Focus on: National and Global Scale Geochemical Mapping for Mineral Exploration and Assessment in China

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Abstract

Geochemical mapping projects in China have provided or are providing a huge amount of information for mineral resources and have made a significant contribution to mineral discoveries due to the high-quality, consistent, and informative data. In this paper, the author takes 3 geochemical mapping projects in China as examples to describe the ideas, methods and roles of geochemical mapping in mineral exploration and assessment: (1) China's National Geochemical Mapping Project (Regional Geochemistry - National Reconnaissance Project, RGNR project) has covered 6 millions of km^2 of China's outcropping regions during the past 25 years mainly using stream sediment samples at a sampling density of 1 per km^2 with analysis for 39 elements. It is one of the most successful geochemical mapping projects for mineral exploration. (2) Deep-penetrating geochemical methods are developed for hidden deposits in the remaining concealed terrains in China, which the RGNR project using stream sediment samples is limited. In order to quickly and cheaply delineate broad geochemical patterns for metallogenic belts or giant ore deposits in large diverse concealed terrains, wide-spaced sampling at a density of 1 sample per 100-800 km^2 was used. In the past 10 years approximately 800 000 km^2 have been covered and new large-scale geochemical patterns favorable for giant ore deposits have been delineated in concealed terrains. (3) Global geochemical mapping in China has been conducted since 1993 as part of the International Geochemical Mapping Project (IGCP259) and the Global Geochemical Baselines project (IGCP360). Five hundred flood-plain sediment samples were collected in large river catchments that cover China and 51 elements were determined according to the IGCP259/360. Some large geochemical anomalies such as Pt and Pd have been delineated that were entirely unknown before. This shows the great potential role of global geochemical mapping in evaluation of the world mineral resources and prediction of the most favorable regions for discovering new large to giant ore deposits.

Introduction

Hawkes and Webb in the 1960s emphasized that geochemical mapping is the aspect of geochemistry of most importance in geochemical prospecting (Hawkes and Webb, 1962). Since the late 1970s, many regional and national geochemical mapping projects with areas of thousands to millions of km^2 were carried out and geochemical maps or atlases have been compiled at various scales. However, many geochemical mapping projects have not played significant roles in mineral exploration. The reasons are that: (a) Many key mineralization elements were not analysed due to analytical problems, (b) The information for trace and sub-trace elements such as Au, Ag, Hg, W, Mo etc. is insufficient due to the high detection limits, (c) The results are not comparable due to the lack of quality control using standard reference samples and standard methods.

Chinese geochemical mapping projects have made the most significant contribution to mineral exploration and new discoveries in China due to the high-quality, consistent, informative and national comparable data. In this paper, the authors will take 3 geochemical mapping projects in China as examples to describe the ideas, methods and roles of geochemical mapping in mineral exploration..

1. China's National Geochemical Mapping Project

China's National Geochemical Mapping Project (Regional Geochemistry - National Reconnaissance Project, RGNR project) was initiated in 1978. It has covered 6 millions of km^2 of China's territory during the past 25 years. It has proven to be one of the most successful geochemical mapping projects in the world, not only because of the immense coverage area and the magnificent contribution to mineral exploration in China, but also because of its creative ideas about obtaining more consistent, informative and national comparable data (Xie et al., 1997).

Different sampling methods have been developed for different landscape and topographic environments in China. Stream sediment samples were used as a sampling medium

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for the mountainous and hilly terrains in China at a sampling density of 1 sample per km^2. Sampling of lag materials or rock debris was developed for desert and semi-desert terrains in northern China. Fine stream sediments and pond sediments or soils were used as sampling media in karst terrains in southern China. Very low-density sampling of stream sediments taken from the mouth of large tributaries was developed for mountainous areas in southwestern China. Analytical problems are a major issue in geochemical mapping. Taking into account issues with geochemical mapping projects in other parts of the world, general guidelines were developed for multi-element analysis (Xie, 1978; Xie, 1995). These include: (1) Detection limits of trace and sub-trace elements must be lower than their crustal abundance values. (2) The analytical data must be inter-laboratory or nationally comparable. (3) Multi-method and multi-instrument approaches should be used.. (4) Analytical quality control procedures have to be established using standard reference samples to monitor the inter-laboratory and within-laboratory bias.

