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MODELING HYDROTHERMAL VEIN-TYPE GOLD DEPOSITS WITH SATELLITE DATA: PAISHANLOU GOLD MINE, LIAONING, CHINA

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Abstract: Spaceborne Deposit Signature (SDS) modeling is a new concept, which is a result of the application of remote sensing techniques in ore exploration. In this study, features of various ore-controlling factors and their recognition criteria were studied based on the interpretation of spaceborne data (Landsat MSS, TM and ETM+ imageries), geology, and gold mineralization patterns. Then, the following procedure was used to develop the model: 1) choosing appropriate image processing techniques; 2) studying the major ore-controlling factors (structures, formations, alterations); and 3) determining the recognition criterion, establishing deposit image model and optimizing target areas. The optimization of target areas using the model was successfully achieved. Satellite image processing revealed strong alteration signatures for potentially economic gold deposits at three new sites (i. e. North, Middle, and South zones) . It is concluded that such strong signatures clearly merit further investigation using more sophisticated airborne data sources such as radar. Three predicted areas proved to be gold-mineralized, for they are similar to those discovered by other geologists with conventional (geochemical and geophysical) exploration methods. Considering the case of the Paishanlou area, this paper illustrates that satellite data can play an important role in gold reconnaissance.

Key words: Spaceborne Deposit Signature (SDS) modeling; fractures; hydrothermal alteration signatures; Paishanlou gold deposit

1 Introduction

Spaceborne Deposit Signature (SDS) modeling means the typical deposit features of major ore-controlling factors, inclusive of structures, formations, dikes, etc. using air- or space-acquired data. Since the genesis of gold deposits is quite complicated and the recognition of alteration signatures involves a wide range of methods and techniques, the SDS model in question was established based upon spectral characteristics of surface objects. Image processing, geological interpretation, research on gold mineralization patterns, and field survey results led to the understanding of image features of various ore-controlling factors and their recognition criteria. One had to pay attention to the study of regional metallogenic conditions, in order to extract as much useful information as possible.

Following the fact that image processing is the basis for establishing the SDS model, various image enhancement techniques were employed in order to get typical image signatures, which truly represent the mineralization process.

2 Materials and Methods

Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) images, acquired in 1980, 2000 and on 12th June 2000, respectively, were used in the analysis. The images were projected on the Universal Transverse Mercator (UTM) coordinate system, Krasovsky spheroid. Image processing was carried out using ERDAS IMAGINE software (version 8. 5) . Maps were drawn with ERDAS MapSheets™ and ViewFinder (version 2. 1) software. Geologic structural figures were drawn using the CorelDraw software.

2. 1 Spatial, spectral and radiometric enhancement

Contrast stretching, density slicing, spatial filtering,

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Fourier transforms, brightness inversion of the digital numbers (DNs), band combinations and band ratioing functions were used for spatial, spectral and radiometric enhancement of the rocks and their alteration styles.

Applying techniques suggested by Crippen[1] and Crippen et al.[2], the following structures were targeted: lineaments, fault lines, discontinuities, dikes, fractures etc. Target alteration styles were iron oxides (goethite and limonite) and clays (propylitic: gypsum-chlorite-epidote-K-feldspar-calcite-albite-adularia; argillic: montmorillonite-illite/smectite-quartz-kaolin-chlorite; sericitic: quartz-sericite-pyrite).

Finally, the image interpretation results, coupled with the knowledge of distribution regularities of gold mineralization and their host-rocks' petrology, led to establishment of the deposit image model.

2.2 Process of establishment of deposit model

Three steps were followed in establishing the Paishanlou gold deposit model.

a) Comprehensive rock petrology and minerogenetic studies were carried out, whereby all host rock-types were identified.

b) Based on satellite data enhancement, interrogation and interpretation, scrutiny of the following signatures and patterns was done: (i) Extensional geologic structures associated with gold deposition were mapped. These included antiforms, synforms, fault lines, dikes, breccias, stockworks, etc. (ii) Areas of hydrothermal alteration styles (i.e. propylitic, sericitic and argillic clays) and mineral composites (i.e. oxides of Fe^{2+} and Fe^{3+}) were mapped. (iii) Different types of gold deposits were distinguished based on their host-rocks reflectance on satellite data.

c) Due to resultant signatures and patterns on Landsat MSS, TM and ETM+ images, new gold-mineralized sites were explored.

