Remote Sensing Technology for Identification of Alteration Information of Gold Deposits in the Eastern Tianshan Area, Xinjiang

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Abstract Based on specific well-exposed rocks useful for high-quality remote sensing interpretation in the gold-prospecting area in the eastern Tianshan, this paper gives a detailed description of a remote sensing model for metallogenic prediction. The model reveals that multi-spectral remote sensing data are integrated with high-resolution remote sensing data, and enhanced extraction and visual description of weak remote sensing information are used for prospecting. This model has tested in the given gold deposit, and used successfully in Au-Cu prospecting in the Kalatage area.

*Key words:* remote sensing, gold deposits, alteration information, eastern Tianshan

1 Introduction

Alteration is a key indication of gold mineralization, and the advanced remote sensing technology serves generally as a significant means for identification of alteration zones. In western China, especially the eastern Tianshan area, where bedrocks are well exposed and favorable for remote sensing interpretation, the remote sensing technique is an economical, quick and effective means for gold prospecting. Consequently, the remote sensing data-based enhanced extraction of weak alteration information is the key to applications of remote sensing in ore prospecting.

As in previous applications of remote sensing to geology, the spectrum for each waveband of the remote sensing data is broad, there shows minor differences in spectrum between the altered rocks and the non-altered rocks, and alteration is weakly reflected on the images. Accordingly, with the conventional remote sensing data processing technique it is not easy to identify the weak information. In recent years, the remote sensing technology has been advancing rapidly, which offers abundant remote sensing data of multi-platform and multi-spectral resolution and multi-spatial resolution, e.g. the panchromatic multi-band spatial resolution is 10 m for TM-7, 0.64 m for QUICKBIRD and 5 m for SPOT-5, which has a multi-spectral band resolution of 10 m; the Sino-Brazil Landsat CBERS has a resolution of 19 m for multi-band data. Meanwhile, significant advance has been made in integration of multi-source information, enhanced extraction and visual description of weak ore-indicating information, and a powerful image processing system has also been developed.

Based on the achievements of the Ninth Five-Year Plan Scientific-Technological Key Problems Tackling Project, the Sino-Belgium joint project and the state key basic research project undertaken by our institute (the Paleo-Asian Orogeny and Metallogenesis Project 09—Identification and Prognosis of Large Ore-concentration Areas, No. 2001CB409809), this paper depicts the effective method and working procedure of multi-platform remote sensing data integration, enhanced extraction and visual description of weak ore-indicating information, which have been successfully adopted in specific landscapes such as the eastern Tianshan for prospecting of Au-Cu deposits.

2 Readable Geomorphologic Maps Acquired from Multi-platform Remote Sensing Data Integration

The acquisition of geomorphologic maps with multiple elements, such as peri-true color, geology, mineral resources, geography and coordinates, is the precondition for the geological interpretation and metallogenic prognosis.

The requirements for remote sensing images differ depending on the different stages of gold prospecting. Based on consideration of a combination of factors such as the economic factor and the experience of recent years acquainted from ore prospecting and prognosis in the Tianshan area, the following three schemes may provide satisfactory basic images for remote sensing interpretation.

(1) In the metallogenic prognosis of large areas (1:200,000–1:500,000), TM and CBERS data with a spatial resolution of 30 m can meet the requirements. Ideal basic
images for geological interpretation can result from a combination of three bands. In the eastern Tianshan, TM741 is the best band combination.

(2) In the metallocenic prognosis of gold belts (1:50,000-1:100,000), satisfactory basic images for interpretation can be obtained through an integration of the TM (resolution 10 m) or CBERS with the ETM or SPOT–P (resolution 10–5 m) based on the multi-band TM data.

(3) Remote sensing interpretation images should be of a scale of 1:10,000 or even larger in 1:10,000- to 1:5,000-scaled prospecting in ore-concentrated areas. This must be supported by such remote sensing data of high spatial resolution as the SPOT-5, SPIN-2, QUICKBIRD or IKONOS. An integration of the multi-band TM or CBERS with high-resolution data can result in the 1:10,000 or 1:5,000-scale thematic images.

The integration of multi-platform remote sensing data can only be fulfilled in an image processing system with the function of RGB-HIS, transformation. Let us take the integration of the TM (resolution 230 m) with the SPOT-P (resolution 5–10 m) as an example: Firstly, the TM741 false color composite images and corrected SPOT-P images of the same area are formed, and the latter are sharply filtered to enhance the high-frequency information. Secondly, the TM741 composite images are transformed from RGB to HIS and the luminance histograms of HIS and SPOT-P are calculated for determination of the respective luminance ranges. And then, the SPOT-P images are scaled to have the same luminance range as I (intensity luminance). Thirdly, the SPOT-P enhanced images are used to replace the channel I. Finally, the channels containing filtered and scaled SPOT-P images, hue (H) and saturation (S) are transformed from HIS to RGB to yield integrated images.

