Paper 77

Exploration Criteria for Appraising Geochemical Anomalies through Mapping Geochemical Systems

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ABSTRACT

The foundation of geochemical exploration of mineral deposits, theory and practice, is based on verifying the presence of anomalous (above background) metal concentrations. Appraisal of such favourable areas involves several criteria including the magnitude of the values, the size of the area, the geochemical zonality of the ore elements, etc. However uncertainty around this issue remains, in spite of extensive works and empirical data on the subject. Our proposed approach could add to the information value of the geochemical method through the use of the new model of the primary halo which, according to available data, includes both enrichment zones and adjacent depletion zones. Such zones can be spatially conjugated in a unified geochemical system. Such systems have been found around deposits of varying composition and style. A good correlation exists between the dimensions of a depletion zone of the ore-forming elements and the content of those elements in the associated enrichment zone. This correlation could be one a key criterion for assessing a favourable region.

INTRODUCTION

In current practice, geochemical exploration of mineral deposits is directed at verifying the presence of anomalous (above background) concentrations of ore elements. These concentrations are a result of the primary process of ore formation and/or the disintegration of deposits in the form of haloes of secondary dispersion. The principles of exploration using haloes were formulated in the pioneering 1930s work N.I. Safronov (1936). In “Geochemistry in Mineral Exploration” by Rose et al., (1979) these are presented as four general criteria for appraising favourable areas: “(i) the magnitude of the values and background; (ii) the size and shape anomalies areas; (iii) geological setting and; (iv) the extend to which the local environment may have influenced the metal content and the pattern of the anomaly”. To these can be added a fifth criterion: the zonality of elements in anomalies (e.g. Grigorian, 1974; Boyle, 1974; Levinson, 1980).

However, much uncertainty still remains about the appraisal of promising areas using these criteria. For example, on occasion a smaller and less intensive anomaly may in fact be more favorable than larger anomalies which may represent only zones of dissemination. There are known examples of false anomalies with high magnitude where ore mineralization is absent (Levinson, 1974). Problems of appraising a favourable anomaly could be largely overcome by considering another criterion which is currently almost ignored: the presence of depletion zones in ore regions, which are manifest in pairs with enrichment zones. Such pair patterns can be outlined as unified geochemical systems (Goldberg et al., 1997, Goldberg et al., 2003). This short paper concerns the principles behind the appraisal of favourable areas through mapping geochemical systems. Examples discussed below include geochemical systems in the Bendigo gold region (Australia), the Irtyshsky polymetallic ore field, Rudny Altai (Kazakhstan) and Kavalerovsky tin region (Russian Far East).

GEOCHEMICHAL SYSTEMS: METHODS OF REGISTRATION AND INTERPRETATION

The Model of Geochemical Systems

There is currently a significant amount of accumulated data indicating that primary haloes include not only enrichment zones but depletion zones as well (e.g. Mackin, 1968, Goldberg and Voronin, 1987; Robertson and Taylor, 1987; Ji Kejian et al., 1992; Goldberg et al., 2003). Enrichment and depletion zones of the ore-forming elements are spatially linked to each other, and may be seen as a single geochemical system (Figure 1) (Goldberg et al., 2003). The characteristics of a geochemical ore system may be summarized as follows:

The structure of geochemical ore deposit systems is characterized by polar zoning, the fundamental feature of a system. Polar zoning can be defined as two separate areas

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(zones) within the system that are distinguished by the concentration or the composition of an element or group of *elements.*

Polar zoning by concentration. The system comprises an enrichment zone and a depletion zone of the ore-forming elements: typically the loss of ore forming elements in the depletion zone is over 40%. The enrichment zone is the nucleus of the system, and is usually located in an outer part of the system.