A multi-element analytical system using XRF as the main techinque with AAS, GFAAS, AF, ES, POL, COL, ISE and LF was developed to determine 39 elements by following the above principles.

Up to 2004, the project has covered all hilly and mountainous terrains of China, an area of more than 6 million km^2. Approximately 850 geochemical map sheets at a scale of 1:200 000 with 39 elements have been compiled.

Statistics show that 71% of the total mineral ore deposits have been discovered by geochemical methods, 19% by geophysical methods, 10% by other methods during the period 1981-2000 (Figure 1). Among the new discoveries by geochemical methods, precious metal deposits make up over 70%. Figure 2 shows the number of gold deposits discovered by geochemical methods from 1970-2000. The number of gold discoveries has increased by leaps and bounds since 1980s as result of RGNR project which started in 1978. The most exciting of them is the discovery of two world-class gold camps with gold reserves in excess of 500 tonnes. One occurs in the greenstone belt located at Xiaoqinling on the boundary of Henan and Shaanxi Provinces. Another occurs in carbonate terrains of southern China and has become the second largest Carlin-type gold camps in the world. The reasons of success in gold exploration in China were described in Xie and Wang (1991) and Wang and Xie (2000).

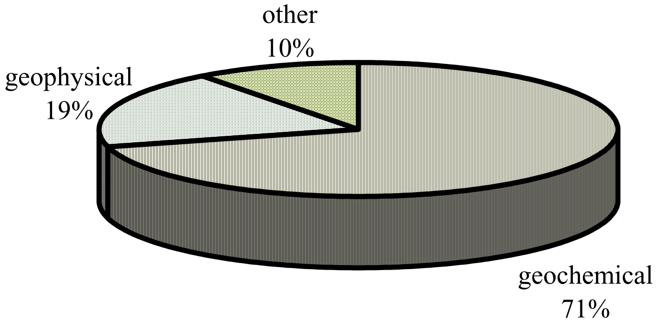

Figure 1: Geochemical methods have played an important role in the discoveries of 817 new deposits in China during the period of 1981-1995.

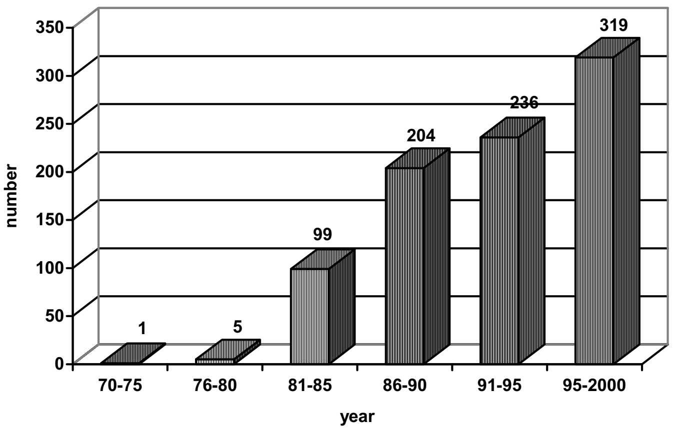

***Figure 2.** Number of gold deposits discovered by geochemical methods from 1970 to 2000.*

Case history 1.1: Discovery of Shanggong gold deposit, Henan province, central China

The Shanggong gold deposit located at Xiaoqinling-Xiongershan hilly to mountainous terrane on the boundary of Henan and Shaanxi province is the first successful case history of gold discovery by using regional stream sediment survey. In the region, Mesozoic granite intrudes Archean metamorphic greenstones. These geological settings are favorable for gold mineralization. However, no economic ore body has been found by geological exploration for many years.