3 Results and Discussion

3.1 Gold mineralization patterns at Paishanlou

The study on the distribution regularities of mineralization is a key link to establishing the SDS model. It is also the basis of determining prognosis guides. Having conducted geological investigations in the field, the distribution regularities of gold mineralization in the studied area are summarized as follows:

a) Gold minerals are contained in fine-grained pyrite and silicified zones, associated with metamorphosed Precambrian rocks. The host rock is composed of gneiss, mylonite and trondhjemite granite, and has a distinctive gold-lead geochemical affinity. The mineralogy of the gold-bearing rocks includes quartz, clays, biotite, calcite, pyrite, epidote, sericite, microcline, feldspars and muscovite.

b) The structure control, which occurred along the Jinzhou-Fuxin deformation zone, is very well expressed (Figs. 1 and 2). By interpreting satellite data, the Paishanlou area has been found to be located within this deformation zone.

c) Gold mineralization at Paishanlou is accompanied by intense alteration of silica and pyrite. The gold bearing rocks in the studied areas were formed in an alteration complex of medium temperature and pressure. The area was under polymetamorphism — ductile shearing and hydrothermal metamorphism (Figs. 3 and 4). The rocks were under intense metamorphism such as dehydration, decarbonation and unmixing; also, propylitic, phyllic or sericitic and argillic alteration styles have occurred in the area.

d) According to the interpretation of satellite imageries, gold mineralization at the studied area is obviously controlled by structures. The structural framework consists of Neoarchean central uplift zone and subsidence zones on both sides of the uplift, which is situated along the Sino-Korean Craton-West Liaoning-Hebei-Shanxi metamorphic belt (granulite-orthogneiss). This area was under the influence of Neoarchean tectonic movement and banded iron formation (BIF, Algoma Fe), with isotopic ages of about 2 500 to 2 600 Ma. Mineralized zones are controlled by deep-seated faults, which have undergone long-term activities, displaying a distribution pattern of electromagnetic trending (Figs. 3 and 4). The deposits are located at the intersections of northeast- and east-striking faults, and in high order or small-scale fault structures. Ore-body localizing structures dominantly depend on mineralization types. Generally, quartz-vein type occurs in shear-zone structures, while altered-rock types are located in compressive or compressive-shearing struc-