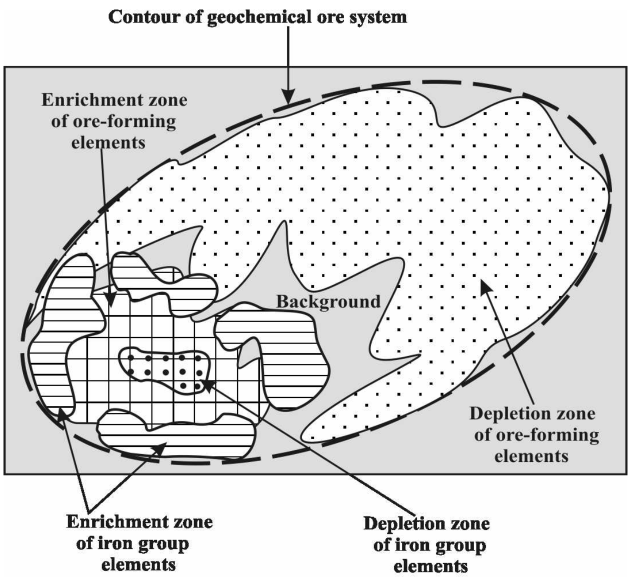

Figure 1: Model of ore geochemical system.

The size of the enrichment zone is, as a rule, an order of magnitude less than the depletion zone. The quantum of enrichment of the ore forming elements in an enrichment zone is of the same order of magnitude as the depletion of those elements in the adjacent depletion zone.

Polar zoning by the composition. The external zone of the nucleus is usually enriched with elements of the ferrous group (e.g. Fe, Sc, Ti, Cr, sometimes Zn and/or Cu); within the nucleus of the system the ferrous group of elements is usually depleted. If the ore mineralization is represented by one of the elements of the ferrous group, then the enriched external zone is formed by other elements of this group. In this work polar zoning by the composition is not discussed.

Systems with these patterns of distribution of the ore elements could be termed “polar geochemical systems.”

The size of the polar geochemical system associated with an individual ore deposit can range between several and several hundred km2. Polar geochemical systems of giant deposits can range from several hundred to several thousand km2. Good correlation exists between the dimensions of a depletion zone of the ore-forming elements and the content of those elements in the associated enrichment zone. This short paper aims to show, using examples of geochemical systems, including gold, tin and lead deposits, that this correlation could be one of the most important criteria for appraising a favourable region.

Registration Techniques of Geochemical Systems

In order to outline geochemical systems, it is necessary to conduct chemical analysis of rock for ore elements with detection limits of elements an order of magnitude lower than its average abundance in the given type of rock.

Statistical interpretation of the data should indicate any anomalously high as well as anomalously low levels of concentration. Standard statistical methods can be applied to this end, including probability plots (e.g. Reimann et al., 2005) or histograms of frequency distribution of the target elements, with the consideration of any textbook data. Examples of such statistical data are given below. Geochemical systems consisting of enrichment and depletion zones generally have a dipolar form. We interpret geochemical system with pattern as a result of the redistribution in the earth of ore and associated elements under the impact of natural electrical fields (Geoelectrochemical model) (Goldberg et al., 1997).

Examples of Geochemical Systems and Data Interpretation

Examples of geochemical systems in the Bendigo region, Australia.

Examples include the giant Bendigo goldfield (697 tonnes of gold) and other large goldfields in the region such as Maldon, Castlemaine and Fosterville, located in Tasman Fold Belt, Victoria (Vanderberg et al., 2000). Bendigo is a classic example of a low-sulfide gold-quartz deposit located in a folded sequence (saddle reefs) of sandstone and shale Cambro-Ordovician age goldfield.

In a regional lithogeochemical survey in the Bendigo area covering an area of 3750 km2, 142 rock samples of granitoids and sedimentary rocks were collected (grid approximately 5 km x 5 km) and analysed at ALS Chemex in Brisbane, Australia. The ranges of gold concentrations in samples of granitic and sedimentary rocks are shown in Figure 2b, samples with <0.5 ppb Au account for approximately 40% of all samples. Gold analyses within the range 0.5 ppb to 4.7 ppb have an average value of 1.29 ppb. This is close to the Clarke value for sediment and granodiorite. A third group of samples contain > 4.7 ppb Au, up to 70 ppb Au. The distribution of gold analyses within the surveyed area is shown in Figure 2c. Four principal geochemical systems could be identified in the surveyed area. The Bendigo goldfield itself is located within a positive gold anomaly (enrichment zone) with an average value of 14 ppb in all rock types, and approximately 100 km2 in extent. To the north is a depletion zone of the order of 700-800 km2, with an average gold content of less than 0.5 ppb in all rock types. In total, the gold enrichment and depletion zones occupy an area of more than 1000 km2 stands out against a gold background. If this depletion zone extends to a depth of 2 km, the volume of depleted rock would be at least 1400 km3 and the extent of apparent depletion would be of the order of 3000 to 4000 tonnes of gold.

