Journal of The Korea Society of Computer and Information
Vol. 20 No. 12, pp. 91-99, December 2015
www.ksci.re.kr
http://dx.doi.org/10.9708/jksci.2015.20.12.091

GIS-based Metallogenic Prognosis of Lead-Zinc Deposits in China

Tang Panke*, Wang Chunyan**

Abstract

In this paper, we introduce the application of several currently-representative methods for mineral resources potential assessment on Geographic information system(hereinafter referred to as GIS), and combined with mineral resources potential assessment performed in China and with lead-zinc deposits taken as an example, summarized and divided minerals prediction and assessment models; on this basis, this paper presented the process of metallogenic prognosis based on MRAS platform, and made a simple analysis on existing problems.

▸ Keyword : GIS, Mineral resources potential assessment, Lead - zinc deposits, Mineral resources prediction and assessment model, MARS, Metallogenic prognosis

I. Introduction

GIS is an emerging technology which has developed rapidly since the 1960s [1]. It gathers computer science, geography, mapping remote sensing technology, space science, information science, environmental science and management into integral whole, organically combines drawing management system with data management system, and overcomes the inherent limitations of graphics system and database system and highlights their advantages. GIS can collect, store, analyse and express space information, process its space orientation characteristics, and organically combines space with attribute information. Recently, GIS has been widely applied into geoscientific field.

Mineral resources potential assessment (commonly called as metallogenic prognosis in China) is to extract useful ore-forming information from a large number of geological, geophysical, geochemical and remote sensing information data and information by modern geological theoretical and scientific methods, transform them into mineral resource information with a higher level of confidence by synthetic analysis, accordingly determine the mineralization-favorable locations of various minerals and further establish prospecting targets, and finally estimate the resources of delineated ore deposits. Thus, scientific prediction and assessment can be performed on occurrence possibility, quantity, quality and economic value of mineral resources in certain areas [2]. Mineral resources potential assessment is of great significance to rational development and utilization of mineral resources and sustainable economic development. The work of mineral resources potential assessment in China since 2006 is an significant resource condition survey with respect to non-oil important minerals; achievements from the work will provide decision basis for formulating mid- and long- term mining industry development plans and mineral resource strategy in China, as well as basis for formulating mid- and long- term economic development plans and deploying geological work. In this work, resource potential of various minerals in China is required to be identified as soon as possible within a shorter period, so as to provide basic information for future mining industries sustainable development. The essential

• First Author : Tang Panke, Corresponding Author : Wang Chunyan
*Tang Panke (tangpanke@163.com), China Non-ferrous Metals Resource Geological Survey, China
**Wang Chunyan (anna729@163.com), China Non-ferrous Metals Resource Geological Survey, China
• Received: 2015. 11. 04, Revised: 2015. 11. 21, Accepted: 2015. 12. 17.
• This study was financed by Subproject "Mineral Resources Patentability Assessment" of China Geological Survey and guided by related experts. Grateful acknowledgements are given to them here.

task is, on the basis of geological conditions of mineralization and regularity of ore formation, to make a rational assessment on mineral resources potential and utilizability of an area using various ore-forming theories and various kinds of geological information, delineate and estimate additional mineral resources, and make guide suggestions on exploration deployment in economical and technological aspects.

GIS technology has been widely applied in mineral resources potential assessment, which provides a possibility for rapid evaluation of mineral resources potential. In GIS platform, real space is simulated in vision, measurement and logic by applying spatial information models organized by computer programs and various kinds of geosciences information and data, various kinds of geological information are randomly extracted, increased and decreased, duplicated, decorated and transmitted, prediction personnel can effectively identify and extract prospecting information by different minerals prediction and evaluation models and prediction factors to finish quantitative prediction of different mineral resources.

