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THREE-DIMENSIONAL VELOCITY STRUCTURE OF THE CRUST IN CENTRAL LAKE BAIKAL FROM LOCAL SEISMIC TOMOGRAPHY

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ABSTRACT. This work deals with the importance of studying seismicity and deep structure of the Earth's crust in the region of the Baikal rift zone. The study presents a three-dimensional velocity structure of the Earth's crust in the central part of Lake Baikal, obtained from the results of tomographic inversion of the travel times of P- and S-waves from more than 800 seismic events. Synthetic tests provide substantiation for the resolution of the tomographic inversion algorithm. The seismic structure of the crust was obtained to a depth of 35 km and has a direct relationship with the geological structure. The three-dimensional distributions of seismic P- and S-wave velocity anomalies are in good agreement with each other.

The sharp contrast between the anomalies may indicate a difference in the material composition of the basement of the Central Baikal basin. At a 15-km depth below the Selenga River delta, there is observed a strong low-velocity anomaly which confirms the presence of a thick sedimentary cover therein. In the basement (at depths of 20 km or greater), to the northeast of the intersection between the Delta fault and the Fofanov fault, there occurs a high-velocity anomaly elongated towards the Olkhon Island. This anomaly is probably related to a rigid block in the earth's crust. The same depths, on the western side of the Baikal-Buguldeika fault, show a reduced Vp/Vs ratio: 1.56–1.65 versus 1.70–1.75 in the adjacent areas. This indicates another type of basement rock composition and the presence of consolidated matter there.

Besides, there has been made a more accurate hypocenter determination for further comparison between seismic events and active fault structures. For the central part of Lake Baikal, the distribution of seismicity mainly corresponds to depths of 10–22 km. The situation is different below the Selenga Delta – the only area where seismicity is observed at depths greater than 22 km, – which can be attributed to complex fault interactions.

The velocity anomalies discussed herein are confined to reliably identified active faults and correlate well with the distribution of seismicity and gas hydrate structures.

KEYWORDS: Baikal rift zone; Central Baikal basin; local seismicity; seismic tomography; Earth's crust

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1. INTRODUCTION

The Baikal Rift Zone (BRZ) is one of the largest continental divergent boundaries. It is characterized by active rifting and the occurrence of lithospheric extension processes. The BRZ includes large lithospheric blocks: Siberian Platform, Amur Plate, and East Sayan, Mongolian and other microplates [Logachev, 2001]. The Global Positioning System (GPS) data show that the Baikal rift is opening at a rate of 3–4 mm yr [Ashurkov et al., 2011, 2016; Calais et al., 2003; Lukhnev et. al., 2013; Sankov et al., 2003]. The collision between the Indian Plate and the Eurasian Plate is evident in the fact that the lithosphere moves in the northeastern and latitudinal directions relative to the Siberian Platform. The Siberian Platform moves very slowly north, and the Amur Plate moves more rapidly southeast [Ashurkov et al., 2011].

No consensus exists on the causes of rifting, although there is no doubt that the BRZ is a tectonically active area. Active tectonic processes reflect the existence of a complex fault system and seismicity [Logachev, 1999, 2003; Sherman, Levi, 1977; Levi et al., 1995, 1997; Sherman et al., 2012]. Continental rifting is usually accompanied by volcanic and magmatic activities. However, the BRZ volcanism evidence was only found for the Neogene period, and there was a decrease in volcanic activity in the Quaternary [Logatchev, Zorin, 1987].

The study area is confined to the Central Baikal basin (Fig. 1). There lies a delta of the Selenga River which is the largest continental delta and a depocenter of Lake Baikal, with about an 8 km thick sediment layer [Hutchinson et al., 1992; Scholz, Hutchinson, 2000]. The Selenga River delta is a depression with a complex fault-block structure and high seismic activity. According to the data on focal mechanisms of large earthquakes, the key role therein is played by the lithospheric extension processes [Misharina, Solonenko, 1972, 1977; Misharina et al., 1983; Melnikova, Radziminovich, 1998]. A complex geodynamic environment in the Selenga River delta is due to the mutually intersecting Delta, Fofanov and Sakhalin-Enkhaluk faults [Lunina et al., 2009].