The quantum of that gold depletion at Bendigo is of the same order of magnitude as the gold enrichment associated with the Bendigo goldfield and associated dispersion haloes (tonnes Au). Substantial depletion zones are also present: adjacent to the other important gold deposits within the survey area, at Maldon, Castlemaine and Fosterville.

Key criterion for the evaluation of a favourable area is the approximately linear relationship between the dimensions of a depletion zone of the ore-forming elements and the amount of metal contained in deposits within that geochemical system. This link, as it applies to the goldfields of the Bendigo region, can be seen in Figure 2d.

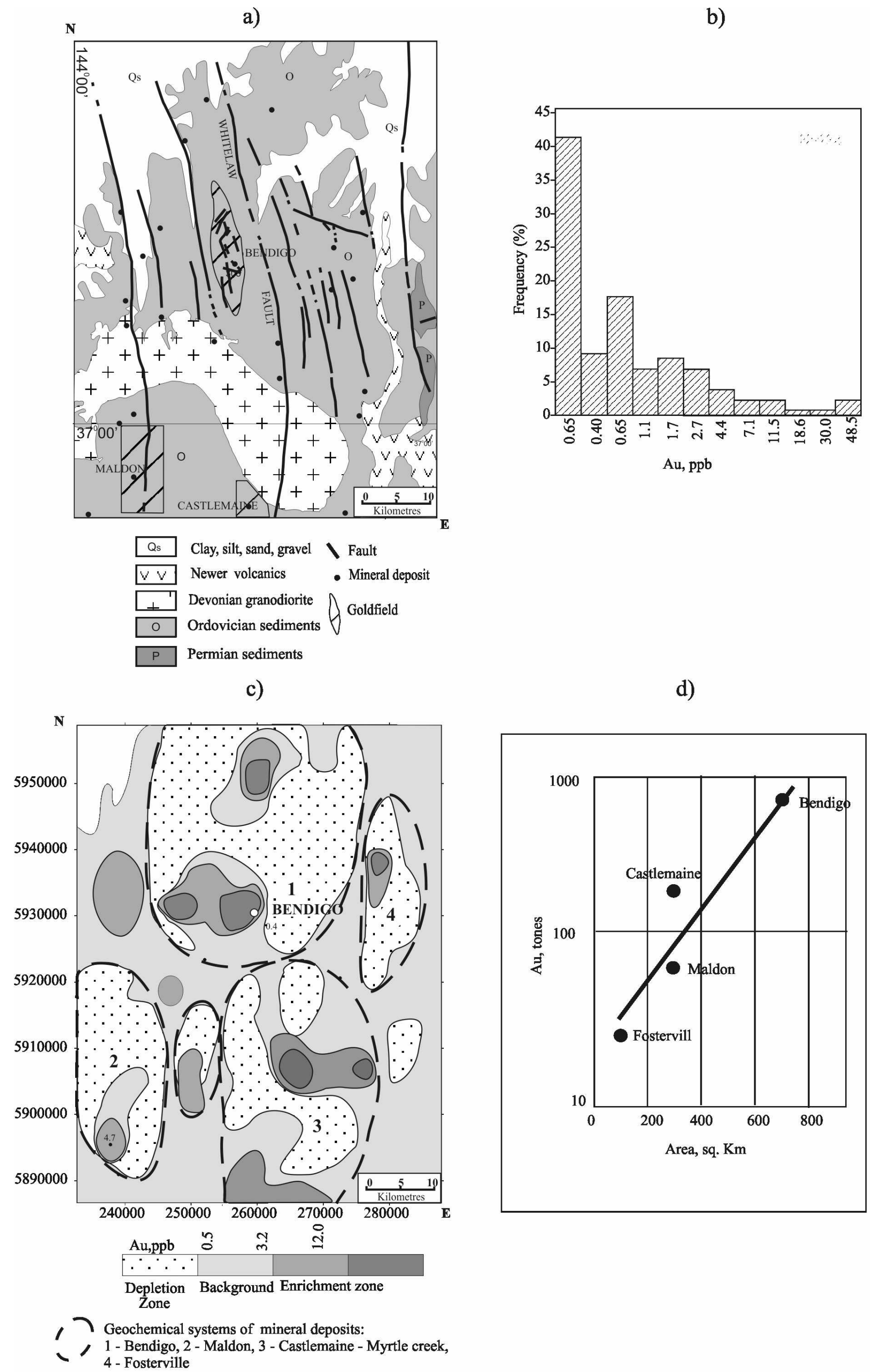

Figure 2: a) Simplified geological map of the Bendigo ore region, Victoria, Australia. b) Histogram of frequency distribution of Au, the Bendigo ore region. c) Geochemical systems of the Bendigo region deposits.d) Correlation between sizes of negative Au anomalies and proven resources of Au deposits of the Bendigo ore region.

Example of Geochemical Systems: VHMS type ore deposits, Irtyshsky Region Rudny Altay, Kazakhstan.

Deposits are located within the limits of the Rudny Altay ore province, which is characterized by numerous polymetallic and pyrite-polymetallic Cu-Zn-Pb deposits. The ore deposits are located within a volcanic-sedimentary series of middle-upper Devonian (Figure 3a). In the centre of the area the Zmeinogorsk granite of the same age is intruded. The rocks have an east-west trend. Deposits are localized within the limits of the block of rock between two steeply dipping faults.

Sample collection and analysis were carried out by the Geological Department of Eastern Kazakhstan. Most of the samples were obtained from bedrock below the zone of weathering (40-60 m), from the drill-core. The density of sampling was 10 –12 samples per km2. Analysis for Pb was carried out using the emission spectrometry, with a detection limit of 2-3 ppm. A histogram of Pb in the area is given in Figure 3b. Three basic populations can be seen with the modes 6.3 ppm, 15 ppm and of >100 ppm. The second population (mode of 15 ppm, mean of 18.7 ppm) corresponds to the Clarke value for the composition of rock (Levinson, 1974; Govett, 1983). The other two populations (modes 6.3 ppm and >100 ppm) correspond to depletion and enrichment zone.

