Remote sensing survey and image analysis of geological relics in Anhui Province, East China

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Abstract: Geological relics are precious non-renewable natural resources that formed, developed and left over from long evolutional history of the earth due to the internal and external forces of geological process. In recent years, with establishment of geological parks, much attention has been paid to develop and protect geological relics, which bear values in terms of scientific research, tourism and economy. As early as in 1989, UNESCO formed geological relics working group that is responsible for protection of global geological relics. There are widespread and various geological relics existing in Anhui Province. It is important to quickly and effectively find out spatial distribution characteristics, locations, types and amounts of geological relics in the province. Based on multi-sourced and multi-spatial resolution remote sensing data, such as ETM, SPOT-5, RapidEye, QuickBird, WorldView-2, IKONOS, GeoEye, YG-2, Radarsat-2 and air photos, through image preprocess, image enhancement of linear information, image stretching, different band synthesizing for different geological bodies, image feature, hue, spatial combination relation and spectrum feature of various geological bodies were analyzed from different spatial scales. Then, remote sensing interpretation marks for typical geological relics were established, and the main geological relics were extracted by visual interpretation combined with field survey. The results show that there are 180 sites of geological relics in the province and 133 of these sites are significant; regional distribution features of geological relics were got and remote sensing image interpretation marks have been formed for major geological relics, which mainly include: (1) structural features, represented by the Tan-Lu Fault Zone; (2) geomorphologic landscapes, such as the Huangshan granite landform, East Anhui and Lu-Zong volcanic landform represented by the Nvshan caldera in Mingguang City, and the Dashushan volcanic landscape in Hefei City; (3) water body landscapes,

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represented by the Chaohu Lake; (4) geological hazard relics, represented by Shitai debris flow.

Key words: geological relics, interpretation marks, multi-scale, image feature, Anhui Province

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1 INTRODUCTION

Geological relics, also called geological heritage, refers to precious non-renewable geological natural remains that formed, developed and left over from long geological periods and geological processes, both internal and external (Zhang, et al.,2009). Geological relics are special, due to their relative rareness, non-renewable, visual fragileness, non-duplication and non-removability (Wu, 2012).As early as in 1989, UNESCO formed a geological relics working group responsible for relevant protection (Weng, et al., 2010). In 1997, it was passed to create a global network of geological relics with unique geological features (Li， 2000). In 1999, the world geological park program was formally started. At the turn of the century, UNESCO put forward a goal to form a total of 500 geological relics' parks at a rate of 20 per year, that created a new situation of geologic relic landscape protection and utilization (Xie，2006). Strict protection and reasonable utilization of geological relics are an important content in economic sustainable development strategy of human society. The precondition of carrying out protection and utilization is how to quickly and effectively discover the spatial distribution, location, kind, amount and scale of geological relics. As a kind of advanced earth observation technology, remote sensing is macro, actual, swift and wide-detecting and provides us with reliable information such as spectral signatures of landforms, geological structures and surface features. The interpreting use of geological data and remote sensing in survey of geological relics is unrivaled by any other method.

2 STUDY AREA

The Anhui Province lies in southeastern part of China, lower reaches of the Yangtze River and the hinterland of East China, which is a transitional zone between the south and north, the east and west in the eastern part of the country. Its geographic coordinates are in the range of 29°25′-34°40′N and 114°45′-119°50′ E, covering 139600 km^2 in area, where landforms are diversified; the Yangtze River and Huai River flow through from west to east, thus dividing the land into the Huaibei Plain, Janghuai Rolling Plain, Wanxi Hilly Area, Wannan Hilly Area and Yanjiang Hilly Plain (Fig. 1). Geological relics show spatial imbalance in abundance and density. They are maximum in kinds, quantity and density in Huangshan, Anqing and Lu'an Cities, such the famous Huangshan World Geopark with both natural and cultural relics, the Tianzhushan World Geopark, and the Dabieshan National Geopark, etc.

