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Modern Problems of Tectonophysics

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In the Institute of Physics of the Earth (IPE, RAS, Moscow) on October 13--17, 2008 the All-Russian Scientific Conference "Tectonophysics and modern problems in Earth sciences" was held. The conference was devoted to the 40-year anniversary of the foundation the Tectonophysics Laboratory in IPE RAS by M. V. Gzovsky. Over 2000 scientists from 26 towns in Russia, as well as from thirteen CIS and nonCIS countries, participated in the conference.

The theses' of the conference, issued prior to its beginning, included 233 reports that were presented (Fig. 1a). At the conference, 134 oral reports and more than 60 posters were presented (Fig. 1b). The current information about the preparation for the conference was published on the website of IPE RAS (http://tph 2008.ifz.ru). According to its representativeness and the scope of scientific problems, this conference stood out from other scientific symposiums on tectonophysics. The "First Tectonophysics Conference" was the first of such conferences held in IPE RAS in 1957 and organized by V. V. Belousov and Gzovsky. If one compares the prominent scientific issues discussed at these two conferences, then one can see the significant progress that has been made in the methodic questions of tectonophysics and in a whole range of problematic tectonophysical investigations as well. However, there are a number of scientific directions that have developed over the last 50 years, which are still regarded as problematic and unable to provide unambiguous answers.

During the 1957 conference, questions, dedicated to the development of the physical grounds of tectonophysics and methods of physical simulation and the study of small tectonic fractures and deformation structures, as well as large faults and folded areas, were discussed. The reports there were prepared by outstanding scientists, such as G. D. Azhgirey, Belousov, M. P. Volarovich, Gzovsky, V. I. Keylis-Borok, P. N. Kropotkin, E. A. Kuznetsov, N. I. Nikolaev, A. V. Pek, P. A. Rehbinder, Ya. B. Fridman, L. E. *Eygelson*, and others. I note that at the conference, a large number of theoretical works, providing the basis for tectonophysical investigations, were presented; while, there were practically no works, connected with the study of tectonic stresses in some specific regional geological objects.

In contrast, during the 2008 conference, considerable attention was given to the results of regional field tectonophysical investigations, methods, and the results of the laboratory studies of stresses and deformations in rocks (tectonophysical simulation). Along with scientific directions, some other questions, connected with the special features of processes of deformation and transformation of matter in a fault body, and the mechanisms for the generation of tectonic stresses in the lithosphere, were discussed. In addition, at the conference, the problems of mining exploration, geological surveys, geophysical researches, and seismology were widely represented in the reports. In the reports, the specific problems of the given scientific directions were discussed in the context of tectonophysical approaches and terms. This wide spectrum of reports demonstrated the dynamic development of tectonophysical methods and concepts in areas adjacent to the Earth sciences.

The main problems of tectonophysics were always related to investigations of the structure and mechanisms of the formation of faults and folds of different scales from the sublocal (initial meters) to the multiregional (thousands of kilometers), the development of the methods of such investigations, and the explanation of sources of action and the peculiarities of the formation of the structures given. Questions regarding the formation of faults and fractures, and also problems of the stress-strained state, which appear in connection with this problem have been developed intensively during the last fifty years. The theoretical study of the regularities of a field near a single fracture, carried out by D. N. Osokina [Osokina, 1989; 2000; 2002; 2004; 2007; 2008], which were expanded by the study of optical-active materials for populations of fractures created a good base for studying natural stress fields. The new analytical research methods of analysis of seismological data of the focal mechanisms in the epicenters of earthquakes and populations of gliding planes, obtained as a result of the study of geological outcrops [Rebetsky, 2007, Angelier, 1989] make it possible to calculate not only the orientation of the main stress axes, acting in a natural rock massif, but also the relative values of ball and deviator components of the stress tensor. Due to the use of additional data such as stresses, dumped in the epicenters of strong earthquakes and data about the lithostatic pressure (surface topography and density section), it is possible to evaluate the absolute values of stresses, distinguishing tectonic and fluid pressures. These methods made it possible to reconstruct a stress field, formed in the area of a catastrophic earthquake area, for the first time [Rebetsky and Marinin, 2006].