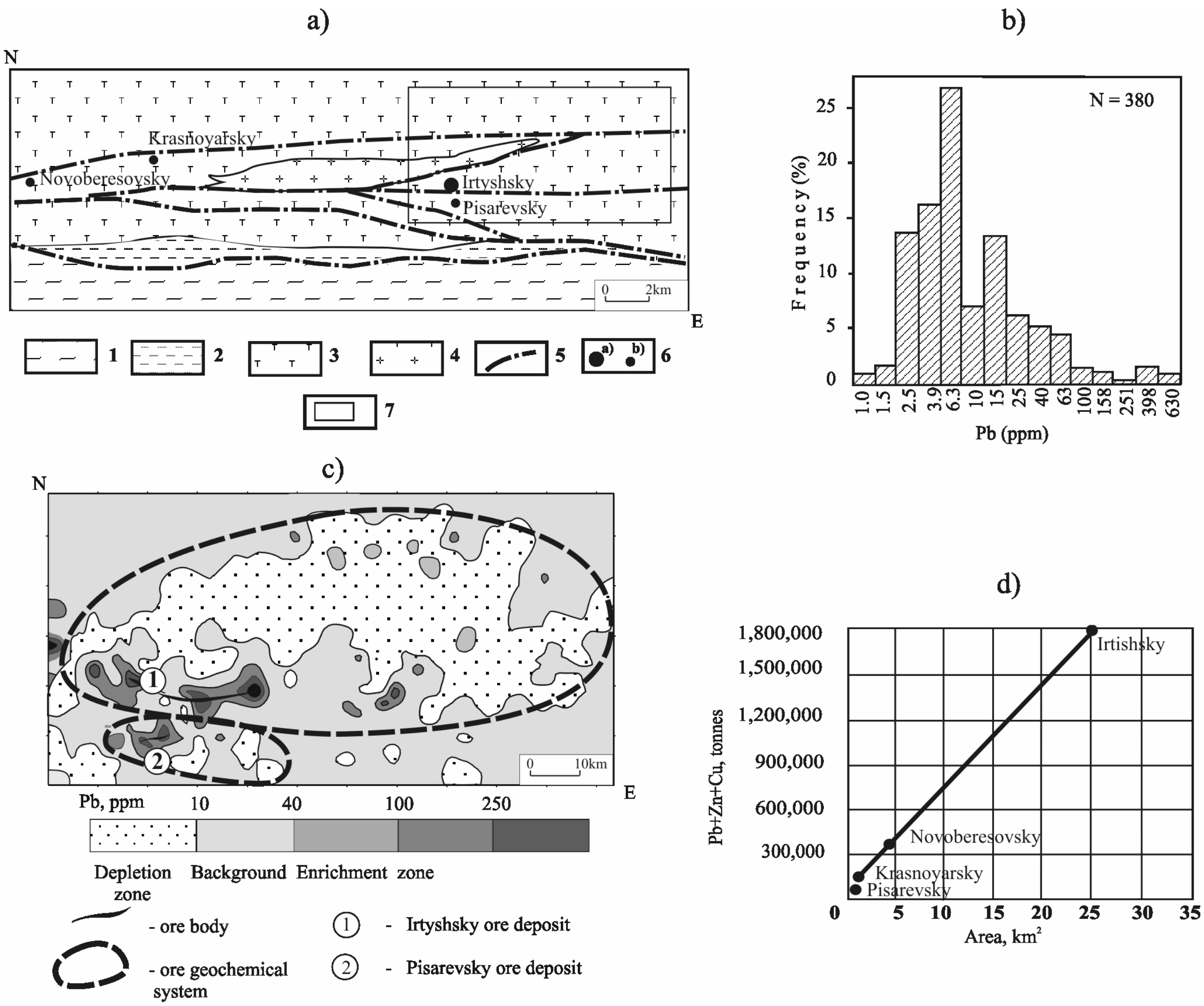

Figure 3: a) Simplified geological map of the Irtyshsky ore district, Rudny Altay, Kazakhstan. 1. Metamorphic sedimentary rock; 2. Sedimentary rock; 3. Volcanic (liparite porphyrite, andesite porphyrite and their tuff) – sedimentary sequence; 4. Granite; 5. Fault; 6. Location of mineral deposits; 7. Exploration area. b) Histogram of frequency distribution of Pb in volcanic-sedimentary sequence, the Irtyshsky ore district. c) Geochemical systems of the Irtyshsky and the Pisarevsky VHMS type deposits, d) Correlation between sizes of negative Pb anomalies and proven Pb resources of the Irtyshsky ore district.

The Irtyshsky deposit contains proven reserves of 1.8 million tonnes of Cu+Pb+Zn (0.5:1:3). The ores are pyrite-rich massive sulfide bodies. A primary enrichment Pb anomaly (> 60 ppm) outlines the ore zone (Figure 3c) and extends in an east-west direction for several kilometres. A halo of Pb depletion (<10 ppm) adjoins the enrichment halo to the northeast. The area of the depletion zone is c. 20 – 25 km2. According to drill data, negative anomalies were traced up to 1-1.5 km in depth.

The boundaries of the geochemical system do not coincide with the geological boundaries (Figures 3a and 3c). Outside the geochemical system, the concentrations of Pb in rock are typically 10 to 40 ppm, corresponding to the background.

To the south of the Irtyshsky deposit is the mineral occurrence, Pisarevskoe (Figure 3a,c). The size of the geochemical system, including small positive and negative anomalies, does not exceed 1 km2. A linear dependence has been established between the size of depletion zones and the reserves (resources) of the ore deposits examined (Figure 3d).