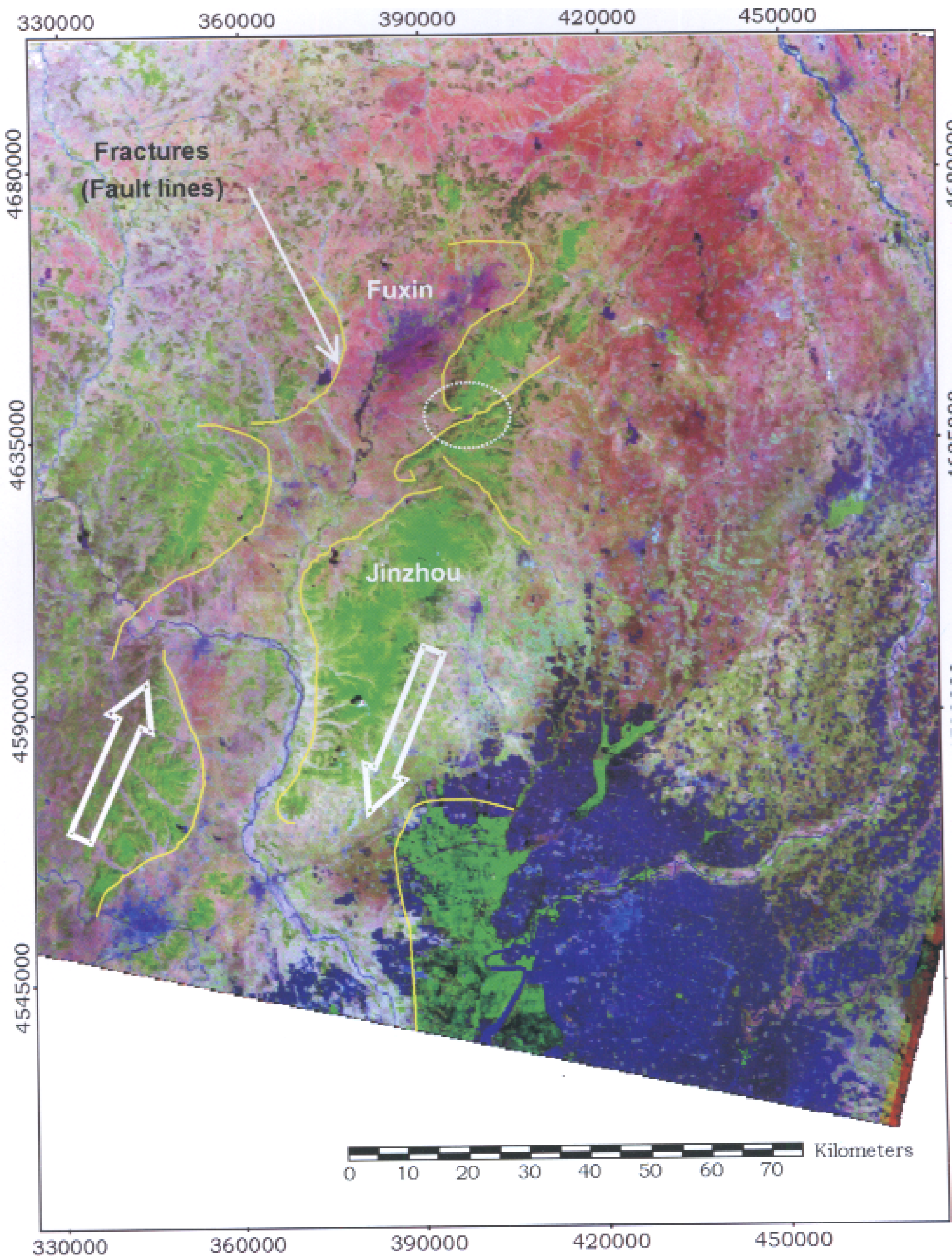

Fig. 1　Landsat ETM+ imagery bands 7-4-2 RGB, showing the Jinzhou-Fuxin accommodation zone

