Journal of Nepal Geological Society, 2011, Vol. 43 (Special Issue), pp. 145–152

Mineral deposits location and depth structure of the Earth's crust

Evgeny M. Nesterov
The Herzen State Pedagogical University of Russia, St. Petersburg, Russia
(Email:nestem26@mail.ru)

ABSTRACT

Recent development on the Earth sciences has given particular attention to investigate the deep structure of the planet, which is necessary to solve the theoretical problems of geodynamics, forecast deeply lying mineral deposit sites more effectively, study issues of seismic danger, predict and lessen natural disaster damage especially caused by Earthquakes and volcanic eruption, and also to do research on the environment protection problems. Continues complex geological evolution of the continent has been underwent for all the Earth history. Different regions of the continent have common patterns both in forming tectonic structures and mineral deposit location.

Maps of deep-layered structures of the Earth's crust for the territory of folded system have been created on the basis of 5- layer model to give an idea of general arrangement and distribution of masses above the basaltic layer of the crust. Some geological aspect of the problem related to metallogenesis, the distribution of polymetallic deposits and the deep structure of masses above the basaltic layer of the crust are discussed. Such investigations give the prognostic possibility for searching deposits on the basis of deep structure investigations. The obtained regional of the deep tectonic structure and mineral deposits location are characteristics also for the areas of Asiatic continent, which can be used for prognosis. Such patterns can be seen in Zaisan folded system in the eastern part of Kazakstan.

Keywords: Depth structure, Earth's crust, mineral deposits

Recieved: 14 November 2010 **revision accepted:** 20 April 2011

INTRODUCTION

The area under present study includes a small part of Northern Balkhash territory - hercynites of Dzhungar-Balkhash folded area, caledonites of Chingiz-Tarbagatay folded system, hercynites of Zaisan zone, hercynites of Rudny Altai. In this paper major features of the geological structure of the investigated region, deep structure of Zaisan folded system, deep structure characteristics, Metallogenetic relations between copper, lead and zinc deposits and the depth structure of the Earth's crust and research results are briefly described.

MAJOR GEOLOGICAL STRUCTURE OF THE INVESTIGATED REGION

Zaisan folded system takes an axial position in Central-Asiatic (Ural-Okhotsk, Ural-Mongol) belt. Central Kazakhstan and Gorny Altai lie almost symmetrically to Zaisan system.

Tectonic mapping of the region is quite often performed differently due to differences in interpretation of regional geological development. On the basis of geological and geophysical data the territory under study can be divided from North-East to South-West into Irtysh, Kalba, Saura, Chara, Zharmin-Tarbagatai zones, respectively. There are Pre-Cambrian, Lower, Middle and Upper Paleozoic Formations in the region. Mesozoic and Cenozoic deposits are limited and found mainly in Cenozoic depressions. The age of most ancient formations on the territory under investigation is believed to be not older than Upper Proterozoic period. Paleozoic rocks although studied non-uniformly but in significant details.

Problems of distinguishing stratigraphic position of the rocks are connected mostly due to monotonous lithologic content and with the similar many terrigenous and volcanogenic massifs and their quick fascial changeability and very rare organic remains. Main results of stratigraphic studies of the region are quoted in works of a number of previous researchers.

Two rock types of different ages and polarity (granitoids and ultrabasics by petrographic classification) form extensive belts of north-western stretch. Intrusions of medium and main compositions are not marked by a linear pattern.

Geological development of the territory during Hercynian cycle was not uniform. At the stage of predominantly descending movements and sludging in Zaisan flexure the eugeosynclinal effusive magmatism of main (West-Kalbinskaya zone) and medium (Zharma-Saurskaya zone) became widely apparent. At the same time the meso-geosynclinal (secondary-geosynclinal) regime with mainly acid magmatism formed in Rudny-Altai zone. At the end

