

Generalization of study experience of Ural ore deposits by method of tectonophysical analysis gravitational field

Vladimir Philatov¹, Lubov Boltnova², and Ksenya Vandysheva^{2*}

¹ Vladimir State University, 600000, 87, Gorky st., Vladimir, Russia

² Ural State Mining University, 620144, 30, Kuibyshev st., Ekaterinburg, Russia

Abstract. Gravity is important in the history of Earth 's formation and evolution. Gravitational accretion, gravitational differentiation of Earth matter by density. Gravitational accretion, gravity differentiation of the Earth 's substance in density, its movement and other processes deform the Earth 's crust, contribute to the formation in it of different scale, shape and metallogenical specialization of plicative and disjunctive structures, with which genetically and spatially related deposits of different minerals. The link between gravity and deformation of the geological medium is its density inhomogeneities. Their role is twofold: they are either formed by gravity stresses or are themselves sources of stress and strain. The method of studying the deformation of the geological medium by gravity is called tectonophysical analysis of the gravitational field. Its physical basis is two fundamental laws: the law of world gravity and the law on proportional dependence between stress and deformation. This method solves two problems.

1 Introduction

Density inhomogeneities are the cause of tectogenesis create anomalies in the field of gravity. Thus, the same source - density inhomogeneity generates two physical fields: the field of deformation (stress) and the abnormal field of gravity. Therefore, there must be a functional relationship between the quantities of these fields. The physical basis of this dependence is the law of world gravity and the laws of deformation of hard bodies, describing their reactions to external force. This external force is gravity.

The original theoretical prerequisite for establishing the relationship between deformation characteristics and gravity was the problem known in the theory of elasticity of displacements caused by an arbitrarily oriented force in a uniform elastic half-space. This task has been generalized in the case where in a uniform elastic half-space there is an arbitrary density non-uniformity in shape and size, the volume of which is uniformly distributed gravity. Elastic modules of half-space and density non-uniformity are assumed to be the same. In this task setting, precise formulas have been obtained linking the

* Corresponding author: vandysheva_ksenya@mail.ru

components of the displacement vector at any point in the half-space to the gravity potential of the density non-uniformity. These formulas allow you to calculate different deformation characteristics: deformation tensor components, pure deformation tensor components, principal values, and determine the orientation of the principal deformation axes, as well as various invariants, i.e., solve the problem of classical tectonophysical analysis. But if in the classical tectonophysical analysis the characteristics of the deformation of the geological medium (and accordingly, stresses) are determined by studying the elements of its deformation (cracks, breaks, folds, etc.), then using the dependencies between the components of the displacement vector and the potential of gravity, these same characteristics can be determined from the results of the measurement of the stress of the gravity field [1].

2 Materials and methods

This is how the first task of tectonophysical analysis of the gravitational field is solved. The result of the second task is to determine the genesis of the geological structure to which a mineral deposit is timed. The rationale for this is as follows:

The main parameter is the dilation or relative change in the volume of the medium, and therefore its density, which characterizes the deformation of the geological medium in gravitational terms. It occurs in local areas or zones. One feature of structure formation is that the morphology of structure and dilation regions are related. Each type of tectonic structure corresponds only to its spatial distribution of dilation regions, corresponding to the mechanism of structure formation.

The density of rocks within the dilation regions varies from 0.01 to 0.40 g/cm³, i.e. these regions are sources of gravity anomalies. Dilation is a form of manifestation of the stressed-deformed state of the geological medium available for study by gravimetry. Therefore, by mapping local gravity anomalies due to relative changes in medium volumes in tectonic structuring, it is possible to determine the probable mechanism of this process.