图 1　反映锦州 – 阜新地区构造变形带的陆地卫星 ETM+ 影像图

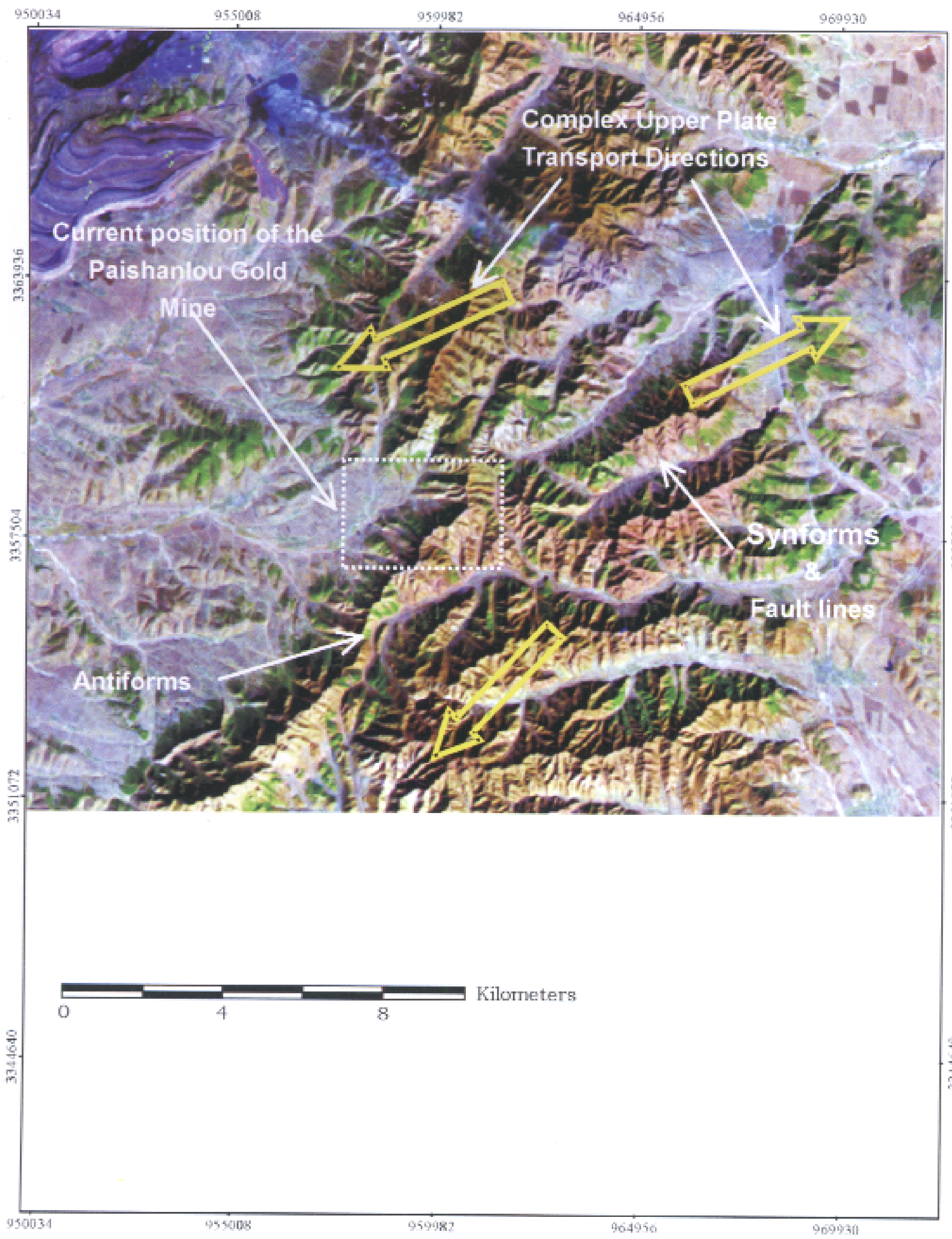

Fig. 2 Landsat MSS imagery bands 4-3-1 RGB, illustrating antiforms, synforms and fault lines at the Paishanlou area. PGM fits well within this newly interpreted accommodation zone

图 2 反映排山楼地区线形构造的陆地卫星 MSS 影像图

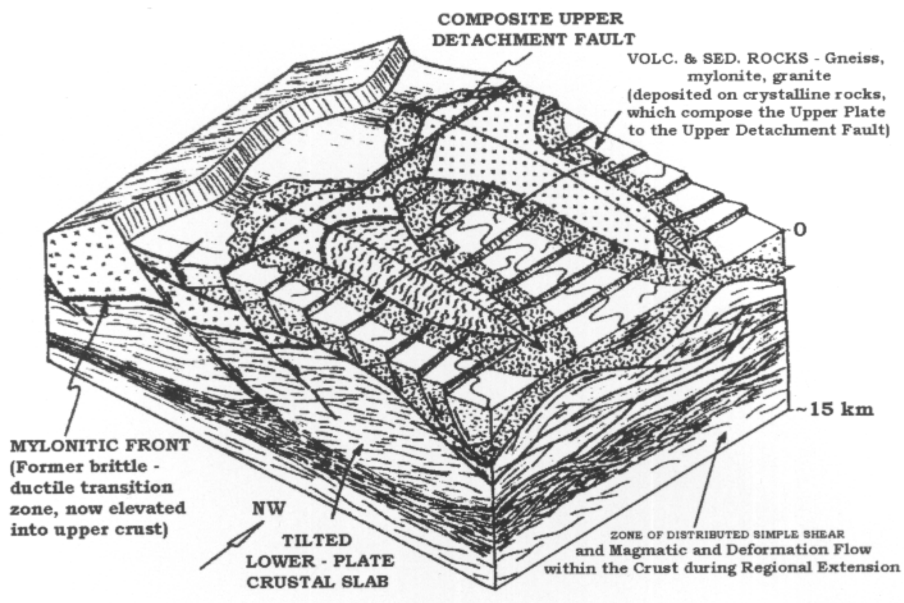

Fig. 3　Diagrammatic model of crustal extension showing truncation of upper-plate normal faults at depth into a gently inclined detachment zone