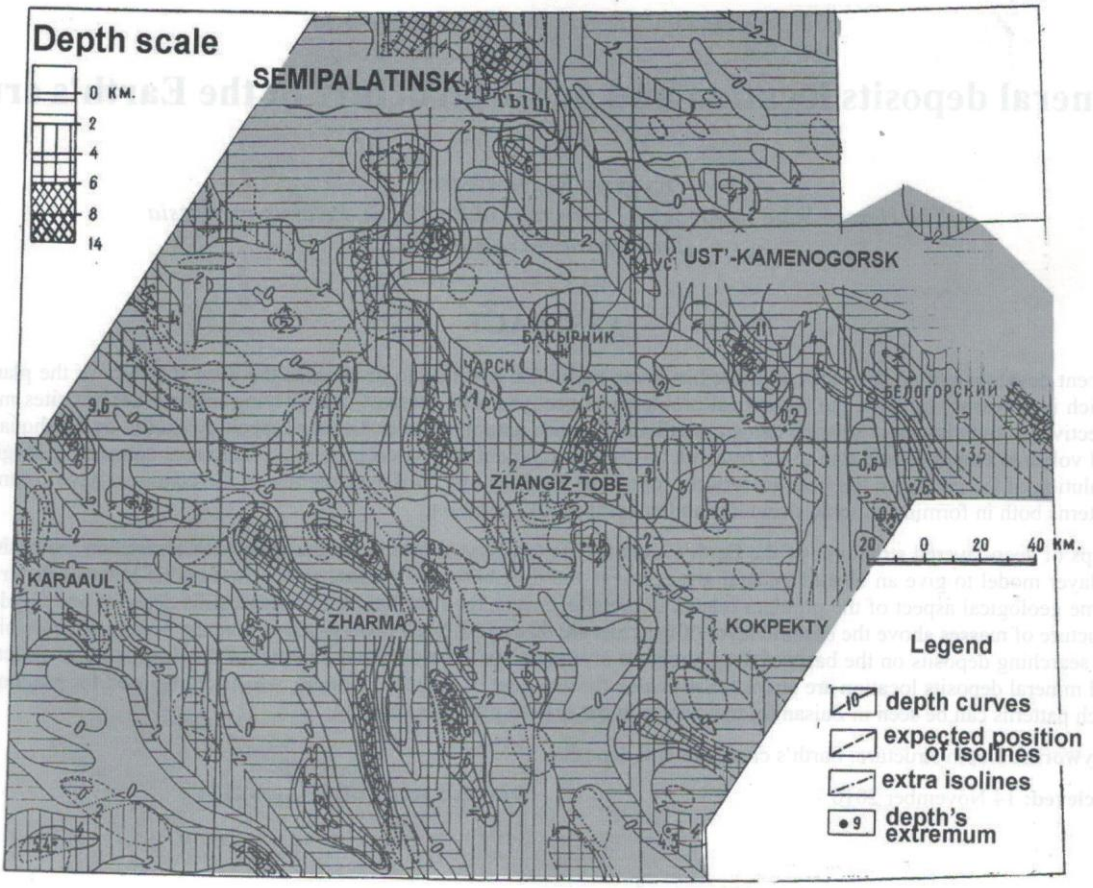

Fig. 1: Map of granite layer width

of lower to beginning of middle Carbonaceous a shift to ascending movements began. It led to reducing and closing of the system. The volume and area of spreading effusive volcanism decreased. At the end of Paleozoic the whole Zaisan system developed as meso-geosyncline although the character of its magmatism was still different in its various zones.

DEEP STRUCTURE OF ZAISAN FOLDED SYSTEM

Zaisan folded system features mass deposits of non-ferrous and rare-Earth metals and their ores. Besides it is noticeable for an essential difference in Paleozoic magmatism and tectonic structure in the south-western and north-eastern parts. This forth an enhanced interest on the part of geologists in studying the Zaisan system deep structure. The studies are carried out either by means of geological and geophysical constructions or by formal processing of gravimetric data. In some cases data received by method of double crossing reflected Earthquake waves was used as a basis for gravity anomalies calculations. The difference in the assumed Earth's crust models, methods of geophysical data interpretation and scopes of used geophysical and geological materials predetermined significant differences between descriptions of deep structures proposed by different authors. Constructions based on formal processing of gravimetric data or dependable (only partially at that) on the data of the reflected Earthquake waves method (REWM) seem to not well grounded. Geophysical investigations data are more valid because they do not depend on prior assumptions on the Earth's crust bottom depth and its inner structural delineation, nor on other data interpretation of which is ambiguous. Still these data need more accurate and specific definition in the light of new geophysical and geological material appearance (Moiseenko and Nesterov 1980).

In particular, it was found that the cut in the Zaisan system Earth's crust in its mid-section is more complicated than it had been thought previously. In this respect the structural model of Zaisan system was revised. The work has been carried out on the basis of the present regional petrophysical, gravimetric, partly aeromagnetic data as well as the author's field observations. The research methods are based on theoretical and practical considerations mentioned in a number of works. New methods have been used while analyzing complex anomalies which combine