3 DATA ACQUISITION AND PROCESSING

By using multi-sourced, multi-spatial resolution remote sensing data, with ERDAS 9.2 and ArcGIS 10.0 as data processing platform, this paper made geometric correction and orthorectification, PAN and multi-spectral data merging, different source data merging, different wave band composition of different geological body, natural false color composition, inlaying and enhancement, so as to achieve accurate extraction of geological relics information.

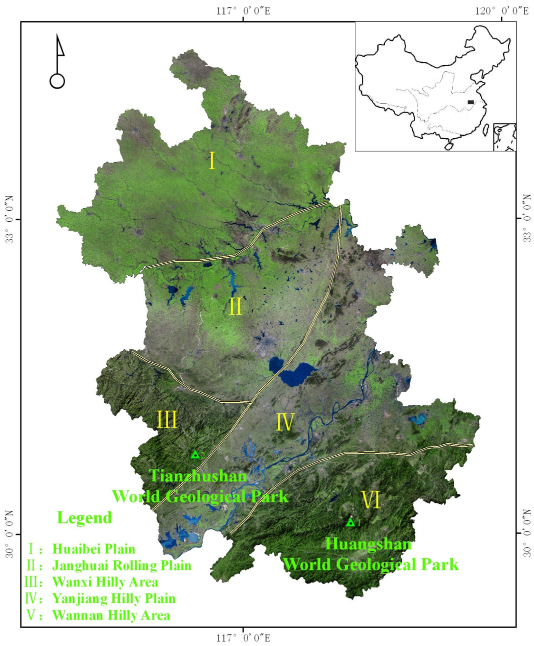


Fig. 1 Geographical location and the remote sensing image of Anhui Province

3.1 Data acquisition

Remote sensing data sources used in the study include ETM, SPOT-5, RapidEye, QuickBird, WorldView-2, IKONOS, GeoEye, YG-2, Radarsat-2 and air photos, with resolution ranging from 0.61 m to 30 m, of which the 5 m-resolution data cover the whole province. The details of these data are shown in Table 1.

Table 1 Parameters of various remote sensing data

Data type	Resolution	Data coverage	Map scale	Purpose
ETM, Beijing No.1	30 m, 32 m	139600 km^2	1: 250000	Used for recognition of landform type and bigger structural features
SPOT-5, RapidEye, YG-2	2.5 m, 5 m	139600 km^2	1: 50000	Used for survey of middle-sized structural features, linear and circular structures, volcanic and granite landforms
QuickBird, WorldView-2, IKONOS, GeoEye, air photos	0.61 m, 1 m	45000 km^2	1: 10000	Used for survey of typical geological relics, geo-hazard relics, ancient smelter relics, etc.

The basic geographic data include: a. Collecting regional geological records, 1: 200000 and 1: 50000 regional geological survey reports, Geological Relics Protection Plan of Anhui Province, etc. b. Collecting 1: 10000, 1: 50000, 1: 250000 geographic maps, DEM data from Radarsat-2 Differential InSAR, and DEM data derived from P5 data, used for geometric correction and orthorectification.

3.2 Image processing

Geometric correction is based on 1: 10000 and 1: 50000 geographic maps as reference coordinates by using 1980 Xi'an coordinate system and Gauss-Kruger 6-degree zone projection. About 20-40 control points such as easily recognized, clear and distinctive-featured road crosses, water-land border points, are evenly chosen from remote sensing image. Geometric correction is performed by using polynomial and bilinear interpolation, with RMS less than 1 pixel. Orthorectification is conducted with corresponding orthoscopic model and DEM in ERDAS 9.2 to meet the need of geological relic's survey.

Two kinds of merging have been done in this study: a) merging of same-sourced data, such as multi-spectral and full-color image, which keeps original spectral features and improves spatial detail expression; b) merging of different-sensor data, which betters image resolution and fulfills superimposition of geometric information, having very good effect of information complementation. Merging methods applied include IHS converter technique, PCA, wavelet transform, Brovey method, linear weighted method for middle- and lower-resolution image, and Pansharping for high-resolution QuickBird and GeoEye image, all produced good results(Chu, et al.,2009; Yang, et al.,2003; Qi, et al.,2003). Enhancement methods used are linear transformation, piecewise linear transformation, non-linear transformation, histogram equalization, highlighting local details of geological relics. After merging and enhancement, remote sensing image becomes more outstanding in linear, circular, appearance and texture features, and the image gets clearer, richer in color and more distinctive in layers, better reflecting the image features of geologic relics and making them more recognizable (Fig. 2).

