Metallograms as an Objective and Illustrative Basis for Metallogenic Analysis

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Abstract. The paper presents results of huge generalization of geological and metallogenic materials on paleosoids of Kazakhstan which allowed for the first time composing the metallogenograms for seventy eight (78) structural-formational zones (SFZ). Their analysis showed that all SFZs of Kazakhstan's paleosoids contain ores and led to development of scientifically substantiated recommendations for planning the prospecting works within the newly identified promising SFZ areas with favourable metallogenic geodynamic conditions and ore-bearing stratigraphic levels.

1. Introduction
The geological industry of Kazakhstan has entered the hard period of substantial depletion of the fund of commercially significant deposits, economic in operation under modern market conditions. Almost all fields identified in the Soviet period are in operation or being prepared for development. Given the current capabilities of mining technologies, the task of provision of the fund of deposits for the times ahead is inevitable. The country's mineral resource base is currently exhausted not only due to extremely little prospecting work carried out over the past 30 years, but also because all easily discovered deposits has almost completely been utilised to date in Kazakhstan, as in the whole world.

This is why the efficiency of prospecting works at present directly depends on analysis of deposit placement regularities by establishing links between ore formation and certain geological formation, revealing the peculiarities of localization of a certain type of mineralization with certain tectonic structures, geodynamic conditions manifested at this or that stage of development of structural and formation zones [1-2, 8-9, 11].

Improvement of the prospecting efficiency seems undoubtedly relating to solving of the above problems. This justified the grant project titled "Identification of promising directions of exploration of mineral deposits based on new data on manifestation regularities in the paleozoids of Kazakhstan", carried out in 2015-2017.

2. The main body
Given the multidimensional nature of the problem, the authors used the formation method, the most universal method of scientific analysis characterized by N.S. Shatsky (1965) as follows: "The formation analysis, if I may say so, in solving the issues of mineral deposits distribution has a preferable value over all others".
Therefore, for zoning the paleosoids, the authors employed the method of structural-formational (metallogenic) zoning developed and widely used since the late 1970s by metallogenists of Kazakhstan A.K. Kayupov, Sh.E. Essenov, V.G. Li and other, [5, 7]. The work was supported by the "Chart of folded systems and structural-formation zones of paleozoids of Kazakhstan", specifying the 78 SFZs (including some subzones), as a base document (Fig. 1).

Figure 1. Scheme of the location of the structural-formational zones of the paleozoids of Kazakhstan (according to G.F.Lyapichev, 1977 with the additions of the authors), mb 1: 2500000.

The analysis of vertical series of Kazakhstan SFZ formations shows that development of each zone was complex, polycyclic, with manifestation of several geodynamic regimes and, accordingly, the formation of various types of tectonic structures, associated with varying endogenous complexity [3].

These bonds become obvious in metallogenograms, which defined the task of compiling them for all SFZ paleosoids of Kazakhstan as "The Atlas of Metallogenograms of Kazakhstan’s SFZ paleosoids". Compilation of the great number of metallogenograms (78) has been implemented in Kazakhstan for the first time and described all SFZ paleosoids as follows: three of the Hercynian including the Uralian, Dzungar-Balkhash and Zaisan folded systems and two of the Caledonian including the Kokshetau-NorthTienshan and the Bozshakol-Shyngys-Tarbagatai folded systems. The "cap" of the metallogenograms with the designation of the corresponding columns is given below.

| System Division Tier | Stratified and intrusive formations | Formations | Paleo environments | Metallogeny |
|----------------------|-----------------------------------|------------|--------------------|-------------|

According to the Geological Dictionary (2011, vol. 2. p. 220), "A metallogenogram is a table of conditions and situations for formation of local metallogenic taxa, made in addition to the
metallogenic map”. Close to this is the definition of metallogenograms given in the "Metallogenic code” [6].

The authors’ version treats a metallogenogram as a document describing geological and metallogenic characteristics of a certain SFZ given in the tabular form. It contains information on SFZ geological formations as lithologic-chronological vertical series of stratified and intrusive formations, a column of vertical series of corresponding formations, a column of formation paleo-situations and a column of manifestations of ore mineralization of different rank (points of mineralization, ore manifestations, deposits of small, medium, large size), tied to levels of host rocks [4, 9, 10].