II. Overview of GIS-based mineral resources potential assessment

With wide application of GIS, mineral resources potential assessment has entered into an informatization stage. In this stage, on the one hand, theory and technology of ore deposit models are becoming better, which provides better geosciences basis for mineral resources potential assessment; on the other hand, rapid development of GIS platform (including computer software and hardware) makes quantitative stimulation, decision support and even expert system come true using a large quantity of geological, geophysical, geochemical and remote sensing data, etc. Moreover, China timely proposed a new concept of "digital land" which refers to realize computerization of territorial resources investigation and evaluation, networking of territorial resources information service and informatization of land resources survey management. Independent copyright MAPGIS (GIS) and MRAS[3] (Mineral Resources Assessment System) have been widely applied in land resources survey.

United States Geological Survey (simplified as USGS) is go-ahead about mineral resources potential assessment; Three-part form of non-fuel mineral resource assessment method is reference for various countries in the world. Besides, Chinese Wang et al. proposed ore forming series prognosis of comprehensive information method from geological, geophysical, geochemical, remote sensing and minerals data, Zhao et al. proposed "three components" 5P geological anomaly quantitative evaluation method system according to the theory of "geological anomaly results into metallogenic prognosis", and Ye et al., in combination with deposit modeling and multi-resource information, proposed deposit modeling and integrated information mineral resources assessment method.

1. Three-part form of non-fuel mineral resource assessment

The three-part Form of Non-fuel Mineral Resource Assessment method is used for mineral resources potential assessment, which is currently being recommended for wide application by USGS; this method was started in 1975, and a more comprehensive method system has been established in the 1990s, and then it was continuously amended. This quantitative evaluation method integrates research achievements of many American experts in mineral resources potential assessment, such as D. P. Harris's mineral resources economic quantitative assessment model, Singer's ore deposit model and standard grade-tonnage model, McCammon's quantitative assessment and expert system and Drew's MARK3 software, and has become a standard assessment method of USGS after the end of 1980s [4-9].

The method comprises three steps : ① to delineate geological areas which are feasible for ore prospecting; ②to estimate contained metal quantity and quality features of possibly discovered deposits by applying the standard grade-tonnage model that matches predicted deposit types; and ③ to estimate number of possibly discovered deposits within metallogenic prospects.

The advantage of three-part quantitative assessment lies in its internal consistency, i.e., delineated targets with descriptive models, grade-tonnage models with descriptive models, and known ore deposits in assessment areas and deposit number estimation with grade-tonnage models. During the process, all available information should be utilized as well as uncertainty be expressed.

2. Ore forming series prognosis of comprehensive information

Wang et al. [10-11], based on geological, geophysical, geochemical, remote sensing, minerals and other synthetic information, proposed ore forming series prognosis of comprehensive information method. The theoretical basis of this method is to consider various kinds of geological data and study results as results of geological bodies observation and sampling statistics, and from Principle of Statistics, ore-forming regularity is also a statistical regularity. For more precisely reveal geological law, it is required that, on the premise of prior geology and with existing mature geological theories as guidelines, geological, geophysical, geochemical and remote sensing data are comprehensively interpreted, information which can express geological regularity is extracted, and organic correlation of these information is studied, thus to constitute an information whole and depict geological regularity. In the method, an metallogenic series genetic model is required to establish under the guide of metallogenic series theory, on this basis, to make statistics, correlate and analyse geological indicators, geochemical indicators, and geophysical and remote sensing geological indictors of known ore deposits of same metallogenic series, develop an integrated information metallgoenic series prospecting model, and then conduct metallogenic series prediction on unknown mineralized units by applying the ore prospecting model.

3. "Three components" 5P geological anomaly quantitative assessment

Zhao et al. [12-14] proposed a "three components" 5P geological anomaly quantitative assessment method recently. The core thought based on the theory that geological anomalies resulted into mineralization is that geological anomalies with different scales correspond to different-class mineral resource bodies, and analysis of geological anomalies with different scales can correspondently identify different ore-finding areas. "5P" refers to different ore-finding areas, i.e., probable ore-forming area, per-missive ore-finding area, preferable ore-finding area, potential mineral resource area and perspective ore body area. The concept and delineation methods of "5P" are systematic summary on whole minerals exploration process. This method is, in the means of mathematics and information processing, to produce ore-generating information by information extraction, correlation, transformation, synthesis, and a series of other processes, to mark anomaly information by this ore-generating information, and finally to delineate "5P" ore-finding areas by ore-generating information delineation and evaluation.