In 1978 a regional stream sediment survey which was as an orientation study for the RGNR Project was conducted across an area of 1470 km^2 at Shanggong area (Figure 3) at a sampling density of 4-5 samples / km^2 (Gong and Wang, 1984). Two to three hundred grams of a fine fraction from the stream sediments was collected at the mouth of the first order of streams. The samples in each square kilometer were mixed together to make an composite sample for analysis. The composite samples were ground to -200 mesh. A 10 gm sub-sample was taken for Au analysis by using chemical pre-concentration emission spectrography with a detection limit of 0.3 ppb.

A regional anomaly with an area of approximately 1000 km^2 was delineated by a threshold of 2 ppb Au (Figure 3). The anomaly is distributed along the boundaries of greenstones and granites and volcanic or sedimentary rocks. Within the regional anomaly, there are 4 strongly anomalous areas delineated by a 3 ppb contour. The largest anomalous center with an area of 150 km^2 occurred at Shanggong with a highest value of 1100 ppb at the center. In 1980 a detailed soil survey was conducted at the center by using a sampling grid of 100 m by 50 m. Three Au anomalous belts associated with As and Ag were delineated and alteration along NE trending faults was found . Large ore bodies were proven by 15 drill holes after a trenching program across the anomalous belts in 1982.

It was due to this successful discovery that a regional stream sediment survey was carried out on two 1:200,000 sheets totaling an area of approximately 15000 km^2.

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Hierarchically nested geochemical patterns have been delineated. A number of gold deposits with gold reserves of more than 500 tones were discovered by a follow-up and detailed survey (Figure 3).

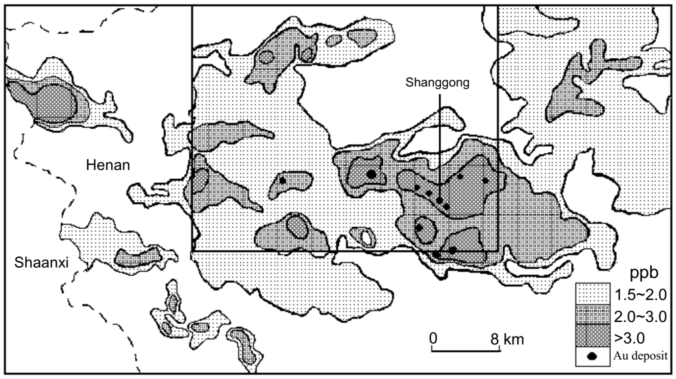

Figure 3: Hierarchically nested geochemical patterns. A geochemical province with an area of approximately 15000 km2 deliniated by a threshold of 1.5 ppb, regional anomalies delineated by a threshold of 2 ppb. A number of gold deposits with gold reserves of more than 500 tonnes were discovered by a follow-up and detailed survey.

Case history 1.2 Carlin-type gold deposit, carbonate terrain, Guizhou, southwestern China

In 1984 as part of the RGNR project a regional geochemical survey was conducted on the Anlong 1:200 000 sheet over carbonate terrain in Guizhou province, southwestern China. Three regional geochemical anomalies of Au with a threshold of 3 ppb and As, Sb and Hg were delineated (Figure 4). The largest one covers an area of 800 km^2 and contains a large concentration center with a contour of 6 ppb.