The study of tectonic structures is important because all mineral deposits are genetically and spatially timed to them. The results of the classical tectonophysical analysis performed at the deposits show that the mineralization within the structures is timed to local areas of quite a certain type of deformation: to areas of stretching or cleavage. Within the fields the main values of deformation and orientation of the main axes of deformation differ from those outside the mineralization [2]. Due to the deformation of this nature, there is an intensive development of brittle and plastic changes in the geological environment, its disturbance is increased, permeability is improved and conditions for ore working are ore-deposits. Therefore, the study of the deformation of the geological environment is necessary not only to determine the mechanisms of formation of tectonic structures, but also to prediction within their limits the areas of perspective for the mineralization.

The use of classical tectonophysical analysis for studying the genesis of tectonic structures is limited by the degree of openness of the object under study, the presence of clearly expressed in the geological medium markers of deformation: cracks, breaks, folds, etc. [2, 3]. Analysis is not possible in the absence of exposure, i.e. if the object under study is closed to sediment thicknesses of sedimentary rocks. Tectonophysical analysis based on the use of gravity field measurement results is largely free of these limitations. Moreover, its application in the use of gravimetric surveys of various scales allows to study the hierarchy of deformation processes.

3 Result and discussion

The solution of a given task of tectonophysical analysis of the gravitational field is carried out depending on the specific physical and geological situation. The first task is the task of calculating and geological interpretation of strain tensor components based on the results of gravity field stress measurement. Such a task is solved if ore deposits are associated with large density inhomogeneities. Tectonophysical analysis was carried out for Tagilo-Kushvinsky iron ore area (TKIOA) [4], Beryozovsky gold ore deposit [5], Novo-Shemur copper-pyritic deposit [6] and a forecast estimate of Uvel area on copper-porphry ore deposit [7] was given.

The gravitational field of TKIOA is characterized by a positive anomaly of intensity of more than 60 mGal, the dimensions of which in plan (24x7 km) exceed the area of TKIOA; Anomaly in plan has the form of oval extended in submeridional direction. The source of the anomaly is the protrusion of ultrabasites formed in the zone of the Main Ural Fault from mantle substance as a result of its movement under the influence of deep stress to the day surface. The reason for the movement of the mantle substance was the disruption of the hydrostatic stress state in the lower part of the Earth's crust. The displacement is due to the relief of the granulite-basalt layer and Mojo surface. The dimensions of the extension of about 15 km, in the cross of the extension - 7 km, its capacity - does not exceed 5 km; Penetration is characterised by excessive density varying from 0.40 to 0.45 g/cm³. All deposits and ore displays of TKIOA are located east of the prowling in a narrow zone, which is drawn parallel to its eastern contact.

The results of 1:50000 scale area gravimetric survey were used to perform tectonophysical analysis. The main deformation values (e_1 , e_2 , e_3), orientation of the main deformation axes, and dilation ($\theta = e_1 + e_2 + e_3$) were calculated at the 500x500 m square mesh nodes.

The TKIOA deformation field is characterized as follows. Dilation of ultrabasites, as a denser object, "sinks" in the accommodating medium, captivating it. Due to this, the vertical strain e_3 is stretch, horizontal e_2 and e_1 is compression, and their orientations are submeridional and subshiro; Dilation has large negative values, i.e. the geologic medium above the protrusion is in compression mode. The nature of the deformation within the ore zone is different. The orientation of the principal strain axes, quantities, and signs of the principal strain values changes dramatically; Dilation becomes positive and small in magnitude, i.e. the geological medium within the ore zone deforms in the stretching mode.

Thus, the ore zone is anomalous in the deformation ratio. This deformation regime was established and maintained for the entire duration of the protrusion, i.e. about 460 million years. It contributed to the improvement of the permeability of the geological medium and was favorable for ore formation in this part of TKIOA.

The oldest Beryozovsky gold deposit in Russia is located north-east of the Shartash granite massif. It is represented by whistles of dikes granitoid porphyres of submeridional and north-eastern strike. Gold is associated with quartz veins: striped, lying in dikes, and located in country rocks.

