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CONDUCTING LITHOSPHERIC HETEROGENEITIES AS A CRITERION OF PREDICTIVE ASSESSMENT FOR PROMISING DIAMOND AREAS (ON THE EXAMPLE OF SIBERIAN KIMBERLITE PROVINCE)

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Results of magnetotelluric tests, carried out in Siberian kimberlite province, are examined from the viewpoint of structural control over location of kimberlite fields and bunches of kimberlite pipes. It is demonstrated that the key factors controlling occurrence of kimberlite magmatism are: deep systems of rift-driven fractures; areas of their intersection within high-ohmic blocks of Earth crust; conducting permeable areas, located at the intersections of deep faults. Various-rank objects of kimberlite magmatism are characterized by a certain combination of geoelectric heterogeneities, differing in resistance, lateral sizes and depth. The province is situated within the boundaries, limited by isolines 180-220 km of current asthenosphere; kimberlite areas – within the contours of high-resistance regional heterogeneities. Fields and bunches of kimberlite pipes are concentrated within boundaries of conducting subvertical zones. These factors can be used as criteria of predictive assessment for promising diamond areas of the ancient platforms.

***Key words*:** magnetotelluric tests, Siberian kimberlite province, kimberlite magmatism, conducting heter-goneities

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In the problem of mineral resources of Russia diamonds, as compared to other commercial minerals, hold a unique position. A diamond, characterized by a plain chemical composition, is nevertheless an exceptionally difficult research object, not only for Earth sciences, but also for solid state physics and inorganic chemistry. It is the most reliable representative of continental lithosphere deep zones, and chemical composition of silicate media of its crystallization reflects specific characteristics of upper mantle constitution.

Productivity of regional occurrence forecasts for kimberlite magmatism and its diamond-bearing variations has been brilliantly realized by the Academy fellow V.S.Sobolev basing on comparison of geologic structures of African and Siberian platforms, which came as the main scientific justification of diamond exploration in the region of the Sakha Republic (Yakutia) in the mid-20th century. The second most important scientific achievement in this field is «Clifford rule», according to which diamond-bearing kimberlites are confined to Earth crust blocks of ancient consolidation – cratons [14]. These achievements in the field of scientific forecasting of primary diamond-bearing capacity from the viewpoint of modern practical exploration geology fall into the category of above-regional forecasting. Transition to a more detailed scale of forecasting attributes greater value to geophysical methods, including magnetotelluric sounding (MTS).

Application results of regional and meso-scale MTS tests on the Siberian platform showed the method's high information value for forecasting various-rank objects of kimberlite magmatism and allowed to justify a deep geoelectric model and corresponding conditions in the Earth crust and upper mantle [10, 11].

Mid-Paleozoic kimberlite province is located in the pinch-out area of large asthenolenses within the platform regions, elevated along the basement surface. The main elements of deep electrical conductivity of the province are crust and mantle conducting layers, whose parameters are defined by thermodynamic regime of the lithosphere. According to petrologic, tectonic and geothermal data, the territory of the province can be classified as one of the least active regions, which did not undergo any significant tecto-magmatic activation in the course of the following post-kimberlite development stages. Occurrence depths of the crust and mantle conducting layers for such conditions amount to 35-40 and 180-220 km respectively. Against the background of regional structure of electrical conductivity, kimberlite regions of the province have anomalous zones and areas. They are situated on different levels of the lithosphere, have different shapes, sizes and electrical resistivity. By contrast with the background conductivity, they can be divided into two groups –

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conducting and non-conducting. From the viewpoint of spatial characteristic, they can be classified as regional (30-100·10^3 km^2), first- (5-30·10^3 km^2), second- (0.5-3·10^3 km^2) and third-order (units and tens of km). Their formation is related to the processes of matter redistribution in the periods of previous activation phases.

