The non-ferrous and noble metals deposits’ position and manifestation in North Ossetia-Alania regarding the anomalies of potential fields

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Abstract. The relevance is determined by the need to create a scientific basis for the reassessment of known ore regions for the presence of highly liquid gold ores and the search for the new gold ore objects in previously unexplored territories to diversify the mining and metallurgical industries of North Ossetia (Alania). The purpose is to reveal the geophysical signs of non-ferrous and noble metals’ mineralization and potential gold content of ore-magmatic systems. The applied methods include the results analysis of the geophysical data use when performing the work within the prospective gold territories’ limits. A combined map construction of the gravitational and magnetic fields’ local anomalies based on the analysis of amplitude characteristics using a geophysical database of the Geological map of the Russian Federation on a scale of 1: 1,000,000 according to the sheet K-38.39 (Makhachkala) as well as the analysis of the spatial distribution of deposits and the manifestations of non-ferrous and noble metals relative to geophysical anomalies. The results obtained can be formulated as follows: the experience of using geophysical data when performing the work within the limits of the gold prospective territories in the Amur region is analyzed. The results of processing the data of the geophysical surveys results in the mountainous part of the North Ossetia (Alania) territory using modern methods for converting the potential fields are presented. The compiled maps of the gravitational and magnetic field’s local anomalies have been prepared. Within North Ossetia (Alania), spatial features of the deposits and ore occurrences of non-ferrous and noble metals with respect to anomalies of the gravitational and magnetic fields have been revealed. The confinement of the granitoid type ore-magmatic systems to negative anomalies of gravity has been established. It has been shown that potentially auriferous ore-magmatic systems are located within the limits of positive magnetic field anomalies.

1. Introduction
One of the foundations for the mountain territories’ sustainable development in the North Caucasus is the diversification of the mining and metallurgical industries [1]. On the one hand, the development and implementation of new more efficient technologies for the extraction and processing of rare-metal and polymetallic ores traditional for the region are proposed [2], on the other hand, the reassessment of known ore regions for the presence of highly liquid gold ores and the search for the new gold ore objects in previously unexplored territories is substantiated [3-5 ]. In the latter case, there is the possibility of a preliminary assessment of the potential gold content for the territories based on modern geophysical technologies.
An experience generalization of using the geophysical data when performing the work within the limits of prospective gold territories as well as the specific examples are given in numerous works [6-10]. In this regard, the study of volcanic structures in the North Caucasus is of interest [11-12]. Geophysical deep data and their detailed interpretation make it possible not only to identify the ore-magmatic systems, but also to evaluate their metallogenic potential [13-21], including the mountainous territories of the North Caucasus [22].

2. Materials and methods
For the study, we used a geophysical database in the form of gravity and aeromagnetic exploration fields digital models specified in the clusters of a regular network of 1000-1000 m to a set of Geological maps basis of the Russian Federation on a scale of 1: 1 000 000 was used according to the sheet K-38,39 (Makhachkala) developed at All-Russian Research Institute of Exploration Geophysics named after A.A. Logachev. Based on these data, the maps of local anomalies of the gravitational and magnetic fields are constructed, selected on the amplitude characteristics’ analysis basis and reflecting the rocks section upper part density characteristics’ distribution.

Local anomalies are obtained as the difference between the initial field and the field averaged over a 20–20 km window. Maps of local anomalies have a large information capacity, since they simultaneously reflect the amplitude, morphological, and texture features of the fields. Since the study area is characterized by high geological heterogeneity, the local field components are calculated as the difference between the field observed and averaged in the local area. When constructing a combined image of fields, a gravitational field map is displayed in the form of a map of contours (in a color scale). A map of local magnetic field anomalies is displayed as the areas bounded by the contour of the “anomalous” value, which corresponds to a quantile of empirical distribution for about 90%

According to the gravitational field local anomalies’ level, a number of separate blocks and structures are distinguished, the boundaries between which, the direction of their strike and correlation with each other are emphasized by a system of geophysical lineaments highlighted by the horizontal gradients of the gravitational field. The latter gradients form the structural-tectonic framework of the territory.