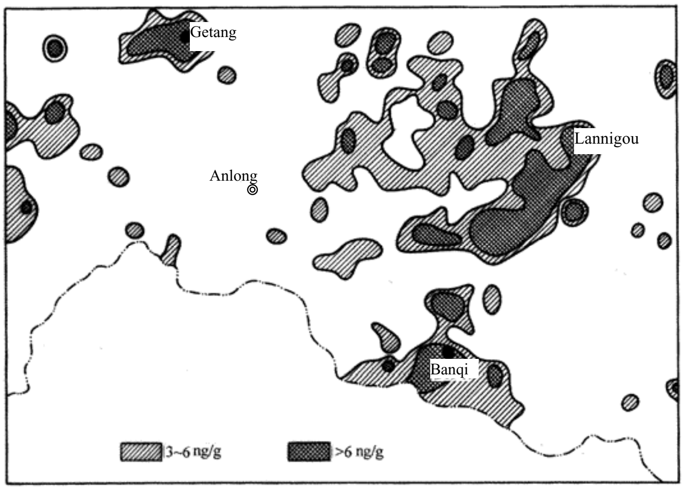

Figure 4: Regional geochemical anomalies of Au delineated by stream sediments in Anlong map sheet at scale of 1:200,000

In 1986 a follow-up stream sediment survey and geological mapping at a scale of 1:50000 was carried out. Mineralization of realgar and cinnabar in rocks was discovered and 51 rock samples were analyzed for gold. Twelve samples had gold values over 1.5 g/t . A detailed soil survey was conducted and a concentration center was delineated. A large gold ore body with gold reserves of more than 100 tones was evaluated by drilling program at Lannigou (Figure 5).

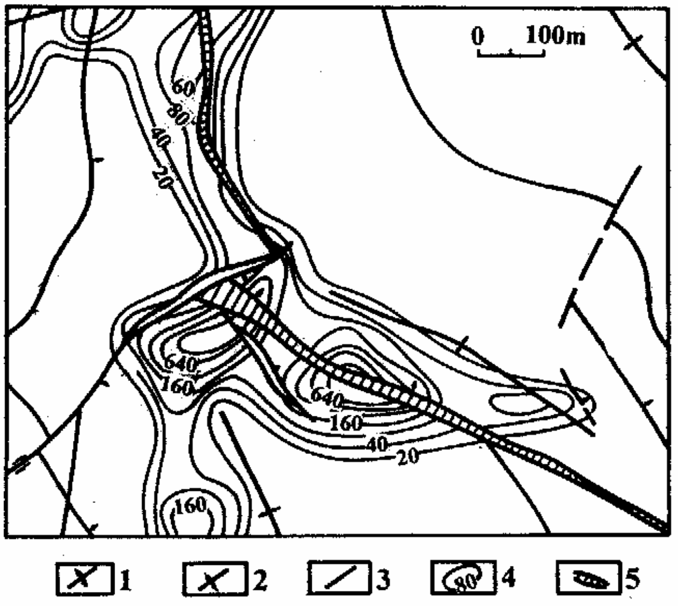

Figure 5: Gold ore bodies discovered within the concentration centers delineated by detailed soil survey (modified from Zhou et al., 1996). Gold in ppb.

This successful discovery led to a series of discoveries of Carlin-type gold deposits in carbonate terrains of southern China, which has become the second largest Carlin-type gold belt in the world next to that in Nevada of the USA.

2. Deep-penetrating geochemical survey for large ore deposits in concealed terrains

The China's National Geochemical Mapping Project mainly using stream sediments has covered all the outcropping or thinly overburden terrains and totals approximately 6 millions km^2. The remaining large diverse concealed terrains in China still remain to be covered by geochemical mapping. However, geochemical methods using conventional stream sediment survey are not suitable or have limited application in searching for deposits hidden under thick cover of transported overburden or thick sequence of post-ore volcanic or sedimentary rocks.

Recently, deep-penetrating geochemical methods including Selective Leaching of Mobile Forms of Metals in Overburden (MOMEO) and Collection of Nanoscale Metals in Earthgas (MAMEG) have been developed (Wang et al., 1997; Wang 1998; Wang et al., 1999; Xie et al., 1999). The methods have been studied in detailed and regional surveys. The research is focused on geochemical mapping using wide-spaced sampling at a density of 1 sample per 100-800 km^2 in order to delineate broad geochemical patterns for giant ore deposits in diverse concealed terrains. The sampling methods and analytical procedures have been developed for desert terrains, alluvial plain, grassy and forestry lands (Wang et al., 1997). In the past 10 years, approximately 800 000 km^2 has been covered. Large-scale geochemical patterns consistent with or favorable for giant ore deposits or large metallogenic belts have been delineated in concealed terrains.