High-resistance heterogeneities are formed in the process of magma intrusion into the crust conducting layer or its defluidization in the course of magmatic activity. Within the boundaries of conducting heterogeneities, the rocks are saturated with minerals-conductors that have good electrical connections and have been added through tectonically reduced and disjunctive faults. Kimberlite fields are usually located within boundaries of large high-resistance heterogeneities, and areas of their localization correspond to conducting subvertical zones, linked to the systems of regional deep faults, responsible for the formation of rift-induced tension structures. Similarities are observed between conducting heterogeneities and gravity and magnetic lows, as well as enhanced heterogeneity of the Earth crust according to seismic data [3, 4]. These attributes combined with the presence of indicator minerals demonstrate that under kimberlite fields there is subvertical conducting heterogeneity with its roots going into the mantle against the background of the crust's resistive structure.

Identification of structural control factors for kimberlite fields, and especially for the zones of deep faults, is an important element in the search for kimberlite magmatism occurrences. Presence of separate conducting zones is not enough to explain spatial location of kimberlite magmatism. Areas of intersection or overlapping of conducting zones are an essential prerequisite to ensure «through» mantle-crust conductivity. In this case, emerging subvertical conducting area provides interaction between the crust and the mantle and creates favorable conditions for the location of kimberlite regions and fields [7]. The objects of special interest are conducting geoelectrical heterogeneities, located at the intersections of deep fault zones, discovered within the boundaries of Yakutsk kimberlite subprovince (YDP) of the Siberian platform.

In the Malobotuobinsk kimberlite region such heterogeneities have been observed at the intersection of Viluisko-Markhinsk and Ukugutsk fault systems. Mirny diamond field is located within three conducting heterogeneities, spatially joined with bunches of kimberlite pipes (Fig.1).

Heterogeneities stretch to the north-east along the Ukugutsk fault system. The first two of them, with similar parameters (depth of top edge 20 km, resistance 80-100 Ohm·m), are in their essence a single conducting area divided by a narrow crust block of higher resistance. The second heterogeneity can be ranked as heterogeneity of the higher order, with the depth of occurrence 10 km and resistance 30 Ohm·m. The third one is characterized by a higher position of top edge – 15 km and lower resistance – 30 Ohm·m. Kimberlite pipes of Mirny field lean towards gradient zones located at the juncture of high-ohmic crust block and conducting heterogeneities (Fig.1). The gradient area contains ore-hosting sections of Western and Parallel fractures, which allows to draw conclusions about the controlling role of discontinuous faults of Ukugutsk system in the formation of permeable crust and distribution of kimberlite bodies within the boundaries of Mirny diamond field.

Extension of Viluisko-Markhinsk zone, in the area of its intersection with Mid-Markhinsk tectonic zone, hosts one more conducting heterogeneity, within the boundaries of which Nakynsk kimberlite field of the *Mid-Markhinsk region* is located. In the area of *Daldyno-Alakitsk kimberlite region* rocks of kimberlite formation are concentrated in the shapes of bunches and chains, forming two contiguous fields – Alakit-Markhinsk and Daldynsk. Location of these kimberlite fields is determined by a complex system of divergent deep rift-driven fractures of Daldyno-Oleneksk and Viluisko-Kotuisk systems. Detected heterogeneities have a complex structure. Daldynsk field is located within two conducting heterogeneities divided by a high-ohmic crust block, both of them can be ranked as heterogeneities of the higher order (Fig.2, *a*). The latter are associated with bunches of kimberlite pipes. Heterogeneity, spatially joined with Alakit-Markhinsk field, represents a zone more than 50 km wide, with interchanging zones of increased and decreased resistance (Fig.2, *b*). Bunches of kimberlite pipes are located within the boundaries of the latter.