The magnetic field is presented in the form of positive local anomalies in the range of values from 20 to 2400 nT (local anomalies are obtained as the difference between the initial field and the field recalculated to a height of 2 km). Local positive anomalies of the magnetic field, caused mainly by the intrusive formations in the upper part of the section in combination with the lineaments highlighted by the gravitational field gradients, organically emphasize and complement the formed blocking of the territory.

3. Results and discussion
In the studies of the auriferous regions in the East of Russia [23], it was found that the gold mineralization possibility of a particular ore-magmatic system is determined in the field of magma and ore-bearing solutions generation. This is due to the geochemical properties of Au, which has a very low clark (n×10-7 %). With the development of granitoid magmatism, this leads to the fact that all the gold contained in the melt is iso-morphically captured by crystallizing silicates. And only excess metal against eutectic ratios under appropriate thermodynamic conditions can leave the melt and enrich the ore-bearing solution. Granite magma itself does not possess such excesses. They can occur during the interaction of granite magma with a gold preliminarily enriched substrate [24]. As the substrate of such a geochemical system, igneous rocks and magmas of the basic and ultrabasic composition, which initially have an increased gold clark, and some black-shale enriched with gold, can act. This explains the confinement of most gold deposits in the world mainly to volcanic complexes of the main composition and to the terrigenous complexes containing the dispersed organic matter [25].

Thus, in deep interaction of acid magmatism with a femic substrate and (or) black shale strata, regions of auriferous fluid generation can be formed. Therefore, in order to assess the prospects of
auriferous ore-magmatic systems, it is necessary to determine the presence of a femic substrate or gold-enriched black shale strata in the region of generation and migration of acidic magmas and through the magmatic fluids.

Areas of acid magmatism deep interaction with a femic substrate, in which the auriferous fluids are generated, are proposed to be identified on the geophysical data basis. For this, it is necessary to determine the presence of a femic substrate in the field of generation and migration of acidic magmas and through the magmatic fluids. It had been previously shown in [22, 26] that such situations can be detected using the gravimetric and magnetometric maps. Gravimetric maps allow a rough approximation to divide the territory into essentially femic and salic areas, i.e. potentially auriferous and potentially non-auriferous. The first of them are usually characterized by the regionally elevated, the second - by the regionally lower gravity values . Within the bounds of both, local negative gravitational anomalies are identified, associated with the bodies of granitoids, which can partially be exposed on the surface, confirming the material composition of these gravitational minima. On aeromagnetic maps, the areas of a femic substrate characterized by an increased magnetic field are also distinguished. The combination of local decompression structures with positive anomalies of the magnetic field may reflect the deep interaction of granitoid magma with a femic substrate, i.e., a situation favorable for the gold mineralization generation. Local gravitational minima in this case will indicate probable foci of granitoid magmatism. The areas of increased magnetic field may indicate a femic substrate. The combined areas of such areas characterize a situation favorable for the gold mineralization generation.

So, for example, as a result of geophysical studies in the Upper Amur Region, the potential gold content of previously identified abnormal geochemical fields based on ore clusters with known gold content was estimated [27]. Negative anomalies of gravity associated with the centers of ore-generating magmatism, as well as positive anomalies of the magnetic field combined with them to one degree or another, turned out to be the important factors in the gold ore clusters control (Fig. 1). The latter fixes the areas of acidic magma interaction with a femic substrate, which is manifested in the enrichment of the near-contact and apical zones of intrusions with magnetic minerals.
**Figure 1.** The forecast scheme for magma-hydrothermal mineralization of the Upper Amur Region according to geochemical and geophysical data (according to [27] with the additions of the authors): 1 - 2 - regions of the anomalous values ratio of the longitudinal seismic waves velocities to transverse; 3 - regional zones of gravity gradients, 5 - local gravitational minima, 6 - maxima of the magnetic field, 7, 8, 9 - abnormal geochemical fields of the ore cluster grade with different perspectives.

