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Physical and geological modeling of dolerite intrusion at collisional suture of Siberian craton – Olkhon terrane system (Western Baikal region)

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Abstract. The Olkhon region is a key structure (geodynamic polygon) straddling the boundary between the Siberian craton and the Central Asian folded belt. In this regard, finding out the history of their interaction in time and space is an interesting and relevant task, the solution of which provides a good opportunity to discuss the prospects for a different interpretation of the array of new geological and geophysical data for the Western Baikal region. The purpose of physical and geological modeling is to clarify the geological structure of the collisional suture of the Siberian craton – Olkhon terrane system to create next-generation geological maps. For this purpose, ground magnetic surveys and petrophysical studies have been conducted at the Anga River section where collisional suture metamorphic features are prominent. These studies included the collection of oriented samples from blastomylonites of various types and the intruding dolerites, aged 500–470 and 290 million years, respectively. According to geologists, dolerites form a dike of northeastern strike, no more than 5 m thick and up to 2 km long. New information on geochronology, petro- and paleomagnetism of the considered dolerites contradicts this hypothesis. The performed physical and geological modeling showed that the dolerites form an intrusive body of a more complex shape than the dike (most likely a sill about 200 m thick), and made it possible to find a compromise solution for the interpretation of previously obtained material. On this basis, it is possible to conclude that fairly active tectono-magmatic events occurred here in the Early Permian, which most likely were associated with the formation of the Angara-Vitim batholith in Transbaikalia. According to the obtained samples (N = 19), after introducing a tectonic correction for the bedding elements of the main fault plane of the Primorsky fault, a virtual geomagnetic pole has been calculated for the Early Permian (295–275 Ma) with coordinates: F = 45° N, L = 133° E, dp/dm = 18.2/19.0°. Thus, to clarify the Aerospace geological map and the history of geodynamic development of the Olkhon region, it is proposed to include a wide range of geophysical methods in the research.

Keywords: Western Baikal region, Siberian craton, Olkhon terrane, Central Asian folded belt, collisional suture, Aerospace geological map, petrophysical legend, physical and geological model

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Научная статья
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Физико-геологическое моделирование интрузии долеритов коллизионного шва системы Сибирский кратон – Ольхонский террейн (Западное Прибайкалье)

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Резюме. Приольхонье представляет собой ключевую структуру (геодинамический полигон), через которую проходит граница между Сибирским кратоном и Центрально-Азиатским складчатым поясом. В связи с этим выяснить историю их взаимодействия во времени и пространстве – интересная и актуальная задача, благодаря решению которой представляется хорошая возможность обсудить перспективы иной, чем прежде, интерпретации массива новых геолого-геофизических данных по Западному Прибайкалью. Целью физико-геологического моделирования является уточнение геологического строения коллизионного шва системы Сибирский кратон – Ольхонский террейн для создания геологических карт нового поколения. Для этого на участке реки Анги, где развиты метаморфические образования коллизионного шва, проведены наземная магнитная съемка и петрофизические исследования с отбором ориентированных образцов из бластомилонитов разных типов и прорывающих их долеритов, возраст которых составляет 500–470 и 290 млн лет соответственно. По мнению геологов, долериты слагают дайку северо-восточного простирания мощностью не более 5 м и протяженностью до 2 км. Новая информация по геохронологии, петро- и палеомагнетизму рассматриваемых долеритов входит в противоречие с этой гипотезой. Выполненное физико-геологическое моделирование показало, что долериты слагают интрузивное тело более сложной формы, чем дайка (вероятнее всего, силл мощностью ≈200 м), и позволило найти компромиссное решение по интерпретации полученного ранее материала. На его основе можно судить о проявлении здесь достаточно активных тектоно-магматических событий в раннепермскую эпоху, вероятнее всего, связанных со становлением Ангаро-Витимского батолита в Забайкалье. По полученным образцам (N = 19) после введения тектонической поправки за элементы залегания главного сместителя Приморского разлома рассчитан виртуальный геомагнитный полюс, соответствующий ранней перми (295–275 млн лет), с координатами: F = 45° с. ш., L = 133° в. д., dp/dm = 18,2/19,0°. Таким образом, для уточнения Аэрокосмической геологической карты и истории геодинамического развития Приольхонья предлагается включение в исследования широкого комплекса геофизических методов.

Ключевые слова: Западное Прибайкалье, Сибирский кратон, Ольхонский террейн, Центрально-Азиатский складчатый пояс, коллизионный шов, Аэрокосмическая геологическая карта, петрофизическая легенда, физико-геологическая модель

Финансирование. Исследования велись в рамках проектной деятельности студентов Иркутского национального исследовательского технического университета (г. Иркутск, Россия) 2024–2025 гг.

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Introduction

The collisional suture of the Siberian Craton-Olkhon Terrane system [1–5] is a unique geological monument for studying various geodynamic processes related to the movement of the Earth's lithospheric plates [6]. The suture extends from the mouth of the Buguldeika River in the southwest to Cape Kaltigey in the northeast (Fig. 1). The continuous length of the suture on land is 150 km, and its width is 1 km. The linear form of the collisional suture is clearly visible on aerial and space images of any scale. The young (Cenozoic) deep Primorsky Fault of the Baikal Rift Zone coincides spatially with the Early Paleozoic collisional suture zone [7, 8]. The Primorsky fault is the largest neotectonic structure and is clearly manifested as a relief scarp along the western coast of Lake Baikal, and during geological mapping it is fixed by a large (300–800 m) shatter zone. The length of the fault is about 200 km. The maximum height of the scarp in the relief reaches 600 m. The main fault surface is defined as a reverse fault with a dip azimuth of about 145–155° and a dip angle of 65–70° [9]. In the Cenozoic period, the fault developed as a diagonal-slip fault.

There is no doubt that the Olkhon tectonic terrane was joined to the Siberian Platform in the Caledonian period, since the entire range of

Fig. 1. Schematic map of the studied sites in the Olkhon area of the Western Baikal region
Red stars on the map indicate the sites with specified numbers; rectangle indicates work site
Рис. 1. Схема расположения изученных обнажений Ольхонского региона Западного Прибайкалья
Красными звездочками на карте обозначены обнажения с указанием номера; прямоугольник – участок работ

processes affecting the rocks of deep fluid systems composing it occurred in the Caledonian and Late Caledonian periods in the range of 485–440 million years [10]. The next stage of the manifestation of tectonic-magmatic processes is associated with the development of the younger Cenozoic Baikal rift zone [7, 8].

Rocks of the Siberian craton and the Olkhon terrane are involved in the structure of the collisional suture (Fig. 2) [1, 5]. The Siberian craton is dominated by speckled blastomylonites from Early Precambrian granites, the Olkhon terrane is dominated by ultrablastomylonites and speckled blastomylonites. The collisional suture is characterized by a monotonous planar texture with a fall to the southeast at angles from 45 to 90°. On the left side of the Anga River, a set of closely compressed tectonic plates with a subvertical orientation, which bear signs of a late collisional stage, can be observed pressed against a resistant craton.

Currently, the only basite dike has been discovered within the Anga site, which breaks through the foliation of the blastomylonites of the collisional suture at an oblique angle (see Fig. 2, *a–c*) [5]. Its continuous length in the bedrock exposure is about 2 km with a thickness of up to 5 m. According to geological data, the dike was considered as synmetamorphic[1] (postorogenic) [11]. The obtained U-Pb age for zircons isolated from dolerites of the dike was 289.6±4.4 Ma (Early Permian) [12]. Earlier, dikes of Early Permian dolerites (275±4 Ma) were studied in the coastal sites of Lake Baikal on the Sharyzhalgai ledge of the Siberian Platform [13]. In addition, the U-Th-Pb results of geochronological (LA-ISP-MS) studies of detrital zircons from Cenozoic sand deposits on Olkhon Island (Sarayskaya Bay) showed 286–310 Ma [14]. It is possible that the introduction of dolerite dikes corresponds well with the epoch of maximum compression (330–275 Ma) of the southern active margin of the Siberian paleocontinent, as a result of which in Transbaikalia (see the inset in Fig. 1) the largest Angara-Vitim granitoid batholith was formed [15, 16]. It is possible that the traces of these tectonic-magmatic processes were reflected in the form of vectors of natural remanent magnetization (NRM, $\bar{I}n$) of a metachronous nature in the Olkhon region [17].