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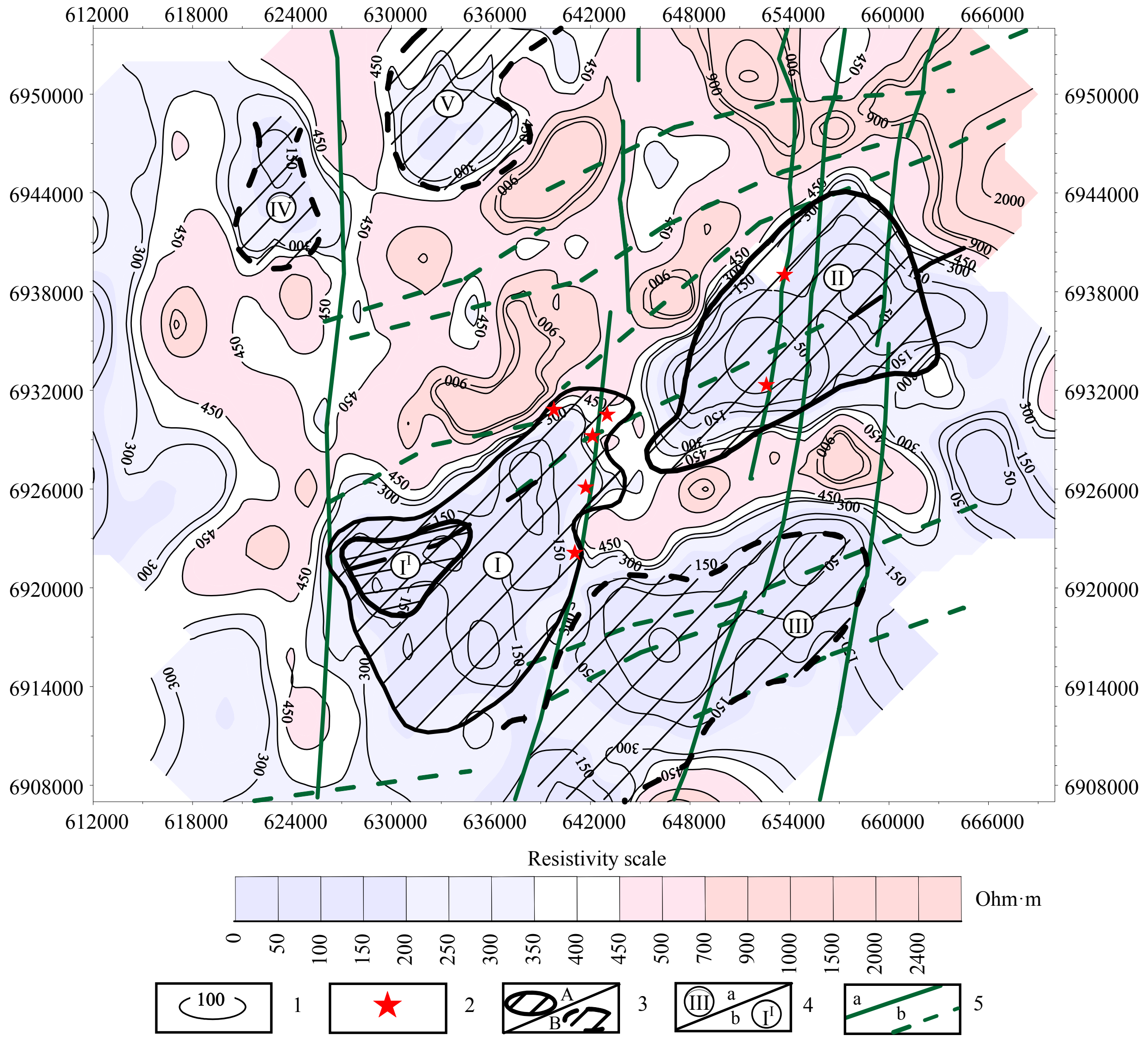

Fig.1.Distribution of electrical resistivity at the depth of 25 km in Malobotuobinsk kimberlite region

1 – isolines of electrical resistivity in Ohm·meters; 2 – kimberlite pipes; 3 – conducting geoelectrical heterogeneities: A – proven, B – inferred; 4 – index number and order of conducting heterogeneities: a – first order, b – second order; 5 – projections: a – fractures of Viluisko-Markhinsk system, b – discontinuous faults of Ukugutsk fracture system

Thus, the following factors control occurrence of kimberlite magmatism in kimberlite regions of YDP:

– deep systems of rift-driven fractures;

– areas of their intersection within boundaries of Earth crust blocks with high electrical resistivity;

– conducting permeable zones located at intersections of deep fractures.

These factors can be used as criteria for predictive assessment of promising diamond areas not only in Yakutsk subprovince, but also in other promising territories of Siberian platform, south-western part of which contains several high-potential regions. First and foremost, those are territories of Krasnoyarsk Krai and Evenk Autonomous Okrug (Angarsko-Tungus and Baykitsk subprovinces), as well as Irkutsk Oblast' (Prisayansk subprovince).