(a) (b)

Fig. 1. Cover photo of volume I of the theses of the conference (*a*) and a photo, taken during a plenary meeting at the conference (*b*).

The resolution of the problem of the mechanism for the formation of different types of folded structures has developed differently. This question, connected with the generation of large deformations, can be considered as the inverse problem of tectonophysics. This issue, initially raised by Belousov, fell into the background. There are currently no works dedicated to this problem. On the one hand, this is due to the complexity of this problem and, on other hand, the ambiguity of the solution of the inverse problem of folding. Nevertheless, recently, progress has been made in terms of resolving this issue. Approaches have been developed [Yakovlev, 2008], which make it possible to conduct an evolutionary reconstruction of folded regions, distinguishing the deformation stages, connected with the sedimentation, folding, and orogenesis. These approaches should be discussed attentively and interpreted carefully because of the complexity of the problem pointed out. However, during further development, they will make an important contribution to the study of mechanisms for the formation of interplate deformation structures.

Work in the field of study of the structure of fault zones [Sherman et al., 1983; Seminsky, 2003; Bokun, 1981, 1988], carried out on the basis of the tectonophysical simulation of results and the analysis of natural data, made it possible to reveal regularities of the formation of these specific sections of the Earth's crust. A series of reports of different scientific schools, concerning the obtainment and interpretation of the satellite geodesy (GPS) data should be noted [Kuzmin and Zhukov, 2004; Sankov et al., 2007]. The methods of tectonophysical simulation have also been developed seriously during the last 20 years [Mikhaylov and Rebetsky, 2008]. This is primarily connected with the development of computer software on the numerical simulation of the stress-strained state in complex features that have the rheological properties of an elastic-plastic and elasto-compressible body. In addition, physical simulation was developed due to the application of new materials and observation methods, but also due to the obvious problems of the fulfillment of the similarly influential conditions of gravity [Gurevich, 1974].

A study of the regularities of the distribution of modern stresses in seismoactive regions [Rebetsky, 2007], on the one hand, made it possible to answer many important questions concerning the mechanisms of the formation of local and regional deformational structures. On the other hand, this gave fresh impetus to the study of the mechanisms for the generation of tectonic stresses and the physics of the epicenter of an earthquake. Whereas, the results of tectonophysical simulation were previously the basis of tectonophysical studies, currently, the data of natural stresses determine the prospects for the further development of tectonophysics.

In particular, the results of the reconstruction of natural stresses for the interplate orogens, obtained with the application of the method of cataclastic analysis of the populations of the mechanisms of seismic centers [Rebetsky et al, 2008], played a fundamental role (more than 70--80%) of the intercrustal and intramantle heterogeneities in the generation of stresses in the upper and middle crust. Actually, this determines the leading role of density heterogeneities and, consequently, gravitational stresses in these regions, in comparison with the stresses, caused by the horizontal motions of lithospheric plates. A study of the relationship between these factors and their manifestation in modern stresses and the motions of the Earth's surface (land and satellite data) is one of the prospective tasks of tectonophysical studies, developing the fundamental grounds of geodynamics.

The results mentioned above as well as the seismological data about the change in the type of mechanisms of the epicenters of earthquakes, occurring at different deep levels of the Earth's crust, require more attentive study of the role of residual stresses, which take place in the process of the gravitational packing of rocks. The possibility of the generation of the greatest compressive stresses in a horizontal direction established in the work [Rebetsky, 2008] as a result of the uplifting of rocks into the upper layers of the Earth's crust, which was subjected to strong residual deformations at depth, gives the possibility of obtaining quantitative assessments and the division of the interplate orogens into districts according to the expected type of the stress state. Further tectonophysical studies and comparisons of stresses forecast by this concept, with the data results of the natural stresses, obtained using the method of cataclastic analysis or from in-situ data will be necessary for the development of this approach. Studies in this direction, together with the fundamental aspect, also have an applied character within mining exploration.

Based on a comparison of the regularities of the distribution of modern stresses in the subduction zones and the interplate orogens, it was established that the level of deviator stresses in the latter are 3--4 times higher. This fact is, to a larger degree, determined by the increased fluid pressure, which acts in the contact zones between lithospheric plates with the faults of the interplate regions.