Since the relevance of creating a new generation of geological maps for the Olkhon region in order to clarify the geological structure of the collisional suture of the Siberian Craton – Olkhon terrane system (Anga site) is beyond doubt, the search and study of such dikes is one of the main tasks for the project activities of students of Irkutsk National Research Technical University (Irkutsk, Russia). To solve this problem, the following field work was carried out:

– field magnetic survey and selection of oriented samples from the bedrock sites (see Fig. 2);

[1] Khromykh S.V. *Petrology of magmatic complexes of deep levels of collisional systems (on the example of the early Caledonides of the Olkhon region of the Western Baikal region): abstract of the thesis of the candidate of geol.-mineral. sciences: 25.00.04*. Novosibirsk; 2006, 21 p.

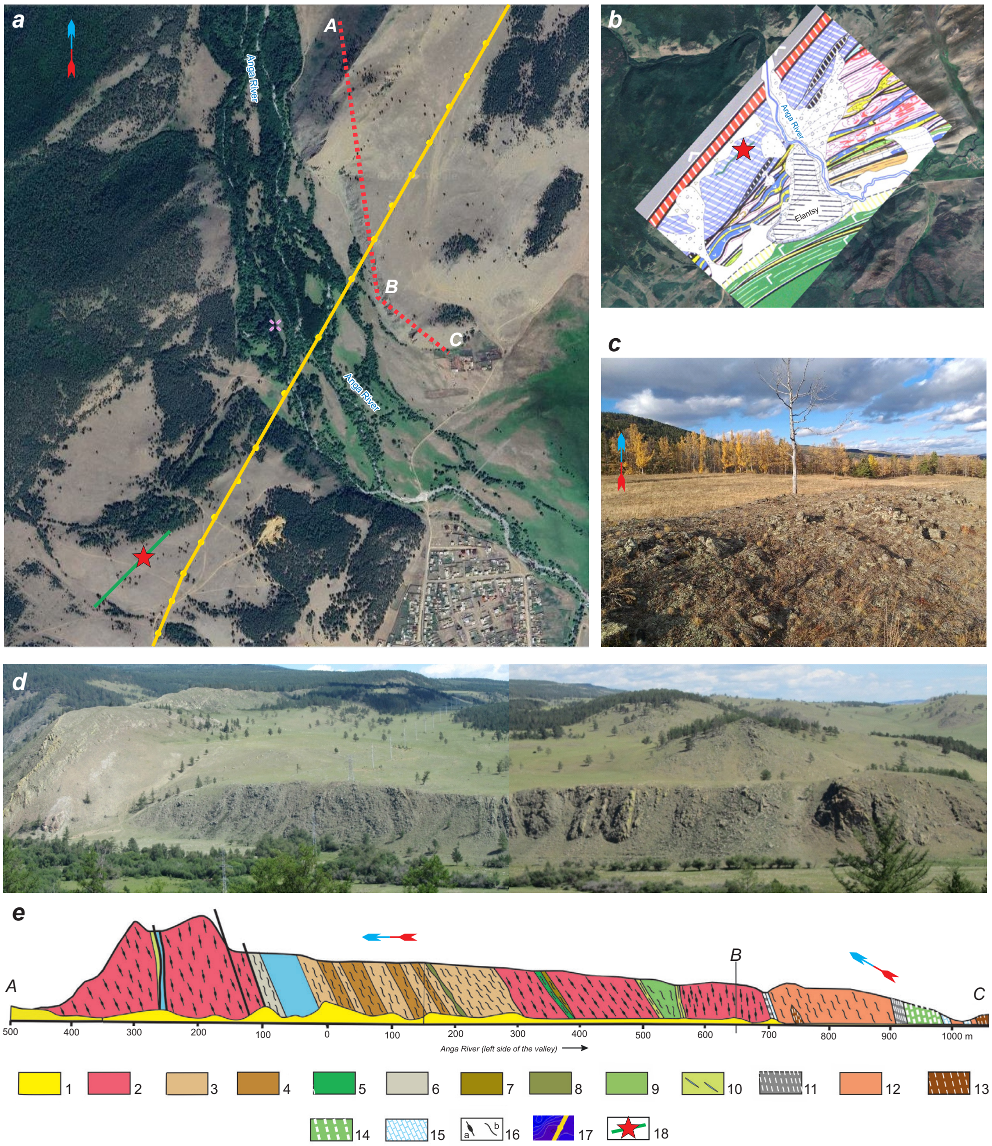


Fig. 2. Geophysical survey site, the Anga River:
a – site diagram; b – geological map fragment [2]; c – 24-60 site;
d – 25-61 site photo; e – A-B-C geological section of 25-61site [5]:
1 – Quaternary formations; 2 – speckled mylonites and blastomylonites from the granites of the Primorsky complex; 3 – finely banded quartz-muscovite–chlorite mylonites; 4 – finely banded muscovite–quartz–plagioclase mylonites; 5 – amphibolites; 6 – muscovite-quartz-potassium feldspar blastomylonites from the fine-grained granites of the Primorsky Complex; 7 – microgneisses with speckled texture; 8 – quartzites; 9 – epidote-actinolite-plagioclase schists in mafic rocks with a linear texture; 10 – epidote-chlorite schists with lenses of fine-grained silicified marbles; 11 – ultramylonites; 12 – mylonitized leucocratic fine-grained granites (Early Paleozoic?); 13 – mylonitized gneisses; 14 – gabbro-mylonites with a flaser structure; 15 – banded fine-grained marble mylonites; 16 – textures: a – speckled, b – schistose; 17 – power lines; 18 – 24/25-60 sites

Рис. 2. Участок геофизических работ, река Анга:
а – схема участка; b – фрагмент геологической карты [2]; c – выход обнажения 24-60;
d – фотография обнажения 25-61; e – геологический разрез A-B-C обнажения 25-61 [5]:
1 – четвертичные образования; 2 – очковые милониты и бластомилониты по гранитам приморского комплекса; 3 – тонкополосчатые милониты кварц-мусковит-хлоритовые; 4 – тонкополосчатые милониты мусковит-кварц-плагиоклазовые; 5 – амфиболиты; 6 – мусковит-кварц-калишпатовые бластомилониты по мелкозернистым гранитам приморского комплекса; 7 – микрогнейсы с очковой текстурой; 8 – кварциты; 9 – сланцы эпидот-актинолит-плагиоклазовые по породам основного состава с линейной текстурой; 10 – эпидот-хлоритовые сланцы с линзами тонкозернистых окремненных мраморов; 11 – ультрамилониты; 12 – милонитизированные лейкократовые мелкозернистые граниты (ранний палеозой ?); 13 – милонитизированные гнейсы; 14 – габбро-милониты с флазерной структурой; 15 – полосчатые тонкозернистые мраморные милониты; 16 – текстуры: а – очковые, b – сланцеватые; 17 – линии электропередач; 18 – обнажения 24/25-60

– laboratory measurements of physical properties and their correct statistical processing;

– geological and geophysical interpretation of materials – three–dimensional physico-geological modeling in the ModelVisionPro-17.5 program (MVP-17.5, Encom Technology, Canada).