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From the perspective of diamond exploration, in the south-western part of Siberian platform the fullest and most thorough examination has been carried out in Tychansk diamond-bearing region of Baykitsk kimberlite subprovince. The region is located in the conjunction zone between Baykitsk anteclise and Tungus syneclise, at the intersection of Kovino-Kordinsk zone dipping to north-west with Bolshepitsko-Kislokansk and Angaro-Solzavodsk zones of deep fractures dipping to north-east. According to geologic data, transverse fracture zones with north-east dip have the greatest significance from the position of kimberlite magmatism control. Bolshepitsko-Kislokansk zone controls location of regions with identified diamond-bearing capacity: Bolshepitsk, Tychansk, Taymuro-Chunsk, Ilimpeysk – and further is retraced as an extension of Daldyno-Oleneksk zone in YDP, which controls location of Alakit-Markhinsk, Daldynsk and Munsk fields of Mid-Paleozoic kimberlites. Angaro-Solzavodsk fracture zone controls location of explosive rocks in Motyginsk region and diamond-bearing sections (Tarydaksk, Enbolaksk, Miryugsk) of Chadobetsk region.

The key information, demonstrating high potential of Tychansk region to contain diamond ore bodies, amounts to the data on wide-spread occurrence of diamonds and associated minerals in its terrigenous sediments of Lower and Middle Carboniferous [9]. Identification of aureoles by the productivity of ore bodies shows that all of them are formed by diamond-bearing (probably, highly productive) kimberlite bodies [2]. However, ore bodies themselves have not been found.