图 3　地壳拉张模式示意图

板块上部的正断层在深部变成缓倾斜的拆离带

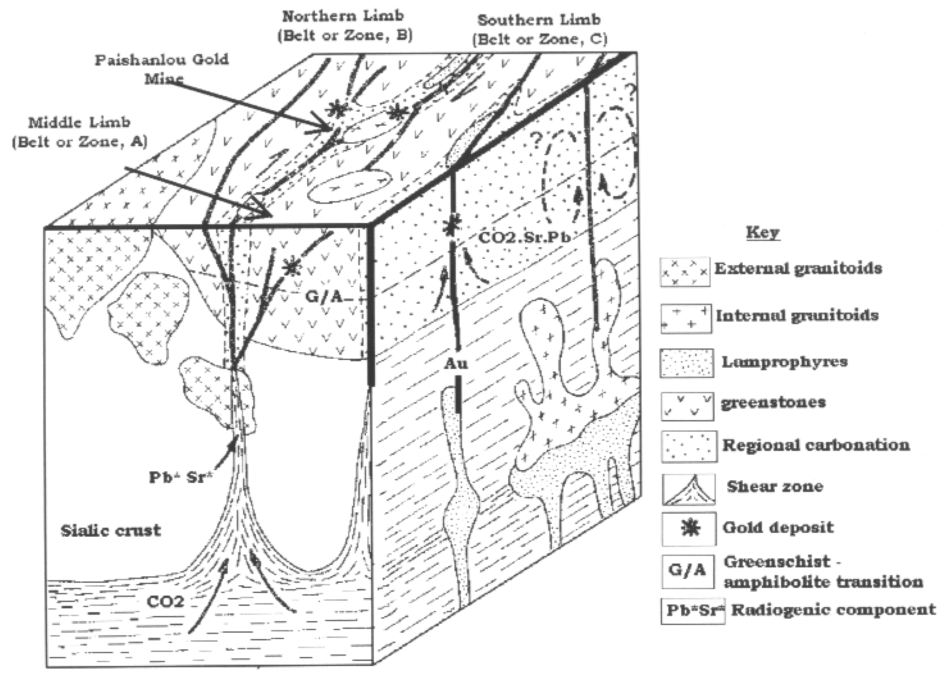

Fig. 4　Proposed schematic diagram showing genetic belts of hydrothermal gold deposits at the Paishanlou area

图 4　排山楼金矿热液成矿带示意图

tures (ductile shear zones).

e) Gold deposits of different types display zonal distribution, which is obvious in the Paishanlou area (Fig. 4 and 5). The orefield can be partitioned into three mineralized zones: (i) north zone (volcanic-type gold deposit zone); (ii) middle zone (granite-type zone); and (iii) south zone (mixed-type zone).

f) Gold mineralization is restricted within gold-source formations. Intermediate-basic volcanic formations are important gold-source formations in the stud-