The main objects of physical and geological modeling are:

– post-collisional dolerite dike (290 Ma) [5, 12];

– its host blastomylonites of the collisional suture (500–470 Ma) in the north-west of the village Elantsy (Anga River) [1–5, 11].

Materials and methods

The first geochronological, petro- and paleomagnetic results obtained from the dolerite dike at the Anga site [12, 18] contradicted geological concepts [5, 11]. Firstly, the number of zircons of different ages isolated from it (more than 90 crystals) does not correspond to the size of the considered intrusive body, a dike with a thickness of up to 5 m. Secondly, the anisotropy of magnetic susceptibility of dolerites does not correspond to the "dike" geotype [19]: the plane of the magnetic stratification cuts the dike strike at approximately right angles (Table 1, Fig. 3, *a*). The same was found for blastomylonites from the dolerite dike exocontact (see Table 1, Fig. 3, *b*). At the same time, for the collisional suture, the plane of magnetic stratification is consistent with its northeastern strike (see Table 1, Fig. 3, *c*). Thirdly, the baked contact test is negative[2]: a sufficiently wide (more than 15 m) zone of remagnetization of the blastomylonites hosting the dike (Table 2, Fig. 4) indicates a metachronous (superimposed, postmagmatic) natural remanent magnetization at sites 24-60 and 25-60, which, combined with the magnetic susceptibility anisotropy, indicates its dynamic nature. Moreover, the virtual geomagnetic pole[3] in the modern coordinate system has a high-latitude position of F = 81° N, L = 348° E, dp/dm = 13.2/16.2°, and a paleolatitudinal fm = 48° is close to the geographical location of the research area. The virtual geomagnetic pole clearly does not correspond to the Early Permian paleomagnetic pole[3] [13] of the dike intrusion. This can be explained either by a magnetic excursion[3] (paleomagnetic anomaly), or by a displacement along the Primorye listric fault. The young age of the dolerite dike, corresponding to the time of the Baikal rift zone, is also possible.

This behavior of magnetic characteristics at the studied sites 24-60 and 25-60 can be explained by two variants:

1. The rock block was selectively subjected to strong pressure in the post-Permian period. This variant does not explain the presence of a large number of zircon crystals in the dike, which characterize the main geological events in the region. At the same time, dolerites have undergone low-temperature metamorphic changes, but without textural transformations. They are characterized by a typical ophitic structure: idiomorphic plagioclase laths and xenomorphic pyroxene segregation [18].

2. The site of dolerites to the daytime surface is a part of a more powerful blind intrusive body, a significant part of which (like an iceberg) is buried in the host rocks. This variant is more logical. To prove it, it is necessary to formulate geophysical methods, primarily magnetic exploration and the accompanying study of the

Table 1. Anisotropy parameters of the Anga River section petrophysical taxa magnetic susceptibility
Таблица 1. Параметры анизотропии магнитной восприимчивости петрофизических таксонов участка реки Анги

Site No.	*N*	Parameters of anisotropy of magnetic susceptibility				Semi-axes of the ellipsoid of anisotropy of magnetic susceptibility														
						Major, *K*1					Medium, *K*2					Minor, *K*3				
		L	*F*	*Pj*	*T*	*K*1	*D*, °	*J*, °	*α*1	*α*2	*K*2	*D*, °	*J*, °	*α*1	*α*2	*K*3	*D*, °	*J*, °	*α*1	*α*2
24-60	14	1.02	1.022	1.043	0.047	1.021	313.6	5.6	15.8	10.5	1.001	202.7	74.7	32.1	12.5	0.979	45.1	14.2	32	6.8
25-60	13	1.082	1.081	1.169	-0.007	1.079	289.5	54.8	30.3	14.1	0.998	163.4	22.5	36	26.6	0.923	62	25.5	34.5	16
25-61	44	1.038	1.046	1.086	0.087	1.04	63.3	3.7	37.2	26.6	1.002	186.5	83.2	36.5	32.1	0.958	333	5.7	34.6	25.6

Note. *N* – the number of samples. *L*/*F* – linear/planar anisotropy; *Pj* – degree of anisotropy; *T* – shape parameter; *D*/*J* – declination/inclination; *α*1/*α*2 – semi-axes of the oval of confidence.

[2] Khramov A. N., Goncharov G. I., Komissarova R. A., Pisarevsky S. A., Pogarskaya I. A., Rzhevsky Yu.S., et. al. *Paleomagnitology*. Leningrad: Nedra; 1982, 312 p.

[3] Pechersky D. M., Sokolov D. D. *Paleomagnitology, petromagnitology and geology: a dictionary for related specialties*. Moscow: Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences; 2010.

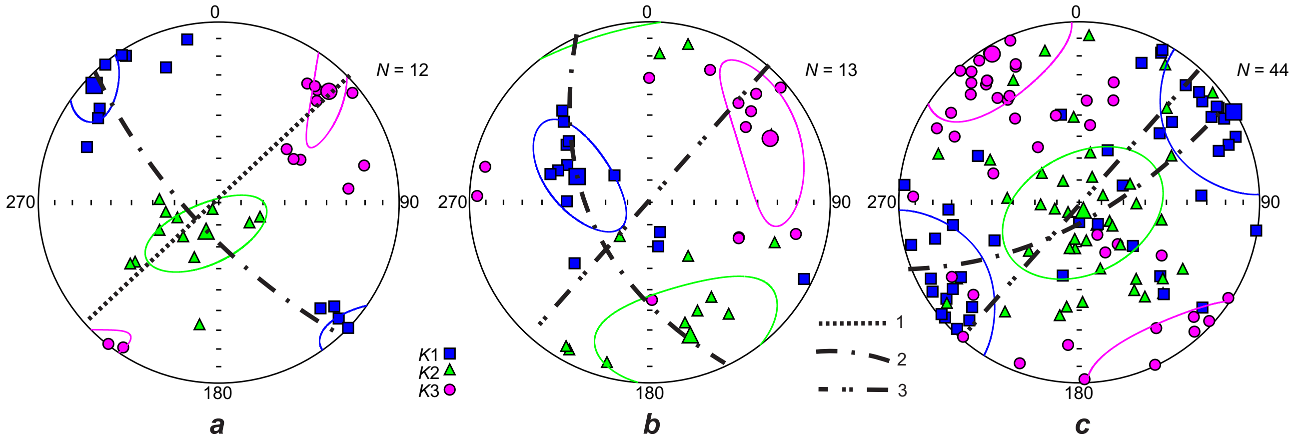


Fig. 3. Magnetic-textural studies:
a – dolerites, 24-60 site; b – blastomylonites from the exocontact, 25-60 site;
c – blastomylonites, 25-61 site
K1, K2, K3 – axes of anisotropy of magnetic susceptibility of ellipsoid major, medium and minor respectively
1 – dike strike azimuth; 2 – magnetic stratification plane; 3 – blastomylonite strike azimuth

Рис. 3. Магнито-текстурные исследования:
a – долериты, обнажение 24-60; b – бластомилониты из экзоконтакта, обнажение 25-60;
c – бластомилониты, обнажение 25-61
K1, K2, K3 – оси эллипсоида анизотропии магнитной восприимчивости максимальная, средняя и минимальная соответственно
1 – азимут простирания дайки; 2 – плоскость магнитного расслоения;
3 – азимут простирания бластомилонитов

Table 2. Results of paleomagnetic studies of the Anga River section petrophysical taxa
Таблица 2. Результаты палеомагнитных исследований петрофизических таксонов участка реки Анги

Rock type, site No.	*N*	Paleomagnetic directions				The paleomagnetic pole				*fm*, °
		D, °	*J*, °	*k*	α_{95}, °	*F*, °	*L*, °	*dp*, °	*dm*, °	
Dolerites, site 24-60	14 s	168.3	-69.2	14.4	10.8	–	–	–	–	–
Blastomylonites, site 25-60	5 s	168.9	-56.6	8.85	27.2	–	–	–	–	–
General: MCS(*g*) ACS(*t*)	19 s	168.5 284	-66 -80	12.53	9.9	81.4 45	348.3 133	13.2 18.2	16.2 19	48 71
Dolerite dikes of Sharyzhalgai ledge [13]	5 S	270	-84.5	22.1	16.7	50.6	121.4	16.7	17	79
Mingling-dikes of the Olkhon region [17]	21 s	158.2	-75.6	18	7.7	52	150	12.8	14.1	63

Note. *N* – the number of samples s / sites S, participating in the statistics. *D* – declination; *J* – inclination; *k* – precision; α_{95} – oval of confidence with 95% probability. *F* – latitude; *L* – longitude; *dp*/*dm* – semi-axes of the oval of confidence; *fm* – paleolatitude. MCS/ACS – modern (*g* – geographic) / ancient (*t* – tectonic correction) coordinate systems. See the text for explanations.

magnetic properties of petrophysical taxa for the formation of petrophysical and physical and geological models.