The thematic images acquired from the aforementioned process possess not only abundant multi-level colors of the TM false color composite images but also high resolution of the SPOT-P panchromatic images. Therefore, this process has enriched the information volume, improved the visual effects, and enhanced the identifiability of geological information.

Because there exist intensive silicification and wide-range faded alteration in the gold deposits of the eastern Tianshan, e.g. the Kanggur gold deposit, the altered rocks show a light hue clearly different from the unaltered rocks on images, so that the faded alteration zones can be quickly delineated with the help of the integrated images.

3 Multi-level Separation Extraction Technique of Weak Alteration Information

The alteration information can be enhanced, extracted and manifested visually through the following steps: enhance the weak alteration information by using ratio and principal factor analyses, gradually eliminate the interfering information by mask and classification, form anomalous images by re-coding and false color composite, and then integrate the anomalous images with the background images to form visual maps showing distribution of alteration anomalies.

3.1 Ratio processing
Different minerals have different spectral characteristics, and so they show distinct differences in absorption and emission in different bands. Especially, as most altered minerals contain the \( \text{OH}^- \) or \( \text{CO}_3^{2-} \) hydroxyl, they have strong absorption and strong emission in the TM7 and TM5 bands respectively, whereas ferrous oxides and hydroxides like limonite and jarosite show emission in the TM3 band, and absorption in the TM1, TM2 and TM4 bands (Drury, 1993).

Ratio processing can enhance the differences between altered rocks and unaltered rocks, e.g. the TM5/TM7 ratio can be used to enhance the information of argillization and carbonization, while the TM3/TM1 ratio can enhance that of alteration of ferrous minerals such as pyritization and limonitization.

3.2 Crosta transformation
The Crosta Transformation (FPCS) was put forward by Crosta and Moore (1989). Based on proper vector load factor analysis of the principal components of six TM bands, a combination of TM1, TM4, TM5 and TM7 was chosen for principal component analysis to acquire enhanced images of clay minerals (image H), while a principal component analysis of the TM1, TM3, TM4 and TM5 combination yields enhanced images of ferrous oxides (image F).

It can be seen clearly from Table 1 that in the TM1, TM4, TM5 and TM7 bands, the proper vector load factor of the principal component PC4 has relatively high absolute values, which are 0.537 and –0.841 for the TM5 and TM7 respectively. One is positive and the other is negative, whereas other bands show lower load values. This indicates that the information of PC4 originates mainly from the TM5 and TM7, forming image H. According to the spectral characteristics of minerals, clay minerals show an obvious absorption peak in the TM7 and relatively high emission in the TM5. Therefore, the PC4 enhances the argillization information, and the alteration anomalies are reflected by light hue on the images.

Table 2 shows that the TM1 and TM4 contribute the highest load factor values of 0.678 and –0.726 respectively in the PC4. Other bands contribute lower load factor values. Consequently, images F depends mainly on the TM1 and
Table 1 Principal factor analysis of hydroxyl-bearing minerals in the Kanggu’ertage area

<table>
<thead>
<tr>
<th>Band</th>
<th>TM1</th>
<th>TM4</th>
<th>TM5</th>
<th>TM7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of band</td>
<td>88.3</td>
<td>58.2</td>
<td>106.5</td>
<td>66.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principal factor</th>
<th>Signature vector</th>
<th>Signature value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td>0.328</td>
<td>0.381</td>
</tr>
<tr>
<td>PC2</td>
<td>0.821</td>
<td>0.336</td>
</tr>
<tr>
<td>PC3</td>
<td>-0.463</td>
<td>0.860</td>
</tr>
<tr>
<td>PC4</td>
<td>-0.057</td>
<td>0.043</td>
</tr>
</tbody>
</table>

Table 2 Principal factor analysis of ferruginous oxides in the Kanggu’ertage area

<table>
<thead>
<tr>
<th>Band</th>
<th>TM1</th>
<th>TM3</th>
<th>TM4</th>
<th>TM5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of band</td>
<td>88.3</td>
<td>65.7</td>
<td>58.2</td>
<td>106.5</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>18.3</td>
<td>20.6</td>
<td>20.6</td>
<td>37.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principal factor</th>
<th>Signature vector</th>
<th>Signature value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td>-0.344</td>
<td>-0.408</td>
</tr>
<tr>
<td>PC2</td>
<td>0.669</td>
<td>0.339</td>
</tr>
<tr>
<td>PC3</td>
<td>-0.649</td>
<td>0.438</td>
</tr>
<tr>
<td>PC4</td>
<td>0.678</td>
<td>-0.726</td>
</tr>
</tbody>
</table>

TM3. As ferrous oxides show absorption in the TW1 and high emission in the TM3, PC4 can enhance alteration information of ferrous oxides, and the light hue indicates alteration anomalies in its ratio images.