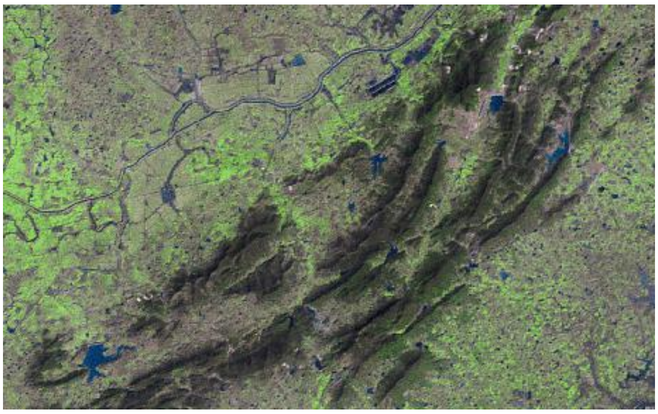


Fig. 2 Remote sensing image after merging and enhancement

4 ESTABLISHMENT OF INTERPRETATION MARKS AND IMAGE ANALYSIS

Spectral features of ground objects decide image features of the objects on remote sensing image. Interpretation marks are established on the basis of analysis of the appearance, size, hue, shadow, spatial combination relationship and spectral features of various geological relics shown on the remote sensing image, and of related geological, topographical, soil, hydrological, vegetation, climate and human activity factors, which are important to quickly interpret different geological relics on different spatial scales (Yang,1988; Wang, et al.,2010).

4.1 Structural features

(1) Linear structure. Linear structures are shown on remote sensing image as very distinguished spatial extension of lines or belts. As a result of structural faulting activity, both sides of fault and the fault itself are evidently different from the neighboring area in aquifer, rock composition and texture, and even the vegetation, all these will have anomalous reflections on spectra, showing differences in image hue, texture and water system pattern. These differences become interpretation marks of linear structures, such as the biggest and most famous Tan-Lu Fault in eastern China, which is a major fault zone among a series of NNE huge faults in the East Asia continent and well-developed in Anhui Province with representative remote sensing features (Fig. 3).