This paper considers local earthquake tomography which allows a velocity model and earthquake hypocenters to be simultaneously refined based on the P- and S-wave arrival times [Nolet, 1990]. For the Baikal region, there were created several tomographic models [Kulakov, 1999, 2008; Mordvinova et al., 2000; Burkholder et al., 1995; Gao et al., 2003; Petit et al., 1998; Tiberi et al., 2003; Yakovlev et al., 2007; Zhao et al., 2006] which have similar characteristics (high velocities for the Siberian Platform and low-velocity anomalies for the upper mantle of the South Baikal basin) but may differ in detail. Based on the results of the studies conducted using local data [Kulakov, 1999; Petit et al., 1998], beneath the Baikal folded area, up to a depth of 20 km, there can be found a large negative anomaly that changes to positive one. In [Yakovlev et al., 2007], the regional data were used to obtain the crustal and upper-mantle velocity anomalies. According to the results obtained, the authors identify negative anomalies coinciding with the Cenozoic volcanic areas. The abovementioned results, however, do not provide information on the detailed structure of the Earth's crust in the area we are interested in.

This paper discusses three-dimensional velocity-structure determination of the crust in the Central Baikal basin by local seismic tomography with simultaneous refinement of hypocenter parameters of the earthquakes. Local seismic tomography reveals block structure of the earth's crust, thus providing insight into the understanding of tectonic processes in the study area. The results obtained herein make it possible to consider in more detail the crustal velocity structure of the Central Baikal, as compared to previous seismic tomography studies conducted in the Baikal region.

2. GEOLOGICAL AND GEOPHYSICAL DESCRIPTION OF THE STUDY AREA

There are two major hypotheses about the formation of the BRZ. These are the concepts of active and passive rifting.

The idea of active rifting is related to the presence of mantle plume beneath the Baikal which causes lithospheric uplift and extension [Logatchev, 1993; Logatchev, Zorin, 1987; Zorin, Turutanov, 2005]. One indication that this theory might be right is the existence of high heat flow – the heat flow in the BRZ is variable (from 40 to 200 mWt/m^2) but tends to be greater than the mean value [Golubev, 2007; Duchkov, Sokolova, 2014]. Based on the deep seismic sounding (DSS) data, evidence was also found for the asthenosphere low-velocity protrusion (7.7–7.8 km/s) beneath the Baikal which is interpreted as an anomalous mantle [Song et al., 1996]. In accordance with the gravimetric data, positive anomalies of the Bouguer reduction are the indicator of basic-ultrabasic igneous rock intrusions [Khain, Lomize, 2005; Gao et al., 1997], negative anomalies correspond to large-scale mantle inhomogeneities [Dobretsov et al., 2019].

Another factor to be considered is passive rifting. This model is based on plate interactions which cause the lithosphere extension. According to this concept, the extension is due to the collision between the Indian plate and the Eurasian plate, and to the subduction of the Pacific plate [Nicolas et al., 1994; Peltzer, Tapponnier, 1988; Zonenshain, Savostin, 1981]. There are also combined theories of the rift formation which imply two to three formation stages [Logachev, 2003; Achauer, Masson, 2002; Chemenda et al., 2002; Lesne et al., 2000; Mats, 2012, 2015; Petit et al., 1998].

The Baikal basin is the largest part of the BRZ. There can be distinguished three main basins of Lake Baikal – South, Central and North [Logachev, 2003]. The estimates of sediment thickness reported for the Baikal basin are different. The seismic reflection survey (SRS) of the lake yielded sediment layer thicknesses ranging from 7 to 8 km in the North and Central basins [Hutchinson et al., 1992]. Seismic refraction profiles (SRP) obtained in the Central basin showed that the sediments therein are up to 9.5 km

thick [Ten Brink, Taylor, 2002]; the greatest depth to basement – up to 14 km – was obtained for the South basin [Suvorov, Mishen'kina, 2005].