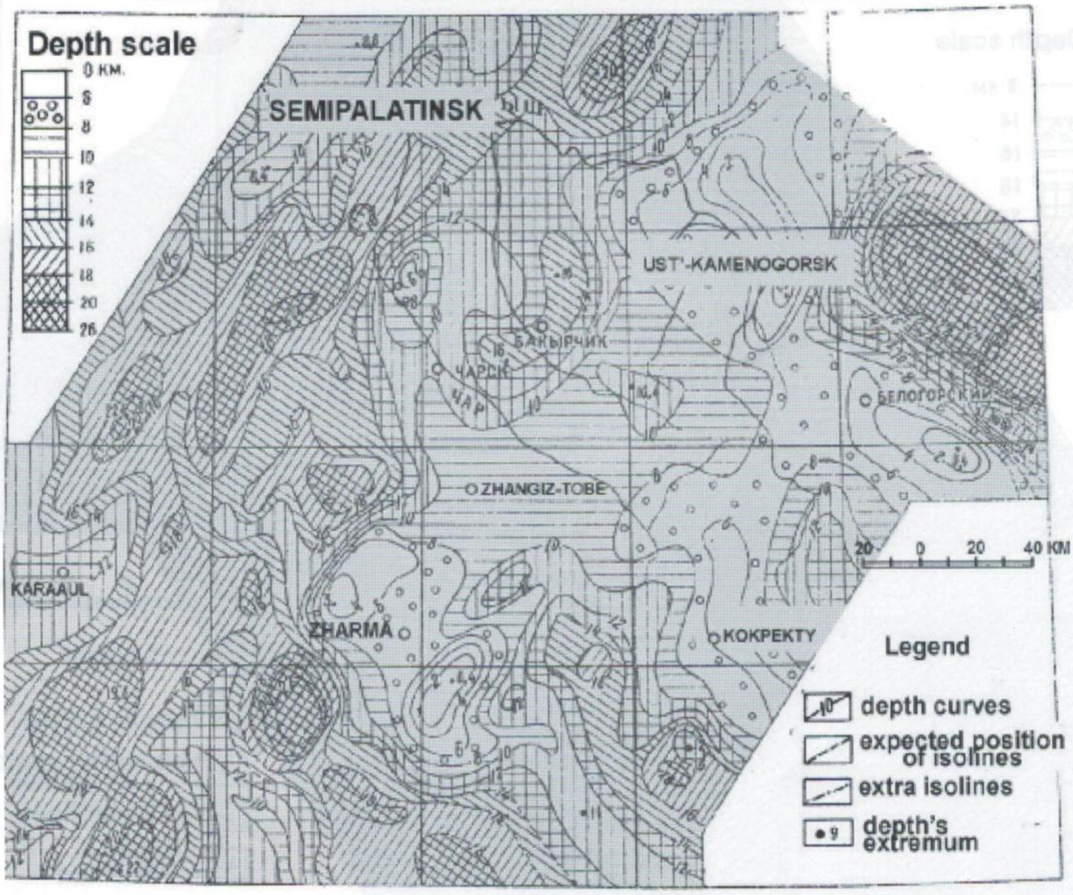

Fig. 2: Map of gabbrodiorite layer width

the gravitational force of two bodies with excessive density of the same polarity. Comparing the resulting picture of the deep structure with the profiles showed a near resembleness of the reflecting horizon position with the roof of basalt layer.

DEEP STRUCTURE CHARACTERISTICS

Width comparison of over-basalt sections of the Earth's crust has not shown any accurate correlation between width of volcanogenic-sedimentary and other layers. Such correlations between the other layers are also weak. Only in the area of Kalbinsky granitoid belt there is a direct relation between width of granite and diorite-granodiorite layers (Figs.1 and 2). Widening of the granite layer is often connected with narrowing of the diorite-granodiorite layer.

Changing width of one layer is not obligatory followed by changing width of another layer. There is a distinct relation in width between diorite-granodiorite and diorite-gabbrodiorite layers: while one of them widens, the other becomes narrower. Some local thickening and thinning are exceptions. The position on the map of the diorite-granodiorite layer thickening and thinning has a shift towards the central part of the region in comparison with similar bodies of diorite-gabbrodiorite layer. A direct dependency is seen between the diorite-granodjorite and diorite-gabbrodiorite roof behavior. When one sinks or rises the other does too. Only a few local points do not have such a correlation. The roof reliefs of diorite-gabbrodiorite and basalt layers (Fig. 3.) have little in common as to details of their morphology. Only a common tendency of rising of the roof of one layer when the other's roof sinks stands out. There is also a characteristic shift of the diorite-gabbrodiorite layer roof flexures' axes toward the center of the region as compared to the basalt layer roof flexures. The roof of each upper layer has axial shift of flexures towards the center of Akzhalsky elevation.

The above mentioned width and relief correlations of different layers in over-basalt section of the Earth's crust reflect differences in layers' mass dispersion, which manifest dissimilarity not only in dimensions and forms but also in orientation of thickening and thinning of layers. Thus irregularities of volcanogenic-sedimentary and granite layers stretch mainly to north-west. North-eastern, latitude and meridian stretches are rare and only among local thickening and thinning.