The determining role of the influence of fluid pressure on the process of brittle failure [Rebetsky, 2006] raises the problem of the study of the factors, responsible the change of the fluid pressure in fault zones, and the possibility of its estimation, which is also regarded as a prospective task of tectonophysics.

The results of the analysis of the stress field in the region of the preparation of strong earthquakes [Rebetsky and Marinin, 2006] showed that the level of deviator stresses in them is not the highest, as follows from Reid's model of the epicenter of an earthquake. The epicenter of a strong earthquake is connected with the region of the average effective pressure level and the maximum shearing stresses, and the beginning of its "splitting" appears in the region with the maximum voltage gradient. These facts make it possible to examine Richter's concept as the determining one for the seismic center regarded as the region of the lower strength. A study of the regularities in the stress field and evolution of strength in the region of the preparation for a large-scale brittle failure (earthquake) is one more future task of tectonophysics.

In addition, another perspective task of tectonophysics, closely connected with the two previous ones is the study of physical and chemical processes, occurring in fault zones in the upper and middle crusts. Within this problem, the faults should be considered as specific geological bodies, whose mechanical properties are connected with such processes as the dilatancy, dispersion (milonitization), and compaction of rocks. In connection with this, the Rehbinder effect, determining the change in the dimensionality of crystals and grains, and stress-metamorphism of rocks, occurring in sections of specific milonite and ultra-milonite states [Rebetsky, 2008] can be considered as an important feature that changes the strength properties of rocks. This area and the two previous areas of study also determine the penetration of tectonophysics in the fundamental problems of geomechanics and the physics of the epicenter of an earthquake.

The analysis of the mechanical behavior of rocks of the Earth's crust at a different level of depth shows that the processes, discussed above as leading processes in a fault body are also manifested here. The difference consists of the fact that, whereas in a fault body, sections with a different type of leading process are arranged mosaically and fairly chaotically, in the Earth's crust they are characterized by a deep zonality. Within these studies it is necessary to develop models of the rheologically stratified Earth's crust, taking into consideration the special features of its structural structure from the macroscopic to the megascopic levels. In addition, it is necessary to develop tectonophysical approaches for the interpretation of these geophysical data in terms of mechanics.

One more additional direction of tectonophysical studies is connected with the new type of data, obtained using the methods of 3D-seismic surveys in the study of sedimentary cover in the areas of hydrocarbon deposits. Fracture systems are observed here, which correspond to the mechanism of the horizontal displacement [Gogonenkov et al., 2007]. The economic importance of this problem requires special tectonophysical studies. The fault structures, distinguished by these methods enable the application of the results of tectonophysical simulation for their analysis [Rebetsky et al., 2008], which is used at the present time for the interpretation of geological and seismological data.

The necessity for the development of research projects in the last two directions actually determines the penetration of tectonophysical approaches and methods in geophysics. Moreover, they require the development of the corresponding methods for the interpretation of geophysical data.

Tectonophysics has come a long way in terms of its development. Many areas, which Gzovsky recommended as potential areas for research, have been successfully developed. However, having moved considerably in the methodic direction and having applied new study methods for a wide range of tectonically active regions, several crucial problems have recurred repeatedly. In some cases, the new data has led to a revision and reconsideration of the solution to problems that had been considered as already resolved. The actual problems of modern tectonophysics are as follows:

–Study of the mechanisms of generation of tectonic stresses near the boundaries of lithospheric plates (subduction and spreading zones) and inside the lithospheric plates within the boundaries of orogens and shields;

–Explanation of the role of the forces of gravity in the generation of the modern stress field;

–Study of the mechanism of the formation of a large-scale brittle failure in the Earth's crust (earthquake);

–Problems of studying large deformations of folded orogens and the development of methods of the tectonophysical reconstruction of the evolution of these regions;

–Study of the structure and rheological properties of the layers and subcrustal lithosphere of the Earth's crust, on the basis of the modern data about the state of the stress of mountainous areas;

–Development of studies of specific features of the structure and physical processes in the body of a tectonic fault;

–Research of the regularities of the natural stress state and its evolution in areas of mineral deposits.

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