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POSTMAGMATIC TECTONICS OF BASEMENT GRANITES OF THE FAR EASTERN SEAS OF RUSSIA

Introduction

It is currently accepted [1–4] that two main features are characteristic for granite massifs: formation of dome structures and intensive structural processing of rocks. The study of post-magmatic granite structural geology within various regions of Eurasia (the Caucasus, Tien Shan, Gobi Altai, Baltic Shield, the bases of the Far Eastern seas, etc. [5–9]), which allowed to specify a number of features of posthumous granite tectonics important for the issue considered.

Upon becoming the magmatic bodies and a part of the consolidated layer the granite massifs remain an important component of the tectonic life of the base. In particular, the introduction of granite massifs into sedimentary deposits of the cover of the Far Eastern seas of the Russian Federation and their structural and material processing has taken place at the post-magmatic, relatively cold stage of the existence of granites, upon they entered the consolidated layer, which is typical for many other granite massifs of the base [10–12].

Upon cooling and entering the foundation the granites are subject to intense 3D structural disintegration at macro, meso, micro and nano levels. Disintegration is expressed as follows: the formation of large, most often rhombohedral and lenticular fragments, brecciation, cataclase of mineral grains and their parts, the appearance of peculiar structural parageneses (fan and slice structures, granite-marble melange, dynamic recrystallization, etc. Resulting from the above processes, a significant part of the granite bodies volume is converted into a cataclosed mass. Considering the variety of scales and forms of structural processing of rocks, a feature of granites is the disintegration at the level of mineral grains and their communities, which is associated with their composition and primary structure and which reflects the rheological exclusivity of granites relative to other base rocks [2]. Upon entering the base, the granite bodies do not become its passive components, but are advanced, sometimes following a significant (tens and hundreds of millions of years) time interval after crystallization and cooling, to higher horizons of the earth's crust relative to the primary occurrence and form dome structures expressed in the surface of the base and deposits of the overlapping cover. In some cases, granites, when tectonically introduced into sedimentary framing, form piercing bodies. One of the types of piercing bodies are granite protrusions. Protrusions can form independent bodies of significant volume, but may complicate the structure of large dome structures, for example, the Susamyr granite batholith of the Northern Tien Shan (**Fig. 1**)

The article contains the results of tectonogeodynamic paleoreconstructions and numerical spatio-temporal basin modelling, which allowed to reveal the structural features and formation conditions of the base of the Far Eastern seas of the Russian Federation, as well as the occurrence of crystalline protrusions in the pre-Cenozoic bases at the stage of prototectonics and posthumous tectonics, which are primarily due to heterogeneity of the viscous properties of various layers of the earth's crust, i.e. its tectonic and material stratification. A large-scale lateral redistribution of the substance, its outflow out of the areas of increased compression and injection into areas of geodynamic shelters has taken place at this stage. Mechanisms of the formation of a void space within protrusions have been considered. A conceptual model of the formation of petroleum deposits within the granite massifs of the base has been proposed.

Keywords: Far Eastern seas of Russia, structural-tectonic framework, posthumous tectonics, modeling, prototectonics, protrusions, basement, shelf.

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Various methods and mechanisms of advancement of "cold" granite masses to the upper horizons of the crust have been considered, whose review is given in [9]: action of isostasy and archimedean force; postmagmatic granitization; density inversion; wedge-shaped form of bodies, due to which they are squeezed upwards; replacement of the mantle lithosphere by the asthenosphere, etc. These mechanisms are somehow probably involved in the process of exhumation, but they do not consider the need for volumetric mobility of granite masses, without which their shift within the space is either impossible or complicated due to friction forces arising on the contact of the granite body and the rocks of the frame [13].

All mechanisms of structural processing of granites lead to the disintegration (granulation) of rocks and their loosening. Media with a discrete structure (granular substances) have a number of specific mechanical properties that explain many aspects of the behavior of granites at the post-magmatic stage of their evolution.

Both data of mechanics of block and granular media and mesomechanics [14–16] demonstrate that the transition of rocks to a discrete condition reduces their effective viscosity, also reduces shear resistance and causes the effect of dilatancy, which contributes to the volumetric mobility of rock masses and their raid current. Hereby the special plastic states arise discretely, which explains the appearance of multiple sliding surfaces (cleavage, shale, slice structure) and sub-layer heterogeneity of the tectonic flow. Volumetric mobility is a fundamental property of the block medium, but the basic mechanism for its implementation is the cataclastic flow.