Tectonophysical analysis was performed using 1:200000 scale gravimetric survey results. Analysis showed that in the southern and central parts of the ore field, the principal values of e_1 and e_2 are tensile; $e_1 \geq e_2$ and the first main direction has North northeast orientation; $e_2 = e_3$. In the northern part of the ore field, the main strain values e_1 and e_2 stretch, small in magnitude, have north-eastern and north-western orientations. The dilation within the entire ore field is positive; In the northern part it is small in size, in the southern and central parts it takes on the greatest values. Thus, the dynamic mode determined a positive dilation within the ore field and a deformation that is good for laying faults in the north-server-east direction. This regime is due to the Chartash granite

array. In the southern part of the ore field there are many dikes, dilation is high. Their number is decreasing north as dilation decreases. They are practically non-existent in the area of zero dilation values. This indicates a genetic association of dikes with the granite array. The geological medium contacts the area of high values of dilation in the circuit of industrial gold mineralization, is characterized by sharp variability of main values and orientations of main deformation axes, stretching mode and low level of positive dilation.

The Novo-Shemurskoe copper-colchedan deposit is located on the North Ural between two arrays: the «Money Stone» and the South-Pomursky. The geophysical basis for tectonophysical analysis of the area of this deposit was the results of gravimetric surveys of scale 1:10000 and 1:5000. Geological interpretation of tectonophysical analysis results as well as for other deposits showed close, genetic connection of dynamic mode of Novo-Shemur deposit formation with its structure, tectonics, as well as with spatial position of ore bodies, types of ores and nature of geochemical halos.

Despite the difference in genetic types of deposits, their deformation structure (tectonophysical characteristic) has common and stable features. Within ore zones there is a mode of stretching, there is a small level of positive dilation and abnormal in magnitude and orientation main values and main axes of deformation. These deformation characteristics can probably be considered as criteria or geological invariants of deposits. Some have previously been identified by classical tectonophysical analysis.

Based on these deformation signs and on the results of tectonophysical analysis of the gravitational field (scale of gravimetry survey 1:50000), a forecast estimate of Uvel Square (South Ural) for copper-porphyry ore manifestation was given.

The reasons for the deformation of the geological environment in these areas were three close in petrochemical composition and petroplottic characteristic of granite massifs: Novo-Ukrainian, Kamensky and Chernorechensky, lying among denser volcano-sedimentary rocks.

According to the results of tectonophysical analysis, based on the previously established patterns of deformation characteristics of ore deposits [4-6], the ring zone with a width of about 0.5 km was identified as the most promising one. This zone is characterized by a small level of positive dilation and a sharp change in its limits of values and orientations of the main deformation values. Inside and outside the zone, dilation is negative. Copper-porphyry ore was previously detected in the northern part of the ring zone. These, as well as other geological and geophysical data, gave the basis for the conclusion that the ring zone is a tectonic structure promising on the impregnated ore occurrence.

The solution of the second problem is to determine the mechanism of formation of geological structure or its nature on the basis of tectonophysical analysis of its field of gravity is given for Durinsky deflection along the roof of salts of Verkhnekamsk deposit of potassium salts [10], Chuksin fault structure [11] and Birgildin-Tominsky ore node [8]. Both the fault structure and ore hub are on the South Ural.

The study of these objects showed that tectonophysical interpretation of formation processes of geological structures and mineral deposits gives reason to change the concept of gravimetric anomaly (as well as anomaly of any other geophysical field in general): anomaly is not a trivial local fragment of gravity field with extreme quantitative and qualitative characteristics (positive anomaly, negative anomaly). An anomaly is some area with a well-defined and stable morphological structure due to patterns of geologic medium deformation or mechanism of geologic structure formation.

The morphology of anomalous zones of all ore objects within the Birgildinsky-Tomin ore node has common features: the field of gravity is an alternation of positive and negative local anomalies, which in plan form ellipses, the long axes of which are oriented differently than the axes of regional anomalies. This feature is universal, since it is

characteristic of many Ural deposits of various industrial-genetic type, i.e. it can be used under favorable physical-geological conditions for prediction of deposits and ore manifestations [9]. This gravimetric morphological feature, as prognostic, contributed to the discovery within the Birgildinsky-Tomin ore node of a gold-porphyry deposit named Bereznikovskiy [8].