The methodology of complex research at the Anga site in order to form a physical and geological model provided for:

1. Conducting a ground-based magnetic survey in order to search for dolerite dikes using

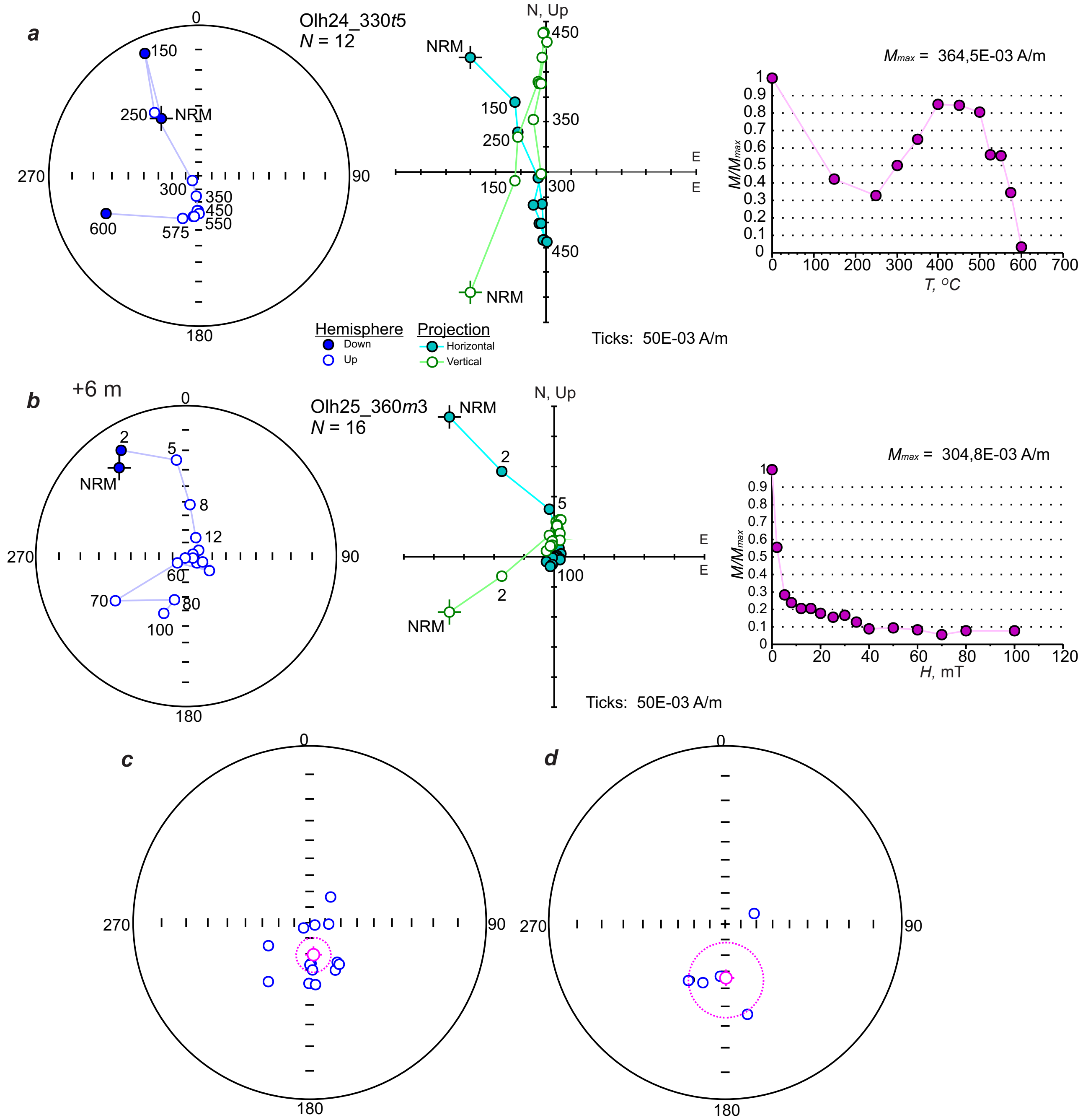


Fig. 4. Results of laboratory paleomagnetic studies:
a – dolerites, 24-60 site; b – blastomylonites, 25-60 site; c – direction of characteristic vectors of natural remanent magnetization of dolerites, 24-60 site; d – direction of characteristic vectors of natural remanent magnetization of blastomylonites from the exocontact, 25-60 site

Рис. 4. Результаты лабораторных палеомагнитных исследований:
а – долериты, обнажение 24-60; b – бластомилониты, обнажение 25-60; c – направление характеристических векторов естественной остаточной намагниченности долеритов, обнажение 24-60; d – направление характеристических векторов естественной остаточной намагниченности бластомилонитов из экзокнтакта, обнажение 25-60

a standard technique[4] with a high-precision magnetometer MMPOS-1/2 (Institute of Physics and Technology of the Ural Federal University named after the first President of Russia B.N. Yeltsin, Russia), whose work is based on the Nuclear Overhauser effect (a sharp amplification

[4] *Instructions for magnetic exploration (ground-based magnetic survey, aeromagnetic survey, hydromagnetic survey).* Leningrad: Nedra; 1981, 263 p.

of the nuclear magnetic resonance signal during saturation of electronic paramagnetic resonance or the interaction of the spins of different nuclei). At the preparatory stage, the design of the observation network, verification and standardization of equipment, and the organization of accounting points for variations in the geomagnetic field were carried out. During field measurements, the module of the full magnetic induction vector is recorded along profiles or routes with a given frequency, and variations are recorded synchronously at the reference point.

