraction is very important in mineral exploration and metallogenic prognosis.

GAO et al [11−12] did some preliminary studies about pegmatite information extraction based on optical remote sensing in Altay. The pegmatite extraction using radar remote sensing has not been carried out yet. For the lush vegetation, optical remote sensing is mainly used for structure and lithology interpretation, partly used for pegmatite extraction in natural expose and man-made recovery. Pegmatite covered by forest is difficult to be extracted by optical remote sensing. However, radar remote sensing can do because of its penetrating capability of forest canopy and shallow soil. Therefore, the pegmatite extraction based on the combination with optical and radar remote sensing has good guidance for rare metals prospecting.

2 Study area

The study area is located on the southern slope of Altay, the region of Fuhai County, Xinjiang. Its north is the boundary of Mongolia (see Fig. 1). It lies in 88°45′E−89°00′E and 47°50′N−48°00′N, with continental arid climate of the north temperate zone. It is cloudy in spring and cold in winter, and the annual average air temperature is about 3−4 °C with an average elevation of 2.2 km, steep terrain, and long period of snow cover. Only the period from June to September is open to traffic. Irtysh River runs through this area and brings the high rate of vegetation coverage. It lies between the two major tectonic units of Altay and Chungar. The variety of geological structure provides excellent conditions for

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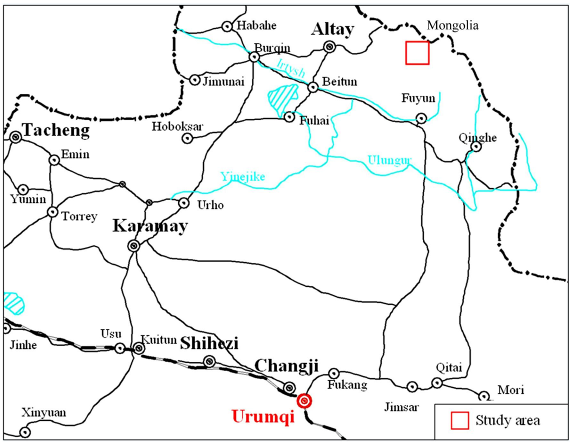

Fig. 1 Location of study area

mineralization, especially for rare metals.

3 Data and method

3.1 Remote sensing data

Compared with granite, the scale of pegmatite is relatively small, which is only meters to tens of meters in across, tens of meters to hundreds of meters in length (see Fig. 2). Figures 2(a) and (b) show the QuickBird image and field photo of pegmatite, respectively. The spatial resolution of remote sensing image used to extract pegmatite must be high. The remote sensing data used in this work include RapidEye, QuickBird and ENVISAT-1 satellite data. RapidEye satellite data include five multispectral bands with spatial resolution of five meters: Band 1(blue) 440−510 nm, Band 2(green) 520−590 nm, Band 3(red) 630−685 nm, Band 4(red lacing) 690−730 nm and Band 5(NIR) 760−850 nm. The spatial resolution of panchromatic color and multispectral image of QuickBird satellite are 0.61 and 2.44 m, respectively. There are five modes for advanced synthetic aperture radar (ASAR) sensor of ENVISAT-1 satellite. In this work the image model of ASAR was used, with spatial resolution of 30 m. RapidEye data were mainly used to extract pegmatite information base on spectral angle mapper (SAM). The ASAR data play a supplementary role in mapping the distribution of pegmatite. QuickBird data were used for interpretation and validating the results of extraction. All images were corrected based on topographic maps with the scale of 1:50 000 and projected with Gauss-Kruger coordinate system. The methods and procedure of data process are shown in Fig. 3.

