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Systems of Lineaments of Magnetic and Gravity Anomalies in the Zone of Convergent Interaction of the Amur and the Eurasian Tectonic Plates

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Abstract

We studied the spatial distribution of anomalies of the gravitational and the magnetic fields at the border between the Amur and the Eurasian plates. Methods of statistical analysis showed that the systems of anomalies of geophysical fields fit into the regular spatial structures and are controlled by lineaments of latitude, longitude and diagonal stretch, as well as zones of plastic-elastic flow of rocks (shear-zone). These facts allowed us to establish time of formation of the orthogonal system of geophysical fields anomalies in the strike azimuths (84-354^0). As a result of comparing diagonal system of geophysical fields anomalies with spatial distribution of the fields of contemporary seismicity and epicenters of strong earthquakes, an assumption was made that the diagonal system of lineaments fit into zones of tectonic deformation and has been controlling the epicentral fields of contemporary seismicity since the Mesozoic period of seismotectonic activation. The main result of this study is the synthesis of early scientific works and getting new ideas about the spatial distribution of anomalies of geophysical fields. Establishing the sequence of forming isolated systems of anomalies and relationships between geophysical fields and seismicity is the subject of further research.

Keywords: geophysical fields, lineaments, shear-zones, activation, crustal deformation, seismicity, earthquakes, prediction

1. Introduction

In course of geological study of the structure of the crust, the analysis of spatial distribution of geophysical fields anomalies is essential. Problems of tectonic zoning of spatial models of gravitational and magnetic fields tend to reflect major tectonic dislocations and the position of the contact zones of individual crustal blocks in the form of grouping and consistency in certain azimuths of extended linear zones - lineaments (Alaa A. Masoud and Katsuaki, 2011; Yuanyuan Li et al., 2011).

Start of theoretical studies of the lineament structures and large-scale irregularities of the earth's crust has been given in works (Hobbs, 1904; Hubbert, 1937), which are being successfully developed at present with the use of new technologies for analyzing digital models, such as geophysical fields and landforms (Anokhin, Odessa, 2001; Arellano-Baeza et al., 2006; Anokhin, Maslow, 2009; Gilmanova et al., 2012; Loiane et al., 2014). New technologies make it possible not only to track the date of lineaments formation, and, hence, geophysical fields in geological time scales (Loiane et al.,2014), but, also to track changes in the structure of lineaments due to the influence of strong earthquakes (Arellano-Baeza et al., 2006).

Study of the tectonic structure and tectonic nature of geophysical fields in the Northeast of Asia within the Aldan-Stanovoy megablock (Figure 1) have laid the foundation of work (Kazan, 1965; Grishkyan, 1968; Malyshev, 1977). Subsequent synthesis of structural, geophysical and geological data from works (Stativa et al., 2006A; Stogniy et al., 1996; Popov, Smelov, 1996;Trofimenko, 2010) revealed that in this region lineaments and the anomalies of geophysical fields that reflected them formed multidirectional orthogonal systems with north-eastern and north-west spread (Stativa et al., 2006 B). These lineaments on the surface are recorded in the form of zones up to 15 km thick and up to several hundred kilometers length. They are predominantly spread to the north-east (45-75°) and to the northwest (300-320°), vertical or near-vertical planes placement of planes and control the position of granitisation fields.

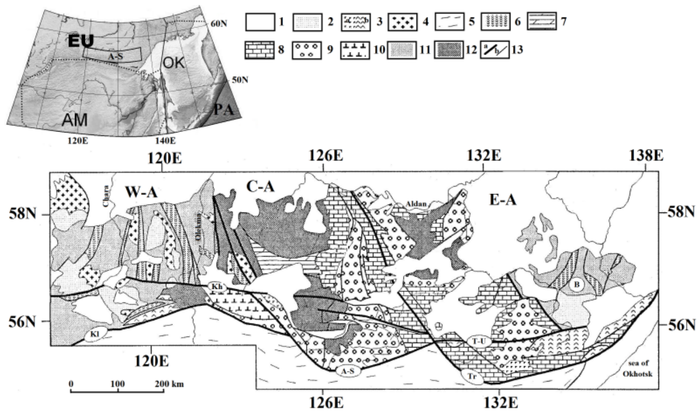

Figure 1. Block diagram of the Aldanian Shield structure and lineaments of the Aldanian-Stanovoy megablock

Designations. Overview map: EU, PA - Eurasian and Pacific plates; AM, OK - Amur and Okhotsk microplate; AS - Aldanian-Stanovoy megablock.