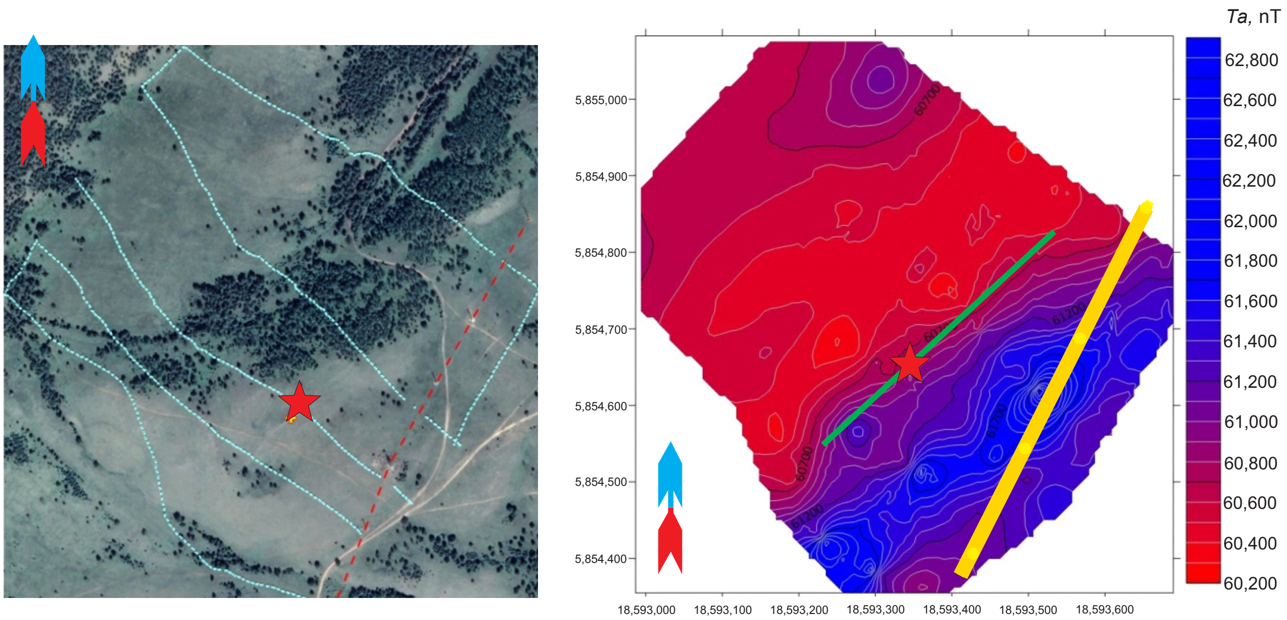
The data obtained was processed in the Surfer program, which interpolated and mapped the magnetic field of the site. At the initial stage of processing, the influence of power lines on the survey results was minimized by controlling the parameters QMC (Quality Measured Calculated) and ST (Smart Tweezers). To visualize the general distribution of the magnetic field, a map of the isolines of magnetic field is constructed (Fig. 5). In order to identify areas of quiet and distorted fields, magnetic field transformations were performed: the initial and smoothed regional fields were calculated, then a map of local magnetic field anomalies was obtained by subtraction. To specify the structure of the fault-related zone, a plan of magnetic field profile and a plan of magnetic field gradient were constructed. They served the basis for carrying out lineament analysis.

2. Selection of oriented samples (lumps of rock) from the bedrock sites (see Fig. 2) according to the generally accepted method[2] in the modern coordinate system.

3. Sample preparation is the production of 3–4 cubes with an edge of 20 mm from each lump of rock, which in total amounted to about 105 cubes.

4. Primary measurements of volumetric density σ, magnetic susceptibility æ и and natural remanent magnetization vectors.

Petrophysical studies[5] characterizing the gravitational and magnetic state of rocks *in situ* were carried out. At this stage of the research, volumetric density σ, natural remanent magnetization vectors $\bar{I}n$, induced magnetization $\bar{I}i = æ\bar{T}$ (where $\bar{T}$ is the magnetic field vector in the work area) and total magnetization $\bar{I}s = \bar{I}n + \bar{I}i$, which determine the type of observed (anomalous and local) magnetic field. In turn, the magnetization vectors ($\bar{I}n$, $\bar{I}i$ and $\bar{I}s$) are determined in space



a b

Fig. 5. Results of ground magnetic survey of the Anga River section:
a – position of profiles (dotted line), power lines (dashed line), and 24-60 and 25-60 studied sites (asterisk); b – map of the full magnetic field vector
Рис. 5. Результаты наземной магнитной съемки участка Анга:
а – положение профилей (точечная линия), линии электропередач (пунктирная линия) и изученных обнажений 24-60 и 25-60 (звездочка); b – карта полного вектора магнитного поля

[5] Molchanov A.A., Dortman N.B. *Petrophysics: a reference book. Vol. 2. Technique and methodology of research.* Moscow: Nedra; 1992, 256 p.

by three components: magnitude (respectively *In*, *Ii* and *Is*), declination ($0 < D < 360°$) and inclinaiton ($-90° < J < 90°$). The *In*/*Ii* ratio characterizes the Koenigsberger ratio (the *Q* factor).

The above studies were carried out using modern equipment and instruments: magnetic susceptibility æ meters (KLY-3s and MFK1-FA, AGICO, Czech Republic) and spin magnetometers for measuring natural remanent magnetization vectors (JR-6, AGICO, Czech Republic). Computer programs Statistica-6 [20] and PetroStat [21] were used to present graphical and analytical factography during petromagnetic studies.

5. Physical and geological modeling. To solve this problem, the MVP-17.5 program was used. It allows you to build geological models and compare their simulated characteristics with field observation data. This program also automates the process of direct modeling, which allows you to verify the decision on the suitability of a particular physical and geological model and predict some properties of objects. The program is a three-dimensional shell that can be used to create simple geological models with a high level of performance or complex models with a large number of objects. Each model consists of one or more solid objects (sphere, prism, cylinder, etc.) embedded in a homogeneous medium. In turn, each object has unchanging physical properties, but as a result of the combination of many objects, complex models of the underground environment can be formed. During the modeling process using the MVP-17.5 program, three-dimensional objects (petrophysical models) are always created. One of the advantages of modeling in MVP-17.5 is the ability to operate not only with scalar (magnetic susceptibility, *Q* factor, natural remanent magnetization value), but also with vector magnetic parameters characterized, in addition to magnitude *I*, by declination *D* and inclination *J*. The program allows you to work interactively simultaneously with gravitational and magnetic fields, which, combined with appropriate three-dimensional images (perspective), maps and sections, as well as other geological materials, helps to extract essential information about the properties of the object of interest. The session files contain all the data, models, and their displays, and are useful as a means to return quickly to the same work directory the next time you work with the MVP-17.5 program. This makes it possible to adjust old parameters and introduce new ones, thereby constantly improving the physical and geological model of study objects.

Results and discussion

The measurements made during the pedestrian survey (see Fig. 5, *a*) allowed us to build a magnetic field map (see Fig. 5, *b*). The intensity of the observed field varies from 60,200 to 62,800 nT. A positive magnetic anomaly of the northeastern strike can be traced in the southeast of the Anga site. The studied intrusive body of dolerites is located on the northwestern flank of the anomaly (in the gradient zone). No other magnetic anomalies associated with post-collisional dikes within the development of the blastomylonites of the collisional suture have been identified at the Anga site.

The results of statistical processing of petrophysical research data at the Anga site are shown in Table. 3. Dolerites from the dike (volumetric density σ = 3,042.2±8.2 kg/m^3) are characterized by relatively elevated values of magnetic parameters: æ = 2,834×10^{-5} SI, *Ii* = 1,375×10^{-3} A/m, *In* = 792×10^{-3} A/m, *Q* factor = 0.58 units. Inclination of natural remanent magnetization vector is negative: *Jn* = -25°. Blastomylonites from the dike exocontact have increased values of *In* = 145×10^{-3} A/m, *Q* factor = 0.45 units and decreased æ = 368×10^{-5} SI ompared with blastomylonites at a considerable distance: *In* = 65×10^{-3} A/m, *Q* factor = 0.29 units and æ = 435×10^{-5} SI. According to these indicators, it is obvious that the blastomylonites on contact experienced a temperature effect from dolerites (hornfelsification). The data we obtained on the current magnetization of dolerites were taken into account when constructing a physical and geological model for different variants.

In the first variant, we tested the hypothesis of geologists who considered the dolerite intrusion in the form of a dike with a thickness of up to 5 m. Solving the direct problem of geophysics [22], we approximated the dolerite dike by a vertical plate (Fig. 6, *a*). However, the model anomaly clearly does not fit into the observed magnetic field profile, and the RMS (Root Mean Square) error exceeds 25. According to direct modeling, it became obvious that the observed magnetic field can be created by more powerful two or more bodies of dolerites (Fig. 6, *b*). In this case, the discrepancy (error) between the observed and model fields decreased.