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Case history 2.1: Wide-spaced sampling in alluvial terrain, eastern China

As a part of the Circum-Pacific Rim metallogenic belts, Eastern China has attracted researchers and exploration activities for many years. Many mineral deposits have been discovered in the region. The largest gold field in China is in the northeastern Shangdong province, located in the easternmost part of the study region. However, the transported alluvial overburden prevents assessment of the mineral potential. Cost-effective regional geochemical methods for penetrating through the alluvium and delineating geochemical provinces generated from large ore metallogenic provinces have been applied.

A deep-penetrating geochemical survey at a sampling density of 1 sample per 400km^2 was carried out on an area of 160 000 km^2. Figure 6 shows distribution of Au by using the Selective Leaching of Mobile Metals method. It clearly shows that four large regional anomalies (I, II, III and IV) with gold values of more than 2.0 ppb have been delineated in the study region. Among them, the largest one (I) approximately 6 000 km^2 in the northeastern region, is not only consistent with the distribution of the known large and giant gold deposits but also extends further south into the transported overburden areas. This will facilitate the search for new concealed deposits. The Regional Geochemistry - National Reconnaissance (RGNR) project using stream sediment surveys analysed the <0.2 mm fraction and failed to give any response in this transported overburden region. The southern anomaly (II) of more than 2.0 ppb has been delineated around another known large gold deposit, which the stream sediment data also failed to indicate because of the transported cover. The other two large regional anomalies (III) and (IV) in the NW and SW concealed regions are unknown and still remain to be further investigated. A geochemical province delineated by the content contour of 1.2 ppb is distributed along the Tanlu deep fault system, but the concentration centers delineated with higher values are distributed in the secondary faults on both sides of the deep fault system.

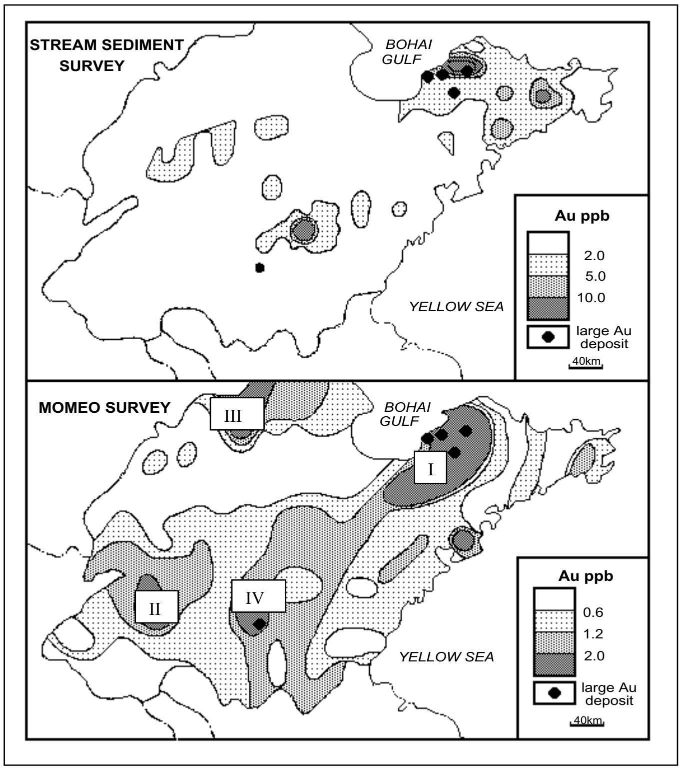

Figure 6: *Comparison of gold distribution patterns delineated by using stream sediment survey and deep-penetrating survey.*

Case history 2.2: Wide-spaced geochemical survey in arid desert terrains, northwestern China

Northwestern China is a large unexplored or under-explored terrain. Substantial areas are extremely arid and covered by regolith sediments concealing prospective bedrock sequences. More recently, interest was rekindled by the discovery of a large porphyry copper deposit with copper reserves of more than 10 millions of tons in the desert terrain of the Eastern Tianshan , Xinjiang, northwestern China.