4. Methodology of deposit modeling and integrated geological information for mineral resource potential assessment

The methodology of deposit modeling and integrated geological information for mineral resource potential assessment is developed by China's many years of experience summary of mineral resources potential assessment; it was proposed by Ye et al. [15-16] at the beginning of a new round of mineral resources potential assessment of China. The core of this method is, in GIS platform, with deposit geological model as guide and metallogenic prognosis and analysis of geodynamics structural formation as basis, to fully and systematically analyze geological, geophysical, geochemical, remote sensing, mineral resources information and other information obtained by geological prospecting and exploration, and to scientifically conduct potential assessment of unidentified minerals resources using the GIS-based mineral resources quantitative prediction method. Deep analysis of geological setting and integrated information, and development of deposit models are premise of mineral resources prognosis; establishment and application of basic space database which includes geological, geophysical, geochemical, remote sensing and heavy-minerals data, are basis of mineral resources prognosis; to rightly understand and depict time-space distribution of significant mineral resources, to select accurately essential factors for prediction, and to effectively identify and extract prospecting information are the key to mineral resource prognosis; while to apply modern computer spatial data analysis technique and to reasonably carry out information integration and mineral resources location and quantitative prediction are the effective path for prediction.

This method combines with geophysical, geochemical, remote sensing, mathematics and other tools, from the perspective of metallogenic theory [17-20], makes analogy and determines areas that are similar to known metallogenic series, thus to achieve ore-prospecting prediction and better reflect the advantage of model prediction and integrated information prediction. Metallogenic series theory is to reveal metallogenic regularity from the perspective of 4D space; accordingly, by applying metallogenic series theory, present-day metallogenic prognosis is transformed from plane multi-information prediction into stereoscopic space location and quantitative prediction under the guide of geological theory.

III. GIS-based metallogenic prognosis of lead–zinc mineral deposits in China

1. Lead–zinc minerals prediction and evolution model

Both of America's "Three-part form of non-fuel mineral resource assessment" and China's deposit modeling and integrated geological information for mineral resource potential assessment stress the importance of a prediction model. Some experts who are engaged in exploration technology and statistical prediction research believe ore-finding areas can be also delineated and deposits can be discovered without need to consider different deposit type. However, if we merely use quantitative methods to delineate metallgoenic prospects instead of considering deposit type, it will result into practicability lost in final results. Therefore, internationally accepted potential assessment methods are all based on a deposit model, so as to ensure the scientificity and objectivity of assessment results

The mineral resources prediction and evaluation model refers to deposit types division for mineral resources prediction and evaluation service, which is, based on deposit genetic type and industrial type and with mineral deposit metallogenic series as theoretical basis, to study metallogenic regularity and prospecting direction of mineral deposits from the perspective of "4D space" which includes "time, space, mineralization and product". It is mainly used for summary of modeling prediction, construction of essential factors of prediction model and determination of prediction methods [21]. The mineral resources prediction and evaluation model is a basic unit for mineral resource prediction; its division and statistics are basis and necessary condition of the whole lead-zinc minerals, and its content is mainly reflected by ore-forming time, main prediction factors, typical deposits and other aspects. In combination with historical division basis [22-25], the mineral resources prediction and evaluation models of lead-zinc mineral deposits in China were divided into nine types: stratabound carbonate type (MVT-type), carbonate-fine clastic type (SEDEX type), sandstone-conglomerate type, sedimentary-reworked type, continental volcanic type, marine volcanic type, magmatic hydrothermal type, skarn-type and weathering crust type. The classification scheme of models is outlined as follows.

(1). Stratabound carbonate type (MVT-type)

This type is hosted in sedimentary rocks consisting mainly of carbonate rocks; it was formed by hot brine action, showing epigenetic signatures. It commonly has no relationship or is not directly related to magmatism. Deposits of this type commonly have lead paragenetic (associated) with zinc (and silver in most cases). Hot brines might have formed layered, vein-like, pipe-type and other ore bodies (mostly layered) in different ore-forming environments, like ore-forming depth, lithology and structure. Stratabound carbonate type lead-zinc deposits are a major type of lead-zinc deposits in China, which are widely distributed in China, but concentrated in northwest, southwest, south central and south China. This type of deposit has currently a measured reserve of 1/3 of China's total reserve.

