

ACTIVE BAIKAL TECTONICS[#]

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Structural-geological and seismoacoustic studies carried out in 1989–94 within the Baikal Rift Zone, for the first time show the internal active tectonic structure of the present Baikal Rift lake basin. A series of smaller structure features are distinguished not only by morphology but also by degree of recent activity. Based on the recent structural-geological, seismological, and geophysical data on the deep structure of the sublithospheric mantle beneath Baikal, a more precise estimation is given to the structural characteristics of the active tectonic stress field and to kinematics of rift faults.

Active tectonics, Baikal, seismoacoustical profiling, fields of tectonic stresses, strains, listric faults

INTRODUCTION

In the modern relief of southern Siberia, the Baikal Depression is a unique lacustrine and sedimentary basin that "recorded" rich information about the evolution of the natural environment and the climate in Central Asia for more than 35 Ma of geological time. The main concern of this publication is to discuss problems of active tectonics affecting the formation of this lake basin. By active tectonics the authors mean the Neogene-Quaternary manifestations of tectonic movements and deformations expressed in young sedimentary layers, young relief of rift depressions and their mountain framing. This study is based on data of structural-geological and seismoacoustic studies in the Baikal Depression performed on the basis of international cooperation.

The first seismoacoustical studies on Baikal Lake were carried out in 1977–82 by geophysicists of Moscow State University, Institute of the Earth's Crust, Irkutsk, and Institute of Oceanology, Moscow. The seismoacoustic profiles were chiefly concentrated on Northern Baikal. After an interruption between 1982 and 1988, the seismoacoustic works on Baikal started again in 1989 under the leadership of the Limnological Institute, Irkutsk, Geological Institute, Moscow, and Hamburg University, Germany. The 1990 series of seismoacoustical profiles were mainly situated at the south of Lake Baikal, whereas the water area of the Central Basin remained poorly investigated. In 1991–92, the one-channel seismoacoustic profiling was continued by the United Institute of Geology, Geophysics and Mineralogy, Novosibirsk, with participation of the Institute of the Earth's Crust, Irkutsk. The seismoacoustic profiles were arranged to fill in "the blanks" remained after the earlier studies, their net covering more or less uniformly the North-Baikal Basin. At the same time, the research workers of the Limnological Institute, Institute of Oceanology, and the USA Geological Survey (Woods Hole) carried out about 3,600 km of seismoacoustic high-resolution profiles [1]. All, or nearly all, seismoacoustic records at present available were kindly presented by their authors to the Institute of the Earth's

[#] As compared with the Russian version, this paper is extended.

Crust for geological interpretation in order to study the tectonic structure of the sedimentary body beneath Lake Baikal.

RESULTS OF DETAILED STRUCTURAL-GEOLOGICAL MAPPING AT THE SHORE OF LAKE BAIKAL

Simultaneously with the seismoacoustic studies on the lake, the Institute of the Earth's Crust realized special structural-geological investigations along the shore. These studies were aimed at mapping active faults on the land and their tracing on the lake bottom according to the results of seismic studies to end up with the compilation of a map of active faults of the Baikal Depression and adjacent territories. The structural-geological investigations were carried out over the entire perimeter of the lake as well as on key sites near Olkhon, at the Svyatoi Nos Peninsula, and Tunka Rift Depression. A short description of the results obtained is given below.

ISLAND OF OLKHON AND ADJACENT AREA

The island of Olkhon and the adjacent area are large tectonic blocks framing the Mid-Baikal Basin at the NW. They are lowered relative to the uplifted Primorsky Ridge by 500–700 m. The lowering was accompanied with block warping along the Primorsky Fault, the southeastern block flanks being elevated relative to the northwestern ones. The Primorsky Fault is one of the major structure features of the Baikal Rift Zone. The zone of the Cenozoic tectonic reworking of the basement crystalline rocks is about 4 km, while the fault zone itself is expressed in the Olkhon relief as a graben valley. The Primorsky Fault is a normal fault with a small strike slip component. The direction of horizontal strike slip movements is debatable. For example, S. I. Sherman [1] believes it is dextral, while K. G. Levi [2] considers it sinistral. The discussion arose because in the process of field works both sinistral and dextral strike slip wrench faults were observed in the fault zone so that it is difficult to make a definitive conclusion about the character of horizontal movements. It is quite possible that at different planes in the fault zone, traces of differently oriented movements are observed as a result of changes in the stress state of the Earth's crust in the Baikal Rift Zone during the neotectonic stage. This was established on basis of the structural-geological analysis of tectonic fracturing of the basement rocks and Cenozoic-dated formations in the zones of major active faulting of the rift zone [3–5]. Taking into account the hinge warping of the Olkhon and Near-Olkhon blocks, it is reasonable to suppose that the Primorsky Fault is a listric normal fault [6, 7]. Listric faults are quite typical of the tectonic structure of the island of Olkhon, its adjacent area, and the Maloe More Strait. As a rule, they are bow-shaped in plan and are faults with the shear component in different directions at different flanks of the faults.

In the near-surface portions of the faults the adjoining rocks are subjected to intense physicochemical processes as formation of various types of weathering crusts. Washing of broken and weathered rocks from the fault cavities is frequently observed resulting in sag-and-swell topography. Sometimes, loose young sediments are sucked in open cavities of the faults and cover the faulting zones. Detailed study of mutual relations between the out-worked relief and the active faults has shown that the width, θ , (in meters) of sag bottoms, sometimes, of rivers and rivulets flowing in cavities of the faults, is connected with the thickness of zones of maximum tectonic effects on basement rocks (in fault zones), mf (in meters), by a direct dependence of the form:

$$\ln \theta = (1.9 \ln mf - 1.2) \pm 0.3, \quad (1)$$

$$\ln mf = (0.4 \ln \theta + 0.8) \pm 0.1, \quad (2)$$

with $r = 0.83 \pm 0.12$ and $n = 23$ [7]. The following test of the efficiency of this equation in other parts of the Baikal Rift has demonstrated a good convergence of the parameters θ and mf observed and calculated from equations (1) and (2). These equations were used for estimating the thickness of zones of active faults on the map (Fig. 1).