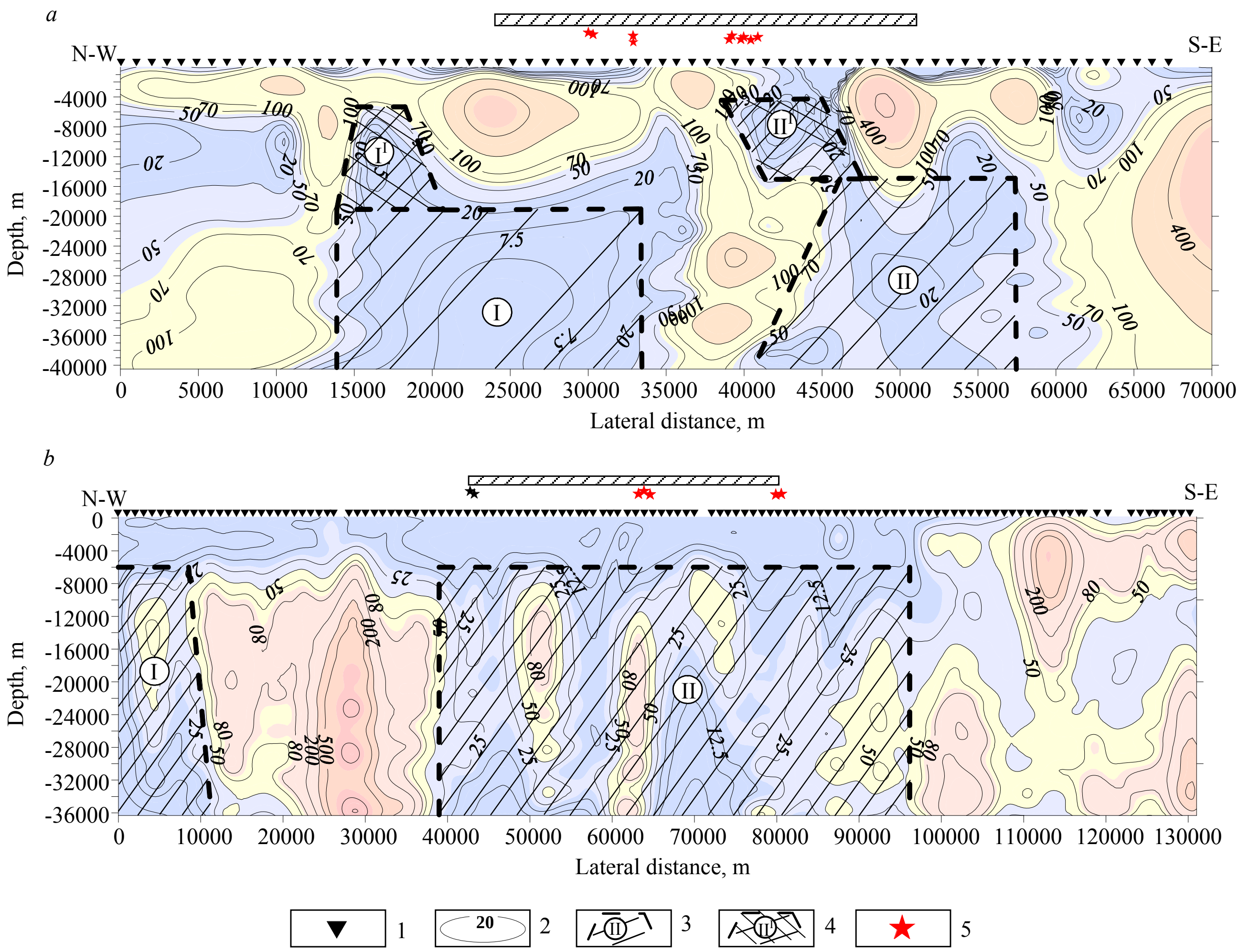

Fig.2. Deep geoelectrical sections: *a* – through Daldynsk kimberlite field, *b* – through Alakit-Markhinsk kimberlite field
1 – points of MT sounding; 2 – isolines of electrical resistivity; 3 – conducting heterogeneities of the 1st order; 4 – conducting heterogeneities of the 2nd order; 5 – kimberlite pipes