The geological part of the developed metallogenograms resides on huge bulk of materials including all intrusive, volcanogenic, volcanic-sedimentary and sedimentary formations of paleosoids of Kazakhstan, published over the last 60 years. This archive has been enhanced by later works. Within the frame of the project, the list of utilised sources has accumulated more than 5,000 titles, shaped as "The Bibliographical Reference Book of Geology and Metallogeny of Paleozooids of Kazakhstan”, which has been prepared by the authors for publication.

Base materials utilised by the authors for developing the lithological-chronological series of geoformations of the Kazakhstan’s paleosoids, primarily include the following works: “Explanatory notes to the Geological Map of the Kazakh SSR scaled 1:500,000” (1979-1981); "The Geological Structure of the Kazakh SSR” to the Geological Map by V.F. Bespalov scaled 1:1,000,000” (1971) and "The Geological Structure of Kazakhstan” (2000); work by N.A. Afonichev and N.G. Vlasov "The Geological Map of Kazakhstan and Central Asia” scaled 1:1,500,000” (1986); “The Correlation Charts of Magmatic Complexes of All Folded Systems of Kazakhstan” (1989), the 4-volume monograph "Magmatic Complexes of Kazakhstan" (1982-1984); “Decisions of the III Kazakhstan Stratigraphic Meeting on pre-Paleozooids and Phanerozooids” (1991), reference explications to maps of GDP-200 (1993-2000) and many others. In order to define metallogenic specialization of formations, the authors used both materials of thematic metallogenic studies and numerous reference books (52 books, 1993-2000).

In general, the delivered metallogenograms contain complete geological-metallogenic information about each SFZ, creating an integrated picture on their ore content. The ore content of structural and formation zones of folded systems, shown in Tables 1-5, was identified as a result of the analysis of metallogenograms of the 78 SFZ paleosoids of Kazakhstan.

Table 1. Ore content of structural-formational zones of the Ural fold system - I (I - 1 - I - 7) and their metallogenic specialization.

| Name of structural-formation zones (SFZ) | Qualitative characteristic of ore content (the number of objects in the structural-formation zones) | Metallogenic specialization of SFZ |
|----------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------|
| Sakmarsko-Or-Ilekskaya SFZ 1-1         | Cr, Ni-Co, Fe, Mn, Cu (Zn-Pb), coal (180)                                                   | chromium-nickel-cobalt-iron-manganese-polymetallic gold-chromite-polymetallic |
| Western Mugodzharskaya SFZ 1-2         | Au, Cr, Zn, Cu, Ag, Mo, W, Fe, Mn, Ti, Hg, shungite (44)                                      | gold-iron-chromium-copper-rare metal with rare earths |
| East Mugodzharskaya SFZ 1-3            | Au, Fe, Cr, Cu-Mo, Cu-Au-Mo; Au – Ag, Cu-Mo-W-Nb-Ta; TR-Zr-Nb (Mo-Be-Th) Ta-Nb-Zr; (38)     | iron-chromium-gold-rare-earth     |
| Irgizskaya SFZ 1-4                     | Fe; Cr; Au; Ta, Nb, Be, Sn (Li, Rb, Ce, Y); Ni-Co, Al, U, asbestos; facing stone (32)        |                                   |
| Troitskaya SFZ 1-5                     | Au, Fe, Cr, Pb- Zn, Cu (24)                                                                 | gold-iron-cobalt-iron-gold-uranium-polymetallic iron ore-gold-polymetallic |
| Valerianovskaya (Kostanayskaya) SFZ 1-6| Fe, Fe (Co), Fe (Cu), Fe (Co, Cu, Mn), Fe (Co, Cu, Pb, Zn), Cu, Au, Zn-Pb (46)              |                                   |
| Ubaganskaya SFZ 1-7                    | Fe, U, Al, Ti-Zr (6)                                                                        | iron-uranium                     |
**Table 2.** Ore content of the structural-formational zones of the Zhongar-Balkhash fold system - II (II - 1 - II - 23) and their metallogenic specialization.