Main diagram. Aldanian shield blocks: WA - West Aldan; C-A - Central Aldan; E-A - East Aldan; B- Batomgsk microblock.

Numbers stand for: 1 - Riphean-Phanerozoic formations; 2 - complexes of proterozoic sediments Pt1; 3 - gabbroids (a) and anorthosite (b), Pt1; 4 - granitoids, Ar2- Pt1; 5 -Stanovoy complex of the Proterozoic age; 6 - Greenstone belts; 7 - amphibole gneissic series and gabbro-plagiogranitoids; 8 - orthoamphibolite, twopyroxene plaghio gneissic, and garnet-plaghio gneissic strata; 9 - hypersthene-gneissic, garnet-gneissic and two-pyroxene-gneissic strata; 10 - granulite-basite formation;11 - tonalite-throndhemite gneisses; 12 - granite, and charnokite and enderbite gneisses; 13 - tectonic boundaries: (a) - regional, (b) - sutures. Kl - Kalaro-Stanovaya; Kh - Khaninskaya; A-S - Amgino-Stanovaya; Tr - Tyrkandin-Dzhugdzhur; T-U - Timpton-Uchursk.

Many researchers indicate facts proving that systems of faults were formed in the Archean age and subsequently underwent repeated activation in later periods. For example, faults in the diagonal direction, according to views of authors (Kazansky, 1965; Grishkyan, 1968) were formed during the late Archean. Nevertheless, so far the problem of determining the periods of fault systems formation relate to controversial issues.

During geological development of the earth's crust, in periods of both slow tectonic and fast seismotectonic activations, anomalies of geophysical fields experience changes as a reflection of physical properties of rocks. Most intensively the processes of reformation of the structural plan of spatial anomalies should occur in seismically active regions in the areas of interaction of tectonic plates and lineaments that divide them (Heleno C. et al., 2014). Due to this fact, there is a problem of determining the spatiotemporal relationships between systems of faults with different courses and, consequently, of determining periods of formation of geophysical fields anomalies.

Thus, studying spatial structure of geophysical fields is one of scientific areas of research in the various applied problems of structural geology, tectonics, metallogeny, geodynamics and seismotectonics. Research data get a special role in seismically active zones (Joseph and William, 2002).

Preliminary data about geometric formations of lineament structures in the Aldan-Stanovoy megablock using methods of statistical analysis of geophysical fields spatial distribution are described in works (Stativa et al., 2006A; Stativa et al., 2006B; Stativa and Trofimenko, 2006; Trofimenko, 2010).

This work sets tasks of clarifying periods of formation of extended zones of geophysical anomalies by comparing these systems with spatial position of zones of elastic-viscous rocks flow (shear-zones) (Melnikov, 2008), and the tasks of finding patterns in distribution of spatial field of seismicity within the zone of interaction between the Amur and the Eurasian lithospheric plates.

2. Results of Statistical Modeling of the Geophysical Fields Spatial Structure

To study lineament structures of the Aldan-Stanovoy megablock for distribution of geophysical fields, the method of statistical analysis of the spatial distribution of crustal faults geophysical features characteristically manifested in gravitational and magnetic fields have been used. Compared with the initial maps of the gravitational and magnetic fields, diagrams of their linear elements have the advantage that they only retain orientation, length and location of fields characteristics, reflecting linear tectonic and stratigraphic contacts of rock complexes with various physical properties.

A detailed analysis of statistical distributions of azimuths of gravitational and magnetic fields anomalies showed that (Figure 2), in the graphs appear statistically significant local maxima, of which we can make a pair of mutually orthogonal systems: (3-273^0), (26-296^0) (35-305^0 *) (40-310^0) (64-334^0) (70-340^0) (84-354^0). The error in determining the preferred direction of maxima ranged from ±3^0 to ±5^0.