The coast of Lake Baikal is composed of heterochronous rocks. The western shoreline of the Baikal is composed primarily of the Archean and Archean-Proterozoic basement and sedimentary complexes of the Siberian Platform, and the eastern – by the Phanerozoic rocks of the Sayan-Baikal Fold Belt [State Geological Map..., 2009; Gvozdkov, 1998; Grudinin, Chuvashova, 2011]. Among the synrift sediments of the Baikal region are the Upper Cretaceous Cenozoic rocks whose accumulation period corresponds to rifting and Lake Baikal basin formation times [Mats, 2012]. The Upper Cretaceous–Paleogene deposits which

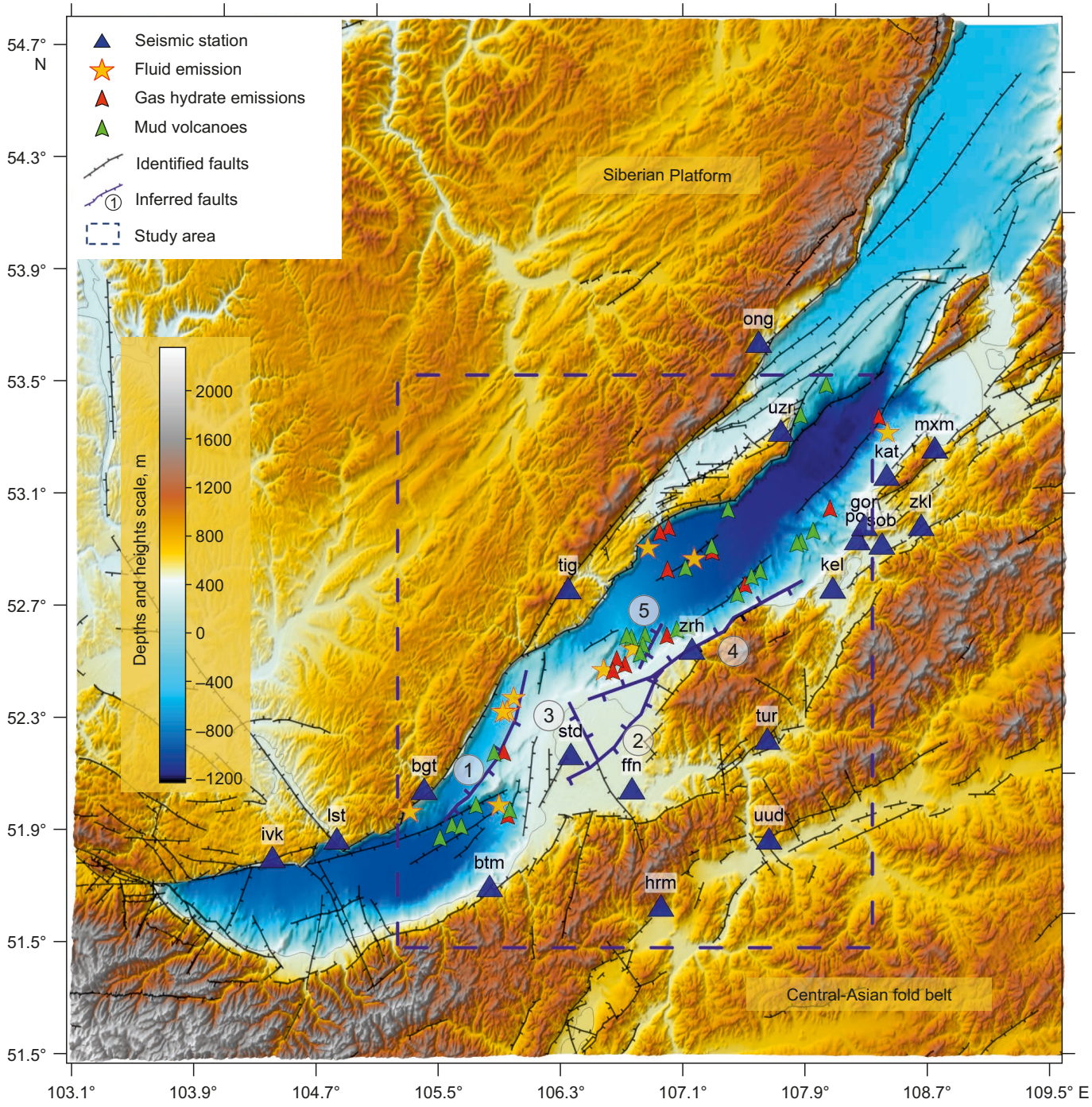

Fig. 1. Map of relief and main structural and tectonic elements in the area of the Baikal depression.
The map shows reliably identified Pliocene-Quaternary faults [Lunina, 2016]. Numbers in circles correspond to the faults under discussion: 1 – Baikal-Buguldeika, 2 – Delta, 3 – Fofanov, 4 – Sakhalin-Enkhaluk, 5 – unnamed.
Green and red marks represent mud volcanoes and gas hydrate emissions, respectively. Fluid ejections are shown by yellow stars [Khlystov et al., 2018]. Seismic stations correspond to blue triangles. The herein-considered area is shown as blue dashed lines. Digital elevation model for Lake Baikal was taken from https://www.gebco.net/ where the data is freely available.

are lacustrine or alluvial in origin occur within the Selenga River delta and Olkhon Island [Logachev, 1974; Mats, 2012, 2015]. The Quaternary deposits which are widespread in all intermountain and submontane troughs have been derived from different types of soft rocks and are of different geneses. A detailed outline of the Cenozoic deposits within the Baikal basin is provided in [Mats et al., 2001]. In view of the diversity of rocks bordering the lake, in could be assumed that the Baikal basement has a complex uneven-aged block structure.