| Name of structural-formation zones (SFZ) | Qualitative characteristic of ore content (the number of objects in the structural-formation zones) | Metallogenic specialization of SFZ |
|----------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------|
| Karasor-Nurinskaya SFZ II-1            | Mn, Cu, Au (5)                                                                                   | manganese-copper-gold             |
| Sarysuiskaya SFZ II-2                  | Au (5)                                                                                           | gold ore                          |
| Tekturnamaskaya SFZ II-3               | Au, Ni (Co), magnesite (3)                                                                        | gold ore                          |
| Uspepskaya SFZ II-4                    | Zn-Pb, Cu, Be (W, Mo, Bi) (36)                                                                  | Polymetal - rare metal            |
| Zhaman-Sarysu SFZ II-5                 | Au, Pb-Zn, W-Mo, Cu, (19)                                                                        | gold-polymetallic-rare metal      |
| Aktau-Tasural-Kyzylaspinskaya SFZ II-6  | Pb-Zn, Au, W-Mo, Cu, Fe, Sn (48)                                                                 | polymetallic-gold-rare metal      |
| Akzhal-Aksoranskaya SFZ II-7           | Pb-Zn, W, Cu (15)                                                                                | polymetallic - rare metal         |
| West Tokrauskaya SFZ II-8              | W-Mo, Au, Cu, Pb-Zn (48)                                                                         | rare-metal-gold                   |
| South-Tokrauskaya SFZ II-9             | Pb-Zn, Cu, Au (Ag), W-Mo (35)                                                                    | polymetallic-gold-rare metal      |
| Zhantauskaya SFZ II-10                 | Au, Cu-Pb-Zn, W-Be-Tl (22)                                                                       | gold-polymetallic                 |
| East-Tokrauskaya SFZ II-11             | Au, Pb, Cu (Mo) Ta-Nb, Ba (26)                                                                   | gold-polymetallic                 |
| Kotanemel-Kalmakemelskaya SFZ II-12    | Au (Ag), Cu (Ag, Mo, Zn) Ba, Mn (13)                                                             | gold ore                          |
| Bakanasskaya SFZ II-13                 | Cu (Mo, Au, Ag, Re), Au (3)                                                                       | copper                            |
| Tasty-Kusak-Kotyrasan-Altynemelskaya SFZ II-14 | Cu-Mo, Mo, Be-Mo, Au (14)                                                                 | copper-porphyry-rare metal        |
| Severo-Balkhashskaya SFZ II-15         | Au, Mo-Cu (6)                                                                                    | gold ore                          |
| Sayakska SFZ II-16                     | Cu, Cu-Co, Sb, As (18)                                                                           | copper-gold                       |
| Kazyk-Itmurundy-Tulkulamskaya SFZ II-17| Au, Cu (6)                                                                                        | gold-copper                       |
| Tastauskaya (North Zhongarskaya) SFZ II-18 | Au (scattering), (18)                                                                           | gold ore                          |
| Sarkandskaya SFZ II-19                 | Au, W (4)                                                                                        | gold-rare metal                   |
| Central Zhongarskaya SFZ II-20         | Au, Cu (Ag), Sn, W, Hg (8)                                                                        | gold ore                          |
| Borotalinskaya SFZ II-21               | Mo, Sn, W (3)                                                                                    | rare metal                        |
| Tekeli (South Zhongar) SFZ II-22       | Pb-Zn, U, marble (8)                                                                             | polymetallic                      |
| Ili SFZ II-23                          | Au, Pb-Zn, coal, agalmatolite (23)                                                                | gold-polymetallic                 |

**Table 3.** Ore content of the structural-formational zones of the Zaisan fold system - III (III - 1 - III - 8) and their metallogenic specialization.