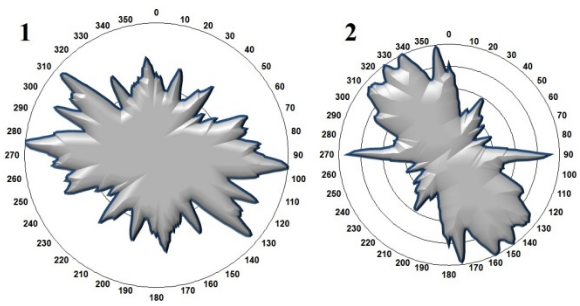

Figure 2. Statistics of distributing spreads of azimuths of anomalies of linear elements of the gravitational (1) and magnetic (2) fields

Figure 3 shows spatial position of the lineament structures built on statistical distributions of the anomalies of geophysical fields in azimuths (3-2730) and (84-3540).

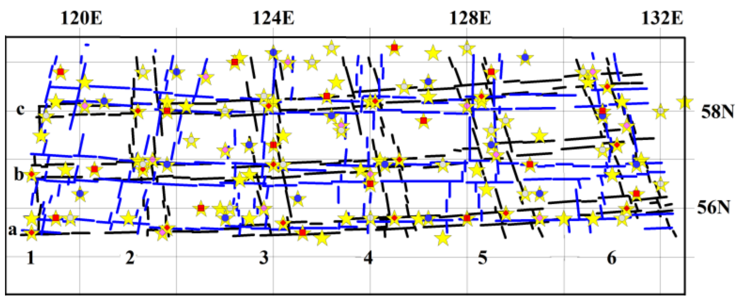

Figure 3. Spatial position of domains of system (3-2730) ±30 (blue) and a similar system (84 and 354 °) ±30 (black) of the Aldan-Stanovoy megablock

Designations. Asterisks are intersections of the lineament structures of all selected systems; digits (1-5) are numbers of meridional zones from the west to the east; (a-c) are denominations of latitudinal zones from the north to the south:

It may be noted that the structures of lineaments with azimuths (3-273^0) ± 3^0 and azimuths (84 and 354 °) ±3^0 have sides with meridional length of the domain about 120 km and latitudinal width of 120 to 180 km. In whole, in the studied territory, zones of mutually orthogonal lineaments are sustained by their spread. However, in the southern and the south-western part of the territory, starting with latitude 570, either a displacement of center lines of selected meridional zones, or partial or complete destruction of the lineaments is observed.

Similar geometric constructions made it possible to establish that system (35-305^0*) ±3^0 is similar to system (26-296^0). The average length of domain side is 150 km. In system (40-310^0) ±3^0, domain boundaries appear more regularly with a spatial period of 120 km. The inner area of domains is filled with indicators, predominantly of the north-west spread (310^0). Domains with the largest number of indicators form a regular network of mutually embedded domains of the second order. System (64-334^0) ±5^0 and a system that is similar to it (70-340^0) ±5^0 form a regular network on the whole territory with the spatial period of 120-140 km (Trofimenko, 2010).

3. Analysis of the Obtained Results and Determination of the Age of Primary Systems of Gravitational and Magnetic Anomalies

3.1 Structural-Tectonic Positions of Systems of Geophysical Fields Anomalies

The designated areas of high density of linear indicators of lineaments by the results of statistical analysis of geophysical fields anomalies spatial distribution (as models of tectonic disturbances from geophysical data) were compared with the materials of geological - geophysical and structural-tectonic exploration of the region (Popov, Smelov, 1996; Melnikov, 2008).

It was found that system (84-354^0) fits most major faults in the territory of the Aldan-Stanovoy megablock (Figure 1, 3). Comparison of the spatial position of the domains with the theoretical studies and models presented by authors (Hubbert, 1937; Kazansky, 1965; Trofimenko, 2010) made it possible to make the assumption about availability of self-similar systems domain of tectonic disturbances in the studied area.