The solution of the prediction and search task within the Birgildinsky-Tomin ore node was carried out taking into account that tectonic structures form hierarchical systems [12]. Therefore, the results of gravimetric studies of different scales were used to study them.

The main structural plan of the ore field of this deposit is formed by fracturing disorders of the north-east, north-west and less often subshirov extension, which are zones of intensive fracturing of rocks. These breaks controlled ore-metasomatic processes. But the prevailing development within the ore field was the fracturing zones of the northeast direction, which together with their separating blocks of relatively denser rocks are mapped in the field of gravity by a system of alternating positive and negative local anomalies, i.e. the deformation structure of the ore field is reflected in the morphology of the gravitational field.

Results of 1:50000 scale area gravimetric survey were used to study the deformation structure of the ore field. The study of the deformation structure of the deposit itself and the determination of the regularities of the spatial position of the gold ore was carried out by means of a high-precision gravimetric survey performed on a network of 10 x 10 m with a mean square error of determining the abnormal value of gravity in the Buge reduction equal to $\pm 0,017$ mGal.

The deformation structure of the deposit is mainly represented by two elements: linear tectonic zones of the north-west direction and areas of dilation decompression of subshirov orientation rocks.

Gravity field of dilation decompression sections is characterized by system of linear local negative anomalies of gravity with intensity of mGal 0.05 - 0.20, which are located in a link-like manner. Parcel boundaries are mapped by lines of maximum horizontal gravity gradients. The width of the decompression sections is 50 - 70 m on average, and their boundaries represent transitions from more permeable to less permeable rock blocks. Long axes of negative anomalies are oriented in the north-west direction.

The results of the testing carried out in the mining (grooves, wells of the string drilling) confirmed the close connection of the gold mineralization with the deformation structures of the deposit and the preferred timing of the mineralization to the zones of transition from less dense rocks to more dense blocks of rocks. Most ore subsections are located along lines of maximum values of horizontal gradients. Areas of dilation decompression and their connection with tectonic structures of the north-west extension were the most favorable for the mineralization. Of the 36 wells drilled within these sites, condition ores were cut to 28, and non-condition ores were cut to 6; Out of 60 wells drilled outside such areas, conditioned ores were opened in only one well, in 11 - non-standard wells, the remaining wells turned out to be ore-free.

Gold mineralization has also been established in the isometric rod-type structure. By the nature of the gravitational field, deformation within this structure did not result in the formation of extended tectonic disturbance. therefore, gold mineralization here is distributed evenly and the content of gold is lower than in the areas of dilation decompression of rocks. 18 wells with a depth of 20 to 476 m were drilled within the rod; In all met gold mineralization with gold content from 0.9 to 0.3 g/t.

4 Conclusion

Experience with the method of tectonophysical analysis of the gravitational field has shown that despite different genesis of deposits, their deformation characteristics are close and significantly different from those of the media containing these deposits. This conclusion confirmed the data previously obtained by classical tectonophysical analysis that the main values of deformation and orientation of the main deformation axes within the deposits are different than outside the deposits, i.e. the process of deformation of the geological medium during formation of the deposits is specific.

This difference is particularly distinct in the magnitude and sign of the first invariant of strain tensor - in dilation and, as a consequence, in morphology of local anomalies of gravity field. In the field of gravity the deformation structure of deposits is mapped in the form of a link-shaped system of positive and negative local anomalies, the orientation of which is different from the orientation of the regional field of gravity of the ore area.

The indifference of the deformation structure of deposits relative to their genetic type makes it possible to consider quantitative characteristics of the deformation process as search-prognostic signs or criteria, i.e. to treat them as peculiar geological invariants reflecting one of the essential and natural sides of ore formation processes. Therefore, it is useful to use them (as positive experience has shown) in conjunction with other geological-geophysical, geochemical and geomorphological features to predict deposits.

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