In order to quickly get an overview of the mineral potential of covered terrain, wide-spaced sampling was carried out in an area of approximately 150 000 km^2 at a density of one sample per 100 km^2. Fine fractions of regolith samples were collected from the weakly- cemented sandy horizon at a depth of 20-40cm. The soil samples were subjected to analysis for 33 elements as determined by ICP-MS/OES, GF-AAS, HG-AFS and CP-AES. Geochemical maps and interpretation maps using GIS were generated. Figure 7 shows that the results not only give prominent expression to the known large gold deposits but also delineate new large-scale targets of gold. New occurrences of gold have been discovered by a preliminary follow-up survey within these new geochemical anomalies.

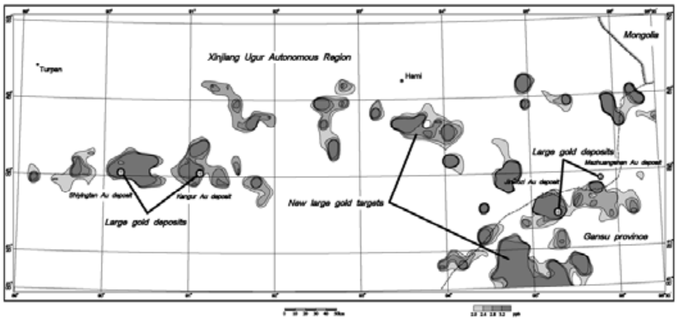

Figure 7: *Gold anomalies delineated by wide-spaced deep-penetrating geochemical survey in desert terrain, northwestern China.*

3. Global Geochemical Mapping in China

Research on global geochemical mapping in China has been conducted since 1993 as part of the International Geochemical Mapping Project that commenced in 1988 (IGCP259) and the Global Geochemical Baselines project (IGCP360) that commenced in 1995. The aims of the IGCP259 are to establish a common primary database at an international level and to provide a framework for the adoption of standardized methods for national mapping. The aims of the IGCP360 are to cover the whole land surface of the earth with approximately 5000 sampling cells and to

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determine 71 elements of the composite samples collected from these cells (Darnley, et al., 1995). The results obtained from the two projects could provide geochemical maps and natural geochemical background values of our planet, a network for monitoring the earth's environment and a frame of reference for more detailed national geochemical mapping.

There has been much controversy and debate about the selection of sampling media with representative average values of elements for each 160 km×160 km cell. The Environmental Geochemical Monitoring Networks Project (the EGMON project) (Xie and Cheng, 1997) was launched in 1993 as a pilot study for the IGCP360 trying to find a suitable universally available sampling medium that represents a very large area. Five hundred flood-plain sediment samples were collected in large river catchments over the whole country (Fig. 8) and 51 elements were determined according to the IGCP259 recommendation. The geochemical maps produced by such wide-spaced sampling are surprisingly similar with the maps based on the RGNR project data (Figure 9). Although the original purpose was for environmental monitoring, some large geochemical anomalies such as Pt and Pd have been delineated (Figure 10). The gigantic Pt-Pd endowment in this block shows great promise for discovering economic Pt-Pd mineralization. An exploration strategy of progressive reduction of the target area and stepwise increase of the sampling density was undertaken. This example shows the great potential role of global geochemical mapping in evaluation of the world