Other orientations of faults at the regional and local levels found earlier by various authors are also confirmed by statistical analysis of the distribution of linear elements of geophysical fields anomalies. In addition to the existing models of the Aldan-Stanovoy megablock (Grishkyan, 1968; Popov, Smelov, 1996), results that indicate the presence of a domain structure for all selected systems were obtained. Moreover, the domain structure retains the principle of self-similarity. In other words, not only faults of certain orientation, but faults orthogonal to them are ranked.

Comparison of this study results with the results of simulation by authors (Gilmanova et al., 2012) of the gravitational field in the Bouguer reduction made using the method of analysis of digital fields show the correspondence of basic structural "gravitational" lineaments in azimuths 64 and 296^0. Taken together, results of these model constructions generalize findings and conclusions of previous studies.

3.2 Models of Forming Geophysical Fields Anomalies Systems

Diagonal rhombic structures (domains) are formed as transpressure under horizontal compression, theoretical model of which is considered in (Woodcock & Fisher, 1986). Figure 4A shows two systems: orthogonal (84-354^0) as a primary or basic grid of breaks and diagonal (40-310^0), which could be formed as a grid gaps in the implementation of the indenter. Within the studies area under horizontal (sublatitudinal) compression in the model (Woodcock & Fisher, 1986) indenter is the Batomgsky block located on the eastern edge of the Aldanian Shield (Figure 1). Figure 4.B-C shows a scheme of mutual position of systems (84-354^0) with systems (26 -296^0) and (35-305^0).

Regular mutual placement of the systems allowed, in addition to model (Woodcock & Fisher, 1986), to develop a model where it is possible to form structures in azimuths (26 - 296^0) and (35-305^0), in the form of a diagonal mutually orthogonal grid on the primary (main) system of first order breaks (Figure 5).

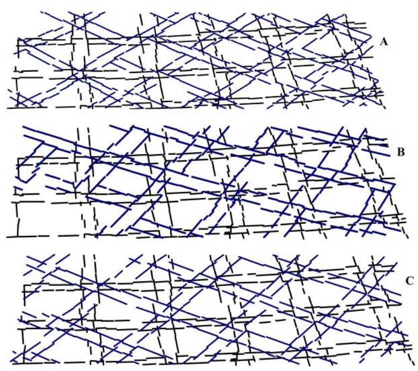

Figure 4. Scheme of mutual placement of diagonal lineament in azimuths (40-3100), (26 -2960) and (35-3050) on a primary orthogonal system of lineaments

A - relative positioning of systems (84-354^0) and (40-310^0); B - (84-354^0) and (26- 296^0); C - (84-354^0) and (35-305^0). The system of coordinates is similar to that in Figure 3.

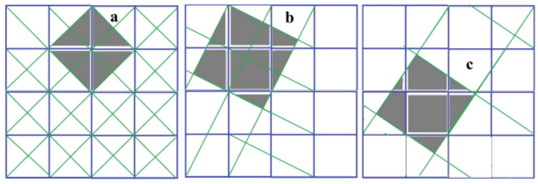

Figure 5. The model of forming system of domains in different azimuths on the primary orthogonal grid of faults a- domain of system (45-315^0) ±30 according to (Woodcock & Fisher, 1986); b - domain of system (26-296^0) ±30; c - domain of system (32-302^0) ±30.

Systems similar by azimuths of spreads (26-296^0) - (35-305^0) and (84-354^0) - (3-273^0) are spatially combined (conjugated) by systems (Figure4.B-C). Theoretical value of angles (Figure 5) is arctg (1/2) = 26.56^0 for system (26 -296^0) and for system 35-305^0 - arctg (2/3) = 33.69^0. System (64 - 334^0), being complementary to system (26 - 296^0), since 26^0 +64^0 = 90^0, is also formed as a subordinate system.

The presented geometric models show that the presence of one (primary) orthogonal system of faults as a result of long-term variable loads on the Aldan-Stonovoy megablock makes it possible to explain the origin of all existing systems in the area of collision interaction of the Amur and the Eurasian lithospheric plates. This can be proved by the fact that 90% of intersection points of lineaments are concentrated within the orthogonal systems (84-3540) and (3-2730): latitudinal "a-c" and meridional "1-6" (Figure 3).