3.2 Spectrum measurement

About 120 rock samples were selected for spectrum measurement using the all-band portable spectrometer (SVC GER3700). The wavelength range of SVC GER3700 is from 350 to 2 500 nm, with the spectrum resolution of 1.5 nm in 300−1 050 nm wavelength, 6.5 nm in 1 050−1 900 nm wavelength, and 9.5 nm in 1 900−2 500 nm wavelengths. The spectrum curves of representative rock samples are presented in Fig. 4. It shows that pegmatite has a highest reflectance, granite comes second and

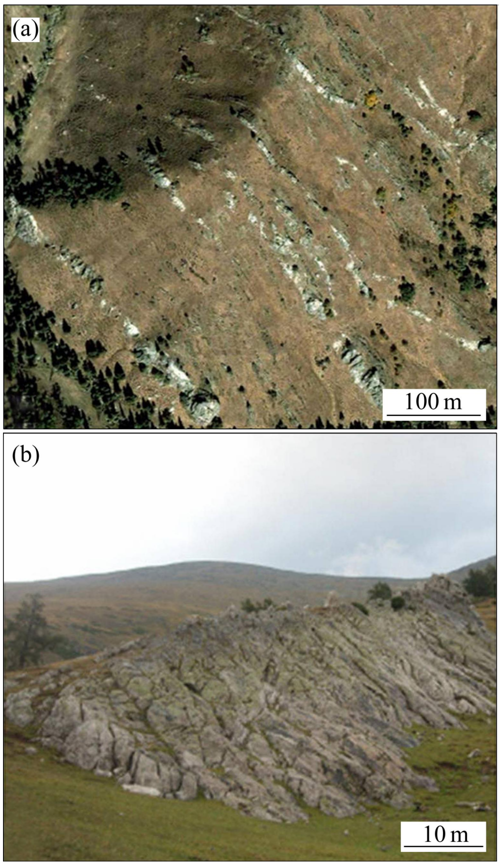

Fig. 2 Image feature and shape photo of pegmatite: (a) QuickBird image; (b) Field photo of pegmatite

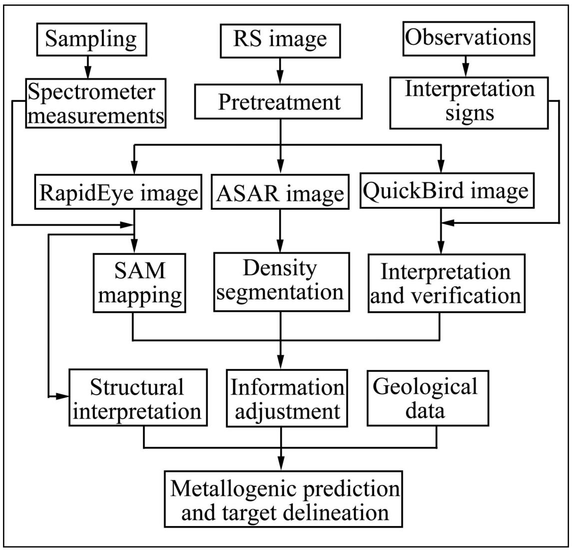

Fig. 3 Methods and procedure of data process

schist has the lowest. The reflectance of pegmatite rises from 0.36 to 0.76 and shows a clearly ascendant curve in the range of 400−900 nm, while granite shows a slightly ascendant curve with the change from 0.29 to 0.46. Pegmatite and granite can be separated based on the difference of their spectrum.