(2). Carbonate-fine clastic type (SEDEX type)

This type mainly refers to a class of deposits that are generally not directly related to magmatism, and is considered to have been formed in passive continental margin and controlled by continental margin rift basins. Ore-hosted rocks are fine clastic and carbonate rocks and ore is of hot brine origin. This type of deposit was formed nearby syndepositional faults or in second-order or third-order basins controlled by syndepositional faults; it is of syndepositional deposits and called as eruptive-sedimentary deposit as well. The type of deposit is generally large-sized, and occurs as stratiform and stratoid configuration; lead is commonly paragenetic (associated) with zinc (and silver in most cases). Fine clastic type hot brine ore-forming hydrothermal fluids can be divided into deep hydrothermal fluid and shallow hydrothermal fluid according to their occurrence depth. Different depths result into various configurations of ore bodies; deep hydrothermal fluid was located in ascending channels, forming vein-like and pipe-like ore bodies, while upper hot water deposition occurred, forming stratiform, stratoid and lenticular ore bodies. This type is also a major lead-zinc deposit type in China, which is widely distributed, but concentrated in northwest, southwest, south central and south China.

(3). Sandstone-conglomerate type

This type refers to a class of deposits that are hosted in marine or continental sandstone, arkose and conglomerate, and commonly have no relationship or are not directly related to magmatism. In this type of deposit, lead is commonly paragenetic (associated) with zinc (and silver in most cases). This type of deposit is less distributed in China, but single deposit is large-sized, such as Jinding lead-zinc deposit, Yunnan Province and Wulagen lead-zinc deposit, Xinjiang.

(4). Sedimentary-reworked type

This type refers to a class of deposits, in which ore bodies are hosted by sedimentary rocks and ore redistributed as affected by regional metamorphism and magmatic hydrothermal fluids. This type of lead-zinc deposit is relatively sporadically distributed in a small scale, including northeast, northwest and southwest provinces. The measured resource reserve of this type makes up a small proportion.

(5). Continental volcanic type

This type refers to a class of lead-zinc deposits that occur in continental volcanic rock areas and are hosted in volcanic rock, subvolcanic rock and volcanic sedimentary rock. Continental volcanic type lead-zinc deposits in China mainly concentrate in northwest and eastern China; in addition, they are sporadically distributed in northwest, northeast and southwest China; the measured resource reserve of this type in China accounts for approximately 5%. This type of deposit commonly has paragenesis (association) of lead, zinc and silver. Some deposits with gold, silver and copper as main minerals are commonly also associated with lead and zinc.

(6). Marine volcanic type

This type is relative to the continental volcanic type. Marine volcanic type deposits in China are mainly distributed in northwestern, southwestern and southern provinces, with a measured reserve accounting for about 10% of China's total reserve. This type of deposit mostly has copper paragenetic with zinc, and commonly associated with lead, silver, gold and other minerals.

(7). Magmatic hydrothermal type

This type refers to a class of deposits that are closely related to intermediate-acid hypabyssal to super hypabyssal small intrusions; magmatic hydrothermal lead-zinc deposits are extremely distributed in China, including northwest, southwest, north, central, east and south China, with a measured reserve of approximately 14% of China's total reserve.

(8). Skarn-type

This type is a class of deposits that are considered to have been formed by hydrothermal replacement of ore-bearing hydrothermal fluids produced from intermediate-acid intrusions contacting with carbonate rocks, etc.; this type of deposit generally has typical skarn mineral association. Skarn-type lead-zinc deposits are widely distributed in China, including northwest, northeast, north, east and south China. This type of deposit has a measured resources reserve of 19% of China's total reserve.

(9). Weathering crust type

This type is redistributed product mainly formed by weathering and leaching and denudation of primary lead-zinc deposits under hot and humid climate and appropriate topography and structural conditions; it is mainly distributed in southern China. This type of deposit mainly occurs as occurrences and mineralization spots, with less of medium-sized deposits; it has a measured reserve of 1% of China's total reserve.