Table 3. Descriptive values of physical parameters of the Anga River section petrophysical taxa *in situ*
Таблица 3. Дескриптивные значения физических параметров петромагнитных таксонов участка реки Анги *in situ*

Rock type, site No.	*n*	Magnetic susceptibility, 10^{-5} SI		Induced magnetization, 10^{-3} A/m		Natural remanent magnetization, 10^{-3} A/m						Koenigsberger ratio, units	
		æ	*e*	*Ii*	*e*	*In*	*e*	*D*, °	*J*, °	*k*, ед.	α_{95}, °	*Q*	*e*
Dolerites, site 24-60	16	2834	1.1	1375	1.1	792	1.11	356	-25	2.71	28.02	0.58	1.09
Blastomylonites from exocontact, site 25-60	28	368	1.27	324	1.27	145	1.2	273	33	5.62	12.65	0.45	1.13
Blastomylonites on the left side of the Anga River, site 25-61	61	435	1.24	225	1.24	65	1.32	348	45	2.47	14.94	0.29	1.11

Note. *n* – the number of dice; *e* – the standard multiplier; *k* – precision; α_{95} – oval of confidence with 95% probability. *D*/*J* – declination/inclination. See the text for other explanations.

At the next stage of the physical and geological modeling, we launched an automatic inversion taking into account three intrusive bodies, different in thickness and depth. At the same time, the values of the magnetic parameters were fixed, and only the values of the geometric parameters were changed (Fig. 7, *a*). As a result, the RMS error decreased to 4.8. Since the bodies were characterized by the same magnetic values, we combined them into one object, approximating it with a more complex body, the polygon (Fig. 7, *b*). And even in this case, the RMS error remained almost at the same level.

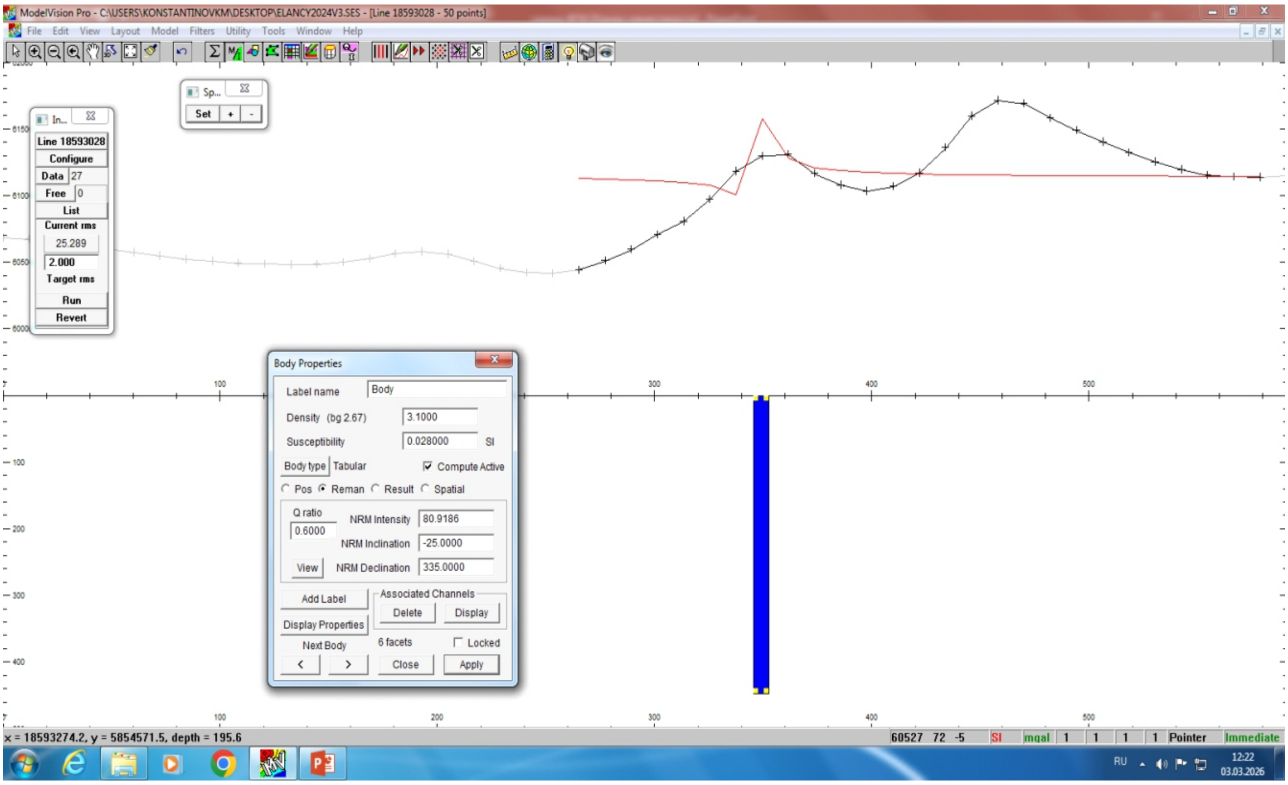
At this stage of the research, the constructed physical and geological model (see Fig. 7, *b*) of the upper section of the Anga site explains:

1. High content (96 crystals) of zircons of different ages, the geochronology of which corresponds to the main geological epochs of the geodynamic history of the development of the Olkhon region [12, 14, 23].

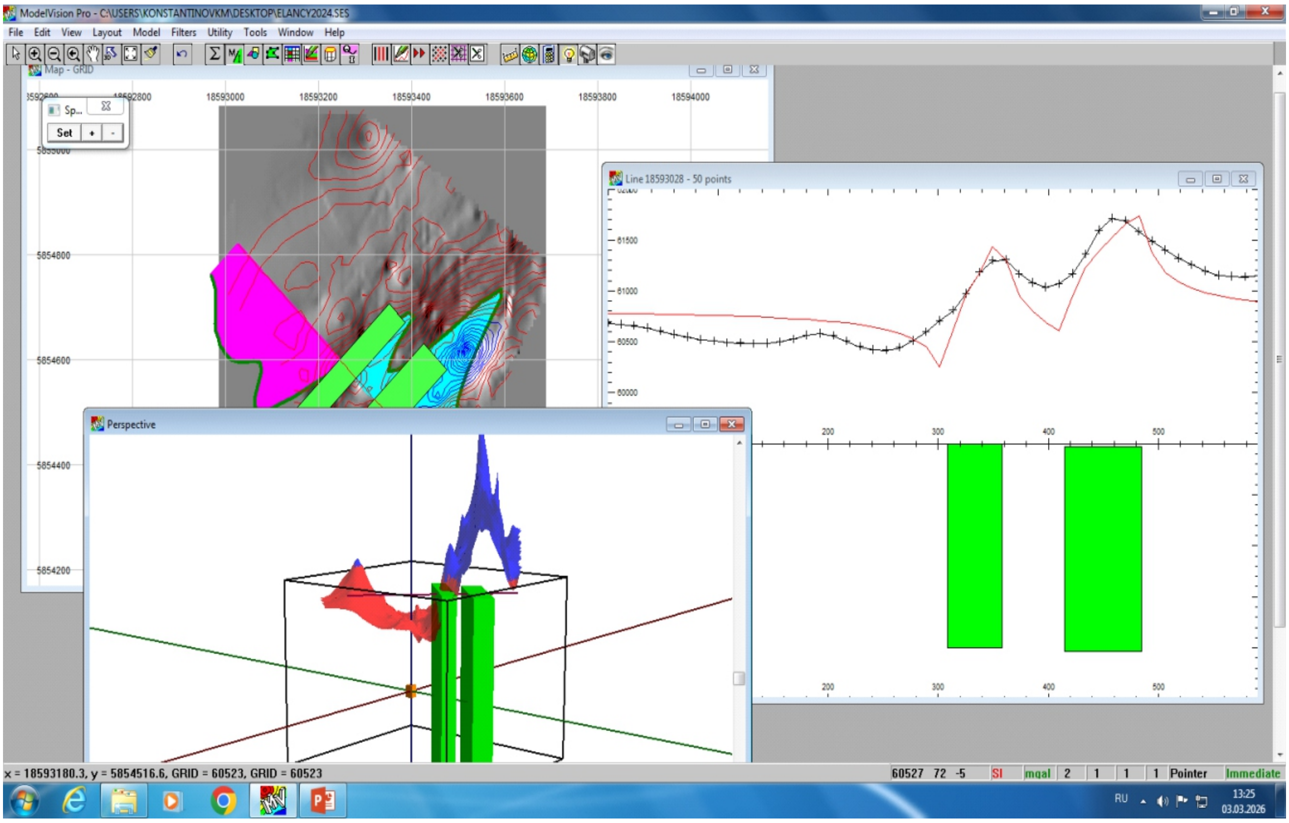
2. The behavior of the anisotropy of magnetic susceptibility of dolerites (site 24-60), which does not correspond to the "dike" geotype (see Fig. 3, *a*). This behavior of the magnetic stratification plane (the *K*1 and *K*2 axes) fully corresponds to a high-power body in which magma differentiation processes took place. In addition, the behavior of the anisotropy of magnetic susceptibility of blastomylonites from the exocontact (site 25-60) becomes understandable. Its difference (see Fig. 3, *b*) from the blastomylonites (see Fig. 3, *c*) of the valley of the Anga River (exposure 25-61) can be explained by pressure from the dolerite body (petromagnetic stress inhomogeneities) [19].