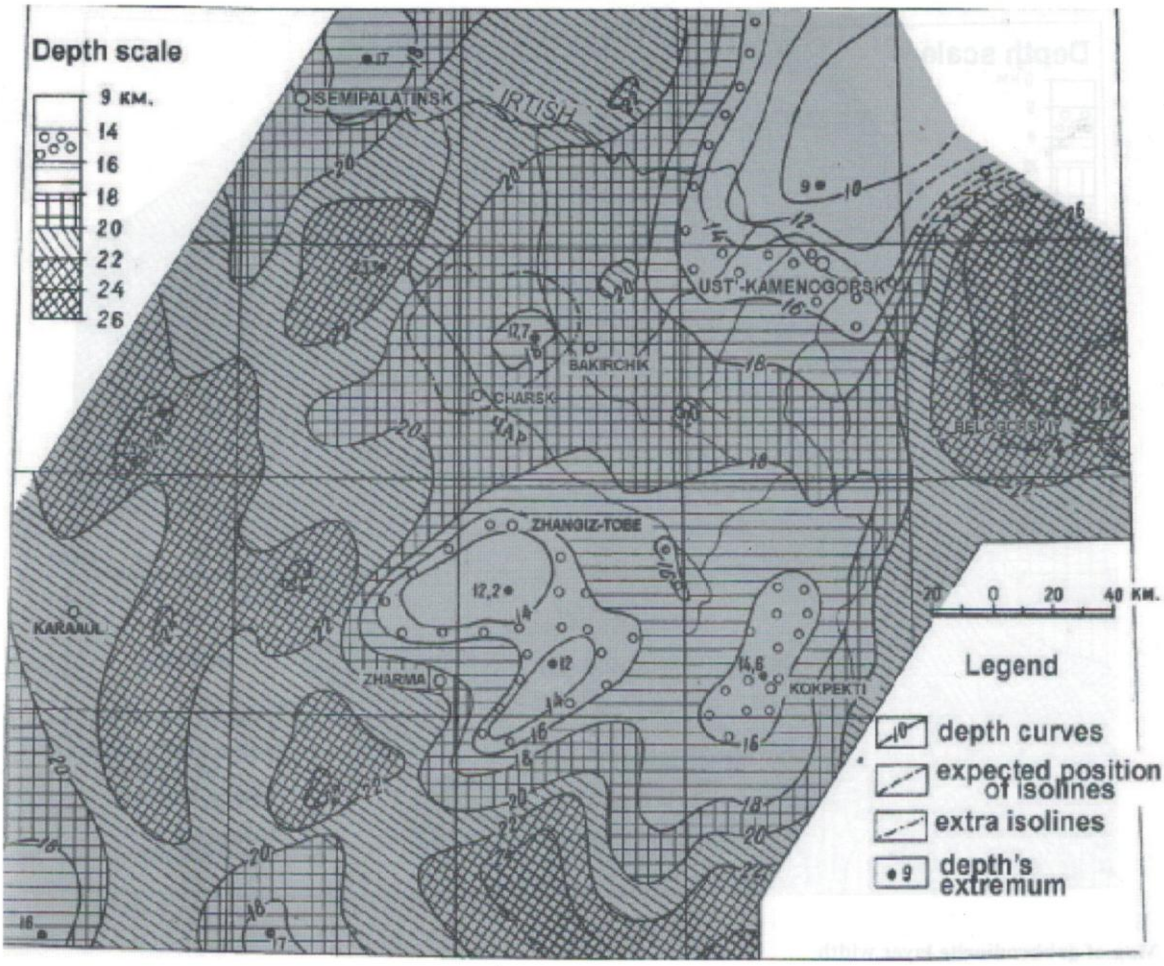

Fig. 3: Map of basalt layer roof relief

North-east oriented irregularities play an essential part in distribution of masses in diorite-granodioritic layer. They distinctly frequent the north-eastern part of the region, excluding its south-eastern part. North-west oriented stretches of thickening and thinning are prevailing in the south-west of the region as it is seen in the granite layer. Large and small north-east oriented thickening and thinning are predominant in diorite-gabbrodiorite layer. North-east stretched irregularities are seen only in the south-eastern third of the region, but their outlines are not distinct. It is worth noting that the north-east orientation of thickening and thinning is most noticeable in the north-western half of the region, where the width of the layer is maximal. The basalt layer roof relief stresses predominant north-eastern orientation of its irregularities practically on all territory of the region (Fig. 3). But north-west oriented irregularities are clearly seen in the south-west. The basalt layer roof is characterized by large, outlined similarly to isometric, elevations and defluxions diminishing to a certain extent the precision of north-eastern stretches of the roof irregularities.

Presently the causes of the mentioned change in the character of mass distribution towards the Earth's crust depth are not clear. Judging by the known relations between the width of the crust's over-basalt section layers and geosynclinal sediment accumulation, one can suggest that each layer corresponds in general to the structure-forming complex of a certain age. In this case the distribution and orientation of the layers' thickening and thinning reflect the space characteristics of geosynclinal flexures and elevations at different stages of the geological history of the region. In fact, the lay-out of location of the volcanogenic-sedimentary and granite layers irregularities, especially in regard to their elements orientation, generally repeats the structural map of mid-upper Paleozoic formations. An exception is Zhangiztobinsky granitoid belt, the position of which could have been defined not mainly by the peculiarities of geosynclinal sediment accumulation, but by inflow of juvenile material in the deep fault.