As noted, the cavities of active faults contain pockets with the Cenozoic crust of weathering. Often confined between rigid walls of faults, these deposits are sensitive to tectonic movements and react to them by forming systems of fractures. Usually, these are very thin, hair cracks, with sliding striation often observed on their planes. These specific slickensides which appeared in clay rocks are rather unstable to weathering reagents and cannot be preserved for long geological time, which is indicative of relatively young age of movements along the faults to which they owe their origin.

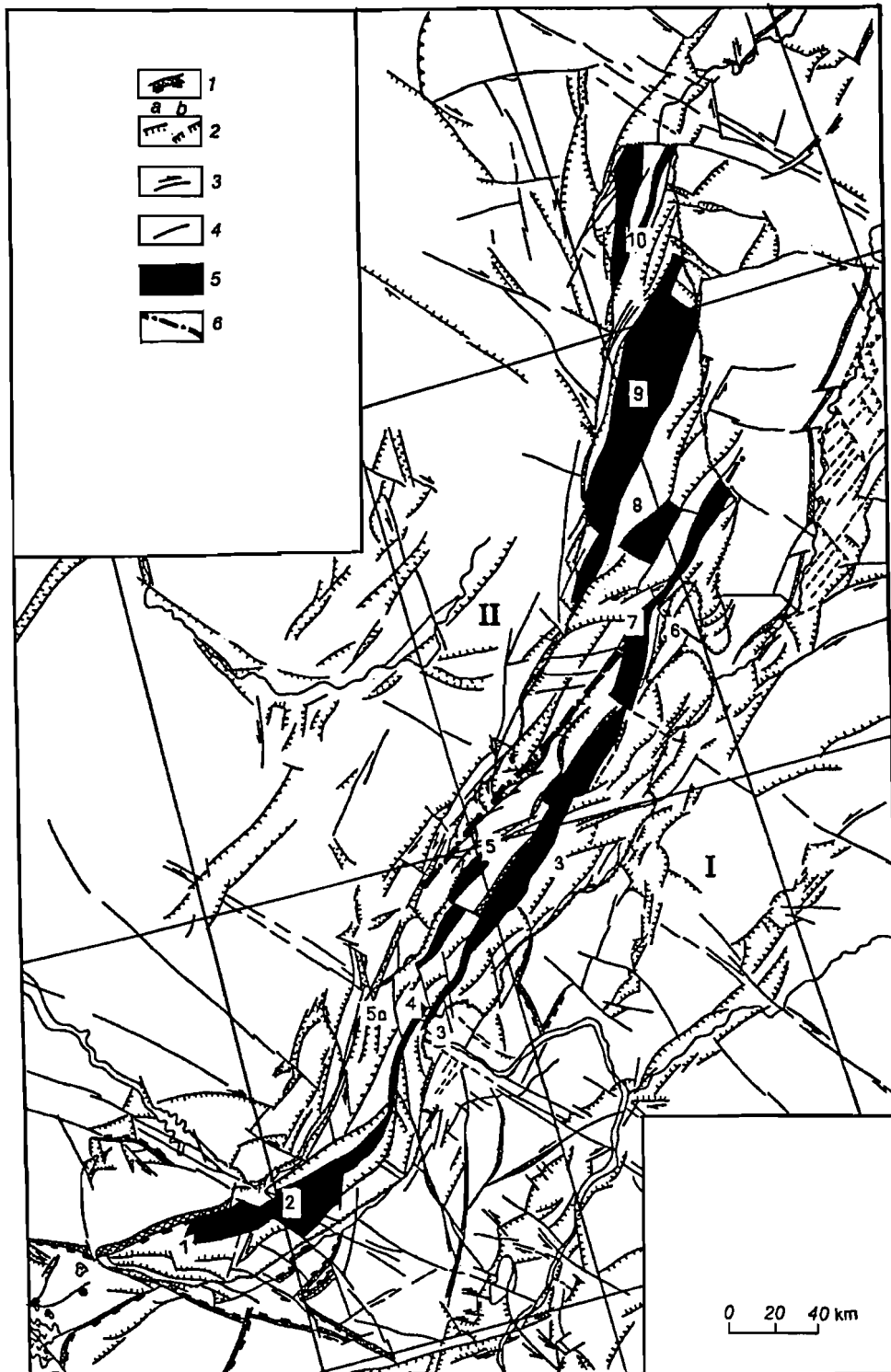


Fig. 1. Scheme of principal active tectonic features of the Baikal Basin and adjacent territories: 1 — active faults with estimated thickness of zones of rock alteration; 2 — normal faults: a — established, b — supposed; 3 — strike-slip faults; 4 — faults with non-established type of displacements; 5 — blocks which are the most subducted beneath the lake level; 6 — the boundary between the South and North Baikal basins. The numerals stand for the structural features: I — South-Baikal Basin; II — North-Baikal Basin; 1 — Kultuk Depression; 2 — Mishikha Depression; 3 — Selenga-Chivyrkui Graben; 4 — horst of Posolskaya Banka; 5 — Olkhon Graben; 5a — graben of "Buguldeisky Koridor"; 6 — Svyatoi Nos Uplift; 7 — horst of the underwater Akademichesky Ridge; 8 — Malo-More-Ezovsky Depression; 9 — Kedrovsko-Tompudinsky Depression; 10 — Rel-Kichera Depression.