2. Basic geological database of lead - zincmineraldeposits

Basic geological databases are information basis to conduct metallogenic prognosis, which mainly includes national 1:5,000,000 scale and 1:2,500,000 scale digital geological maps space databases, space databases of 1:500,000 scale digital geological maps of various provinces and 1:200,000 scale digital geological maps of various provinces, space database of mineral producing areas, Regional Gravity Database, aeromagnetic database, remote sensing image database, regional geochemical database, 1:200,000 scale natural heavy-minerals database, work degree database and typical deposits database.

3. Metallogenic prognosis for China's lead - zinc deposits

China Geological Survey performed lead-zinc mineral resources potential assessment by applying MRAS (Mineral Resources Assessment System).

MRAS, as a GIS system designed based on MAPGIS, can realize the following functions:

Integrated management function of multi-geoscience information-fully integrates various kinds of basic geological databases;

Spatial inquiries function of multi-geoscience information-provides condition query and GIS space interactive query function of space databases;

Overlay and Integration-overlay and integration of information;

Buffer analysis-is used to analyse distribution law of mineralized spots with different widths on sides of faults or fold axis, etc., and thereby to determine the correlation of deposits and faults and fold axis, as well as the maximum influence region of structural controls.

Spatial entity statistical function-area and length measurement is the basic results of GIS topology analysis; regions/domains with different definitions can automatically gain correspondent attribute information on GIS platform.

Powerful visual tool-visualization in GIS is expressed by visualized modification and compilation of space data; visualization in scientific computing is expressed by isoline, image and 3D visualization, scientific computation interactive visualization and other aspects. Users can produce visual images according to model parameters and then adjust the parameters according to visual images till they get the optimal solution.

GIS mapping-outputs series maps for resources assessment according to the needs of mineral resources potential assessment.

Through MRAS system, according to the different mineral resources prediction and assessment models of lead-zinc deposits as mentioned earlier, mineral resources potential assessment was conducted for lead-zinc mineral deposits, which includes quantitative delineation, optimization and resources estimation of minimum predicted areas[26], under the support of geological, geophysical, geochemical, remote sensing and other basic geological databases and combined with geological conditions of lead-zinc mineralization and ore-forming regularity research, etc. Generally, this work includes the following steps:

① To determine the lead-zinc mineral resources prediction and assessment model and related essential factors of prediction, to compile the mineral resources prediction type distribution map and to determine the predicated work area range and scale for prediction, and then to determine the prediction scope of this type of deposit;

② Typical deposit research: is to select typical deposits according to the lead-zinc mineral resources prediction and assessment model as outlined earlier, to overlie and integrate various geological factors and essential factors for prediction extracted, and to analyze metallogenic regularity;

③ To develop the lead-zinc regional metallgoenic model and to produce special maps for metallogenic prognosis by analysis of overlay and integration of regional geological factors and essential factors for prediction on the basis of typical deposits;

④ To establish the regional comprehensive assessment model; this is basis of lead-zinc mineral resources prediction and assessment as well as premise of analogy and information transformation. On the basis of integrated geological information mapping and regional deposit geological model research, to extract essential element information for prediction, and to make analogy and transformation on various factors in the correspondent regional deposit geological model, and thus to establish the regional lead-zinc mineral resources comprehensive assessment model;

⑤Localization prognosis: is to delineate the scope of lead-zinc mineral resources prediction (lead and zinc are delineated respectively)-this is also one of major objectives of lead-zinc mineral resources potential assessment; the selected prediction area is namely the area hosting lead-zinc deposits with a higher confidence level.

⑥ quantitative prediction: is to estimate the number and correspondent resources of lead-zinc deposits-this is also one of major objectives of mineral resources potential assessment; to perform probability estimation on preceding delineated prognosis areas by using mineralization probability and to estimate resources in predicated areas; in the work of lead-zinc mineral resources potential assessment, to estimate resources in MRAS using integrated information quantitative method and subjective evaluation method on the principle of 500m, 1000m and 3000m depths.