The developed model of mutual arrangement of systems of geophysical anomalies fit into the idea of existence of three dominant systems of crustal deformation in Northeast Asia: latitudinal-meridional (coupled systems of linear elements of fields 3 - 273^0, 84 - 354^0), north-west of the Paleozoic (coupled systems 64 - 334^0, 70 - 340^0), north-east - Mesozoic (system 40 - 310^0), corresponding, respectively, to the main periods of Archean-Proterozoic and Paleozoic-Mesozoic tectonic deformations of the Aldan-Stanovoy megablock. Mutual spatial arrangement of bimodal (3-273^0 and 84-254^0) and trimodal (26-296^0, 35-305^0 and 40-310^0) stretches of linear elements of gravity and magnetic fields may also indicate that changes in the Paleotectonic environments and related orientations of strain vectors in the territory of the Aldan-Stanovoy megablock did not occur simultaneously and sharply, but gradually and smoothly, which may find an explanation in the uneven (cyclic) rotation of the Amur plate.

3.3 Clarification of the Formative Period of System (84-3540) When Compared with Zones of Elastic-Plastic Flow

The developed model of inherited development of fault systems assumes availability of primary faults grid, which in this case is a system in azimuths (84-364^0) or (3-273^0). According to the compliance of the spatial position of these systems (Figure 3) to the main structural lineaments of the Aldan-Stanovoy megablock (Figure 1), time of their formation is not later than Archean - Proterozoic period (Gorokhov et al., 1981).

Concretization of the date of forming the basic system of anomalies in azimuths (84-354^0) was made possible by comparing the spatial position of individual elements of the system with zones of elastic-viscous flow of rocks (shear-zones).

Within the Aldanian Shield, same as in other areas of foundations of ancient platforms (Hamimi et al., 2014), zones, which are composed of rocks of adjacent blocks, slightly metamorphosed formations, anorthosite intrusions, granitoids, mylonites and blastomylonites, are mapped. They seem to ligate adjacent terranes as zones of tectonic melange (Melnikov, 2008). A detailed structural analysis of internal structure of these areas shows that they all formed using the mechanism of shear flow of rocks and are typical brittle-plastic shear-zones. All in all, within the Aldanian shield, four shear-zones are separated: Kalar, Amginsk, Tyrkandinsk and Ulkan (Figure 6).

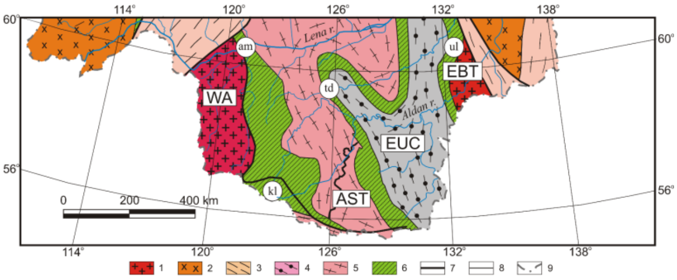

Figure 6. The structure of foundation of the southeastern part of the North Asian craton

1 - granite-greenstone terranes; 2 - tonalite-trondhjemite terranes; 3 -Proterozoic orogenic belts; 4 - granulite-paragneiss terranes; 5 -granulite-orthogneiss terranes; 6 - large zones of shear flow (shear zones); 7- large fault borders; 8 - minor faults; 9 - the south-eastern boundary of the North Asian craton. In circles are shear-zones: am - Amga, kl - Kalar, td - Tyrkandinsk, ul -Ulkan. In squares are terranes: WA - West Aldanian, AST - Sutamsky, EUC - Uchursk, EBT- Batomgsk.

The Kalar brittle-plastic shear-zone separates the West Aldanian granite-greenstone terrane located to the south of the Tyndinsk tonalite-trondhjemite-gneiss terrane and can seen in the sub-latitudinal direction at the distance of about 650 km, 50 to 150 km wide. Various types of pegmatites and layered gabbro ultrabasite plutons 1.8 -1.9 billion years old seem to seam together plates and blocks of different age and types in the Kalar Shear Zone (Melnikov, 2008).