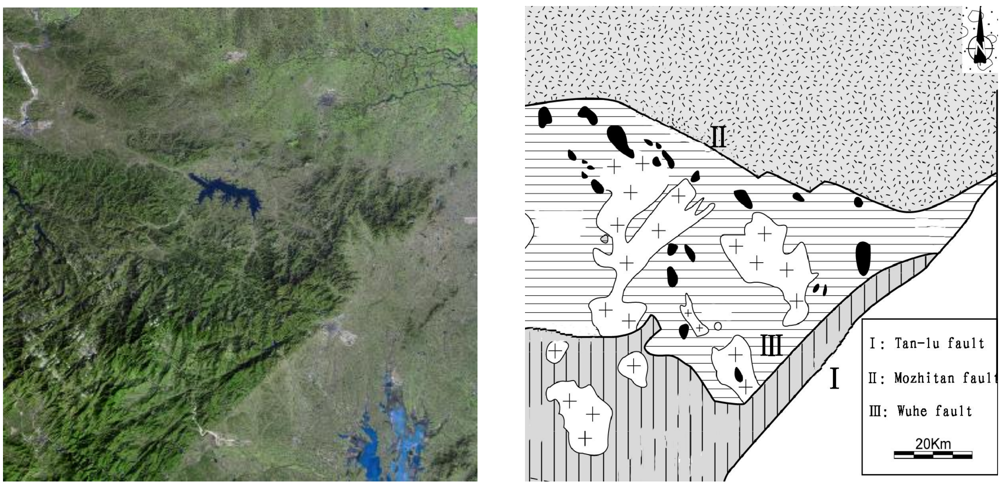
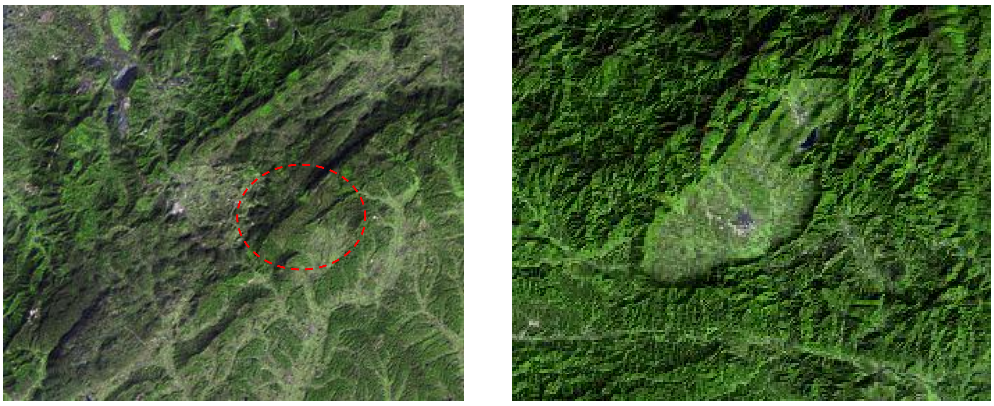


Fig. 3 Image of the Tan-Lu Fault Belt and its interpretation

(2) Circular structure. Circular structure is sub-rounded, hollow ring or arc-like pattern on the remote sensing image, resulted from landform, water system, hue or texture effect, specifically from fold, superimposed fold-formed dome or structural basin, hidden rise, down-warping basin, arc fault, turbine-like fault array, ring-like combined fault (Fig. 4).



(a) Ore-host circular structure (b) Intrusive body

Fig. 4 Interpretation markers and image features of circular structures

4.2 Geological landscapes

(1) Volcanic landform. Volcanic landscape is typically represented by volcanic vent in Anhui Province, which is shown on remote sensing image mainly as oval-shaped, horse-shoe-like, circular or radial pattern. Regionally, a single volcanic edifice mostly occurs as a separate cone or domal uplift, a combination of more volcanic edifices as banded, beaded or intersecting volcanic cluster, and their features on remote sensing image are represented by the Dashushan volcanic landscape in Hefei City and the Nvshan caldera in Mingguang City, respectively (Fig. 5).

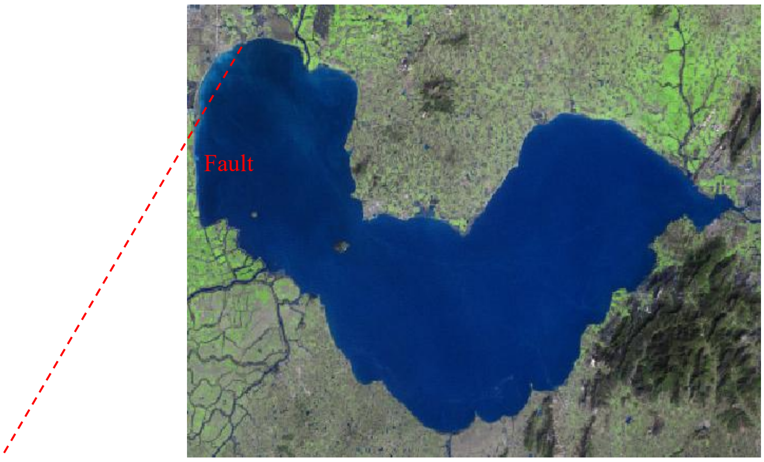
Fig. 5 Interpretation marks and remote sensing image features of volcanic vent

(2) Granite landform. Granite intrusive bodies are developed in Anhui Province, and they mainly compose the mountain bodies of Huangshan, Jiuhuashan, Tianzhushan and Guniujiang, which are shown as clear cut with darker vegetation hue, brownish green color on remote sensing images. Owing to weathering, the exposed granite rock has higher reflection, shown as white color; as a result of geo-structural process, it shows mutual cuttings, a number of radial linear structures interweaving inside a ring. See the typical remote sensing image interpretation marks of granite landforms from the Huangshan World Geopark, as shown in Fig. 6.