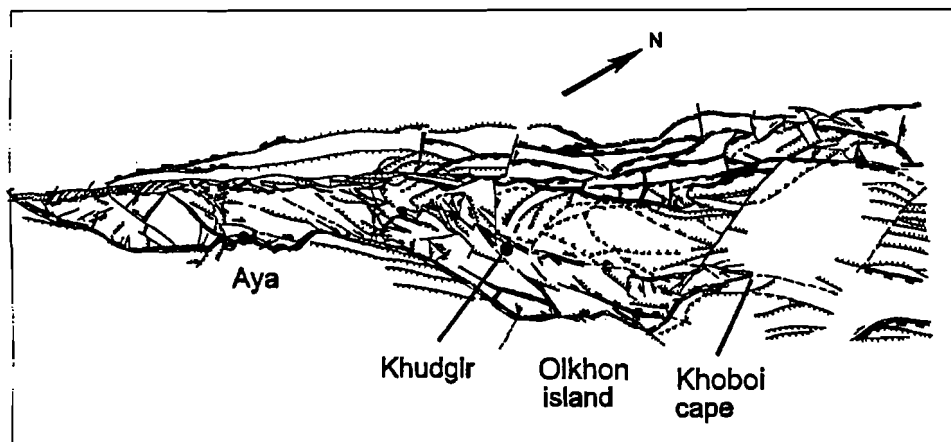


Fig. 2. Scheme of location of tectonic elements of Priolkhonie. Notations are given in Fig. 1.

The Olkhon and near-Olkhon blocks are separated from the Mid-Baikal Trough by the Morskoi Fault branching off the Primorsky Fault near the Buguldeika R. mouth (Fig. 2). Analysis of seismoacoustic materials in combination with the results of structure of geological mapping on land suggests that the underwater Akademicheskoy Ridge and both of the above-mentioned blocks form a single structure — a diagonal intertrough isthmus separating the Middle- and North-Baikal basins. This isthmus is dissected by a series of faults across its strike. Two of them are accessible to study, since they are situated in the terrestrial portion of the isthmus, while the rest is mapped under water by geophysical methods. On land, the cross faults are expressed in relief by the Anga R. graben valley and the Olkhonskie Vorota Strait.

The complex of active faults in the near-Olkhon zone, island of Olkhon, and Primorsky Ridge cuts the rift zone basement into platy and lenticular blocks of various size. The majority of these faults are very old, activated in the Cenozoic. In general, the lenticular recent structure of the basement plays a considerable role in seismic activity in this region [9].

SVYATOI NOS PENINSULA AND CHIVYRKUI BAY

The Svyatoi Nos Peninsula is a large tectonic block of the rift zone basement, situated near the northeastern closure of the Mid-Baikal Basin. It is connected with the flank of the trough through an isthmus made up of Cenozoic deposits. In essence, this is a typical intratrough isthmus framed by grabens at two sides. One graben is a major structural element of the Mid-Baikal Basin. It lies on the northwest of the peninsula. On SE and E, the peninsula is framed by the graben of the Barguzin and Chivyrkui bays. On all sides, the peninsula is tectonically bounded, chiefly, by faults or strike slip-wrench faults. In its internal structure, the graben of Chivyrkui Bay is similar to the Maloe More Strait. Listric faults are widespread in the flanks of Chivyrkui Bay. Nearly all small islands are of tectonic nature. The peninsula itself is subdivided by faults into four segments, one of which, the eastern one, is lowered along orthogonal faults and is an intermediate step of the graben of Chivyrkui Bay. There are hydrothermal sources along active faults.

TUNKA DEPRESSION AND TUNKA-SOUTH-BAIKAL INTERTROUGH ISTHMUS

The Tunka Depression is the best studied feature of the Baikal Rift Zone. There are many publications concerning its basement geology and Cenozoic sedimentary filling, relief and structure of its basement according to geophysical data, geomorphology of its mountain framing, fault tectonics, and peculiarities of stress state, and other aspects of geology and tectonics. The Tunka Depression can give insight in the formation of the Baikal trough.

Many features of the active tectonics of the Tunka Depression are similar to structures of the South-Baikal Depression. These are folded deformations in the sedimentary filling [7, 10], fault tectonics, and stress-strain state [11, 12]. Most likely, the only serious difference is that there are no traces of Cenozoic alkaline-basalt volcanism in the South-Baikal Depression, which was intensely expressed in the Tunka Depression.

The active tectonic features of the Tunka Depression were studied in a different detail nearly by all authors of this paper. Special attention was given to map of dislocations in the sedimentary depression filling to search for signs of the youngest dislocations in the zone of the Tunka wrench-strike slip fault on the Nilovsky and Elovsky spurs separating the depression into three independent basins, also to characterize the junction of the Tunka and Major Sayan faults and, finally, to establish the interrelations between the Tunka and South-Baikal depressions near the Tunka-South-Baikal isthmus.

Young tectonic dislocations in the Cenozoic sediments of various ages were discovered near Monda Village, at the western closure of the depression, at the Nilovsky Spur, near the Nilovsky health resort, immediately in the zone of the Tunka Fault (Arshan health resort), and at its eastern segment near the Tora Depression, at the Elovsky Spur and northern spurs of the Khamar-Daban Ridge framing the depression on the south.

The interrelation between the Tunka and Major Sayan Fault has remained unclear, and the nature of the junction of these faults is still under discussion. It has turned out that they both are not connected with each other and are evolving independently as active tectonic structure in this part of the rift zone. Approaching the zone of the Major Sayan Fault, the Tunka Fault splits into a series of branches to form a typical "horse-tail" structure. The branches are listric wrench-strike slip faults, which in the region of the eastern closure of the Tora Basin drastically turn SEward and SSEward. It is significant that the arched shape of the faults in plan, typical of listric faults, is also typical of separate links of the Tunka Fault and fragments of the normal faults and wrench-strike slip faults running along the Khamar-Daban Ridge foot at the south of the depression.