Appearance of cold crystalline protrusions of the base is primarily caused by the heterogeneity of the viscosity properties of different layers of the earth's crust, i.e. its tectonic and material

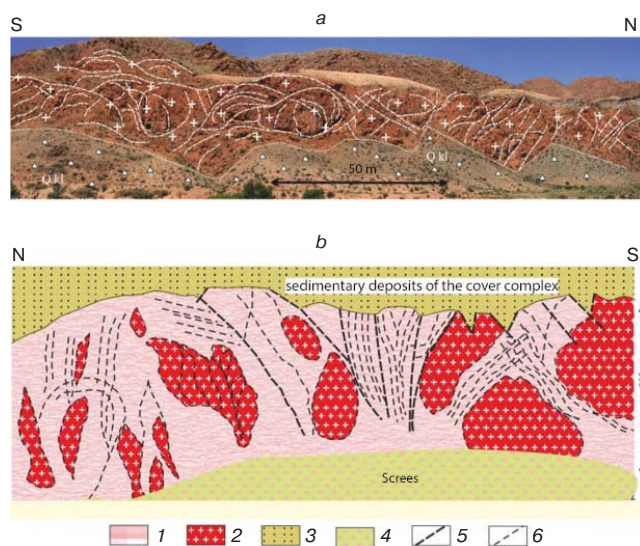


Fig. 1. Examples of infra- and morphostructure of granite domes (Northern Tien Shan) (using data [2]):

a – the southern side of the Kochkor deep, fragmented and cataclased granites with characteristic spherical separation; *b* – the Susamyr massif; 1 – intensely fragmented and cataclased granites; 2 – relatively slightly fragmented granites; 3 – volcanic sedimentary deposits of the Paleozoic; 4 – colluvial deposits; 5 – splittings; 6 – crack systems

stratification. A large-scale lateral redistribution of the substance, its outflow out of the areas of increased compression and injection into areas of geodynamic shelters occurs as well. The reality of such processes has been confirmed by numerous tectonophysical experiments and structural models [17–22].

Study techniques and results

The study of conditions for the formation of the base of sedimentary basins of the Far Eastern seas has been based on tectonic-geodynamic paleoreconstructions reflecting the interaction of chumps and blocks of the consolidated earth's crust. In the methodological respect, the given models are based on the principle of displaying heterochronous folded, volcanogenic-folded, and metamorphic structural-material complexes (systems) of the base including their further processing. To obtain a more complete historical and geological picture, as well as further (upon the initial consolidation) processing of the base, it has been determined that the model should display its multi-tiered (at least two-tiered) structure as a consequence of the multiphase nature of its formation, which is especially typical for marginal continental regions. Complex tectonic processes accompanied by magmatic phenomena are being considered as the basic factors in the formation of the initial base (upon the formation of the primary earth's crust) and its further processing.

The basic research method used in the work has been also a numerical spatio-temporal basin modelling, which allowed to specify the conditions for the formation of the base of the Far Eastern seas of the Russian Federation. To create spatio-temporal models of the Seas of Bering, Okhotsk and Japan, basin analysis has been performed using the technology of numerical basin modelling and PetroMod (Schlumberger) software [2, 18], which allowed to create dynamic spatio-temporal

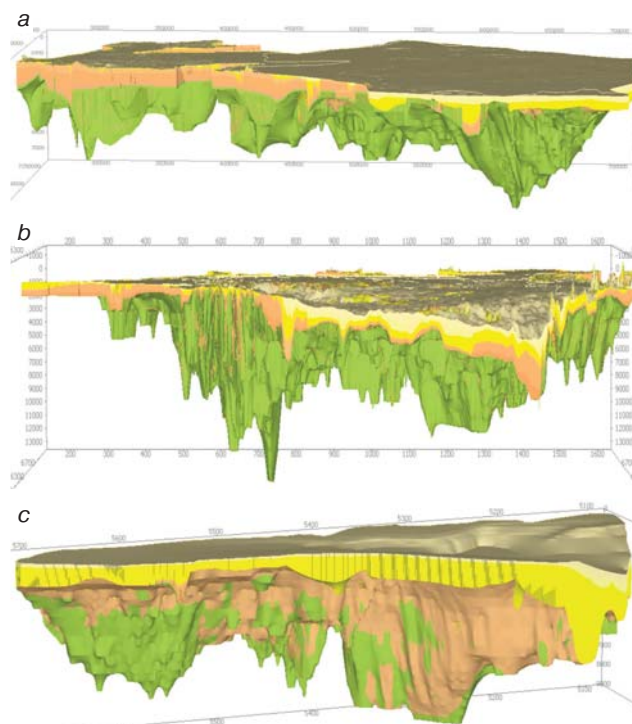


Fig. 2. Three-dimensional space-time models:

(*a*) – the Bering Sea; (*b*) – the Sea of Okhotsk; (*c*) – the Sea of Japan

models of the Seas of Bering, Okhotsk and Japan (Fig. 2), to clarify the relief structure (Fig. 3) and the surface structure (Fig. 4) of the base of the Far Eastern seas.