Example of Geochemical systems: Sn mineral deposits in the Kavalerovsky ore district, Russian Far East

All the deposits in the Kavalerovsky Sn district belong to the cassiterite-sulphide type and are found in overlapping Mesozoisandstone and shale (Figure 4a). It forms linear folds and is broken by meridional and sub-meridional faults that control the Sn deposits. The Kavalerovsky Expedition carried out sampling of the bedrock over an area of 500 km2. The samples (6000 rocks) were analysed by emission spectrometry in the expedition's laboratory; the detection limit for Sn was 1

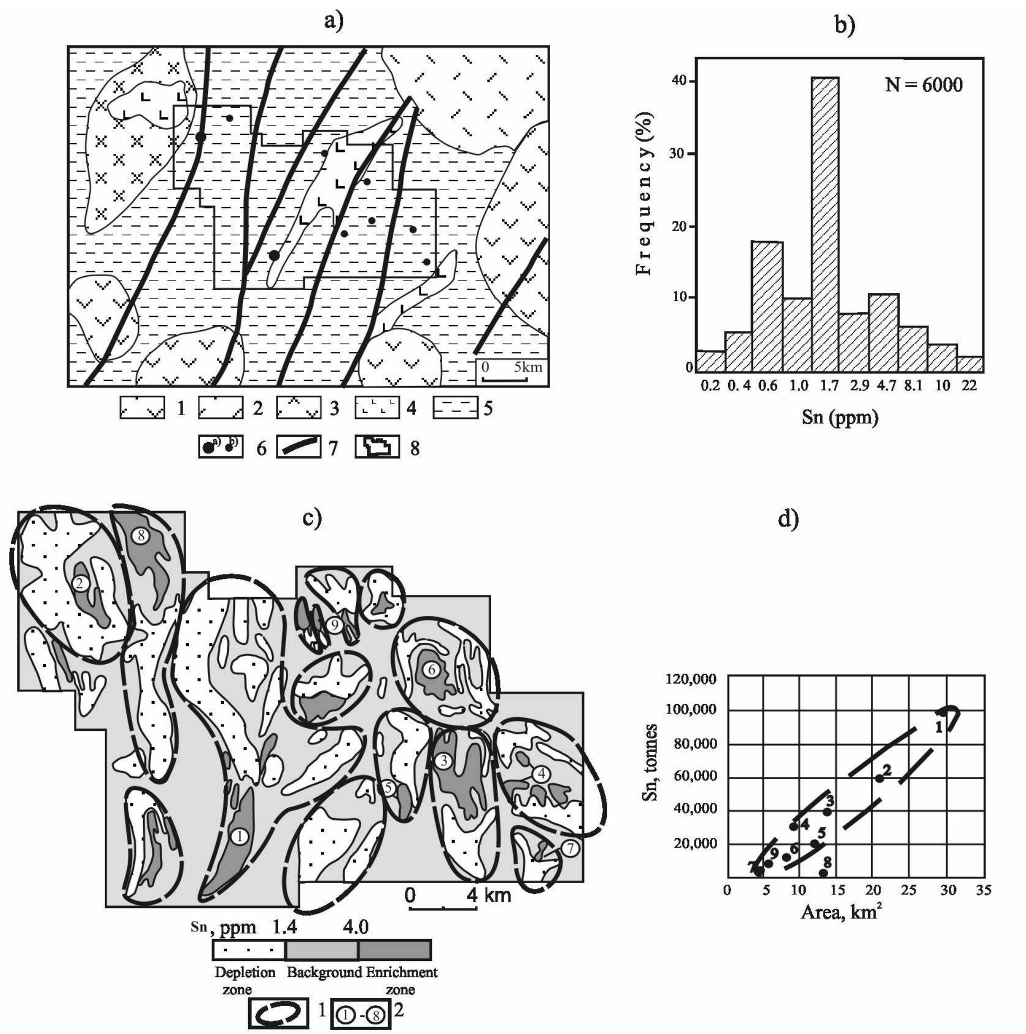

Figure 4: a) Simplified geological map of the Kavalerovsky ore district, Far East, Russia. 1. Dacite; 2. Riolite; 3. Monzonite; 4. Basalt; 5. Sedimentary rock; 6. Sn deposits: a) Large b) Small; 7. Fault. b) Hostogram of frequency distribution of Sn, the Kavalerovsky ore district. c) Geochemical systems of Sn deposits of the Kavalerovsky ore district. 1. Geochemical system; 2. (1-9). Sn ore deposits. d) Correlation between sizes of negative Sn anomalies and proven resources of Sn deposits of the Kavalerovsky ore district. (1-9) – Sn ore deposits.

ppm. The frequency distribution for Sn for the entire set of samples is shown in Figure 4b. The histogram identifies three populations of less than 1.4 ppm, 1.4-4 ppm, and more than 4ppm. The interval between 1.4 and 4 ppm is close to the average content of the given rocks; content of a sample is less than 1.4 ppm, this can be seen as a depletion zone. The geochemical pattern of Sn in the three populations is shown in Figure 4c.