Northwest-oriented faults are widespread in the mountain framing, which also are arch-shaped in plan. It is interesting that the faults of this spatial orientation coincide with fields of Cenozoic basalts, and this suggests their magma-controlling role. If this assumption is true, then knowing the spatial orientation of these faults one can restore the orientation of major normal stresses, which allowed magma eruption, on the one hand, and, opening of rift basins on the other. This is interesting for the reason that the age of basalt covers within the Tunka Depression is known (it varies from 18 to 10 Ma, i.e., from Lower to Middle Miocene, and younger), and this will permit to establish the stress-strain field and kinematics of young faults.

It is also important that the Major Sayan Fault actually continues SEward in Transbaikalia, which was earlier assumed on the basis of analysis of gravimetric fields (Fig. 1). It is however expressed in the relief of southern Prebaikalia and western Transbaikalia in different ways. In Transbaikalia it is not apparent as a single lineament but is disintegrated into some subparallel fault zones, which is probably connected with its specific reaction to the field of stresses during rifting. In the Cenozoic structure of the region it is now a sinistral upthrust-strike slip fault, although at earlier stages of the Cenozoic evolution it could play the role of "pure" strike slip fault or even transform fault [13]. Unlike the Tunka Fault, the Obruchev wrench-strike slip fault joint with the Major Sayan Fault, being similar in this respect to the Chersky Fault framing the South-Baikal Basin on the south. The reasons of this phenomenon are still hard to understand, but its explanation lies in the pre-Cenozoic history of the region development.

Concerning the relationship between the Tunka and South-Baikal basins cursory inspection of the map shows that the first depression is displaced relative to the second one according to the right-hand shear rule. This apparent phenomenon, however, is not documented in the geological structure of the basement of rifting troughs. Moreover, the displacements that took place in the Cenozoic along the Major Sayan Fault are typically sinistral. The evidence is also the focal mechanisms of recent earthquakes.

MAP OF ACTIVE FAULTS AND STRUCTURAL-GEOLOGICAL REGIONALIZATION OF THE BAIKAL DEPRESSION

Based on the structural-geological studies at the shore of Lake Baikal and seismoacoustic studies in its water body, joined to information of airborne and satellite survey as well, a map of Baikal active faults was compiled on a scale of 1:1,000,000. The scale was chosen so that it would provide a safe interpretation of the factual material within the depression and its mountain framing with equivalent details. The results are given in Fig. 1.

The density of active faults, understood as a number of faults per unit area, is maximum in the region of the Baikal Depression. It should be remembered, however, that within this depression we deal with fractures in the sedimentary body beneath Lake Baikal and, therefore, not all of these faults result from tectonic deformations. Some of them have no relation to active tectonics and can be due to consolidation of nonequigranular sediments in the process of their accumulation.

Figure 1 distinctly shows basic structure elements of the Baikal Rift Depression and adjacent territories.