3. A negative baked contact test, according to which a metachronous natural remanent magnetization of a dynamic (piezoremanent) nature was formed in dolerites and their exocontact (hosting blastomylonites) (see Fig. 4). If we accept the geologists' variant, then the reason for its appearance could be postmagmatic (for example, neotectonics) processes during the formation of the Baikal rift zone [7, 8]. However, on the other hand, for the blastomylonites of the left side of the Anga River in site 25-61 (see Fig. 2) no such pattern has been established in the vectors of the characteristic of natural remanent magnetization [12, 18].

For the physical and geological model of the sill, a completely opposite picture is formed: at the time of its formation, primary vectors of natural remanent magnetization of thermoremanent nature were formed in dolerites, while blastomylonites in exocontact were magnetized due to temperature and pressure at a greater distance from the contact of the intrusive body. In this case, the dynamic effect of the Baikal rift zone on the natural remanent magnetization vectors of dolerites (site 24-60) and blastomylonites (site 25-60) is excluded. Then, following logic, a tectonic correction should be introduced into the directions of the characteristic natural remanent magnetization of rocks of sites 24-60 and 25-60 for the tilt of the Primorskiy fault surface (see above), due to which the block could experience rotation in space (see Table 2). When recalculating from the modern coordinate system to the ancient one, the position of the virtual geomagnetic pole of rocks of sites 24-60 and 25-60 corresponds with the Early Permian



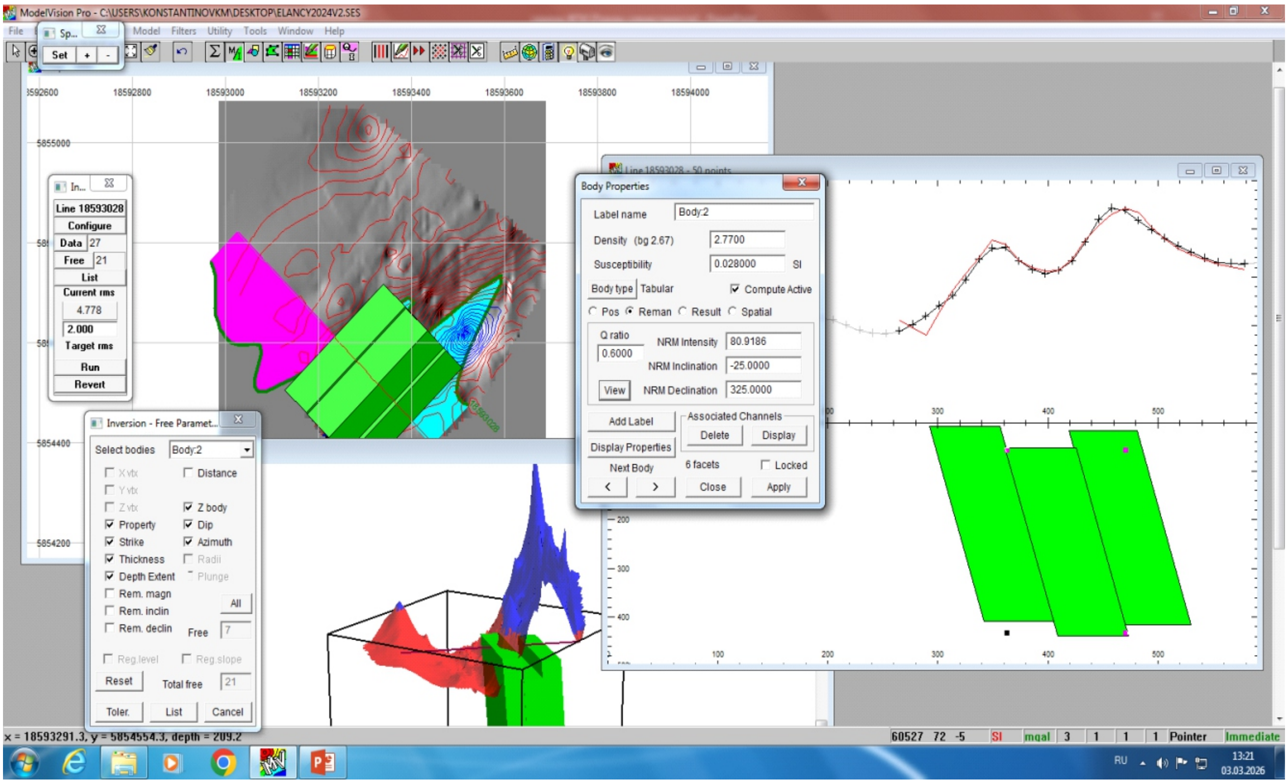
a



b

Fig. 6. Screenshot of the direct problem solution in MVP-17.5 program:
a – magnetic anomaly from dolerite dike, according to source [5];
b – physical and geological modeling for two intrusive bodies

Рис. 6. Скриншот решения прямой задачи в программе MVP-17.5:
а – магнитная аномалия от дайки долеритов согласно источнику [5];
b – физико-геологическое моделирование для двух интрузивных тел