The study area is confined to the Central Baikal basin. The important structures therein are the Delta, Fofanov and Sakhalin-Enkhaluk faults.

The Delta fault in the estuary part of the Selenga River (Fig. 1) is the major seismoactive structure there [Lunina et al., 2012], with normal-fault kinematics. The displacement along the fault occurred under the NW-SE extension conditions. The activation of this fault is due to the Tsagan earthquake of 1862, which gave rise to the formation of the Proval Bay. The formation and evolution of the Proval Bay have been described in detail in [Shchetnikov et al., 2012], in the context of the analysis of common morphological characteristics of the Baikal rift.

Orthogonally to the Delta fault, there runs the Fofanov fault (Fig. 1). This fault penetrates deeply into the crust up to the upper mantle [Solonenko, 1981] and is identified through the geomagnetic survey. The fault separates the blocks with different depths to basement; according to [Lunina et al., 2009, 2010], it is the right-lateral strike-slip fault with its highly seismic northern part.

The Sakhalin-Enkhaluk fault (Fig. 1) intersects with the Delta fault on the coast near the northeastern Proval Bay, strikes northeast, and is interpreted as a normal fault. It belongs to the most seismically active faults; with numerous thermal springs thereon [Solonenko, 1981; Lunina et al., 2009].

Geodynamic complexity of the Selenga River delta is determined by the mutually intersecting Delta, Fofanov and Sakhalin-Enkhaluk faults [Lunina et al., 2009]. It is worthy of note that the seismicity of these faults occurs at depths greater than 22 km, whereas in the rest of the Central Baikal basin it is confined to depths of 10–22 km [Radziminovich, 2010; Suvorov, Tubanov, 2008]. According to the electromagnetic monitoring data, the Selenga River delta has a mosaic (block) structure with alternating uplifted and subsided small blocks [Nevedrova, Epov, 2004; Lunina et al., 2009].