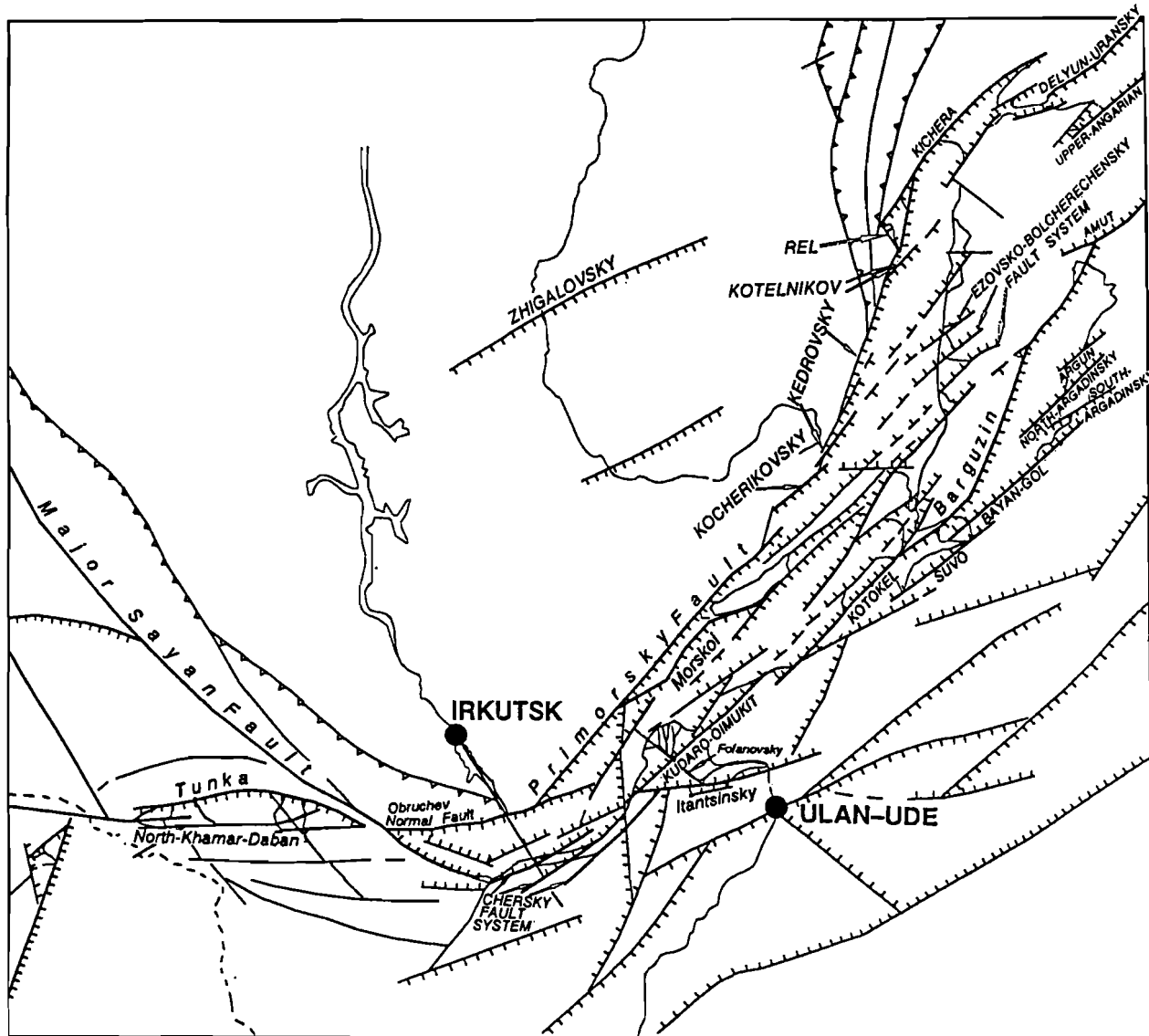


Fig. 3. Schematic location of the main faults of Baikal Rift Zone.

First of all, these are zones of large active faults – Major Sayan, Tunka, Obruchev, Primorsky, Barguzin, and others that governed the development of the Baikal Rift Zone in the Cenozoic (Fig. 3). At first glance, the Baikal Depression is subdivided into two large depressions: South-Baikal and North-Baikal, ones which are separated by the Olkhon isthmus and underwater Akademicheskyy Ridge [14]. The pattern of fracture elements in the Baikal Depression, however, distinctly shows three smaller basins – South-Baikal proper, Middle- and North-Baikal. These basins, in turn, are inhomogeneous in their internal structure. They consist of still smaller depressions which differ in tectonic and sedimentary style.

The South-Baikal Basin includes two depressions – Kultuk and Mishikha (Fig. 1).

The Kultuk Depression is bounded by the Obruchev Fault on the north, by the Major Sayan Fault on the west, by the Angara Fault on the east, and by a system of active faults which is called the Chersky Fault, on the south. This lozenge-shaped tectonic block is characterized by the intense development of folded deformations in Cenozoic sediments, as mentioned above, and abundant tectonic fracturing. The latter was studied in weathering crusts in the zone of the Obruchev wrench-strike slip fault and in Miocene and Pliocene-Quaternary deposits, along the Chersky Fault zone. The major consideration here is that in general

the sedimentary body of the depression itself does not contain a great number of tectonic fractures, and that the folds in the sediments formed as a result of sinistral displacements at the base of the depression.

The *Mishikha Depression* is bounded by the Angara Fault on the west, by the underwater continuation of the Obruchev wrench-strike slip fault on the north and by the Chersky Fault, on the south. The small-block structure of the sedimentary body is typical of this depression. There are few, if any, folds in the sedimentary body; the sediments lie subhorizontally, but it is rather difficult to date the fractures, because we have no knowledge about the geometry of the sediments at a depth greater than 1.5 km beneath the lake bottom. It is only known that the crystalline basement lies here at a depth of more than 8 km under lake level [15]. Another important fact is that the fractures in the Mishikha Depression are situated subparallel to its flanks, but ultimately, as they are traced eastward, they appear to converge into a narrow tectonic zone at the latitude of Posolsk Settlement, which then turns NEward and participates in the structure of one of the Mid-Baikal Basin grabens.

The last to be noted here is the structural role of the Angara Fault, which seems to be an ancient pre-Cenozoic feature of the Earth's crust activated in the process of rifting. It acted as a dextral slip-upthrust fault during the Cenozoic. Most likely, there were no considerable tectonic movements along the fault, although it is a quite extended structure traced along the Angara Valley from the inner field of the Irkutian Amphitheater in Transbaikalia up to the Gusinoozersky Depression (Fig. 1). In the Cenozoic, it played probably the role of a screen that determined differences in style of tectonic development of the Kultuk and Mishikha depressions [16].

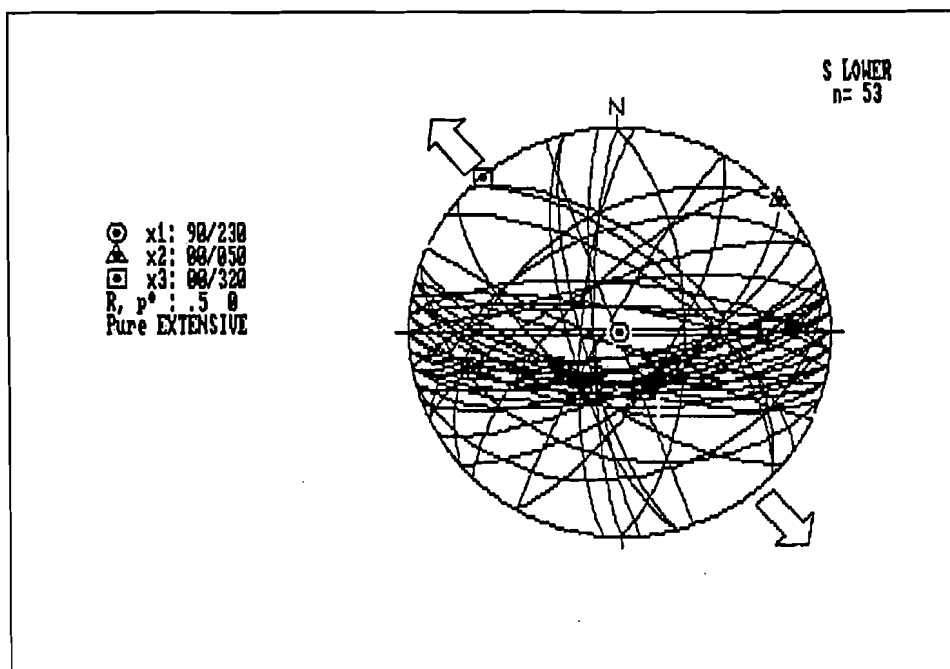
At least, five structural features are distinguished in the Mid-Baikal Basin — Selenga-Chivyrkui Graben, crest-like horst of Posolskaya Banka, Buguldeisky Koridor Graben, Olkhon Graben and Svyatoi Nos Uplift. The Buguldeisky Koridor, however, is recognized only conventionally. This name is given to a fragment of the Olkhon Graben activated during the Pliocene-Quaternary.