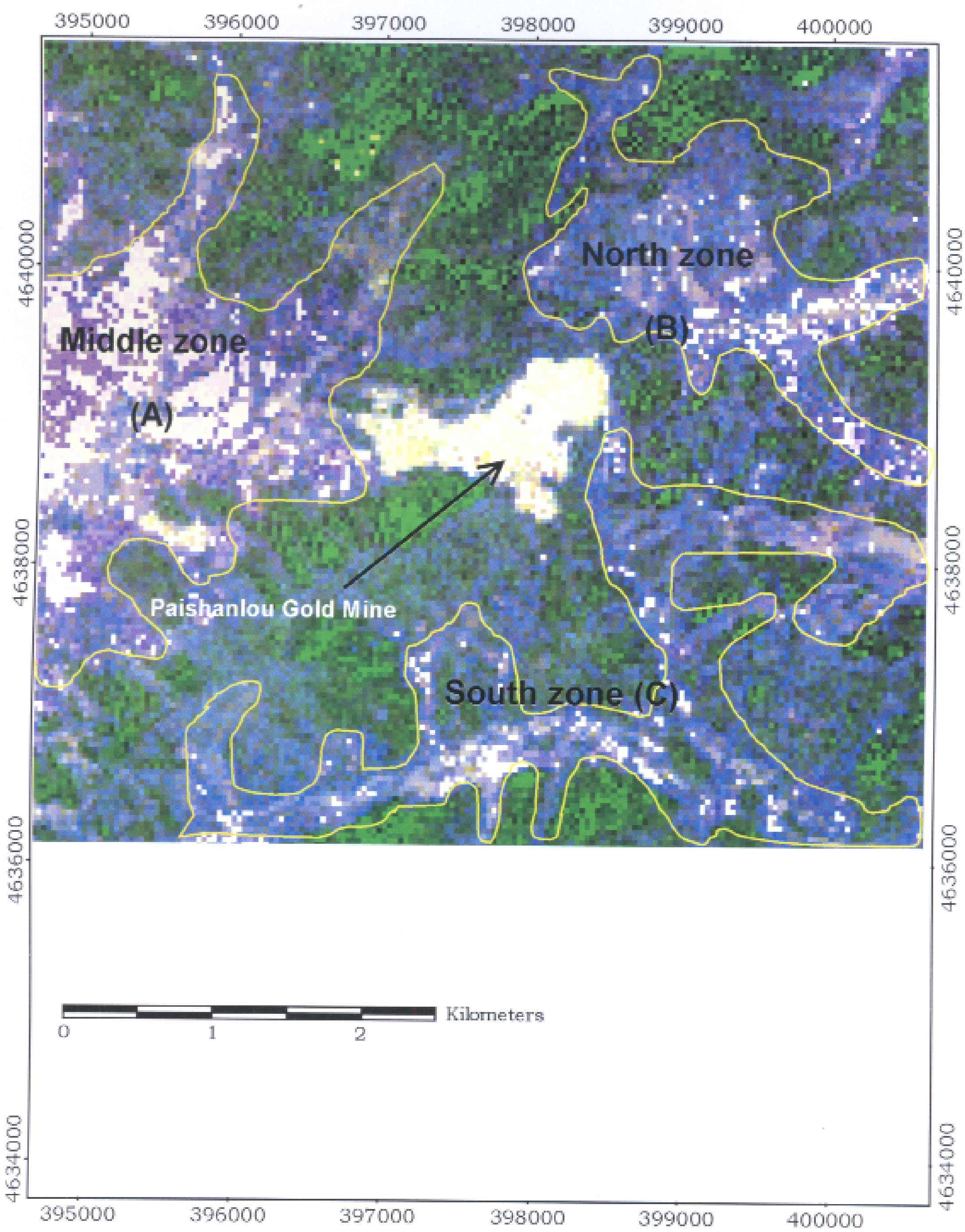

Fig. 5 Landsat ETM+ hydrothermal ratio image, depicting variations in clays and hydroxyl-bearing minerals (and/or carbonates) in yellow or pale yellow (5/7); and ferric and ferrous iron content variations in purple(3/1) and blue(4/3).

图 5 反映不同热液蚀变程度的陆地卫星 ETM+ 影像

ied area. For example, gold mineralization is strictly controlled by bimodal volcanic formations of Neoarchean (the northern and southern zones, belts or limbs) and intermediate-basic volcanic formation of Ordovician-Silurian and Carboniferous systems, demonstrating that gold mineralization tends to be developed in pre-existing gold-source formations.

g) Gold mineralization is related to Middle-Late Variscian magmatism and hydrothermalism. The granites relevant to gold mineralization are mostly intermediate (acidic-intermediate granites, belonging to a group of granodiorite and taking the shape of small irregular intrusions such as offshoots and stockworks) . Gold mineralization has a close (time and space) relationship to hydrothermal activities derived from the Variscian acidic-intermediate magmatism, which provided favorable conditions for gold migration and concentration (Fig. 4).