Figure 2 shows the layout of ore deposits and ore occurrences in the mountainous part of North Ossetia (Alania). Anomalous regions of geophysical fields are distinguished based on the amplitude characteristics’ analysis. Local anomalies are obtained as the difference between the initial field and the field averaged over a 20–20 km window. As a result, the separate blocks are distinguished, the boundaries between which are emphasized by a system of lineaments highlighted by the horizontal gradients of the gravitational field. The magnetic field is presented in the form of positive local anomalies in the values range from 20 to 2400 nT, obtained as the difference between the initial field and the field recalculated to a height of 2 km. They are caused mainly by intrusive formations in the upper part of the earth’s crust. The scheme formed as a result of the geophysical data complex analysis is essentially the geophysical basis for the forecast-metallogenic map.

The connection of ore deposits of the main types of ore-magmatic systems with negative anomalies of the gravitational field is obvious. Moreover, the vast majority of ore-magmatic systems are reflected in them. An exception is the pyrite type. So, the Buronsky ore cluster with the pyrite type deposit of the same name is confined to the periphery of a positive gravity field anomaly.

**Figure 2.** The location of deposits and metal minerals ore manifestation in North Ossetia (Alania) with respect to geophysical anomalies: 1 - lineaments highlighted by the gradients of the gravitational field, 2 - arrays, stocks, dikes of granodiorite-porphyry in the Neogene-Pleistocene Teplinsky complex; 3 - 8 - types of deposits and ore manifestations: 3 - polymetallic quartz-vein (Sadonsky), 4 - copper-polymetallic quartz-vein, 5 - copper-pyrites (Bouronsky), 6 - gold-silver quartz-vein, 7 - ore manifestations and mineralization points of the molybdenum-copper-porphyry type containing gold, bismuth, antimony, arsenic, etc.
In most cases, negative gravity anomalies are most likely associated with the centers of ore-generating magmatism. In some cases, the positive anomalies of the magnetic field partially or completely coincide with gravitational minima. The areas of such a coincidence fix the deepest areas of acidic magma interaction with a femic substrate, which is manifested in the contact and apical zones enrichment of intrusions with magnetic minerals. Indirectly, this deep interaction is confirmed by the geochemical modeling carried out earlier [28–29] and showing that the rocks formation of the Teplinsky intrusive complex could occur due to partial melting of the main metamorphic substrate (amphibolites of the Buulgen series), and that the initial melt was formed during \( P \geq 13 \) kbar, which corresponds to the order depths of 40 km.

In many cases, in the sites of such a coincidence ore clusters or their individual parts (ore fields) are located. A preliminary analysis of the prospecting materials within such areas showed the gold mineralization presence. This is especially true for the Tanadon ore cluster. Therefore, based on the above-mentioned concept, such areas in the presence of direct gold signs are promising for the gold mineralization discovery.

4. Summary

Studying the experience of using geophysical data when performing forecasting and prospecting operations within the gold prospective territories in the Amur Region showed high efficiency and the possibility of its use in other regions.

The processing of geophysical survey data on the mountainous part of the North Ossetia (Alania) territory using modern methods of transforming the potential fields made it possible to compile a composite map of gravitational and magnetic fields’ local anomalies.

The confinement of ore-magmatic systems of the granitoid type to the gravity negative anomalies is established. Potentially auriferous ore-magmatic systems are located within the limits of positive magnetic field anomalies.

The scheme formed as a result of the complex geophysical and mineralogical data analysis is essentially the geophysical basis for the forecast-metallogenic map.