It was mentioned above that, being a morphologically integral feature of the Baikal Depression, the Mid-Baikal Basin consists of two linear grabens differing in degree of activity in the modern stage of its evolution.

The *Olkhon Graben* is a narrow elongated feature of the Mid-Baikal depressions and is situated along its NW flank from latitude of Cape Bol. Kadiilny to dry valley of the Sosnovka R. at the eastern bank of the North-Baikal Basin to envelop the Svyatoi Nos Peninsula on the west. The morphological expression of this graben in the bottom relief changes along the strike. (In places it is actually a graben, but somewhere this is a high tectonic step). In many places, this graben is crossed by transversal zones of latitudinal and northwestern strike. These are chiefly strike slip or wrench-strike slip faults. It is separated from the eastward Selenga-Chivyrkui Graben by a system of elongated, relatively high crest-like isthmuses joint together through tectonic steps. The character and morphology of tectonic steps are well seen on seismoacoustic records of a number of profiles, while the crest-like isthmuses — Posolskaya Banka and Svyatoi Nos Peninsula — are morphologically expressed in subaqual and land topography.

The crest-like *horst of Posolskaya Banka* plays an important role in the evolution of the portion of the Baikal Depression which immediately approaches the Selenga R. delta. At its SW closure, the horst was studied by means of a manned submersible "Pisces" [17]. It has been established in particular that at the lower part of the slope formed by a fault, Miocene deposits are outcropping at a depth of about 800 m, and extends up to the very top of the bank. This is evidence that the horst began to rise, probably, in the Pliocene. It is significantly younger than the lower portion of sediments in the Selenga R. delta [14] and, probably, exerted a significant effect on its development in Pliocene-Quaternary by limiting the penetration of subaerial delta deposits in the Buguldeisky Koridor Graben. This horst extends in the form of a morphological uplift in the northeast to the Anga mouth latitude, and farther NEward it is traced in the form of a tectonic step, acting as a natural divide between the Olkhon and Selenga-Chivyrkui grabens.

In the modern stage of evolution of the Mid-Baikal Depression, the *Selenga-Chivyrkui Graben* is its main structural feature (Fig. 1). It starts beneath the Selenga Delta on the SW and is closed in Chivyrkui Bay on the NE. Like the Olkhon Graben, it is crossed throughout its extension by a series of cross faults, often wrench-strike slip faults. A distinctive feature of the Selenga-Chivyrkui graben is its high seismic activity. During the last century, at least, 5 or 6 violent seismic events occurred there. One of them, the 1862 winter earthquake, led to the formation of a famous bay, Proval Bay, situated on the northeastern slope of the Selenga Delta. In 1992-93, the back suture of this tectonic block was explored additionally and, as a result, a system of fractures were detected in loose sandy-clay deposits of the delta which allows to define the orientation of the main normal axes of tectonic stresses under which this devastating earthquake took place (Fig. 4). In general, the earthquakes occurring in the Selenga-Chivyrkui Graben are often characterized by interesting geological



h Fig. 4. Systems of tectonic fractures in the Cenozoic sediments of the Selenga River delta and a stress tensor reconstructed according to them. Upper hemisphere of the Schmidt net.

phenomena not typical of the normal tectonic evolution in the Baikal Rift Zone. Thus, for example, the Mid-Baikal 1959 earthquake was accompanied with mud volcanism [18, 19]. The Selenga-Chivyrkui Graben appears to be the most interesting object for study of manifestations of active tectonics in the Baikal Trough.

An important structural feature of the Baikal Depression is an interdepression isthmus formed by the island of Olkhon and the underwater Akademicheskoy Ridge, the *Olkhon-Akademicheskoy Isthmus*. It functions as a natural divider between the South- and North-Baikal depressions and is interesting by the fact that in both overland and underwater parts it is covered by a thin layer of Cenozoic sediments. On the island of Olkhon, these sediments fill small lows on its northwestern slope. The lower age boundary of the Cenozoic sedimentation seems to reach the Paleocene [20]. The section, however, is not continuous and it is not evident that all the stratigraphic units characterize the process of the formation of this isthmus. Judging by the results of seismoacoustic studies on the underwater Akademicheskoy Ridge, the Cenozoic thickness in pockets of the crystalline basement is not more than 300 m and, as supposed, the Miocene, Pliocene, and Pleistocene sediments participate in the section.

The entire isthmus is bordered by systems of active faults on the NW and SE, but it should be noted that the amplitudes of displacement along the fault of the SE slope of the underwater ridge and the island of Olkhon are considerable and are estimated at some kilometers, while on the NW slope the amplitudes of the tectonic displacements are small and distributed over a series of small fractures. At the same time, it is necessary to underline that the faults limiting the isthmus are separate branches of the Primorsky Fault, which begins to branch at the Buguldeika mouth. In addition, the isthmus is cut by cross faults of sublatitudinal and northwestern strikes, chiefly, by wrench-strike slip faults. The terrestrial continuation of the interdepression isthmus between the island of Olkhon and the underwater ridge on the eastern flank of the North-Baikal Depression is the Barguzin Ridge spur ending at the lake shore by Cape Valukan.