Results and discussion

According to the results of study and modelling, the base of the Far Eastern seas of the Russian Federation has been formed by the Upper Jurassic-Cretaceous granites and volcanics of the continuation of the East Asian regional volcanic-plutonic belt, and the relief of the base has been divided by granite massifs-intrusions and protrusions. An important aspect of study of the formation of the base of the Far Eastern seas of the Russian Federation is the research of the structure and tectonic evolution of granite massifs at the post-magmatic stage of their existence. Upon becoming the magmatic bodies and a part of the consolidated layer of the sedimented basins the granite massifs remain an important component of the tectonic life of the base. Within the granite massifs and the surrounding mountain masses, a peculiar structural-tectonic ensemble appears, which indicates a large-scale structural restructuring of the rock complexes and their volumetric -plastic flow. Tectonic activity of granite bodies at the posthumous stage is reflected in the structural features of the sedimentary cover, as well as in the formation of a peculiar variety of clastite at the border of the protruding bodies and sedimentary frame.

Studying the granites in different regions [2, 15, 23, 24] proved that upon cooling and joining the base they were subjected to intensive structural processing. Structural mechanisms explaining the volumetric flow of cold crystalline masses and the formation of granite protrusions are described by M.G. Leonov [13, 15, 16]. These studies of granite massifs upon becoming intrusive bodies were subject to volumetric structural processing (macro-, meso- and micro-disintegration, brecciation, cataclase

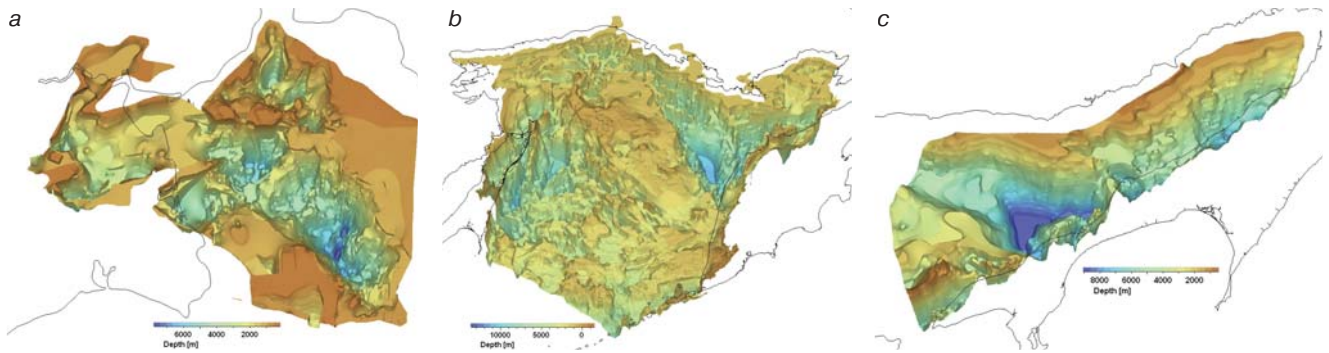


Fig. 3. Three-dimensional model of the basement surfaces:
(a) – the Bering Sea; (b) – the Sea of Okhotsk; (c) – the Sea of Japan

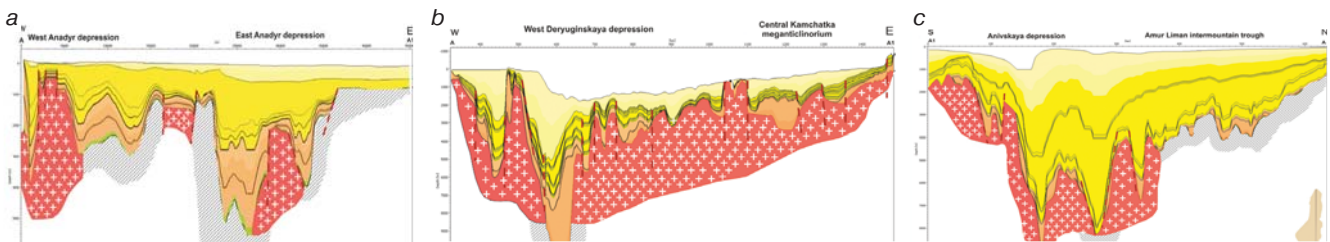


Fig. 4. Two-dimensional structural models (profiles) through:
(a) – the Bering Sea; (b) – the Sea of Okhotsk; (c) – the Sea of Japan

of mineral grains). Following particular structural paragenesis have been developed therein: structures of slides, fans, protrusive-shear paragenesis, granite-marble melange, etc. Volumetric disintegration leads to the loss of connectivity and the appearance of a granular structure. Characteristic features of granular media are the following: reduction of the effective viscosity of the rock; manifestation of superplasticity; dilatancy repackaging of rocks; ability to cataclastic volumetric flow; increase in shear rate depending on the degree of loosening of the material.