The Amga shear-zone separates the Central Aldanian composite terrane from the West Aldanian and Tynda terranes located to the west and south of it, and cuts off the Kalar shear-zone (Figure 6). It has an arc shape seen in the plane and can be seen at a distance of about 650 km. The width of the zone varies from several to 150 km. Rocks that connect different plates are presented here with granites and pegmatites 1.9 - 2.0 billion years old. Similar or close age have the gabbro-diorite-plagiogranites of the Ungrinsk complex, which have been metamorphosed into amphibolite facies. In general, the structure of the Amga shear-zone consists of the Archean rocks of amphibolite - epidote-amphibolite facies, Early Proterozoic ortho-gneiss and para-gneiss strata of the sub-granulite - granulite facies, Archean and Early Proterozoic fragments of greenstone structures and differentiated plutons of ultrabasic and basic rocks that have experienced widespread structural metamorphic processing in the range between 2.15 - 1.9 billion years.

Tyrkandinsk brittle-plastic shear-zone separates the East Aldanian superterrane from the Central Aldanian one in the west and from the Tynda one in the South of the composite terranes (Figure 6). It has a curved shape in plan and can be traced at a distance of about 1,650 km with its width ranging from 50 to 200 km. The age of magmatic zircons defined using the U-Pb isochron method is 1.9 billion years (Bibikova et al., 1989). The Ulkan Shear Zone by its internal structure, material composition and age of formation is no different from the Amga and the Tyrkandinsk Shear zones.

In general, formation of brittle-plastic shear-zones of the Aldan-Stanovoy megablock that connected its disparate terranes into a single continental block occurred in the age range of 2.1-1.8 billion years (Brandt et al., 1981).

Qualitative analysis revealed that the fragment of the latitudinal anomalous zone in the azimuth 840 at the latitude 56W from meridian 122E to meridian 126E (Figure 3) is spatially coincident with the Kalarsk shear-zone and meridional anomalous zones in azimuth 354^0 at longitudes 121E, 126E and 132E (Figure 3) - with the Amga, Tyrkandinsk, and Ulkan shear-zones (Figure 6).

Spatial relationships between the pulse-meridional adjacent systems (3 - 84 and 273^0 - 354^0) (Figure 3) and shear-zones of the Aldanian shield (Figure 6), composed of geological formations of detected age, leads to the conclusion that the spatial anomalies of geophysical fields in these azimuths (3 - 84 and 273^0 - 354^0) were formed in the period not later than 1.8-2.1 billion years ago.

3.4 System of Active Lineaments (40-3100), Seismicity and Prediction of Location of a Strong Earthquake

Comparative analysis of spatial distribution of earthquakes and the developed tectonics model of the Aldanian-Stanovoy megablock by statistical distribution of anomalies of geophysical fields has shown that the system of lineaments with azimuths (40 - 310^0) fits into the structure of the seismic field, and all gravitate epicenters of strong earthquakes tend to the points formed by intersecting of lineaments of the system, or to axis lines (Figure 7).

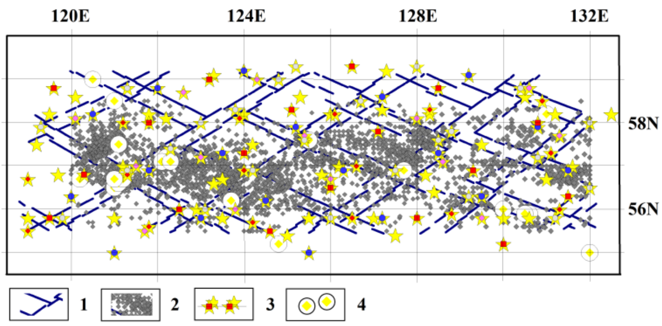

Figure 7. A fragment of the spatial structure of domains of a diagonal system of lineaments of geophysical fields with azimuths (40-3100) with epicenters of earthquakes and the points of all selected systems

Legend: 1 - lineaments of anomalies of geophysical fields in azimuth (40-310^0); 2 - dimensional field of earthquake epicenters, 3 - lineament intersection points of selected seven systems of anomalies of geophysical fields; 4 - strong earthquakes.