The North-Baikal Depression is morphologically uniform of the surface and actually consists of at least three independent depressions – Malo-More-Ezovsky, Kedrovsky-Tompudinsky, and Rel-Kichera. The inner field of the depressions is hardly disturbed by young fractures, and intense deformations take place only at the sides of the depressions. By virtue of some local features, the active faults are better accessible for the intermediate study along the western shore of the lake.

The most tectonically dismembered is the *Malo-More-Ezovsky Depression*. On its NW and SE side, it is

framed by extended fault zones branching off the Primorsky Fault near Mukhor Bay and the Maloe More Strait. Listric normal faults are widespread along the border of the depression sides, and in the southwestern part it is intensely dissected by faults. Its most subducted sites are adjacent to the NW slope of the underwater Akademichesky Ridge. The Malo-More-Ezovsky Depression is a seismically weakly active feature of the Baikal Depression like the North-Baikal Depression as a whole. An increase in the density of epicenters of weak earthquakes is observed along the NW slope of the Akademichesky Ridge and on the northeastern closure of the depression.

The Kedrovsky-Tompudinsky Depression is situated north of the Malo-More-Ezovsky and is separated from it by an extended fault zone. The faults are limited to the borders of the blocks, trending NE at the southern limit, consisting of a complex system of faults. The whole block seems to collapse relative to the northern basins (Fig. 5). In general, the depression is weakly active seismically, although some increase in density of epicenters of weak earthquakes is observed in its northeastern part.

Farther northward lies the Rel-Kichera Depression. Nearly all around it is fault-bounded, and its inner field is also dissected by fractures, subdividing it into a series of scarps of varied ranks. There are two subparallel grabens in its axial part. The main role in the depression structure is played by the strike slip-wrench faults of the NW and NE strike. Of the three depressions forming the North-Baikal Basin, the Rel-Kichera Depression is the most seismically active in the modern stage of development (Fig. 6).

STRAIN-STRESS STATE OF THE EARTH'S CRUST AND ITS RELATIONSHIP WITH LOCAL RIFTING

Structural-geological research at the shore of the lake provided information about the tectonic stresses affecting the development of the Baikal Depression. These data are based on a rich collection of strikes and dips of tectonic fractures in fault zones. The tectonic fracturing was studied not only in the basement rocks

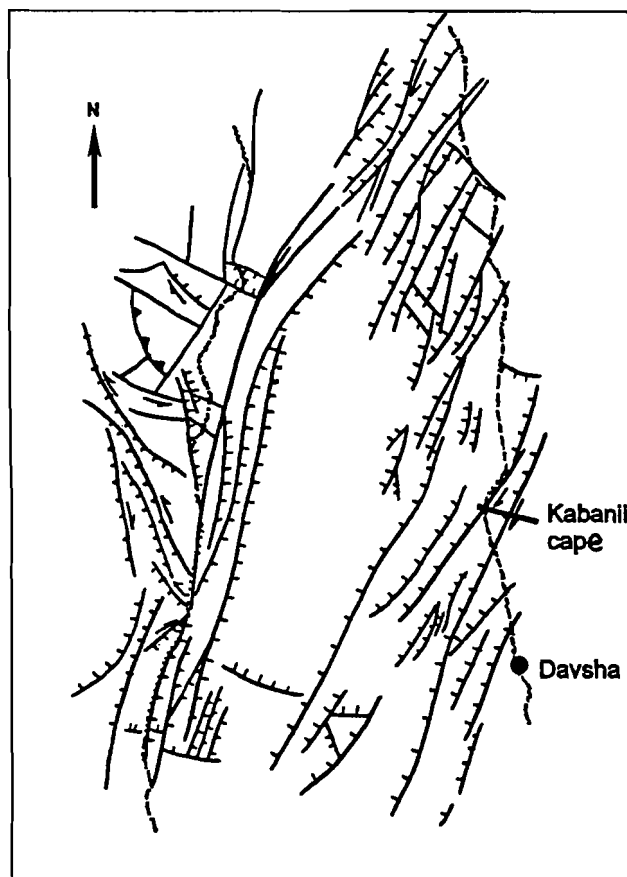


Fig. 5. Schematic ~~X~~ location of tectonic elements of the north part of Baikal. Notations are given in Fig. 1.

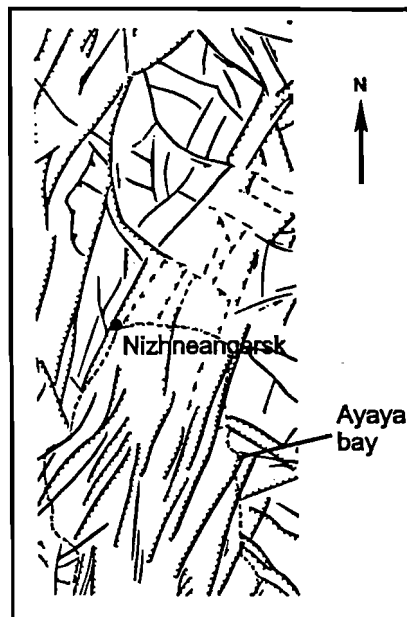


Fig. 6. Schematic location of tectonic elements of the Rel-Kichera depression. Notations are given in Fig. 1.

but also, for the first time, in the Cenozoic sediments filling the depression. In addition, to analyze them, seismological materials were used, concerning focal mechanisms of earthquakes.

Similar investigations carried out in the past and widely reported in the Russian geological literature indicate a specific character of tectonic stresses in the Baikal Depression and relative persistence of the orientation of the extension axis of the strain ellipsoid in the NW-SE direction. Some deviations from this directions NE- and SWward were also observed [21].

The present paper is an attempt to quantitatively estimate these deviations taking into account the directed spreading of anomalous mantle matter beneath the Baikal Rift lithosphere, in connection with the kinematics of active faults.