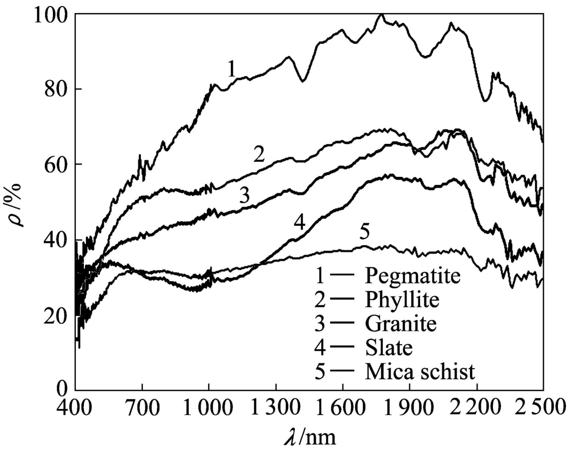

Fig. 4 Measured spectra curves of typical rocks

3.3 Pegmatite information extraction

3.3.1 Spectral angle mapper

There are several kinds of spectral mapping methods including binary coded, SAM, LS-Fit, Linear spectral separation, continuous spectrum elimination and spectral characteristics adaptation [13]. Compared with maximum likelihood and minimum distance classification, SAM classification determines the type of pixel according to the similarity of the image pixels with the reference spectra based on the threshold value derived from the priori knowledge. The reference spectra can be acquired from standard spectrum database or remote sensing images. In this work, the measurement data were obtained from SVC GER3700. Pegmatite information was extracted by ENVI software with the SAM module using RapidEye image. The classification procedure includes four steps: minimum noise fraction rotation transformation, pixel purification, endmember extraction and SAM classification[14]. According to the statistical results, the best maximum angel of SAM is 0.12°. The SAM classification rules and result images of pegmatite are shown in Fig. 5. Figure 5(a) shows that the higher gray level of image, the smaller spectral angle between image and pure pixel, and the greater likelihood of defining to pegmatite. Figure 5(b) shows the result of the pegmatite classification of SAM.

3.3.2 Density segmentation of ASAR image

Different from optical remote sensing image, ASAR image has the special capability of extracting the pegmatite under the forest canopy and shallow soil. In this work, two ASAR images with the spatial resolution of 30 m were used to extract some information of large-scale pegmatite. Pegmatite has the highest backscattering coefficient of 12−14 dB, granite ranks second of 9−12 dB, lithological comes third of 5−8 dB, and the bare land surface has the lowest one, only 2−8 dB. On one side, part of bare river bed and granite may create some confusion. On the other side, due to the angular reflector effect of terrain, some peaks and valleys show high backscattering coefficient. These two factors will create some interferences to extract pegmatite information. The distribution of pegmatite can be classified into two levels based on the density segmentation of ASAR image (see Fig. 6): Level 1: >13.5 dB, Level 2: 12−13.5 dB. Because the error of pegmatite classification is probably high, QuickBird image is used to correct the distribution result of pegmatite based on interpretation.

3.3.3 Interpretation and correction

Pegmatite occurs mainly in the contact zone between granite and metamorphic rocks. The spectral reflection of pegmatite exposure is very high in RapidEye and QuickBird image. In ASAR image, its backscattering coefficient is also high. Therefore,

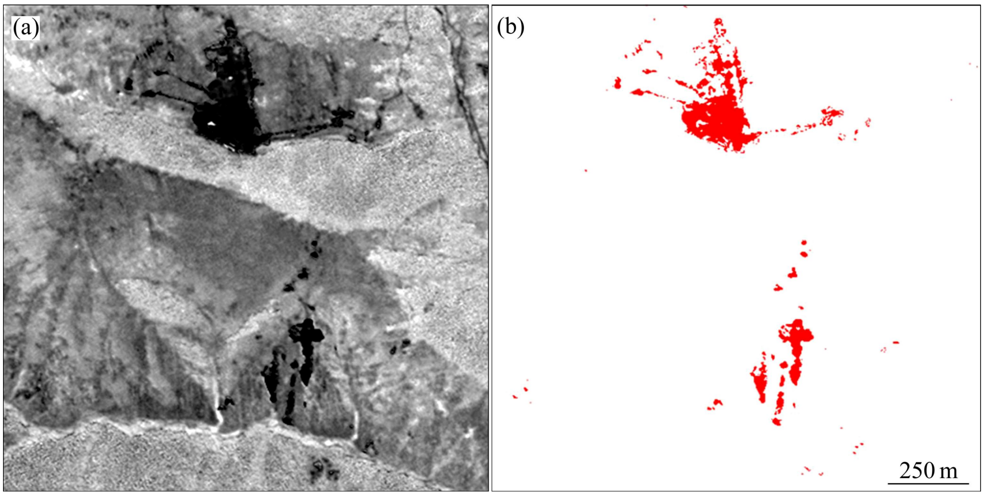

Fig. 5 SAM classification rules and results images of pegmatite: (a) Map of SAM rules; (b) Map of SAM classification

pegmatite shows the white or shallow tone in image, which can be easily distinguished. The natural exposure of pegmatite in metamorphic rocks shows the shape of ridge on the landscape and some obvious banded characteristics. Pegmatite in granite was controlled by a certain tectonic zone. For example, in the area of Heidaqian-Kuermutu, pegmatite was controlled by a NE-trending fault. Pegmatite occurs in the outer contact zone of metamorphic rocks and shows the characteristics of tensile vein. Some show the intrusive contact with wall rock, and some cover above metamorphic rocks. Based on the manual interpretation of QuickBird image, pegmatite information extraction of RapidEye image and density segmentation of ASAR image, superimposed layers and field observations data were used for comprehensive analysis and correction. Finally, the distribution of pegmatite in Azubai area was generated (See Fig. 7).