Hereby the special plastic states arise discretely, which explains the appearance of multiple sliding surfaces (cleavage, shale, slice structure) and sub-layer heterogeneity of the tectonic flow. All of these contribute to the occurrence of volumetric mobility of rock masses, the basic mechanism of which is the cataclastic flow, and as a result, piercing structures of the protrusion type are formed. They may be classified by many granite massifs both buried and exhumed to the Earth's surface. Granite massifs deformation is expressed in multiscale volumetric disintegration of rocks, ultimately leading to the appearance of huge masses of cataclasites. Granites turn into friable (granular) rock i.e. kakerite, breccia, cataclasite. This rock being new in its physical properties, under the impact of external tectonic forces and (or) realization of internal (latent) energy, starts to move (flow) within space and change its original shape. The spatial shear of granite masses, as well as the formation of dome morphostructures, vertical and horizontal crystalline protrusions take place. They form complex structures, piercing the foundation and the sedimentary cover that overlaps thereof, enter the surface and create a mountainous relief. Appearance of cold crystalline protrusions of the base is primarily caused by the heterogeneity of the viscosity properties of different layers of the earth's crust, i.e. its tectonic and material stratification. Upon cooling and entering into the composition of the consolidated layer of the earth's crust of granite bodies, i.e. at the posthumous stage, the granite

clastites are formed, at least due to the two basic processes: hypergenic (chemical and physical weathering) and tectonic (prototectonics and posthumous disintegration). A complex of deformations, corresponding to a voluminous brittle-plastic shear flow has occurred in the base of the Far Eastern seas during the period of prototectonics and posthumous tectonics of granites. The structurally material processing is clearly manifested in certain varieties of granites, which form crystalline protrusions. Therefore, it can be concluded that the granite massifs of the base of the Far Eastern seas consist of an inhomogeneous mass of individual varieties of granites, but individual blocks of these massifs has been developed into various tectono-magmatic phases of activity. Relative to the above features of crystalline protrusions, which complicate the foundation, an intensive structural-material processing has taken place in certain varieties of granites. In our opinion, due to the occurrence of volumetric mobility of rock masses, the basic mechanism of which is the cataclastic flow, the piercing structures of the protrusion type have been formed in the base of the Far Eastern seas, which are associated with the formation of a secondary pore space and the appearance of traps for hydrocarbons, allowing to justify the intragranular hydrocarbon deposits available.

Conclusion

1. The internal tectonic zoning of the base of the Far Eastern seas – i.e. the Seas of Bering, Okhotsk and Japan - has some common features expressed by its homogeneous three-component structure, which also manifests itself at the level of their geological and geomorphological structure. The uniform components are the following:

- areas of development of the oceanic or suboceanic crust of deep-sea (back-arc) basins varying in area, ranging in age from the Upper Jurassic-Cretaceous to Cenozoic, repeatedly affected by the further phases of tectonic-magmatic activation;

- development belts of the Cenozoic block-magmatic base of the island arcs, sometime including the processed blocks of the base of an older, Paleozoic or Cimmerian consolidation.

- extensive alpine/newest (synoceanic) shelf platforms, differentiated by the depth of the bottom, sometimes partially destroyed by the latest destruction, including chumps or large blocks of Precambrian or Paleozoic relatively rigid massifs in the structure of their base.

In the meantime, the base of the shelf regions of each of the Far Eastern water areas has the structure that is either completely individualized or consistent (conjugated) with the structure of the adjacent continental region.

2. According to the results of study and modelling, the base of the Far Eastern seas of the Russian Federation has been formed by the Upper Jurassic-Cretaceous granites and volcanics of the continuation of the East Asian regional volcanic-plutonic belt, and the relief of the base has been divided by granite massifs-intrusions and protrusions. At the stage of prototectonics and posthumous tectonics, the manifestation of crystalline protrusions of the pre-Cenozoic base is observed everywhere, which is primarily caused by the heterogeneity of the viscosity properties of different layers of the earth's crust, i.e. its tectonic and material stratification. A large-scale lateral redistribution of the substance, its outflow out of the areas of increased compression and injection into areas of geodynamic shelters has also taken place at this stage. These processes are associated with the mechanisms of the formation of the void space within the protrusions.

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