Fig. 6 The Huangshan granite landform and its image features

4.3 Water body landscape

In terms of geological relics, water body landscape is generally in the form of a river, lake, waterfall or spring, and shown on remote sensing image as a single hue, such as blue, dark blue, mesh-like, tree-like pattern, also resulted from geo-structural process. See the Chaohu Lake for typical remote sensing interpretation marks, which is mainly controlled by the Tan-Lu Fault, Quanjiao-Huailinzui Fault, Dongguan Fault and Hefei-Huailinzui Fault, totaling 7 in number. Some structural lakes such as the Taiping Lake and Huatinghu Reservoir have the same origin (Fig. 6).



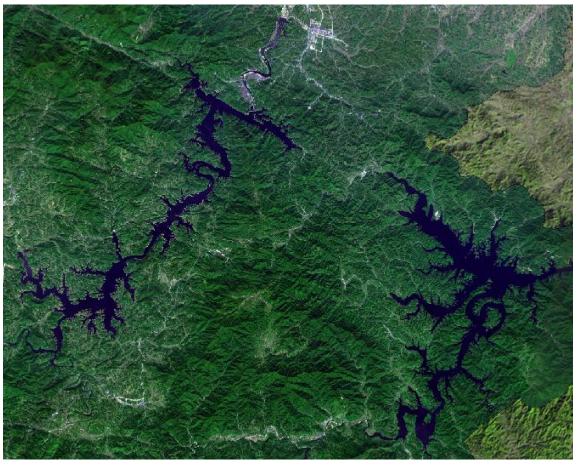


Fig. 6 Interpretation marks and remote sensing image features of water bodies

4.4 Geo-hazard relic landscape

Geo-hazard relics are mainly cavings, landslides, mudflows, depressions in Anhui Province, recognizable on high-resolution remote sensing images or air photos. Cavings occur along valley, river, railway, highway in steep slope sections. Sunny slope is shown as light hue and shady slope dark shadow and irregular patch on image. Landslide mostly occurs in local depressing sections of steep slope of a valley or river. The hue is relatively dark for the edge of landslide mass due to increased aquosity. Natural ditches have deep cut on both sides of the landslide mass, behind which is developed arc anomaly on image. Frontal slope bulges toward valley, typically with small terrain bump or caving deposit. Mudflow is mostly tongue-like, cone-like or fan-like pattern with clear border. Banded flowline and semi-ring stripe are frequently seen in mudflow mass, which are usually developed in gully with flow regime, developed into radial gully (Fig. 7). Depressions often occur around a mine, and water surface in a depressed area is dark in hue, different from blue for usual water body.

5 EXTRACTION OF GEOLOGICAL RELIC INFORMATION AND ANALYSIS OF SURVEY RESULT

Information extraction of geological relics is based on ArcGIS 10.0 platform. According to relevant interpretation marks and spectral information of image, we use visual interpretation to recognize geological relics on remote sensing image, then summarize regional distribution and characteristics of the relics.

5.1 Information extraction method of geological relic

The method used for visual interpretation includes direct interpretation, correlation and reasoning: a) direct interpretation refers to direct locating various geological bodies, volcanic cones, faults, etc. on remote sensing image; b) correlation is putting together with landsat image, air photo and geological bodies to check and supplement each other; c) reasoning is based on relations between geological bodies, geological phenomena and other landform elements to make comprehensive analysis and logic reasoning by using geology, geomorphology, hydrology and botany, then determine attribute of an object.