Prevailing north-east stretching of the diorite-granodiorite and diorite-gabbrodiorite layers' elements in the middle and north-east parts of the region cannot be explained by the near-surface geological structure. Folded and block structures formed by Paleozoic rocks can be seen only in separate parts, as well as fault systems and intrusive chains stretching in accordance with the elements of the depth structure. It is presumable the diorite-granodiorite and diorite-gabbrodiorite layers reflect specifics of the Pre-Mid-Paleozoic thickness tectonic structure. The basalt layer relief characterizing distribution of mass in the whole over-basalt section of the Earth's crust gives evidence that most common features of the section deep structure had formed before the Mid-Paleozoic.

METALLOGENETIC RELATIONS BETWEEN COPPER, LEAD AND ZINC DEPOSITS AND THE DEPTH STRUCTURE OF THE EARTH'S CRUST

The analysis of correlations between location of copper, polymerase, rare metals, and ore deposits and the Earth's crust deep structure, which were brought to light as a result of small-scale geological and geophysical works, showed high possibilities of the depth research for solution of metallogenic problems (Nesterov 1992).

Dependence of deposits location on width and structural peculiarities of different Earth's crust layers are the basis not only for prognosis when searching deeply lying mineral deposits, but also for bringing out sources of ore minerals, defining the roles of each crust layer in ore genesis and solving a lot more issues. Studying interrelations between depth structures and ore deposits led also to evaluation of the practicability of deep geological research depending on its detailed character. In particular, it was determined that a high degree of the Earth's crust partition and detailed mapping of mass dispersion for each layer sharply raise prognostic search and metallogenic informational ability of deep structures (Nesterov 2002).

On the contrary, reducing deep structures to schematic images of consolidated crust as non-layered or two-layer body makes them of little value and even detrimental for solutions of theoretical tasks of regional and genetic metallogeny. Unfortunately, many specialists in deep seismic probing, in the rush for false objectivity and validity, instead of more detailed mapping of the Earth's crust, limit themselves to drawing its fast sections in isolines. Such sections are useful as an auxiliary material for structural profiles, but they do not substitute them. In disputes about correspondence or non-correspondence of geophysical and, in particular, seismic layers to structurally different geological bodies, it is forgotten that difference of the crust physical parameters first of all is a reflection of the whole chemical composition of rocks forming it. This conclusion made long ago and finding more proof in petrophysical data is a theoretical basis of metallogenic studies on deep-geological ground. It evolves possibility and necessity to divide the Earth's crust into geological bodies of different structure. In spite of increasing importance to study structures of over-basalt layer of the crust activity of work in this field is very little. That is why both usage of received prognostic-searching indications and further attempts of solving metallogenic problems on the ground of deep geological-geophysical data are rather difficult. In this respect, more accurate definition of previously found correlations between deposits and crust structure based on finer crust division is thought to be of interest.

DEPENDENCE OF SOME ORE DEPOSITS, LOCATION, THICKNESS OF THE EARTH'S CRUST LAYER IN ZAISAN FOLDED SYSTEM

The over-basalt crust part of Zaisan region was divided into four layers: volcanogenic-sedimentary, granite, granodiorite (diorite-granodiorite) and gabbro-diorite (diorite-gabbro). It is considered that the later two as the lower and upper parts of the diorite layer, which is reflected in the cumbersome names that was given. Such a conclusion was based on the values of their density: 2,72 to 2,83 g/cm^3 (Nesterov 2001).

It was defined correspondingly that the granodiorite layer in the Zaisan system north-eastern and south-western outskirts was poorly developed and that bulges territorially timed to the areas of granite belts development. The fact is that the width of the granite layer in bloated parts appears less in comparison with its earlier definitions and a part of its mass turned out to be moved to the granodiorite layer gave ground to doubt big kindred of the latter with gabbro-diorite layer than with the granite one. Determining of the ore-generic layer for different deposits could to some extent clarify also the degree of similarity between layers of the over-basalt part of the crust. Distribution of deposits regarding width of different layers of the Earth's crust is subjected to certain regularities (Fig. 4). Thus copper, lead, zinc as well as polymetallic deposits in general are related, with a maximum degree, to the regions with minimal width (0-2 km) of granite layer. There are 50 to 67% of deposits.

The number of deposits sharply decreases when the layer width increases. Their distribution has the same character regarding the total width of granite and volcanogenic sedimentary layers, although the percent of the deposits in the modal interval of width noticeably decreases, and lessening of their numbers with increasing the width of conditionally granite layer is smoother. An exception is a group of polymetallic deposits, where the distribution mode shifts to the width interval of 2 - 4 km.