The objects of interest in the avandelta of the Selenga River are the Posolsk Bank and Kukui Ridge. They are tectonically uplifted blocks which previously were the parts of the surface in the Selenga River delta and are adjacent to the same fault [Logachev, 2003]. In [Khlystov et al., 2016], it is reported about an abrupt activation of seismotectonic activity about 1.0–0.8 million years ago which resulted in the separation of the Posolsk Bank and Kukui Ridge from the Selenga River delta and in their further autonomous existence. On the southeast of the ridge, there is a canyon whose formation can be attributed to rifting processes which is evidenced by sharp river bends and step-like canyon slopes. The Kukui Canyon is also known for a large concentration of mud volcanoes and gas hydrates [Khlystov et al., 2018].

The Central Baikal basin is characterized by high seismicity. The most seismically active area is the Selenga River delta. Seismicity distribution in the Baikal area has been considered in many studies since the 1960s (in the works of Treskov, Misharina Golenetsky, Vertlib, Krylov and other scientists). The studies provide evidence that the major earthquakes are confined to depth interval 0–10 km [Krylov, 1980] or 5–20 km [Golenetsky, Perevalova, 1988]; in some of the studies, the source depths are estimated at 30 [Déverchère et al., 1991] or even at 40 km [Déverchère et al., 2001; Gileva et al., 2000]. In [Suvorov, Tubanov, 2008], there was obtained the distribution of seismic sources beneath the Central Baikal in the context of the velocity model based on the DSS data which made it possible to identify a seismically active layer going down under the Selenga depression. A similar result was provided in [Radziminovich, 2010].

3. SEISMIC TOMOGRAPHY DATA AND METHOD

This paper deals with travel times for straight waves (Pg and Sg) recorded at 20 seismic stations. These stations belong to the Baikal and Buryat branches of the FRC UGS RAS. The seismological network is extended along the Baikal and characterized by an irregular distribution of seismic stations. The processing has been performed on the data catalogue containing the travel times of P- and S-waves from local earthquakes over the period 2001–2011. The energy class K for this data sample ranges from 6.5 to 12.2. Fig. 2 shows a seismological network configuration and seismicity distribution. The processing involved seismic records obtained from at least 5 stations located on a maximum distance of 100 km away from the epicenter. After the catalog processing, there were 826 events left, with the travel times of Pg-waves (6406) и Sg-waves (6461).

The paper deals with LOTOS – Local Tomography Software [Koulakov, 2009]. It allows a 3D velocity model and earthquake hypocenters to be simultaneously refined based on P- and S-wave travel times. Travel time calculations and tomographic inversion were based on ray tracing. The tomographic inversion is performed in several iterations, each of which includes more accurate hypocenter determination, and tomographic matrix calculation and inversion. More details on more concrete implementation of the algorithms are provided in [Kulakov, 1999; Koulakov et al., 2002]. The iterative process continues as long as dispersion misfit is constant (decreases by less than 3–5 %). In the present work, the inversion process converged usually after three iterations.

Fig. 3 shows the distribution of rays in the study area and the nodal parametrization of velocity model. An area with sufficient ray coverage implies the in-principle possibility of reconstructing velocity model. It is evident that the coverage area includes the Central basin, northern