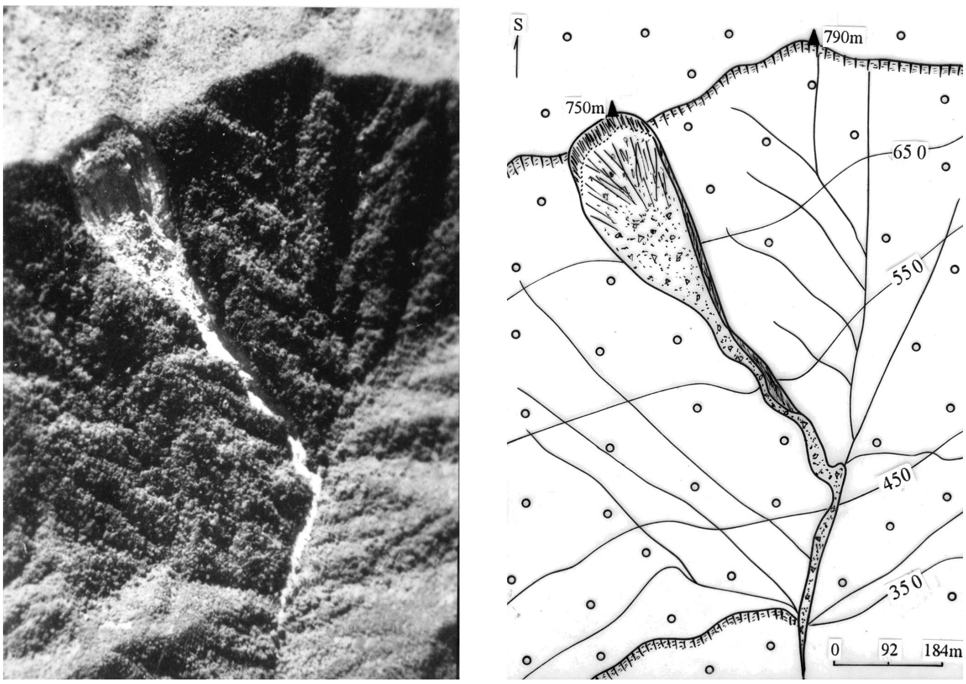


Fig. 7 Features of mudflow hazard on air photo

5.2 Information extraction contents of geological relic

(1) Structural features. Tectonically, Anhui Province lies on the Sino-Korea paraplatform, the Qinling fold system and the Yangtze paraplatform, with complicated geo-structures. Based on spectral features of interpretation marks and structural features, many fault elements can be seen directly on remote sensing image, such as stratum, rock vein, ore body and fold which are cut and displaced.

Interpretations have been made for folds and faults on different scales of image in terms of location, structural size, nature, exposed form, and spatial structure composed by geological bodies or structural features and their sequence of formation. There are 80 sites of structural features extracted in the study area, such as the Tan-Lu Fault, Wanxi Grand Rift in Lu’an City and Tangkou Deep Fault.

(2) Geological landscapes. Based on spectral features of interpretation marks and landforms, we have made classifications for volcanic landform, granite landform and Danxia landform, and determined the scale, range, shape, combination, structural relation and geographic distribution of landforms. There are 56 sites of landscapes that have been interpreted over the whole province, such as the Huangshan granite landform, the Jiuhuashan granite landform and the Xiuning Danxia landform.

(3) Water body landscape relics. According to structures, shapes and spectral features, we have extracted typical structural lakes in the study area and interpreted the location, area, type and geological origin of water body landscapes. There are 22 sites of water body landscapes extracted, such as the Chaohu Lake, Taiping Lake and Huating Lake.

(4) Geo-hazard relics. Geo-hazard relics are mainly recognized on high-resolution images and air photos. According to interpretation marks, the scopes are outlined for cavings, landslides and mudflows to determine their type, scale, distribution pattern and structural forms. There are 12 sites of geo-hazards extracted in the study area, such as the Huainan caving areas and the Shitai mudflows.

5.3 Kinds and quantities of Geological relic

Based on remote sensing interpretation of geological relics and field survey, we have discovered basic geological relic resources in Anhui Province. Generally, there are 180 sites of geological relics in the whole province, of which 133 are of significance. The details of these data are shown in Table 2.