Finally, to obtain lead-zinc predicated areas with different scales of the whole country (China) and various provinces and automous regions as well as their potential resource information and other product information.

IV. Major problems

1. Data

Geological, geophysical, geochemical, remote sensing, placer and other basic geological data constitute the overall basis of metallogenic prognosis. Data is a major problem faced in metallogenic prognosis of various minerals including lead and zinc minerals by GIS platform.

①Precision: as data used for metallogenic prognosis possibly has a great time span, and science and technology development level difference also exists in precision of data obtained in different years, the confidence level of prediction results is affected to a certain degree. In addition, if coordinate systems of space geological data with different sources and projection parameters used for images/maps are different, it is required to perform error correction, projection transformation, mosaic registration, and other series of operations on different space data based on coordinate systems and projection parameters of basic geological maps first and then to perform unification of coordinate system and projection parameters; the precision of geological data is affected during transformation, and thus metallogenic prognosis precision is affected.

② Form: various kinds of large amounts of basic geological data in metallogenic prognosis are commonly obtained by personnel from different professional fields using different equipment and methods; they are different in express form, including texts and maps data that include vector data and raster data. How to effectively integrate and manage different forms of data is always a problem demanding prompt solution for GIS software developers.

③ Platform: Due to economics, property right protection and other reasons, different GIS platforms have output results data commonly used merely in their own platform, or merely provide interfaces for data transformation. Sometimes data has to be transformed by multi-platform as involved some functions realization, however, during data transformation, partial data attributes are commonly lost, which influences metallogenic prognosis results.

2. Personnel

Although GIS has gradually led metallogenic prognosis to automatization field, however, how to effectively organize and manage huge amounts of data in GIS and extract useful ore-forming information still relies on professional quality of professionals. Even some of core links have higher requirements for personnel, including strong specialty and experience. For example, as subjective judgment of prediction personnel poses higher influences on quantity statistics of deposits, higher expertise is needed. In addition, technicians are needed to participate in the extraction of various kinds of basic geological data, and data quality directly correlates to the precision of metallogenic prognosis results.

Ⅴ. Conclusions

GIS-based metallogenic prognosis has directed metallogenic prognosis to develop towards informatization and systematization, which can macroscopically and quickly complete metallogenic prognosis for different mineral deposits. The metallogenic prognosis of lead-zinc deposits in China was finished by MRAS, and results will play a positive role in later sustainable exploration evaluation on lead-zinc deposits. Moreover, it can be believed that the final prognosis results can still be further improved due to data and technicians. However, more precise metallogenic prognosis method system, more comfort man-machine interactive experience, and more convenient information publishing and sharing are undoubtedly the future developing direction.

REFERENCES

[1] Wu Lun, Liu Yu, Wei Zhongya, et al. Geographic information system—principle, method and application [M]. Beijing: Science Press, 2001.

[2] Xiao Keyan, Ding Jianhua, Liu Rui. The discussion of three-part form of non-fuel mineral resource assessment [J]. Geological Review, 2006, 52(6): 793-798.

[3] Song Guoyao, Xiao Keyan, Zhang Xiaohua, Zhu Yusheng, et al. Several problems in mineral resource assessment [J]. Geology in China, 1999 (8).

[4] McCamm on R B, Briskey J A. 1992. A proposed national mineral resource assessment. Non renewable Resources , 1(4):259 ~265

[5] Singer D A. Basic concepts in three-part quantitative assessments of undiscovered mineral resources. Nonrenewable Resources , 1993. 2 (2):69 ~81.

[6] Singer D A. 1994. The relations hip of estimated number of undiscovered deposit s t o grade and tonn age models in three-part mineral resources assessment s. International Association of Mathematical Geology , Geology Annual Conference, Papers and Ext ended Abstract s :325~ 326.

[7] Singer D A. Some suggested future direction s of quantitative resource assessment s. Journal of China University of Geosciences. 2001. 12(1):40 ~ 44.

[8] Singer D A. Progress in integrated quantitative mineral resources assessment s. O re Geology Review s , 2010. 10(3):1 ~ 9.

[9] Singer D A , David M W. Quantitative Mineral Resource Assessments , an Integrated App roach Oxford University Press . 2010.