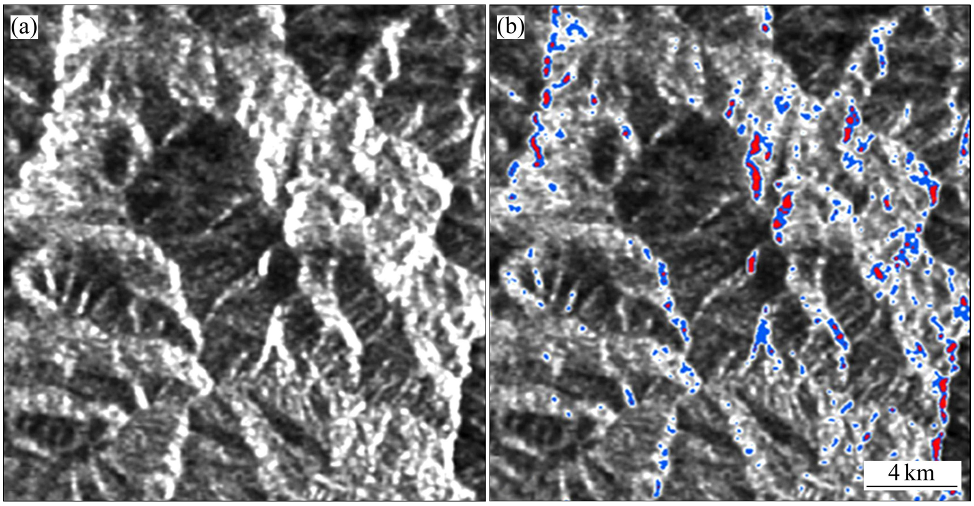

Fig. 6 Backscattering coefficient of ASAR and distribution of pegmatite: (a) ASAR image; (b) Pegmatite information from ASAR