References

[1] Burdzieva O, Zaalishvili V, Beriev O, Kanukov A, Maisuradze M 2016 International Journal of Geomate 10(1) 1693-1697
[2] Drebenstedt K, Golik V, Dmitrak U 2018 Sustainable mountain development 10.1(35) 125–131. doi: 10.21177/1998-4502-2018-10-1-125-131
[3] Parada S, Stolyarov V, Popov Y 2017 Reports on Earth Sciences 477(1) 1256–1259. doi: 10.1134/S1028334X17110058
[4] Ivanov A, Chernykh A, Vartanyan S 2018 Domestic geology 1 18–28.
[5] Zürcher L, Dunlap P, Bookstrom A, Zientek M, Wallis J, Hammarstrom J, Mars J, Ludington S 2019 Ore Geology Reviews. 111 102849-102929. DOI: 10.1016/j.oregeorev.2019.02.034
[6] Zaalishvili V, Chotchaev H, Nevsky L, Olkhovsky G, Tibilov S, Gogichev R 2015 3 28–62.
[7] Kerr Andrew C, Lavis O, Kakar M, McDonald I 2016 J. Geol. Soc. 173(3) 518-530. doi: 10.1144/jgs2015-119
[8] Ma Xiao-lei, Yuan Bing-qiang, Xu Wen-qiang, Song JJ-jun Dizhi yu kantan et al. 2016 Geol. and Prospecting 52(4) 647–656.
[9] Guangxi Zliou Yequan, Pang Baocheng, Li Yuanqiang, Lit Jiawen. 2016 Geoscience 30(4) 770–780.
[10] Kalmykov B, Levin F, Trusov A 2017 Gold and technologies 2 76–82.
[11] Zaalishvili V, Nevskaya N, Nevskii L, Shempelev A 2015 Journal of Volcanology and Seismology 9(5) 333-3380.
[12] Zaalishvili V, Melkov D, Dzeranov B, Morozov F, Tuaev G 2018 International Journal of Geomate 15(47) 158-1630
[13] Hart C 2017 Mineral deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods Geological Association of Canada, Mineral Deposits Division. Spec. Publ. 5 95–112

[14] Anderson P, Cooper M, Stevenson C, Hastie A et al. 2016 Lithos 260 95–106. doi: 10.1016/j.lithos.2016.05.011

[15] Milyukov V, Yushkin V, Kopaeve A, Mironov A, Dem’yanov G, Sermyagin R, Basmanov A, Popad’Ev V, Nasredinov I, Zaalishvili V, Kanukov A, Dzeranov B 2014 Measurement Techniques 56(10) 1105-1110.

[16] Root B, Ebbing J, van der Wal W, England R et al. 2017 Geophys. J. Int. 208(3) 1796–1810. doi: 10.1093/gji/ggw483

[17] Shempelev A, Zaalishvili V, Kukhmazov S 2017 Geotectonics 51(5) 479-488

[18] Zaalishvili V, Nevskaya N, Melkov D 2014 Izvestiya. Physics of the Solid Earth 50(2) 263-272.

[19] Zaalishvili V, Melkov D, Kanukov A, Dzeranov B, Shepelev V 2016 International Journal of Geomate 10(1) 1670-1674.

[20] Zaalishvili V, Melkov D, Kanukov A, Dzeranov B 2016 International Journal of Geomate 10(1) 1656-1661.

[21] Zaalishvili V 2016 Measurement Techniques 58(12) 1297-1303.

[22] Parade C, Chotchaev H 2019 Modern problems of geology, geophysics and geoeology of the North Caucasus. Collective monograph based on the materials of the IX All-Russian Scientific and Technical Conference 166-172.

[23] Eirish L 2009 Geology of Ore Deposits 51(3) 223–232 doi: 10.1134/S1075701509030040

[24] Shcherbakov Yu 1976 Gold and rare elements in geochemical processes (Science, Novosibirsk) 14–33.

[25] Safonov Yu 1997 Geology of Ore Deposits 39(1) 20–32.

[26] Nosyrev M 2016 Pacific geology 35(6) 69–80.

[27] Vyunov D, Nosyrev M, Stepanov V 2007 Bulletin of the Northeast Scientific Center of the Far Eastern Branch of the Russian Academy of Sciences 3 2-9.

[28] Bubnov S, Dokuchaev A, Goltsman Yu 2011 Proceedings of the Institute of Geology, Dagestan Scientific Center of the Russian Academy of Sciences 57 73–75.

[29] Gurbanov A, Goddess M, Paul I 1992 USSR Academy of Sciences. Ser. geol. 11 147–153.