| Name of structural-formation zones (SFZ) | Qualitative characteristic of ore content (the number of objects in the structural-formation zones) | Metallogenic specialization of SFZ |
|----------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------|
| 1                                      | 2                                                                                           | 3                                |
| Zharma-Yuzhno-Saurskaya SFZ -III-1      | Mo, W, Ni, Ta, Au, Cu, Pb, Zn, Fe, Sb (17)                                                    | rare metal-gold-polymetallic     |
| 1                                      | 2                                                                                           | 3                                |
| Sarsazan-Severo-Saurskaya SFZ -III-2    | уголь, Au, Ti, U, Cu, Mo (17)                                                                   | coal-gold-copper-porphyry        |
| 1                                      | 2                                                                                           | 3                                |
| Charskaya SFZ - III-3                  | Au, Ni, Co (31)                                                                                | gold ore                          |
| 1                                      | 2                                                                                           | 3                                |
| West Kalbinskaya SFZ -III-4            | Ta, Sn, Nb, Be, Au, W (14)                                                                     | rare metal gold                  |
| 1                                      | 2                                                                                           | 3                                |
| East Kalbinskaya SFZ - III-5           | W, Ta, Sn, Au (37)                                                                             | gold-rare metal                  |
| Name of structural-formational zones (SFZ) | Qualitative characteristic of ore content (the number of objects in the structural-formational zones) | Metallogenic specialization of SFZ |
|------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------|
| Maryevskaya SFZ IV-1                    | U, Cu, Au, Zn, Mn, diamonds (16)                                                              | copper-modibdenum-uranium         |
| Kalmakulkayskaya SFZ IV-2               | U, Sn, Mn (13)                                                                                | uranium                           |
| Zharkainagachskaya SFZ IV-3             | Fe, U (Mo), Mn, Au (15)                                                                       | iron-uranium                      |
| Kokshetauskaya SFZ IV-4                 | Au, ред. мет. U, Ti, Cr, technical diamonds (74)                                                | gold-rare metal with uranium      |
| Stepnnyakskaya SFZ IV-5                 | Au, Cu-Mo, Sn, Cu-Pb-Zn, Ti (48)                                                              | gold-copper-porphyry             |
| Ishkeolmesskaya SFZ IV-6                | Au, U (Mo), Fe (16)                                                                           | gold ore with uranium             |
| Seletinskaya SFZ IV-7                   | Cu, Au, U (Mo), U (P), Al (34)                                                                | copper-gold ore with uranium      |
| Erementau-Agydymskaya SFZ IV-8          | Au, Cu-Pb-Zn, Fe, Mn, Al, coal (30)                                                            | gold-polymetallic                |
| North-Karagandinskaya SFZ IV-9          | Cu (Mo), Au, Mo, Mn (10)                                                                      | copper-gold                       |
| Central Karagandinskaya SFZ IV-10       | Pb-Zn, Ba, coal, limestone (10)                                                               | polymetallic                     |
| Spasskaya SFZ IV-10                     | Cu (Mo), Mn, Ba (14)                                                                          | copper with manganese             |
| West Sarysu-Tenizskaya SFZ IV-11        | Mn, Al, Au (10)                                                                               | manganese                         |
| East Sarysu-Tenizskaya SFZ IV-11        | Mn, Au (13)                                                                                  | manganese with gold              |
| Atasuyskaya SFZ IV-12                   | Pb-Zn, Mn (Fe) (11)                                                                          | lead-zinc                        |
| Ulutau-Karsakpayskaya SFZ IV-13         | Ba, Fe, Cr-Co-Ni, Ba (Mo), Au, U (43)                                                         | barium-iron ore                  |
| Baikonurskaya SFZ IV-14                 | Fe, Mn, V (P) (10)                                                                           | iron-manganese                   |
| Bolshekaratauskaya SFZ IV-15            | Pb-Zn, Ba, V (Mo-Fe), Au, Cu (58)                                                              | barium-polymetallic              |
| Malokaratauskaya SFZ IV-16              | Pb-Zn, Mn, Ba, Cu, Au (11)                                                                    | lead-zinc with manganese         |
| Shuiiskaya SFZ IV-17                    | Fe, Ba, Cu, U, technical diamonds (18)                                                         | barium-iron ore                  |
| Kendyktskaya SFZ IV-18                  | Au, Pb-Zn, Cu, Ba, Fe, P-V (28)                                                                | gold-polymetallic                |
| Zhailair-Naimanskaya SFZ IV-19          | Au, Pb-Zn, U (Mo), W, Ti, Cr,Co-Ni (27)                                                        | gold-polymetallic                |
| Sarytumskaya SFZ IV-19                  | Pb-Zn, Ba, Sn (W), Au (35)                                                                    | barium-polymetallic (Sn-Au)      |
| Priatasuykskaya SFZ IV-20               | Ba, Fe-Mn, Mo-W-Sn, Au, U (Mo) (30)                                                            | barium iron ore. rare metal      |
| Zhailminskaya SFZ IV-20                 | Fe, Mn, Ba, Pb-Zn (30)                                                                        | iron-manganese                   |
| Bulattau-Buruntasuykskaya SFZ IV-21     | Sn-W-Bi, Cu, U, Mn (20)                                                                       | rare metal copper                |
| Mointinskaya SFZ IV-22                  | Mn, Fe, Au, Sn (Cu, Mo)                                                                       | iron-manganese                   |
| Zheltukskaya SFZ IV-23                   | Pb-Zn, Sn-Mo-Bi, U, Au, Mn (21)                                                                | Rare metal - polymetallic        |
| Zailyskaya SFZ IV-24                    | W, Mo, Be, Cu-Pb-Zn, Au, Cr (18)                                                               | Rare metal - polymetallic        |
| Kastekskaya SFZ IV-25                   | Pb-Zn, Au (7)                                                                                 | polymetallic-gold                |
| Chilik-Kemanskaya SFZ IV-               | Sn-Ta-Nb (1)                                                                                  | rare metal                       |
Ketmenskaya SFZ IV-27  Cu, Ba-Pb-Zn, U (24)  barium-polymetallic with uranium
Terskeyskaya SFZ IV-28  Sn-W (Ta, Nb) (1)  rare metal-rare earth
Kyrgyzskaya SFZ IV-29  Au (Cu) (3)  gold ore
Korzhantau-Ugamskaya SFZ IV-30  Ba, Pb-Zn, Fe, Cu, Al (24)  barium-polymetallic
Zhezkazganskaya SFZ IV-31  Cu, Cu-Zn (15)  copper-polymetallic