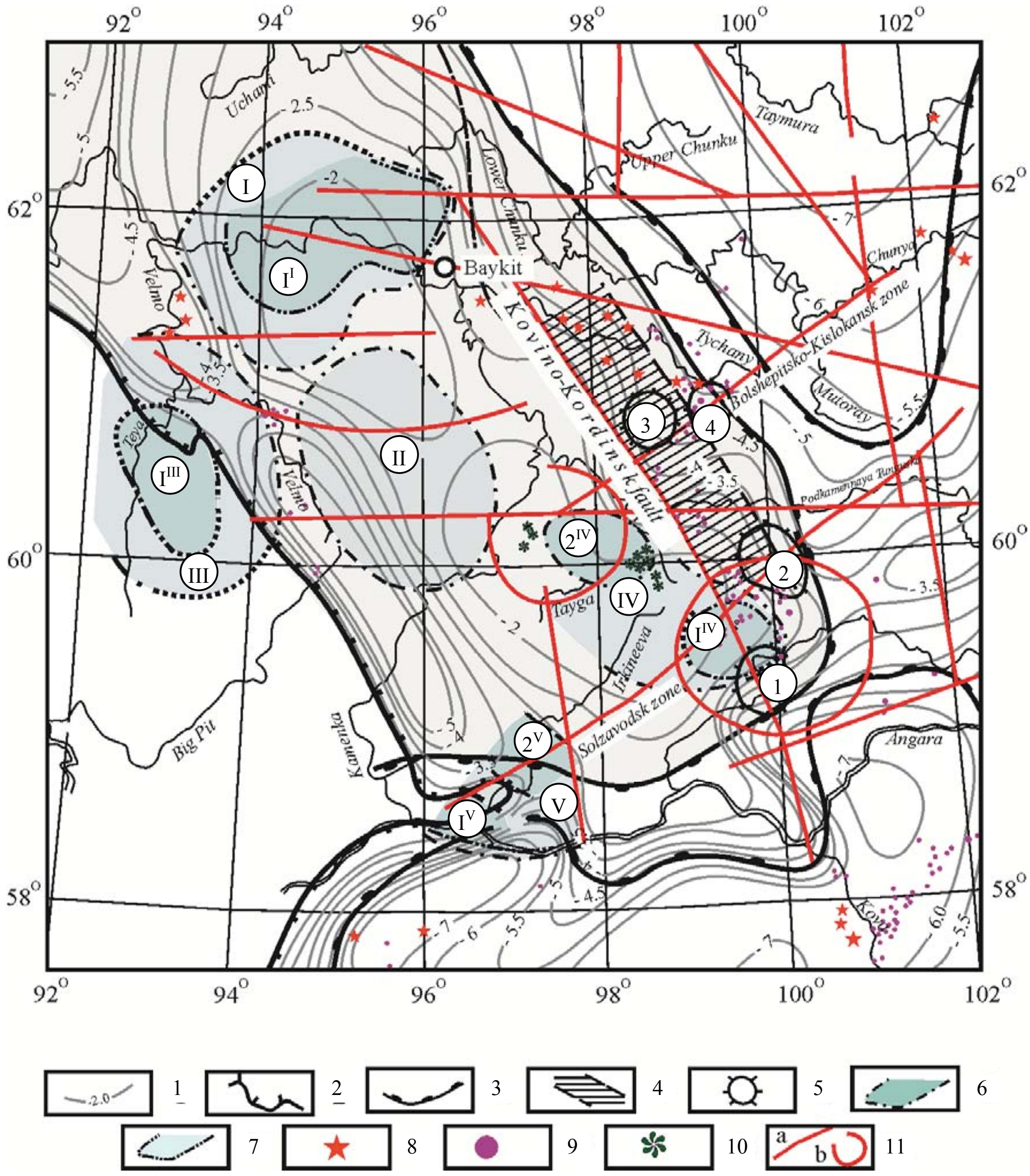

Fig.3. Results of magnetotelluric tests in Baykitsk kimberlite subprovince

1 – surface isolines of pre-Kembrian metamorphosed rocks; 2 – boundary of Siberian platform (outcrops PR1); 3 – contours of kimberlite province; 4 – contours of Kovino-Kordinsk zone; 5 – local elevations: 1 – Chadobetsk, 2 – Tarydaksk, 3 – Khushmukansk, 4 – Shushuksk; 6 – conducting geoelectrical heterogeneities of the 1^{st} order: I – Poligussk, II – Kamovsk, III – Velminsk, IV – Kovino-Kordinsk, V – Irkineevsk; 7 – conducting geoelectrical heterogeneities of the 2^{nd} order: 1^{I} – Poligussk, 1^{III} – Teysk, 1^{IV} – Chadobetsk, 1^{V} – Angarsk, 2^{IV} – Tayginsk, 2^{V} – Irkineevsk; 8 – diamond findings; 9 – pyrope findings; 10 – kimberlites; 11 – zones of deep faults (a) and ring structures (b), Geologic map 1 : 2500 000, 1980

According to data from magnetotelluric tests, the greatest potential of finding diamond bodies within the boundaries of Baykitsk kimberlite subprovince is attributed to the area situated parallel to Kovino-Kordinsk zone, incorporating several conducting heterogeneities (I, II, IV), located at the intersections of deep faults of north-western and north-eastern dips (Fig.3). In the zone of conjuncture between Baykitsk anteclise and Enisei ridge, within the boundaries of inferred Enisei kimberlite subprovince, one more zone of decreased resistivity (III) has been detected. It is confined to the intersection of Ankinovsk zone of deep faults, limiting horst structure of Enisei ridge, and feather-

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ing fault of sublateral dip within the boundaries of Ust-Chapinsk elevation (Fig.3). The heterogeneity is spatially joined with the inferred Velminsk kimberlite field [5, 6]. Minerals associated with diamonds have been detected within the boundaries of a promising area in the left feeders of Chapa river lower course [5]. According to P.P.Kurgankov et al. [5, 6], the ablation of associated minerals into recent alluvium occurs from some intermediate reservoir, located (currently or previously) either at the parting of rivers Big, Small Zhaduga and Big, Small Kolonka, or directly from Ust-Chapinsk elevation.