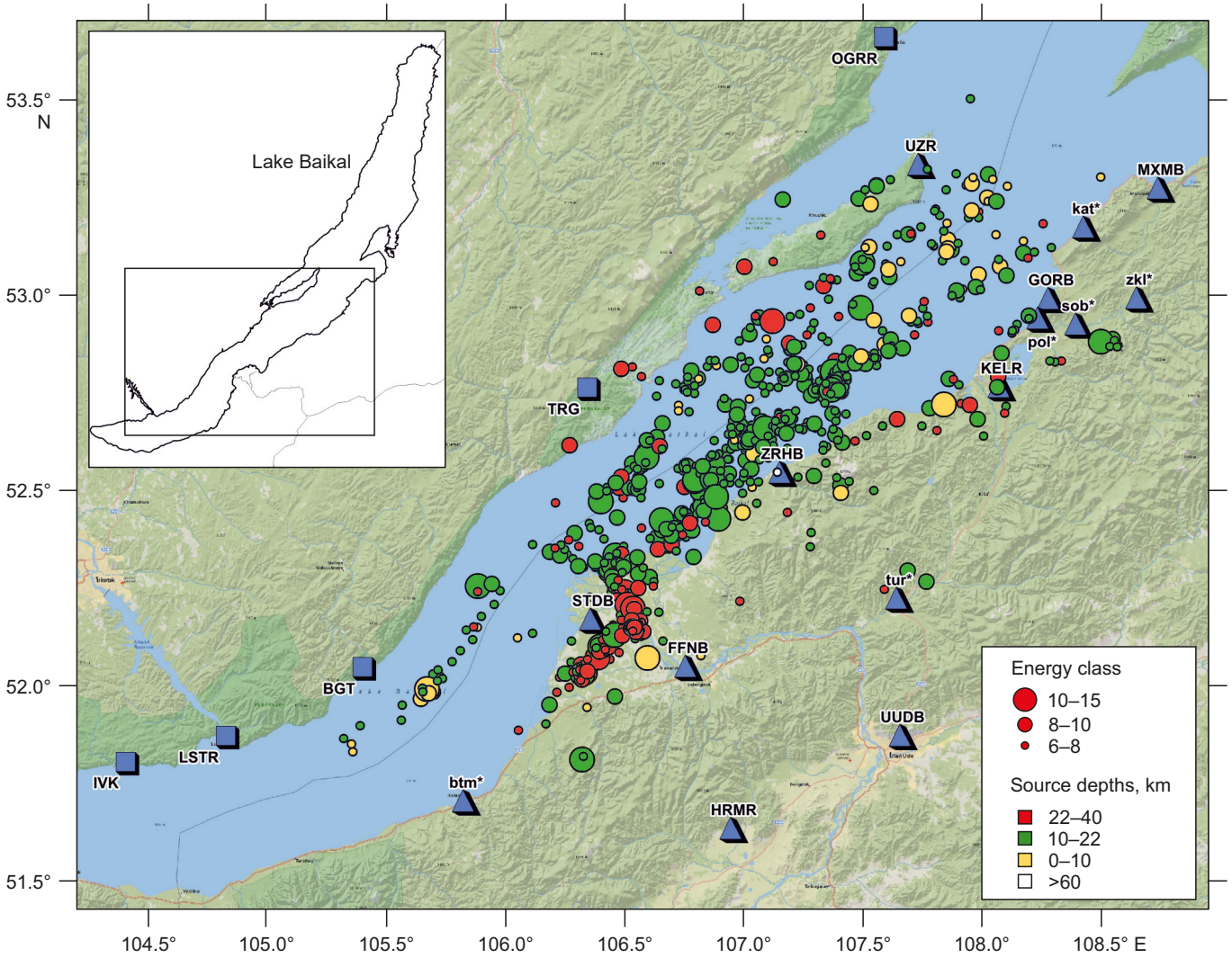

Fig. 2. Distribution of seismicity in the study area (the epicenters are shown after their more precise determination during tomographic inversion).
Triangles are seismic stations of the Buryat Branch of the FRC UGS RAS (* – the regional (local) code of the station), squares are the stations of the Baikal Branch of the FRC UGS RAS. In the insert, the rectangle shows the studied area.

South basin, and a part of the southeastern coast. It has to be noted that the LOTOS algorithm puts emphasis on reducing the influence of the distribution of nodes of parametrization grid on the results. To do this, there has been performed an inversion using different grid orientations (0°, 22°, 45° and 67°in our case). After the results for different grid orientations are calculated, they are summarized in a single model reducing any artifacts related to grid orientation.