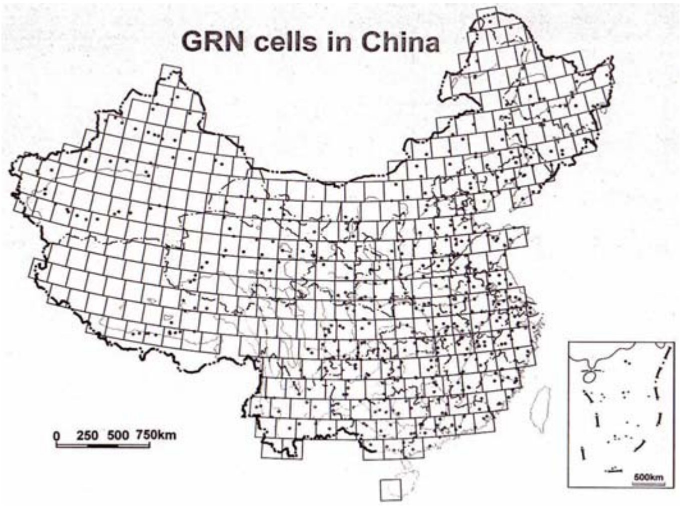

***Figure 8:** Global geochemical sampling sites with the GRN cells in China.*

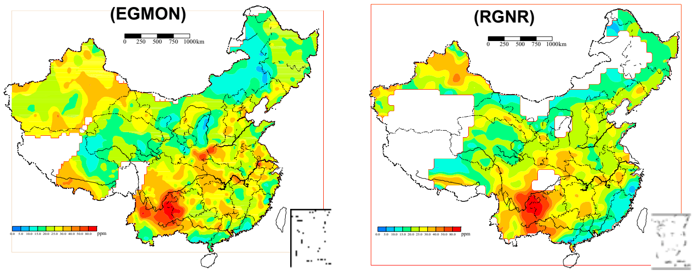

Figure 9: Comparison of copper geochemical maps in China by the RGNR project and the EGMON project. EGMON: 500 flood-plain sediment samples in whole of China, RGNR: 1 stream sediment sample per sq.km and approximately 1,500,000 samples in whole of China. Both maps are produced using average values taken from each 160km by 160km cell.

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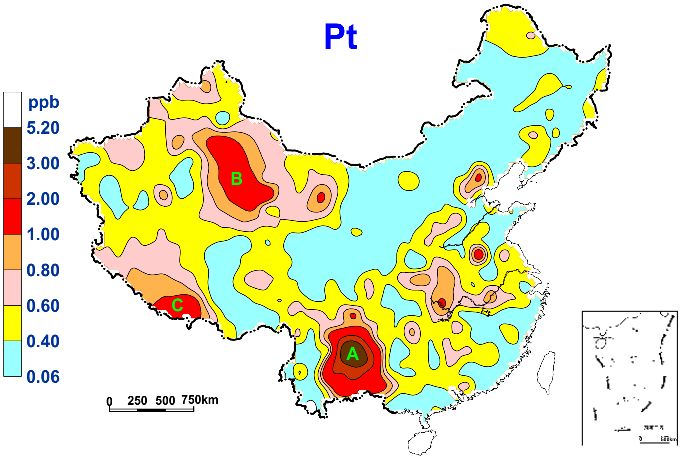

***Figure 10:** Geochemical distribution of Pt in China.*

mineral resources and prediction of the most favorable regions for discovering new large to giant ore deposits.

4. Conclusions

Geochemical mapping at various scales can provide a huge mass of information for mineral resources. It enables geochemists to delineate geochemical patterns at local, regional, to even global scales. The huge mass of direct information and broad geochemical patterns will reduce uncertainty and risk in mineral exploration. Geochemical mapping has greatly extended the ability of the naked eye to recognize direct signals from mineral resources by sensitive analytical methods. This makes it practical to find "micro ore outcrops" which were not observable with the naked eye even in outcropping or sub outcropping terrains. We are underway in detecting extremely faint signals from deeply concealed deposits using ultra-sensitive deep-penetrating geochemical methods. These methods will make a great contribution to mineral exploration in large unexplored or under-explored covered terrains in the future.

Acknowledgements

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