Distribution of deposits with regard to the width of granodiorite layer differs from the previous ones because the majority of the deposits are in the areas completely devoid of that layer. Besides, the overwhelming majority of copper and polymetallic deposits lie within the wide range of layers width 0 to 6 km.

Connection of deposits with the total width of granite and granodiorite layers is mostly similar to that described above. Nevertheless, Puasson's distributions here are more precise,

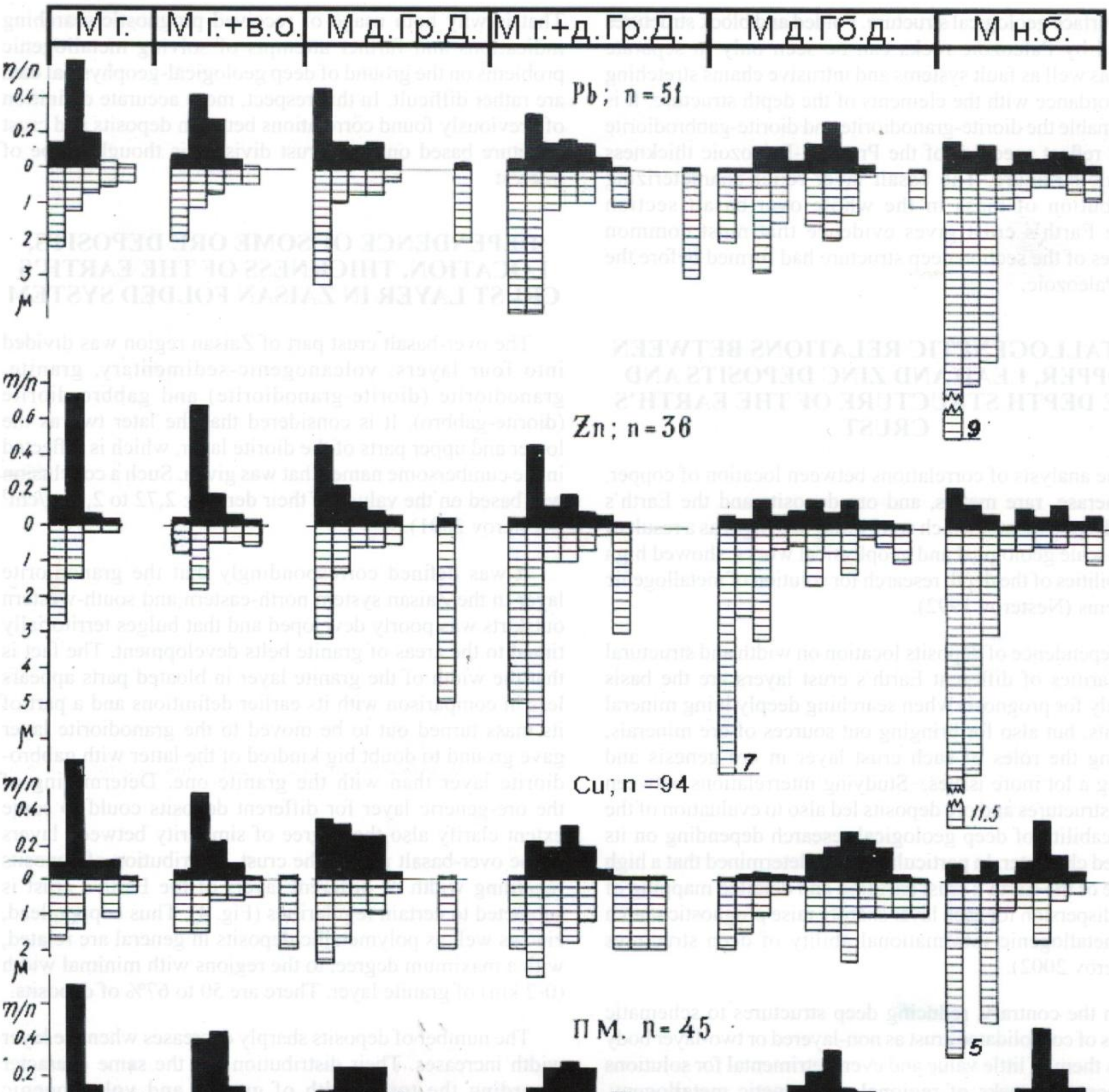

Fig. 4: Bar graphs of distribution related to frequencies of deposits (m /n) and degrees of relation between distribution of Earth's crust masses and location of ore deposits (m).

Legend: (M$_{\text{Ã}}$ — width of granite layer; Ì$_{\text{Ã+ÂÎ}}$ — total width of granite and volcanogenic-sedimentary layers; Ì$_{\text{ÃÐ.Ä}}$ — width of granodiorite layer; Ì$_{\text{Ã+ÃÐ.Ä}}$ — total width of granite and granodiorite layers; Ì$_{\text{ÃÁ.Ä}}$ — width of gabbrodiorite layer; Ì$_{\text{ÍÁ}}$ - total width of layers of over-basalt section. Layers width intervals are shown below - (km), n — number of deposits in a sampling).

and the bar graphs for copper and polymetallic deposits already show signs of normal distribution with maximum lying within the width interval 4 - 6 km.