3.3 Mask process of images

In addition to the geological information we desire for, the TM images also contain other interferential factors such as water bodies, vegetation, residues, mountain shade and clouds, which interfere the extraction of alteration information. These environment pixels on the images can be removed through the mask processing to purify the original images and make the information extraction considerably easier.

3.4 Scattered signal-noise filtering

On the one hand, the enhanced alteration images contain random noise from original data of different bands of TM and false anomalies of high luminance from other ground objects. On the other hand, they bear weak mineralization and alteration information which is scattered because of concealing by unaltered rocks. In order to get rid of these interferences to connect the scattered points of alteration anomalies, a medium-value filter processing with responsible radii of 3–6 pixels was adopted through an analysis of the widow signal-noise distribution and testing comparison of the given areas to refine the hue outline of the alteration zone.

3.5 Image splitting

The alteration information extracted form color composite, band ratio and K-L transformation can be displayed in gray images and color images. The luminance of gray images represents the alteration intensity, and the hue of color images indicates the alteration type. However, the scope, intensity and type of alteration are sometimes not easily identified on the images because of continuous distribution of the gray scale values or the minute difference of hue. Therefore, the enhanced mineralization and alteration information has to be further separated from the background information. To do so, the threshold values of alteration information splitting and the upper and lower limits of each gray scale value should be determined first, based on a combination of histogram statistics from a given alteration area with unsupervised classification of images, so as to ensure the rationality and accuracy of delineation of alteration anomalies.

3.6 Composite superimposition display

The coded or RGB color composite anomalies of mineralization and alteration information acquired from image splitting in various areas were synthesized to the mosaic TM single color images of a certain band. Finally, a regional alteration information map with both background images and clear color anomalies was formed.

4 Applications to Prospecting in the Kanggu’ertage Area

Kanggu’ertage, one of the large gold deposits discovered during the seventh “Five-Year Plan” period, is located in the southeast of Shanshan County, Xinjiang. It is hosted in volcanic rocks of the Lower Carboniferous Aqishan Formation, consisting of andesite, dacite and tuff with intrusion of quartz porphyry, quartz syenite porphyry and rhyolite porphyry. Tonalite intrusion of the late Hercynian was exposed to its southeast. Controlled by the secondary brittle-ductile faults of the Qiugemingtashi-Huangshan ductile shear zone, three parallel mylonite belts are distributed in the gold deposit. The orebodies occur as veins and lenses of gold-bearing altered rocks or quartz veins nearly parallel with the ductile shear zones (Wang, 1993; Ji and Tao, 1994; Feng et al., 2000). According to Ji and Tao, it represents a volcanic-hosted gold deposit featuring alteration-related mineralization controlled by Late Paleozoic brittle-ductile shear zones.

The aforementioned methods were adopted to process the TM data, ETM data, and geological-geochemical-geophysical information, and to carry out the geological interpretation and field testing. Finally, the remote sensing
characteristics of geology of this gold deposit were summarized (Plate I-1 and I-2), and the remote sensing model for prospecting was established. The results are presented as follows.

(1) The deposit is located in the altered fracture zone of a large-scale ductile shear zone. On the TM-ETM composite image, there clearly exist four structural anomalies characteristic of transition from intensive ductile shear to weak ductile shear from north to south. The north part close to the Kanggur shear zone is characterized by intense ductile-brittle shearing and linear lengthening of dark rocks. The middle area represents ductile-brittle deformation with mylonites distributed on its two sides and gold deposit within it. The southernmost is a folding deformation zone with argillaceous and carbonaceous sedimentary rocks distributed, showing folded bedding on the TM image.

(2) Magmatic activity is characterized by multi-phase and iso-domain intrusion. The early-intruding Hercynian granite, large in size, shows light hue on the image. The late-intruding Hercynian tonalite and diorite show dark hue on the TM and ETM images with clear isometric boundaries. The northwest-trending dikes intruded in the diorite body show dark-colored dense lineation. In addition, various shallow-seated intrusives or dikes of different ages are well developed. It indicates that the gold deposit is located in the center of intensive magmatic activity and is the center of fluid activity, to which the multi-phase magmatic activity brought large amounts of ore-forming materials. The multi-phase and iso-domain magmatism provided important preconditions for the formation of the gold deposit (Deblond and Fu, 1999).

Comprehensive studies of the Tianshan indicate that the multi-phase and multi-lithologic magmatic activity is indicative of a prospective area of gold deposits, which is represented by concentric circles of the same hue or intersected circles of various hues on the images (Zhu, 1989; Liu and Dong, 1992; Zhao, 1994). The development of linear structures within the circles indicates good development of dikes.