Stretch of concentration zones of earthquake epicenters in the central part have common azimuth 310^0, and after that, during transfer from one domain to another, consistently changes azimuth 310^0 to 40^0, from 40^0 to 310^0.

In the west of the area (121 HP, 56.5SSH) (Figure 7), there is a tectonic point of intersection of lineaments of five systems (intersection of the latitudinal structure "b" and meridional - "2", Figure 3), with azimuth (3-273^0), (26 -296^0) (40-310^0) (64-334^0) (70-340^0), respectively. This tectonic point attracts strong earthquakes with magnitude M = 6.5 and M = 7.0, with epicenters fitting into the main spatial domain structure of lineaments system (40-310^0).

In the center of the analyzed region (Figure 7, 126 VD, 56.5 SSh), (intersection of latitudinal structure "b" and meridional - "4" Figure 3) there is a point of intersection of six systems of lineaments, i. e. 6 systems converge in the center of the domain system (40-310^0), at the north-eastern border two strong earthquakes have been registered. Southeast fragment of this domain at present is aseismic, however, by analogy with the western domain, it can be considered to be one of the most likely places of tectonic stress release.

Thus, the obtained regularities suggest that the system of lineaments in azimuth (40-310^0) may be associated with the zones of active deformation of the earth's crust and currently controls the seismic process within the area of convergent interaction between the Amur and the Eurasian lithospheric plates.

4. Conclusion

This study presents the results of a statistical analysis of spatial distribution of anomalies of the gravitational and magnetic fields of convergent interaction between the Amur and the Eurasian plates. This area is a seismically active region in North-East Asia, with energy potential of individual fragments which corresponds to ten zones of seismic concussions.

Using methods of statistical analysis of azimuths of linear elements of anomalies, gravity and magnetic stages and other geophysical signs of faults, seven primary directions have been selected with azimuths (3-273^0), (26-296^0) (35-305^0) (40-310^0) (64-334^0) (70-340^0) (84-354^0), respectively.

It has been established that within the Aldanian Stanovoy megablock, these linear data fit into certain fault indicators (lineaments) or systems tightly oriented in space grids, each of which comprises two mutually orthogonal areas that form domain structures.

The length of the sides of domains for different systems is 120 to 150 km and is conditionally called a spatial period of the first order.

Comparison of systems of geophysical fields anomalies with peculiarities of tectonic plan of the area, with zones of elastic-plastic flow of rock masses (shear-zones) showed that systems (3-273^0) and (84-354^0) are spatially correlated with geological - tectonic structures of the first order, formation of which refers to period 1.8-2.1 billion years.

Systems (26-296^0) (35-305^0) and (40-310^0) may be sequentially formed on the primary grid of faults. The order of formation of these systems is the subject of further study and geological interpretation.

In general, this analysis made it possible to establish structural-tectonic position and relative time of formation of individual systems of geophysical fields anomalies. As a result of comparing diagonal system of geophysical fields anomalies with spatial distribution of the fields of contemporary seismicity and epicenters of strong earthquakes, an assumption was made that the diagonal system of lineaments reflects zones of tectonic deformation and has been controlling the epicentral fields of contemporary seismicity since the Mesozoic period of seismotectonic activation.

Determinant result of this study is the synthesis of early scientific works and getting new ideas about geophysical models of Earth's crust in the Aldanian-Stanovoy megablock. The indicated direction of search works for studying relationship of systems of geophysical fields anomalies and seismicity is the subject of further research.

The main direction of further studies is the construction of lineament systems based on new digital elevation model (DEM) technologies and carrying out the lineament trend analysis of the geophysical fields in the western segment of the Aldan-Stanovoy megablock. Eventually, taking into consideration systematization of all data on the age determination of rocks in the study area, this will allow us to establish the time of origin of diagonal lineament systems and the succession in their formation.

Acknowledgments

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