The distribution character of copper, lead and zinc deposits with regard to the gabbro-diorite layer width, in spite of the bar graphs non-preciseness, is principally different from the same for the above lying layers. This is generally normal distribution, although complicated (for lead and zinc) by irregular deviations. A high degree of relation for such deviation, especially noticeable within the width interval of 0 - 8 km, let us think that they resulted from the analysis methods. Values of layer width are read from the map on the deposit point, and if these points are situated over steep sloped of the layer thickening where isopach are very dense, receiving of a high degree of correlation is very probable only because of a small area limited by the neighboring isolines. A most favorable interval of gabbro-diorite layer of 14 - 16 km is marked for copper deposits when their overwhelming majority is located in the region with the layer width of 10 to 20 km. The corresponding intervals for polymetallic deposits equal 12 - 14 km and 8 - 18 km. Most favorable layer width for lead deposits is 12 - 14 km at the background of a wider interval of 10 - 16km. Besides, almost 35% of them fall into the interval of 4 - 6 km. Zinc deposits are distributed with regard to the gabbro-diorite layer width with hardly noticeable regularity: a saw-tooth bar graph shows maximum in the width interval 8 - 16 km and 4 - 6 km.

The total width of the over-basalt section is related to copper and polymetallic deposits concentration in the regions where the section width is 18 - 20 km. Its influence on lead and zinc deposits concentration shows only when they gravitate to sections 8 - 10 km wide.

While comparing the previously achieved data with the mentioned values of Earth's crust layers width favorable for searching, the latter show a noticeable difference from the first. Thus, the most favorable width of conditionally-granite layer for lead and zinc deposits equals that for copper deposits, i.e. it is twice as little as the previously obtained data. It does not increase even in the case when it is defined by the total width of the granite and granodiorite layers. Such lessening of a favorable interval of the mentioned layers width can be explained either by a great preciseness of the deep mapping or by an insufficient preciseness of deposits fixation to the maps of deep structures. New data estimate favorable widths of gabbro-diorite layer for copper and lead deposits, on the contrary, almost twice as big as the widths of undivided diorite layer of the former scheme (12 - 14 km against 7 - 9 km for lead and 14 - 16 km against 9 - 13 km for copper). Such comparisons are hard to draw for zinc deposits because of their inaccurate distribution relatively layer width.

CORRELATION OF DEPOSITS WITH DIFFERENT LAYERS OF OVER-BASALT SECTION OF THE EARTH'S CRUST

It follows from the above description of dependencies between copper, lead and zinc deposits and their locations and width of different crust sections that all mentioned deposits are correlated with the widths of volcanogenic-sedimentary, granite, granodiorite layers. The increasing number of deposits with decreasing layers thickness means that all layers play the part of ore-containing environment in ore genesis. It is stressed by the major quotients of correlation (m) for a small number of deposits located in places where volcanogenic sedimentary and granite layers are absent. At the same time the correlation between deposits and granodiorite layers show another relation. In fact, deposits "avoid" placement in this layer preferring volcanogenic sedimentary and granite layers to it. This fact probably means that the rocks of granodiorite layer are not favorable for copper, lead and zinc ore deposits. This is probably the reason why a considerable part of lead and zinc deposits lies on the plots with comparably big widths (up to 6 km). The deviation from Puasson distribution with copper and polymetallic deposits regarding the granodiorite layer can be explained partly by the presence of genetic relation of copper with the rocks of the mentioned layer. But in no lesser degree this could have been conditioned by tough term of ore concretion. The later assumption seems to us more probable. The diagram of the deposits distribution with regards to total width of granite and granodiorite layers reflects complexity of deposits relations with each of them and does not clarify their character (Fig. 4).

Distribution of copper and polymetallic deposits relative to the total width of granite and granodiorite layers do not reflect the genetic nature. At the same time such relations for gabbro-diorite layer are established most vividly. Actually, the number of deposits and correlation intensity increase with increasing of layer width i.e. with increasing of ore generating mass. Deposits decrease at widths bigger than modal ones is predetermined by their remoteness from ore mobilizing hotbed. The similarity in the character of distribution of copper and polymetallic deposits is obviously connected with the fact that the latter always contain copper. Besides, all of them fall into the category of small ones.