Prospects of *Prisayansk kimberlite subprovince*, according to the majority of researchers [1, 8, 12, 13], are attributed to Uriksko-Tumanshetsk intracratonic mobile zone (UTMZ) of Early Proterozoic origin, consisting of Uriksko-Iysk and Tumanshetsk grabens and Prisayansk trough. Diamond-bearing vein bodies of phlogopite-olivine lamproites have been identifies within the boundaries of Uriksko-Iysk graben. Lamproite veins and aureoles of associated minerals form a band 5-8 km wide and approximately 30 km long and together constitute Ingashinsk lamproite field. In the regional structure plan Uriksko-Iysk graben is one of the elements of Prisayansk province of high-potassium alkali rocks and lamproites, confined to UTMZ. Formation of the zone took place under the conditions of a mature Earth crust, consolidation of which ended with the establishing of early Proterozoic granitoids of Sayan complex. Before this happened (in the beginning of early Proterozoic Eon), active accretion and collision processes on the frontier between Siberian craton and Ural-Mongol-Okhotsk paleo-ocean facilitated thickening of the lithosphere in the zone of UTMZ localization [1]. This led to conservation of favorable thermodynamic conditions for diamond stability in Proterozoic lithosphere. Magmatism data for Uriksko-Iysk graben demonstrate that repeated reactivation was not accompanied by large-scale magmatism and significant structural reorganization, which could have resulted in shrinking of diamond-bearing edges of cratonic lithosphere and reduction of its productivity [12]. Basing on this concept, conclusion has been made that from the viewpoint of regional and local criteria of diamond-bearing capacity this region is one of the most promising objects in the southern part of Siberian platform to contain primary and placer diamond deposits.

Results of geophysical exploration, completed within the boundaries of Tuluno-Tayshetsk section of Prisayansk, allowed to broaden the prospects of diamond-bearing capacities in Prisayansk kimberlite subprovince. Carried out magnetotelluric tests complemented existing notion of deep-seated structure of junction between Siberian platform and East-Sayan Mountains. As a result of complex analysis of magnetotelluric data and materials obtained by other deep geological and geophysical methods, two most stratified surfaces have been identified in Prisayansk province – V_1 and F. The first one serves as a frontier between post-salt and salt sediments, the second one is confined to the boundary between platform sedimentary cover and its crystalline basement. The basement geometry includes three major structural elements of the first order: Prisayansk Vendian-Riphean Trough, Nizhneudinsk Ridge-like Elevation and Chunsk Basin (Fig.4). Prisayansk Trough is clearly distinguished in the foothills of East-Sayan Mountains and settles with the formation of a thick (up to 3 km) mass of Vendian sediments, whereas its thickness in the platform section does not exceed 200 m. Prisayansk Trough falls into the same category as Pribaikal Trough, Nuysko-Dzherbinsk and Berezovsk Basins, as well as Vendian-Riphean troughs, framing Enisei Ridge and Sayano-Baikal Bridge from the side of the platform. All these troughs, as well as Chunsk Basin, are compensation basins of the orogenic belt in Baikalo-Patomsk Upland and Enisei Ridge.

A thick mass of Vendian-Riphean sediments crops out within the boundaries of Nizhneudinsk Ridge-like Elevation, and lateral integral conductivity of the platform cover is observed to increase. Prisayansk conducting heterogeneity of the first order, 20 km in depth, with resistivity of 5-10 Ohm·m, is distinguished in the central part of the elevation at the intersection of deep faults of sub-lateral and south-eastern dips (Fig.4). Within its boundaries it contains Udinsk and Nizhneudinsk heterogeneities of the second order, approximately 10 km in depth and with resistivity 2-3 Ohm·m (Fig.4).