[10] Wang Shicheng, Chen Yongliang. 1999. Integrated information mineral resources prediction indexes of large and superlarge gold deposits. Gold Geology, 5(1):1~2.

[11] Wang Shicheng, Chen Yongliang, Xia Lixian. 2000. Theory and method ore forming series prognosis of comprehensive information. Beijing: Science Press.

[12] Zhao Pengda, Chi Shundu, Li Zhide, et al. Theory and method of mineral exploration. Beijing: China University of Geosciences Press.

[13] Zhao Pengda. 2002. "Three-Component" quantitative resource prediction and assessments: theory and practice of digital mineral prospecting. Editorial Committee of Earth Science-Journal of China University of Geosciences, 27(5):482 ~ 489.

[14] Zhao Pengda, Chen Jianping, Zhang Shouting. 2003. The new development of "three components" quantitative mineral prediction. Earth Science Frontiers, 10(2):455 ~ 462.

[15] Ye Tianzhu, Zhu Yusheng, Xia Qinglin, et al. 2001. Methodology of solid mineral prediction and assessment. Beijing: China University of Geosciences Press.

[16] Ye Tianzhu, Xiao Keyan, Yan Guangsheng. Methodology of deposit modeling and integrated geological information for mineral resource potential assessment[J]. Earth Science Frontiers, 2007, 14(5):11~19.

[17] Chen Yuchuan, Wang Denghong, Xu Zhigang, et al. 2006. Preliminary study of Chinese mineralization system. Mineral Deposits, 25(2):155~ 163.

[18] Chen Yuchuan, editor in chief.1999a. Mineral resource prospect evaluation of main metallogenic zones. Beijing: Geological Publishing House

[19] Chen Yuchuan, editor in chief.1999b. Modern theory and method of mineral resource exploration evaluation. Beijing: Earthquake Publishing House.

[20] Chen Yuchuan, Pei Rongfu, Song Tianrui, et al. 1989. A study on metallogenic series of ore deposits in China. Beijing: Geological Publishing House

[21] Ye Tianzhu, Xiao Keyan, Cheng Qiuming, et al. Mineral quantity Predictive Methods [M].Beijing: Geological Publishing House,2010:10-30.

[22] Chen Yuchuan, Wang Denghong. Classification scheme of prognosis types for important minerals [M]. Beijing: Geological Publishing House, 2010: 97~115.

[23] Xu Zhigang, Chen Yuchuan, Wang Denghong, et al. Metallogenic region subdivision scheme of China [M]. Beijing: Geological Publishing House, 2008:1-10.

[24] Lv Zhicheng, Dai Zixi, Rui Zongyao, et al. Metallogenic theory and prospecting method of overseas lead-zinc deposits[M]. Development and Research Center, China Geological Survey, 2004: 3~8.

[25] Tu Guangchi, et al. Geochemistry of stratabound ore deposits in China (Volume One). Beijing: Science Press, 1984:354.

[26] Xiao Keyan, Zhang Xiaohua, Li Jingchao, et al. 2007. Quantitative assessment method for national important mineral resources prognosis. Earth Science Frontiers, 14(5):20~26.

Authors

Tang Panke Received the B.S. degree and M.S. degree in Mineral Resource Prospecting and Exploration from Central South University, Changsha, China, in 2000 and 2003, and Ph.D. degree in Cartography and Geography Information System from China University of Geosciences, Beijing, China in 2006. Dr. Tang joined China Non-ferrous Metals Resource Geological Survey, Beijing, China in 2006. He is currently a Senior Engineer in China Non-ferrous Metals Resource Geological Survey, Beijing, China. He is interested in deposit geology and GIS application.

Wang Chunyan Received the B.S. degree and M.S. degree in Mineral Resource Prospecting and Exploration from China University of Geosciences, Beijing China, in 2006 and 2011. Ms. Wang joined China Non-ferrous Metals Resource Geological Survey, Beijing, China in 2011. She is currently an Engineer in China Non-ferrous Metals Resource Geological Survey, Beijing, China. She is interested in mineral resources evaluation.