Table 2 Kinds and quantities of geological relics in Anhui

Kinds	Geo-structural features	Geological landscapes	Water body landscapes	Geo-hazard relics
Quantities	80	66	22	12

5.4 Regional distribution and characteristics of geological relics

Various geological relic landscapes in Anhui have recorded a history of 3 billion years of tectonic evolution in the province, and their formation conditions, development characteristics and reserving environments are closely related to specific geo-structural settings in the province. They are remarkably controlled by geo-structural conditions and natural geographic environments in terms of spatial distribution, genetic condition, development pattern and outcropping feature. Seen from the quantity surveyed and distribution of geological relics, the relic landscapes roughly fall in: a) the North Anhui geological relic area; b) the Middle Anhui geological relic area; c) the along-Yangtze River multi-geological relic area; d) the Dabieshan multi-geological relic area; e) the South Anhui multi-geological relic area. The relics show characteristics as following: 1) natural regionalism and natural differentiation in spatial distribution; 2) relatively concentrated in several administrative areas;

3) controlled by geo-structural conditions; 4) co-existing of different geological relic landscapes in space.

6 CONCLUSIONS

(1) With remote sensing as technical means, this paper has systematically and completely discovered the basic conditions of geological relic resources for the first time in the province, accurately determined the location, quantity, kind and scale of the relics, and provided basic data and important basis for development and protection of the relics.

(2) According to regional distribution of geological relics, it has summarized regional distribution features of the relics in the province.

(3) Remote sensing interpretation marks have been established for major geological relics in the province, and image features were also analyzed.

(4) Remote sensing technique is applicable to quick, accurate and effective survey of geological relic conditions in a wide area by using multi-sourced and multi-spatial resolution remote sensing image, to make up for the deficiency of some traditional methods.

(5) It has been proven in practice that earth observation technology has potential in survey of geological relics. This study is a helpful practice and provides a demonstration for carrying out similar work in the future.

REFERENCES

1、Zhang Guoqing.Tian Mingzhong. 2009.The Methods of Investingation and Evaluation of Geological Heritage Resources.*Journal of mountain science*.2009(5).361-369.

2、Wu Zhaoqian. 2012. Geological classification and evaluation of Anhui Province.*Journal of Anhui Province situation*. http://www.anhuiinfo.com/info/?id=16820.

3、Weng Wangfei,Gong qian. 2010. Geological relic resources types and development direction analysis.*Journal of Leshan Teachers College*. 25(5).33-37.

4、Li Minglu,Jiang Jianjun. 2000. Chinese geological heritage and its protection research. *Geology in CHINA*. 277（6）.31-34.

5、Xie Yanping. 2006. Studies on Geo-relices of Geoparks in ZheJiang Province and Coordination between its Conserbation and exploitation.Master dissertation of Zhejiang University.2006.2-3.

6、Chu Jinhai,Peng peng. 2009. The fusion method for quickbird data in mine remote sensing monitoring.*Renote sensing for land &resources*.2009(3),107-113.

7、Yang Wunian,Pu Guoliang. 2003. Digital processing and information extraction of multi-type and multi-temporal remote sensing images for geological hazard in the Yangtze three gorges project region ,CHINA. *Journal of Chengdu University of technology (Science &Technology Edition)*.30(4):378-384.

8、Qi Yueming,Cheng Qiguo. 2003. The Study of the East-west Faulttectonics in the Central and Southern Area of Anhui Province Based on the Remote Sensing Technique.*WEST-CHINA EXPLORATION ENGINEERING*.90(11).77-79.

9、Yang Bailing. 1988. Geological interpretation of synthetical aerial remote sensing data in exposed district. *Chinese Journal of geology*.1988.2.188-195.

10、Wang Gengming,WANG Lihua. 2010. Research on remote sensing extraction of geologic structures in Guangzhou area Guangdong Province based on spot data. *Marine Geology Letters*.26(1).21-24.