The Arsenyevsky deposit (reserves of 60 000 tonnes) (Figure 4c, No 1) is located within geochemical system up c. 30 – 35 km2. The depletion zone is c. 20 - 22 km2, adjoining the enrichment zone. The Temnogorsky deposit (Figure 4c, No 4) is not an economic deposit, with Sn reserves of 4000 tonnes. The area of the negative anomaly is 4 - 5 km2. The size of the enrichment zone is c. 4 km2 and is commensurate with the size of economic deposits.

The size of geochemical systems of Sn ore deposits and, above all, the areas of the depletion zones, show the high degree of correlation with the reserves of metal in the deposits (Figure 4d). This correlation is absent for enrichment zones.

CONCLUSION

The size of a geochemical system's depletion zone provides an indication of the potential of the positive anomaly, and enables a judgment on the scale of the ore metal accumulation.

REFERENCES

Boyle, R.W., 1974, The use of major element ratios in detailed geochemical prospecting utilizing primary haloes, Journal of Geochemical Exploration, 3, 345-369.

Goldberg, I.S. & Voronin, D.V., 1987, Negative geochemical anomalies and their significance for exploration and evaluation of ore deposits: Moskow, Nedra, 52-57 (in Russian).

Goldberg, I.S., Abramson, G.J., Haslam, C.O. and Los, V.L., 1997, Geoelectrochemical Exploration: Principles, Practice and Performance: The AusIMM Annual Conference, Ballarat. 193-199.

Goldberg, I.S., Abramson, G.J., Haslam, C.O. and Los, V.L., 2003, Depletion and enrichment of primary haloes: their importance in the genesis of and exploration for mineral deposits: Geochemistry: Exploration, Environment, Analysis, vol.3, 281-293.

Govett G.J.S. (ed) 1983. Rock Geochemistry in Mineral Exploration.Handbook of Exploration Geochemistry, 3. Elsevier, Amsterdam.

Grigorian, S.V., 1974, Primary geochemical haloes in prospecting for exploration of hydrothermal deposits, Int. Geol. Rev., 16, 12-25.

Ji Kejian, Wu Xuehan, Zhang Guobing, 1992, Ore Source, Water Source and Heat Source for Hydrothermal Deposits and Regularity of Their Distribution: Geological Publishing House, Beijing, China.

Levinson, A.A., 1974, Introduction to Exploration Geochemistry: Applied Publishing Ltd, Calgary, Alberta, Canada, 611.

Levinson, A.A., 1980, Introduction to Exploration Geochemistry: The Supplement, Applied Publishing Ltd, Wilmette, USA, 1980, 615-924.

Mackin, J.H., 1968, Iron ore deposits of Iron Spring District, southwestern Utah: In Ore Deposits of the United States, New York, American Institute Mining Metallurgy Petrology, v. 11, 992-1019.

Robertson, L.D.M. & Taylor, G.F., 1987, Depletion Haloes in rocks surrounding the Cobar ore bodies, NSW, Australia: implication for exploration and ore genesis: Journal of Geochemical Exploration, v.27, 77-101.

Reimann, C., Filzmoser, P. & Garrett, R. G., 2005, Background and threshold: critical comparison of methods of determination: Science of the Total Environment, 346, 1-16.

Rose, A. W., Hawkes, H. E., Webb, J. S., 1979, Geochemistry in Mineral Exploration: Second Edition, Academic Press, London, 657.

Safronov, N. I., 1936, Dispersion haloes of ore deposits and their use in exploration: Problemy Sovetskoy geologii, 4, 41-53.

Vandenberg, A.H.M., Willman, C. E., Maher, S., Simons, B. A., Cayley, R. A., Taylor, D.H.., Morand, V. J., Moore, D. H. and Radojkovic, A., 2000, The Tasman Fold Belt in Victoria, 451.