(3) The deposit is located in the transition zone from intensive compression to extension in large arcuate structures. Arcuate structures are well-developed on the images, in which lineation and lamination are converged toward the south of diorite and scattered toward the east and west. The south of the diorite represents intensive compression, and its east and west represent transition from compression to extension.

As the arcuate structures result from fracturing, diagenesis and sedimentation but genetically dominated by structuring, they are useful for housing ores. Especially, the coupling of multi-level arcuate structures may be favorable for housing large or superlarge deposits, e.g. the Mulongtao gold deposit located in the superimposed position of multi-level arcuate structures. Their main contribution to mineralization is to form a local extensional area in the intensive strain zone of regional compression field, which results in stress difference and stress gradient zones enabling ore-bearing fluids to move in the stress-increasing direction. Orebodies are finally formed in the local dilation zone due to changes of the physico-chemical conditions.

(4) Large altered alteration areas are indicative of large gold deposits. The Kanggur’ertage gold deposit is hosted in the Lower Carboniferous intermediate or acid volcanic and pyroclastic rocks, especially in andesite and andesitic tuff, which show dark hues before they are altered by multi-phase silicification, sericitization, carbonatization and argillization. After alteration the protolith shows lighter hues on the images. Quartz veinlets are weathered to form quartz beaches. The quartz beach in Kanggur’ertage, 50x10 km² in area, shows clear white spots in the light background on TM and ETM images.

The large-scale light-colored anomalies reveal the existence of large areas of faded alteration resulting from intensive fluid activity. Because of the good outcrops, the faded alteration resulting from silicification etc. shows light hues on the ETM single-band images, while the melanocratic alteration shows dark hues on the ETM images. The field investigation indicates that the light hues on the TM and ETM images correspond with silicification, sericitization, argillization and carbonatization. The massive quartz networks formed by alteration were weathered to form quartz beaches widespread in the mineralized zones. Meanwhile, the dark-colored Lower Carboniferous volcanic rocks and argillaceous-carbonaceous rocks were faded under alteration, forming light hues on the TM and ETM images. The carbonaceous clastic rocks hosting the Mulongtao gold deposit were also faded due to quartz veining, alteration and mylonitization, and show light hues on the images, while the unaltered carbonaceous rocks correspond with dark hues on the images.

(5) Circular features with diameters of over 10 kilometers and convergence of multi-cluster linear structures on the images are important indications of gold mineralization-concentrated areas.

Large circular features mostly reflect volcanic activity and magmatic emplacement. The tens of large deposits discovered in the Tianshan and its periphery at present are unexceptionally related to circular features. For example, the circular structure in Kanggur’ertage is a reflect of multi-phase intrusion, that in Xitan corresponds with a vent or caldera and the intrusion of subvolcanic intrusives, and the circular structure developed in Mazhuangshan has resulted from intrusion of multi-phase intrusives and apparatuses.
The Ashi deposit, which is the largest in Xinjiang, is located on the margin of a circular feature with a diameter of 10 km on the image. The Mulongtao superlarge gold deposit, located in the western extension of the southwestern Tianshan, lies in the center of a huge circular structure with a diameter of 80 km, probably revealing the hydrothermal dynamic environment derived from a potassic granite body buried at 4-km depth.

To sum up, the place where the aforementioned five indications all appear may be a potential area for large gold deposits in the eastern Tianshan.

5 Conclusion

Through a comprehensive processing and interpretation of the remote sensing data obtained from a national resources survey project conducted by our institute, a number of Au-Cu prospects were outlined in Kalatange, Hami (Plate I-3). The field examination reveals that there are intensive silicification and Au-Cu mineralization, in the area, which confirms that it is a large prospective area for finding Au-Cu deposits.

Based on the field examination of remote sensing processing in the given ore deposits and prospective areas in the eastern Tianshan, it is concluded that the aforementioned method is a quick and economical method for prognosis of metallic ore deposits in such well-exposed area as the eastern Tianshan. The method can speed up the identification and extraction of ore-indicative information like hydrothermal alteration through an integration of multi-platform remote sensing data and enhanced extraction of weak alteration information. Meanwhile, the commercialization of multi-spectral remote sensing data with high spatial resolution lays a data foundation for applications of the remote sensing technique to various stages of ore prospecting. This enables the remote sensing technique to turn into a direct prospecting method from an indirect one.

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References

Explanation of Plate I

1. Integrated image of TM with ETM in Kanggu’ertage, Xinjiang, China.
2. Image of principal element analysis of TM1, TM3, TM4 and TM5 in Kanggu’ertage, Xinjiang, China.
3. Compound image of remote sensing anomalies and ETM8 in Kalatange, Hami, Xinjiang, China.