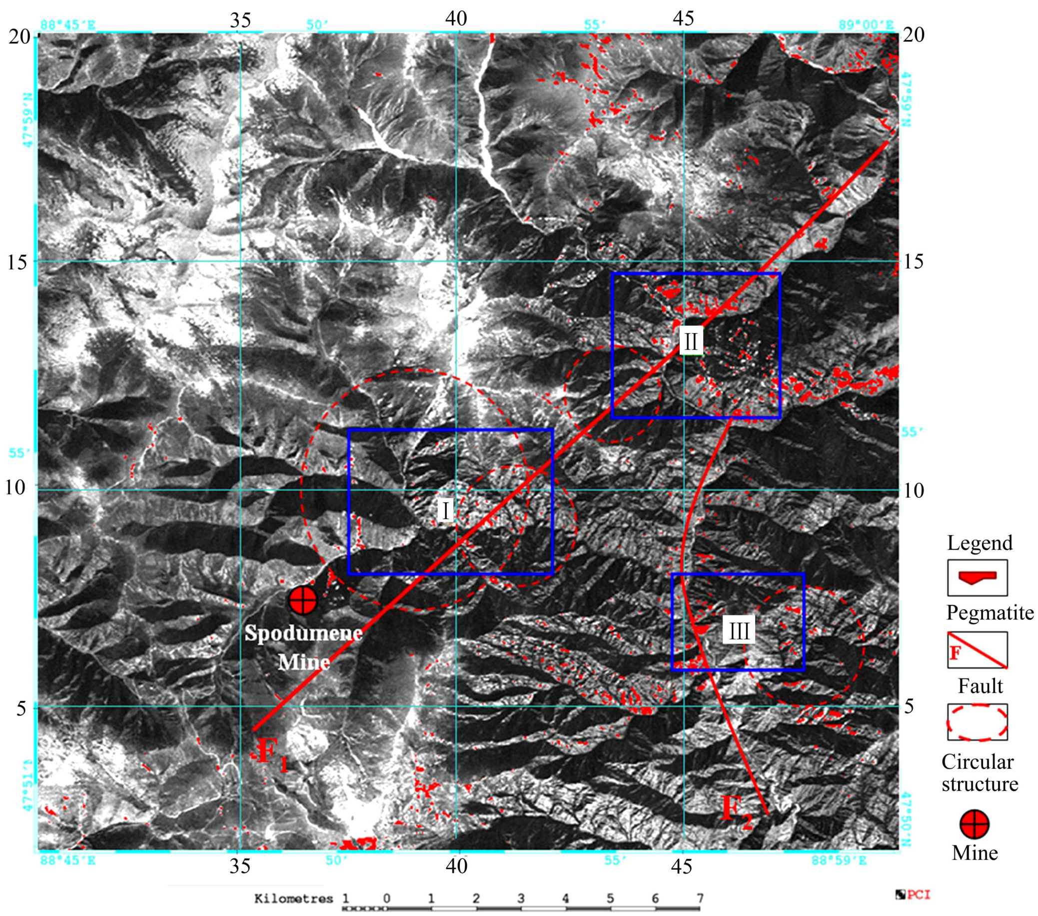

Fig. 7 Map of pegmatite, geological structure and metallogenic prediction

3.4 Structure interpretation

It is conducive to understand the law of mineralization and research the relationship linear and circular structure and regional distribution of mineral resources. Researches show that the cross-cut part of linear and circular structure is the favorable location for metal mineralization and enrichment [15]. Linear and circular structure can be interpreted according to the color anomalies and topography characteristics in remote sensing images. RapidEye image with the spatial resolution of 5 m was used for interpretation and the map of geological structure was generated (See Fig. 7). In this map, there are four circular structures and two faults with NE and NW trending. Multi-factors such as faults, circular structures, abnormal pigmentation zones and pegmatite information can be used to establish the metallogenic model of remote sensing to guide mineral exploration.

4 Metallogenic prediction

On the basis of pegmatite information extraction and structures interpretation, and combined with geological data and metallogenic regularity, three prospecting targets belts were predicted (See Fig. 7), that is, Halong to Azubai target belt (I), Kuermutu to Toyibaguo target belt (II), and Zuolute to Akuoyike target belt (III).

The Halong to Azubai target belt (I) lies in the belt between Halong and Azuba. This zone locates in the intersection area of two ring structures and fault $F1$ and has good geological background. Regional stratigraphy is mainly γ_5 (two-mica granite) and γ_4^{2b} (biotite granite and biotite-plagioclase granite). There are a number of NW and NE faults and some show radial model in the core area. Lots of manmade outcrops of pegmatite is discovered and there is a spodumene mines being exploited. Kuermutu to Toyibaguo target belt (II) lies in the belt between Kuermutu and Toyibaguo, nearby the intersection area of circular structures and fault $F1$. Most of pegmatites lie in the stratum of γ_4^{2b} and γ_4^{2c} (mixed biotite granite and gneissic granite). It distributes in the narrow belt from Kuermutu to Tuoyituoguo and the direction changes from NE to EW. He Zuolute to Akuoyike target belt (III) lies in the belt between Zuolute and Akuoyike, near the west of Kumala Mountains. There are a circular structure and fault $F2$. Biotite plagioclase gneiss is exposed in this belt which is the most favorable site to seek muscovite, gem and rare metals mining.

5 Conclusions

1) The scale of pegmatite are much smaller than other rock mass in the spatial distribution, so there must be a relatively high spatial resolution of remote sensing image. RapidEye image has five Multi-spectral bands with the spatial resolution of 5 m and shows good performance to pegmatite information extraction. The shape and occurrence characteristics of some pegmatite, stratigraphic boundaries and granite intrusion can be observed partly based on QuickBird satellite imagery with the spatial resolution of 0.61 m. Based on the comprehensive analysis of faults, circular structures, pegmatite information and geological data, metallogenic prediction and prospecting targets can be created effectively.

2) Although radar remote sensing has a certain ability to penetrate forest crown and surface soil, the pegmatite information segmented from the image model of ASAR with the spatial resolution of 30 m and unipolar is not very accurate. The extraction results can provide some reference information for geological interpretation and comprehensive analysis.

3) For pegmatite is the important rock for rare metal ore occurrence, the pegmatite information extracted by remote sensing still has great significance for minify target and guide exploration.

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