S. Gao et al. [22], using materials of seismic tomography, have established an anisotropy of the upper mantle beneath the southern basin of Baikal and adjacent Siberian Platform. At a depth of 50–250 km, the maximum velocity of *S*-waves is observed normal to the basic rift structures ($Az. 322^\circ \pm 10^\circ$). Gao et al. interpret this fact as evidence for the presence of flow in the upper mantle beneath Lake Baikal in the NW-SE direction. To follow these authors, it is interesting to compare the direction of the applied forces beneath the lithosphere with the direction of the extension axis in the crust of the Baikal Rift Zone reconstructed by geologic-structural and seismological data and thus to investigate the influence of anisotropy of a geological medium on the character of expression of tectonic forces in the upper crust of the Baikal Rift Zone. As a test parameter, variable *K* was used which indicates a deviation of extending efforts of the reconstructed local stress field from the direction of regional extending efforts applied to the base of the lithosphere. The *K* parameter was calculated by

$$K = |K_b - (K_{g,s} + 180^\circ)| < 90, \quad (3)$$

where K_b is the direction of substance flow in the upper mantle beneath the Baikal Rift Zone established by data of teleseismic tomography [22]; K_g is the strike of the extension axis of a local stress field reconstructed from geologo-structural data; K_s is the strike of the extension axis in earthquake foci according to seismological data [23].

Using a standard program "SURFER", schemes are constructed for the distribution of *K* parameter in isolines for the entire Baikal Rift Zone (Fig. 7). There are maxima and minima of *K* on the schemes of distribution of this parameter. In particular, the maxima are noticed near the Angara source and Selenga delta, where cross fracture structures are expressed, accompanied by tectonic stresses of shear type as well as at the flanks of the rift zone where a trend toward an increased strike slip component of displacements along faults is observed quite distinctly. At the same time, there are examples of the coincidence of the *K* maxima with

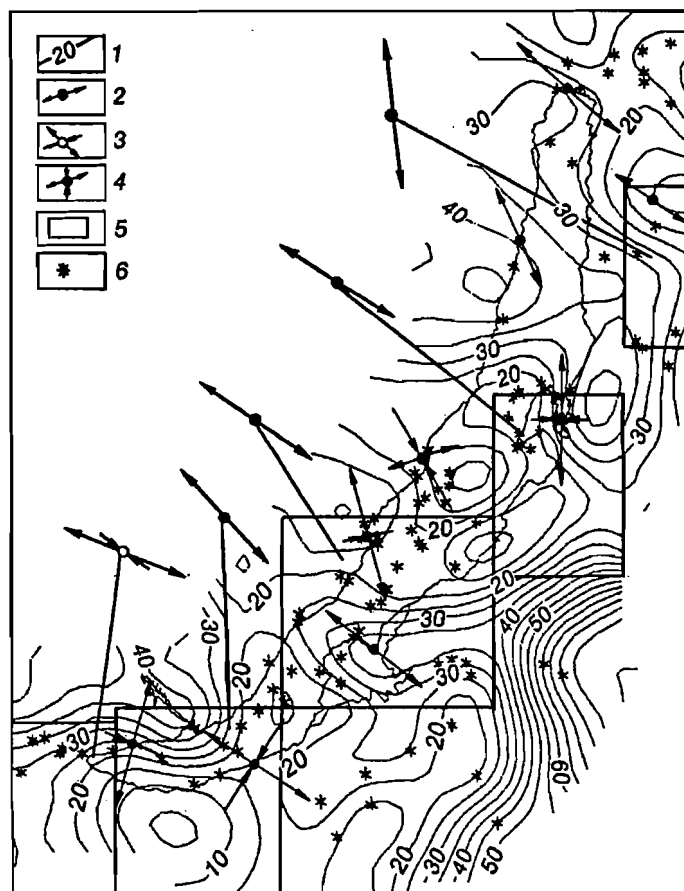


Fig. 7. Schematic distribution of parameter K within the Baikal Rift and on the adjacent territories (explanations in the text). 1 – isolines of K parameter; 2 – orientation of extension and compression axes according to geological data; 3–4 – orientation of extension and compression axes according to seismological data: 3 – compression axis is oriented vertically; 4 – compression axis is oriented horizontally; 5 – regions for which generalized tensors are obtained; 6 – epicenters of earthquakes and locations of tectonic fracturing for which stress tensors used in calculating parameter K are obtained.

the regions of normal fault-type stress fields where the geological structures occupy a crossing position relative to the typical NE strike. The K minima correspond to regions of normal fault-type fields of tectonic stresses with the strike of tectonic structures subparallel to the general Baikal strike.

Let us consider an example of detailed mapping of K parameter near the Svyatoi Nos Peninsula and Chivyrkui Bay. The maximum values of K in both geological and seismological data tend spatially toward the well-mapped transverse geological structures (western shore of the Svyatoi Nos Peninsula) and coincide with the range of strike slip-type stress fields. The minima are typical of the actively developing graben in Chivyrkui Bay, where the Baikal-strike faults and normal fault-type stress fields are most common.

Comparative analysis of the map of distribution of parameter K and fault maps within the territory of the Baikal Rift shows that the maximum transformation of extending efforts of local stress fields relative to the extension axis of the regional field regularly coincides with sites of transverse geological structures of the PR₃–PZ origin, activated during the rifting. The greatest coincidence of extension vectors of local stress fields and regional extension efforts is observed in the fields of actively developing Baikal-strike structures which were reproduced partly in the rifting stage.

CONCLUSIONS

The structural-geological and seismoacoustic studies provide a possibility to obtain a first insight into the

internal active tectonic structure of the Baikal rift. It includes a series of smaller structural features differing not only in morphology but also in degree of modern activity. Based on the modern structural-geological, seismological, and geophysical data on the deep-seated structure of the sublithospheric mantle beneath Baikal, we have refined the structural features of the tectonic stress field affecting the rifting basin and kinematics of rift faults.

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