3.2 Establishment of the SDS model

3.2.1 The granite-type SDS model

a) The gold-productive intrusive bodies are granites and granodiorites, which are in shapes of stocks and offshoots (Fig. 4 and 5) . The granites of this area have higher reflectance, showing yellow colors, making it easy to be discerned on Landsat ETM+ images. Figures 3 and 5 show that, an east-west oriented fault controls these granite bodies, which are distributed in zones and branch-like forms (in shape of bead string) . Just as the faults are truncated at depth, they are truncated along strike by the wave-like, or fluted detachment surface (Fig. 3) . Such truncation of the upper-plate panels is readily visible on MSS, TM and ETM+ images and can be used to identify the presence and geometry of the major detachment faults.

b) Dikes and alterations are well developed in gold-productive granite bodies, demonstrating uneven blue, purple, pink and mottled colors on Landsat ETM+ images (Figs. 1 and 2).

c) The deposition of gold is controlled by regional east-west striking structure, occurring in its subsidiary faults. It is controlled by a group of subsidiary east-west striking quartz veins, exhibiting distinct light yellow features in the image (Fig. 5).

d) There is "color anomaly" in the range of every deposit. Different manifestations of image signatures were obtained with different image methods. For example, in Fig. 2, the color anomalies of eastern areas display a light purple or pink color, which differs from that of the surrounding granites in the color composite image (bands 4, 5, 7). Meanwhile, the ratio composite image (Fig. 5) is expressed as a bright, light yellow or pink color. Better-expressed color anomalies can be seen in Fig. 5. Widespread altered rocks, closely associated with gold mineralization, must have caused these colors.

3.2.2 The volcanic rock-type SDS model

a) The intermediate-basic volcanic formation is controlled by faults, displaying a zonal distribution of east-west orientation. These formations are expressed as white, purple or pale pink on color composite images (Figs. 1 and 2).

b) Deposits are emplaced at the intersections of granites (blue or purple) and faults (pink or whitish), which can be easily recognized in Figure 2.

c) Light-colored alterations related to gold mineralization display gray, light gray and light green in the color composite image (bands 4, 5, 7) . In contrast, with a dark-blue background color caused by intermediate-basic volcanic rocks, the light-colored alterations are distinguished and their spatial distribution is easily delineated.

d) Late small intrusive bodies, which are closely relevant to gold mineralization in space and time, show light purple colors in the color composite image (bands 4, 5, 7). In addition, circular structures, which reflect the center of volcanic activities, are important image signatures for this type of deposits.

3.2.3 The metamorphic rock-type SDS model

Metamorphic rock-type deposits in the studied area are referred to those occurring in the Paleoproterozoic and Ordovician-Silurian metamorphic rocks.

a) The Paleoproterozoic rocks comprise (in ascending order) magmatite, hornblende and gneiss; whereby, in the upper part, metamorphic rock formations characterized the occurrences of bi-modal volcanic rocks. In the principal transform image, migmatite and different degrees of magmatization are well displayed. Bimodal volcanic rocks display dark brown colors on both 2, 7, 5- and 4, 5, 7-band color composite images. So the regional distribution of the third subgroup of Paleoproterozoic (target horizon for occurrence of gold deposits) is distinctly demonstrated. In some areas, these target horizons are controlled by an east-west folding, symmetrically showing zonal distribution along the north and south limbs of the fold.

b) In some areas, combination characteristics of image signatures, which reflect different lithological assemblages, vary distinctly. Ore-bearing strata (basic and intermediate volcanic rocks) display a dark brown color, while granites and quartz diorites display light gray. The dark-red brown color shows alternating banded signatures in the color composite image (bands 2, 7, 5).

c) The light-colored alteration displays gray and light blue in the color composite (bands 1, 7, 5), exhibiting narrow bands and a linear distribution. These image features are remarkably distinct from the dark brown background, which is caused by ore-bearing formations.