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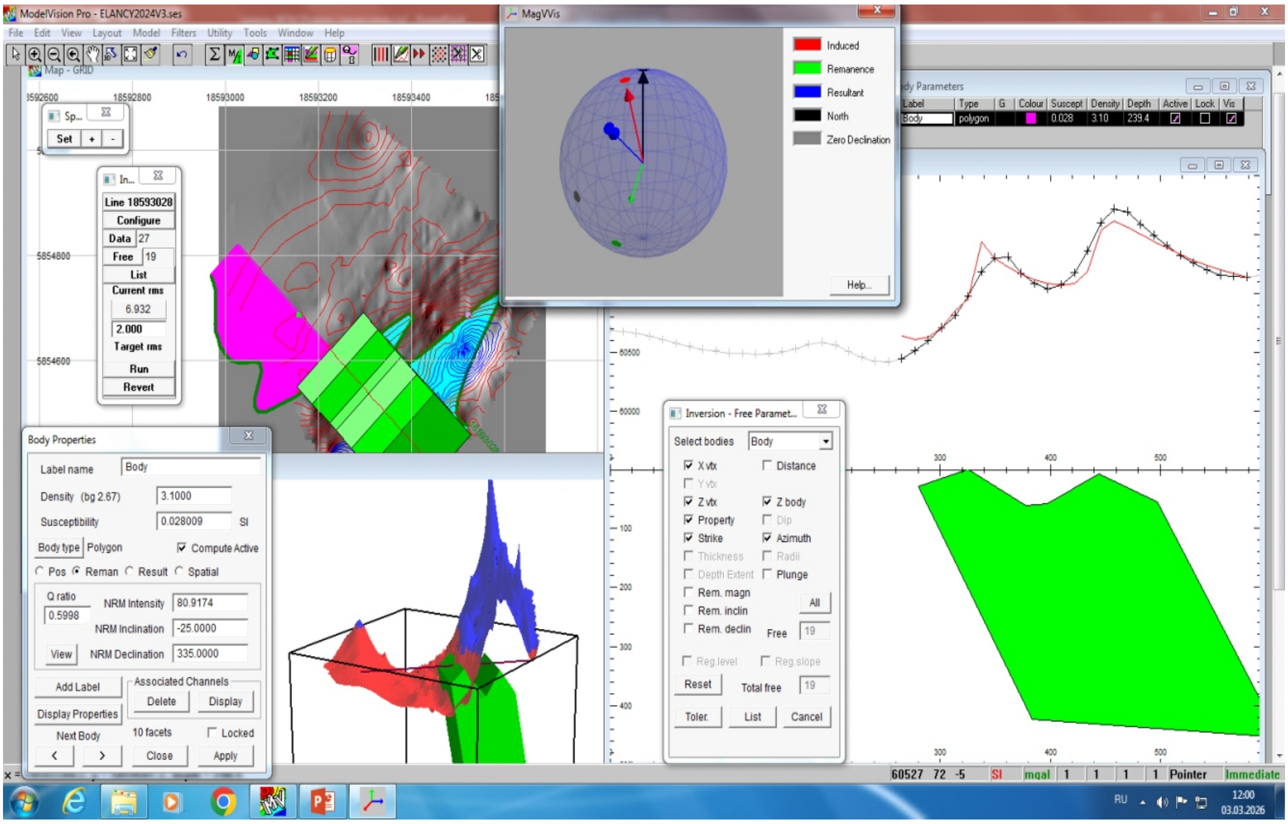

b

Fig. 7. Screenshot of the inverse problem solution in MVP-17.5 program:
a – physical and geological modeling for three intrusive bodies;
b – physical and geological modeling for an intrusive body of complex shape (polygon)
Рис. 7. Скриншот решения обратной задачи (инверсия) в программе MVP-17.5:
a – физико-геологическое моделирование для трех интрузивных тел;
b – физико-геологическое моделирование для интрузивного тела сложной формы (полигон)

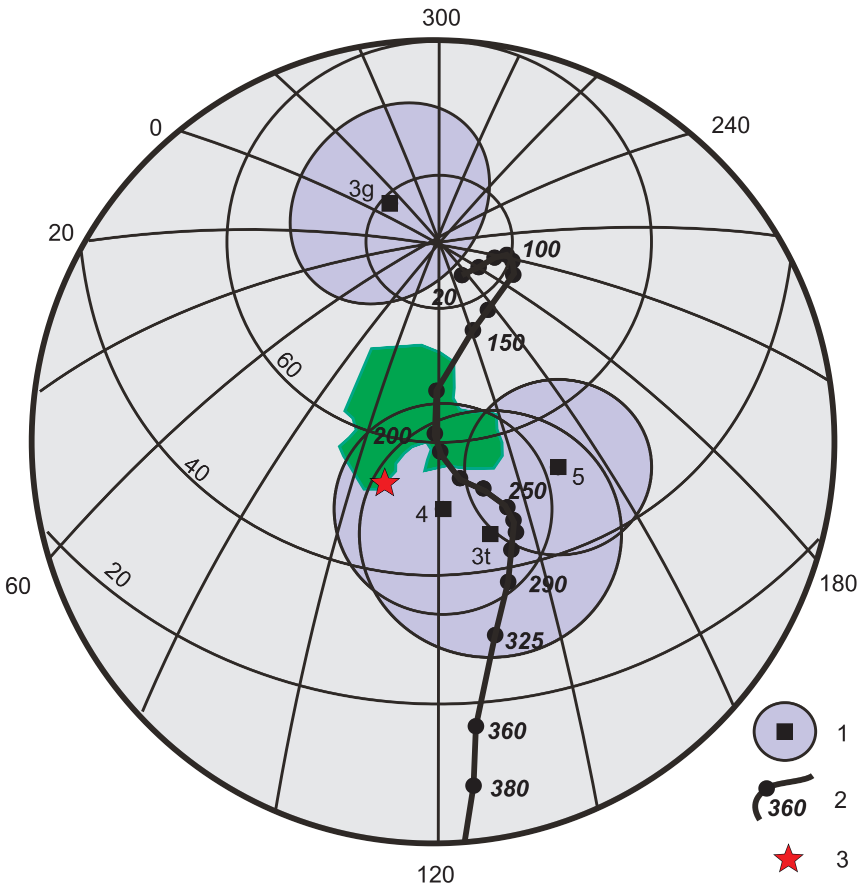

Fig. 8. Illustration of paleomagnetic data interpretation:
1 – virtual geomagnetic poles (numbers correspond to Table 2);
2 – apparent polar wander path[6], numbers indicate age in Ma; 3 – work area
Рис. 8. Иллюстрация к интерпретации палеомагнитных данных:
1 – виртуальные геомагнитные полюсы (номера соответствуют табл. 2);
2 – траектория кажущейся миграции полюса[6], цифры – возраст, млн лет; 3 – район работ

paleomagnetic pole according to the dikes of the Sharyzhalgai ledge of the Siberian Platform [13] and the virtual geomagnetic pole calculated from the metachronous magnetization of the basal dikes of the Olkhon region [17] (Fig. 8).

Conclusions

Physico-geological modeling performed on the basis of petromagnetic data showed that the dolerites studied at the Anga site form an intrusive body with a more complex shape than the dike mapped by geologists [5]. According to the proposed physical and geological model, the metamorphic formations of the collisional suture of the Siberian Craton – Olkhon terrane system in the Early Permian (300–275 Ma) were penetrated by dolerite sills with a thickness of ≈200 m. Most likely, this event is associated with active tectonic and magmatic processes that manifested themselves along the southern mountain-folded margin of the Siberian paleocontinent, as a result of which in Transbaikalia (see the inset in Fig. 1) the largest Angara-Vitim granitoid batholith was formed [15, 16]. To clarify the Aerospace geological map [2] and the history of the geodynamic development of the Olkhon region [23], geophysical research needs to be continued.

It is important to note that the amplitude, nature, and size of magnetic anomalies (see Figs 5–7) allow for effective detection and mapping of promising environments using detailed aeromagnetic survey, which is advisable to use an unmanned aerial vehicle on a larger scale [24, 25]. In the future, it is desirable to combine gravity, seismic and other methods of geophysical surveys with it, which will allow conducting physical and geological modeling with maximum reliability.

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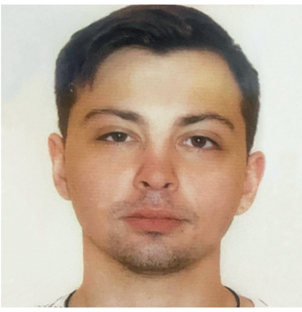

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