Lead and especially zinc deposits also show a genetic relation with gabbro-diorite layer, although not so distinct as the copper ones. Comparatively quick decreasing of lead deposits concentration at width more than 16km probably reflect a tough dependency of ore sediment on the ore mobilizing factor. Such a distribution is possible when the variation interval of minimal ore-concretion temperature is narrow. The second mode in the distribution diagram within the width interval 4 - 8 km is conditioned by sharp variability of gabbro-diorite layer width in the regions of lead deposits development, so even gross inaccuracies in deposits fixation or shifts with regards to the direct source of ore material manifest themselves in significant variations of favorable widths values.

Zinc deposits are timed to a wide interval of favorable widths of gabbro-diorite layer not because of a small number of cases used for diagram drawing but because of a relatively high metal mobility. In this respect zinc is close to copper. The closest relation of almost 30 zinc deposits with the layer width of 0 through 6 km can be explained by their gravitation to the side parts of gabbro-diorite layer thickenings. It is not less probable that such a way of relation is conditioned by absence of a genetic connection of a part of zinc deposits with gabbro-diorite layer. The Puasson type of zinc deposits distribution regarding the width of the whole over-basalt section, common for the functional relation of the parameters, speaks in favor of this assumption. The over-basalt layer in this case acts as an accepting environment. Such interpretation of the distribution diagrams still cannot be recognized as the only truthful. When the over-basalt section of the Earth's crust plays the ore-generating part, deposits can concentrate in the areas of its smallest widths in the region because of a limited range of ore-mobilizing factor for zinc. This influence of the remoteness from the ore-mobilizing hotbed can explain also a very close relation of a large number of lead deposits with the smallest values of the over-basalt section width.

CONCLUSIONS

The correlation between copper and especially polymetallic deposits and the over-basalt section is obviously a genetic one. Also, their most favorable width of the over-basalt section is higher than for lead and zinc deposits, which seems to contradict the melanocratic character of copper deposits. But this contradiction seems, because the section width in such cases is defined by thickening of the gabbro-diorite layer, which takes up to 80 % of the section. Consequently, the correlation between copper deposits concentration and the over-basalt section width stresses their relation with the gabbro-diorite layer. Placement of about 20% of copper deposits, with high correlation quotient, in regions with thin over-basalt part (8 - 10 and 12 - 14 km) is also conditioned mainly by development of the gabbro-diorite layer in the sectional part of deposit sites. In fact, in 12 of 18 of such occasions the granodiorite layer is absent, in 5 cases its width is 0 - 2 km. The total width of granite and volcanogenic sedimentary layers is within 0 - 2 km. The gabbro-diorite layer is ore-generating for polymetallic deposits in general sense. It is most distinctly characteristic for copper deposits. Less precision with lead and zinc deposits is, without doubt, caused by insufficient data for a reliable statistic processing. It is knowledge of the gabbro-diorite layer masses placement and not of the whole diorite layer that is essential for search prognosis. Therefore, singling out and deep mapping of the gabbro-diorite layer present not only theoretical but also practical interest, and once again underlines the importance of possibly finest detailed division of the Earth's crust and investigating chemical characteristics of layers under study.

ACKNOWLEDGEMENTS

The author is grateful to K.P. Kaphle for his helpful comments and suggestions to improve this manuscript.

REFERENCES

Moiseenko, F. S. and Nesterov, E. M, 1980, Features of depth structure in Zaisan folded system. Vestnik LGU, pp. 10-18.

Nesterov, E. M., 1992, Metallogenic relations between copper, lead and zinc in Zaisan folded system and depth structure of the Earth's crust. Vestnik LGU, v. 24, pp. 62-68.

Nesterov, E. M., 2001, Lateral changeability of rock density. Vestnik SPbGU, v. 12, pp. 36-43.

Nesterov, E. M, 2001, Geology of the morning freshness land // Excursions in geology. O.1. – Spec. publ., v. 3, pp. 259-268.

Nesterov, E. M., 2002, Depth structure of Altai-Zaisan part of Ural-Okhotsk belt and regularities of mineral deposits location. Tectonics of East Asia, pp. 13-25.

Nesterov, E., 2009, Geoscience and Natural Sciences in the System of geological formation of the Society // GeoDev. – Dhaka, pp. 25-31.

Nesterov, E., Bulakh, A., and Vlasov, D., 2009, Natural hazards assessment: the reasons and process of destruction of the stone vase monument in the Sankt-Peterburg Summer Garden // GeoDev. – Dhaka, pp. 118-123.

Nesterov, E., Markov, V., and Gildin, S., 2009, Geochemistry of sediments of Inland Lakes of Valaam in Holocene: history of lake Ladoga // European Large Lakes. – Norrtalje, Sweden, pp. 0-12.

Nesterov, E. M, Zarina L., and Mawopulos P., 2009, Ekologiczne problemy obszarów zurbanizowanych. Przyk³ad Petersburga, [w:] W. Kamiñska, M. Mularczyk (red.), Wspó³czesne procesy urbanizacji obszarów wiejskich, IG UJK, Kielceh, pp. 98-116.