3.3 Target optimization

The final purpose of the study on geology, metallogenic regularities and image features of the Paishanlou area was to optimize targets. Based on the analyses of regional geological evolution and gold mineralization distribution regularities, the prognosis criteria of the Paishanlou gold deposits were determined. Exploring the inherent links between the prognosis criteria and image features, and converting the ore-controlling factors (including structures, intrusive bodies, gold-source formations, alterations, etc.) into recognizable sites in the field, three favorable areas (middle, north, and south zones) were predicted.

Taking Figures 4 and 5 for example, according to the established SDS model, considering favorable structures and gold source conditions, image features of ore-bearing granite bodies were also an important criterion in predicting potential areas. The color composite method was used to sieve favorable granite bodies having image features similar to known mineralized granitic bodies at Paishanlou.

3.4 Results after applying the model

This study has successfully demonstrated that, the application of Landsat MSS, TM and ETM+ data, coupled with geochemical and field surveying information, is such a powerful tool that can sufficiently be used in assessing mineral potentials through identification of areas of hydrothermal alteration and geochemical anomalies. Results of satellite image processing revealed strong alteration signatures for potentially gold-mineralized deposits at Paishanlou Gold Mine. Such strong signatures clearly merit further investigation, using more sophisticated airborne data sources such as radar.

After selecting favorable areas, field check was done. Investigations indicated that geochemical anomalies, which represent gold mineralization, had been found in all of the three predicted areas. These results are satisfactory.

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References:

[1] Crippen R E. Development of remote sensing techniques for the investigation of neo-tectonic activity, Eastern Transverse Ranges and Vicinity, Southern California [D]. Ph. D. thesis, University of California, Santa Barbara. 1989. 304.

[2] Crippen R E, Blom R G, Heyada J R. Directed band rationing for the retention of perceptually-independent topographic expression in chromaticity-enhanced imagery [J]. International Journal of Remote sensing, 1988, (9): 749-765.

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参考文献:

[1] 余德辉,王金南.'循环经济'好在哪里[N].经济日报,2001-12-16.
[2]解振华.关于循环经济理论与政策的几点思考[J].环境保护,2004,(1):3—8.
[3]刘成武,杨志荣,方中权,等编.自然资源论[M].北京:科学出版社,2002.
[4]周宏春.循环经济:一个值得重视的发展趋势[N].中国经济时报,2002-10-20.
[5]费伟伟.循环经济:必由之路[N].人民日报,2002-06-19.

RECYCLING ECONOMY: THE SCIENTIFIC FOUNDATION FOR RATIONAL DEVELOPMENT AND UTILIZATION OF RESOURCES

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Abstract: The issues of resources crisis or resources security brought by continuous growth of the world economies urge the quest for a new idea of aggregate resources conservation and circulation economy. Based on ecological law, the paper points out that the economic development in China means to relieve the pressure of resources and to set up a basic model for sustainable development in economy in accordance with the circular model of resource-production/consumption-renewable resources. The authors also set the conception and basic characteristics of Recycling Economy and discuss the necessity and feasibility of developing Recycling Economy in resources. Besides, some relevant countermeasure and suggestions for how to develop Recycling Economy in the resources domain are also brought forward.

Key words: recycling economy; resources development; sustainable utilization; development with coordination

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利用卫星数据建立排山楼热液石英脉型金矿模型

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摘　要:航天矿床标志模型(SDS)是遥感技术在矿床勘探中应用的结果.在遥感数据(陆地卫星 MSS、TM 和 ETM+ 图像)解译、地质特征及金矿化类型研究的基础上,总结了不同控矿因素及其鉴别特征.通过如下步骤建立模型:(1)选择适当的图像处理技术;(2)研究主要控矿因素(构造、地层、蚀变);(3)确定鉴别标志,建立矿床图像模型,优化找矿靶区.应用该模型优化靶区已获得成功.卫星影像处理显示,在 3 个区域(南带、中带、北带)具有反映金成矿的强烈蚀变特征.实地调查证明,这 3 个预测区具有金矿化,它们与常规勘探方法(地球物理、地球化学)发现的其他矿化相似.该模型在排山楼地区的应用结果表明,卫星数据在金矿普查中可以发挥重要作用.

关键词:航天矿床标志模型(SDS);断裂;热液蚀变标志;排山楼金矿