Table 5. Ore content of the structural-formational zones of the Bozshakol-Shyngys-Tarbagatai fold system - V (V-1 - V-9) and their metallogenic specialization.

| Name of structural-formational zones (SFZ) | Qualitative characteristic of ore content (the number of objects in the structural-formation zones) | Metallogenic specialization of SFZ |
|------------------------------------------|-------------------------------------------------------------------------------------------------|----------------------------------|
| Bozshakolskaya SFZ - V-1                | Pb, Zn, Ba Au, Cu, Mo Cr, Mn, hard coal, limestone (10)                                        | copper-porphyr-pyreite           |
| Kendyktsinskaya SFZ - V-2               | Au, Pb, Zn, coal, cement raw materials (6)                                                    | gold-polymetallic               |
| Maikainskaya SFZ - V-3                  | Au, Ag, Ni, Co, cement raw materials (14)                                                      | pyrite-barite-polymetallic with gold |
| Ekibastuz-Shidertinskaya SFZ – V-4      | Au, Ag, Cu, Pb, Zn, уголь; цементное сырье (6)                                                  | gold-copper-polymetallic        |
| Arkalykskaya SFZ - V-5                  | Au, Ag, Pb, Zn, Ba, Cu, Mo, Ni, Co, Ti, Zr, coal (20)                                           | gold-polymetallic               |
| Central-Shyngyzykaya SFZ – V-6          | Au, Cu, Fe, Zn, Mo, Pb (7)                                                                       | gold-polymetallic               |
| Abralinskaya SFZ - V-7                  | Au, Ag, Pb, Zn, Mn, Cu, Mo, Ba (12)                                                            | gold-polymetallic               |
| Kosmurun-Akbastauskaya SFZ - V-8        | Au, Ag, Cu, Zn, Mo (5)                                                                          | polymetallic-copper-gold        |
| Prishyngyzkaya SFZ - V-9                | Au, Ag, Fe (3)                                                                                 | gold ore                        |

3. **In conclusion**, it should be noted that for the soonest replenishment of the mineral resource base with new competitive deposits, it is necessary to sharply increase the volume of prospecting works, efficiency of which directly depends on reliable scientific substantiation of their directions.

With significant reduction of the geological sector in the country, the provision of scientifically grounded recommendations to prospecting geology in order to improve its efficiency is, no doubt, possible only upon works similar to the above said project which delivered the "Atlas of metallogenograms ...". Execution of such works by exploration and mining companies is excluded totally, due to their orientation strictly on already known fields. In their view, work for the times ahead is not appealing. Identification of perspective areas on the basis of determination of reliable ore content factors of this or that kind of raw material is the only way to increase efficiency of prospecting works at the present stage of geology.

4. **References**
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