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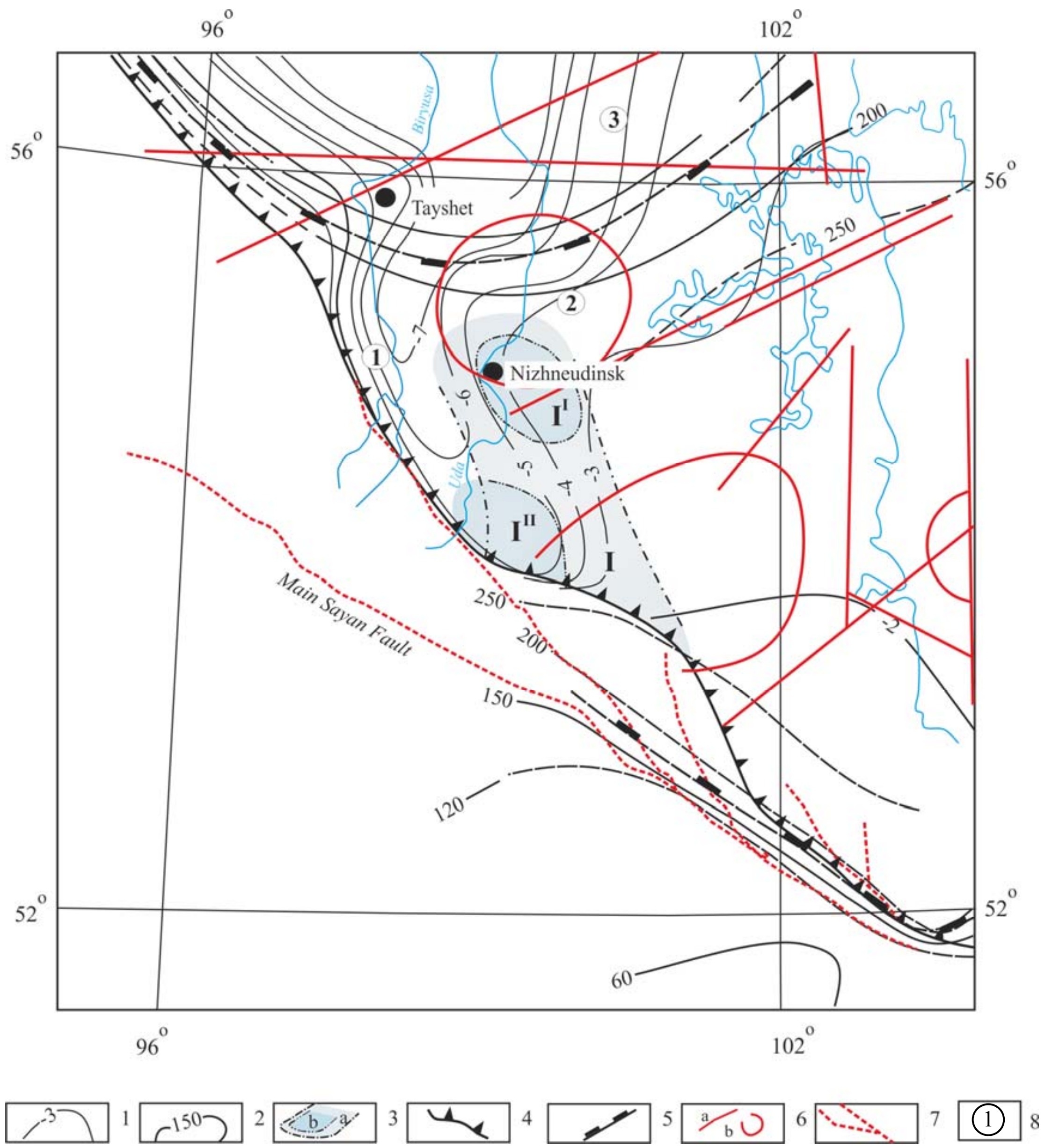

Fig.4. Results of magnetotelluric tests in Tuluno-Tayshetsk section of Prisayan subprovince

1 – surface isolines of pre-Kembrian metamorphosed rocks in km; 2 – surface isodepth of asthenosphere in km; 3 – contours of conducting geoelectrical heterogeneities: a – 1st order (I – Prisayansk); b – 2nd order (I^{I} – Nizhneudinsk, I^{II} – Udinsk); 4 – boundary of Siberian platform; 5 – contours of kimberlite province; 6 – deep faults (a) and ring structures (b), Geological map 1:2500 000, 1980; 7 – faults; 8 – basement structures: 1 – Prisayansk Vendian-Riphean Trough, 2 – Nizhneudinsk Ridge-like Elevation, 3 – Chunsk Basin

Conclusion. Analysis of results of magnetotelluric tests, carried out within the boundaries of kimberlite regions of Siberian province, demonstrates that proven and inferred kimberlite fields are spatially joined with conducting geoelectrical heterogeneities. These heterogeneities are located at intersections of multidirectional ore controlling zones of deep faults and are distinguished against the background of Earth crust blocks with high electrical resistivity.

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