The result of tomographic inversion depends on the choice of regularization parameters of smoothing and amplitude damping. Optimal parameters are selected based on synthetic tests. Large parameter values ensure uniqueness and sustainability of the solution but smooth it, thus reducing the level of detail of the model obtained. Small parameter values are the causes of unsustainability of the solution – in the model there appear velocity anomalies which have little impact on travel times as they are not driven by data. In App. 1 there are presented the results of checkboard tests. First, these tests allow determining optimal regularization parameters (absence of any other anomalies in the models obtained). Second, they allow determining resolution of the observation system involved, i.e. the area and the dimensions of velocity anomalies which are reliably reconstructed for the available seismicity distribution and station location. Based on the test results, it was concluded that interpretable anomalies are those which have horizontal dimensions 30 km or greater (App. 1, Fig. 1.1).

For ray tomography it is important to choose the initial velocity model because its proximity to the true model provides precise tomography inversion results. It was based on the one-dimensional model of the Earth's crust derived from the DSS method [Song et al., 1996]. Then the model was refined using LOTOS software tools (the one-dimensional model was refined so that the velocity anomalies had a mean of zero at all depths. As a result, there was obtained the initial velocity model shown in

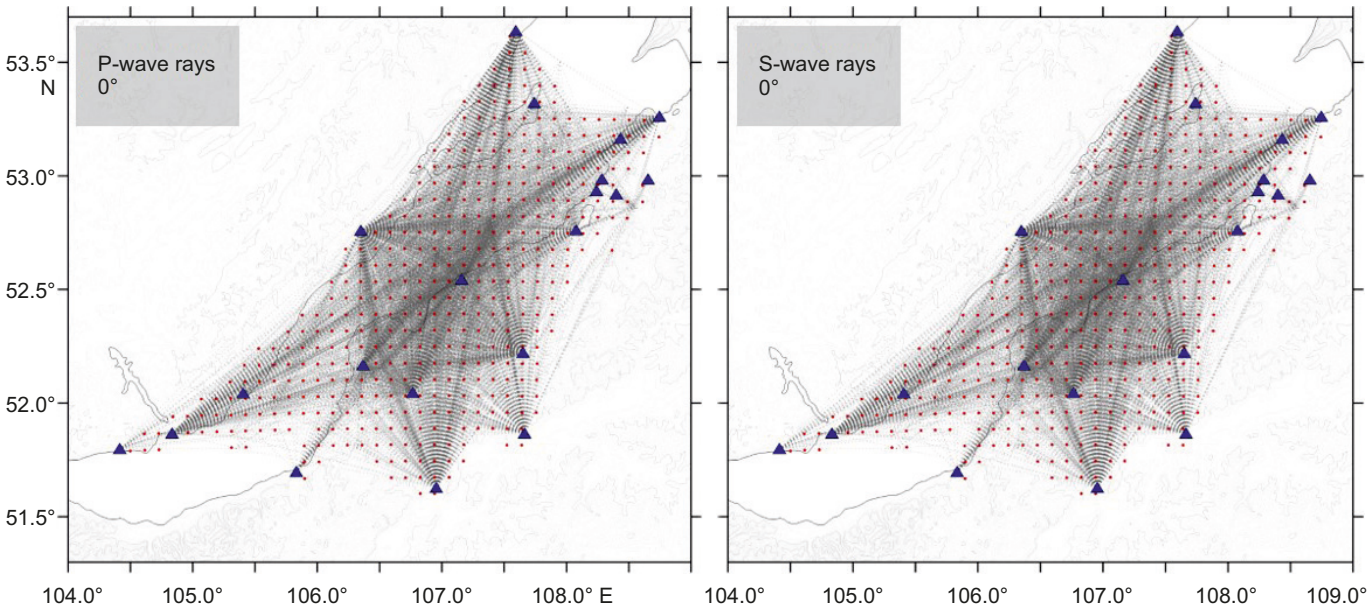

Fig. 3. Distribution of P- and S-wave rays (gray lines), seismic stations (blue triangles) and nodes of parameterization grids with orientation of 0° (red dots).

Table 1 (the velocity between the presented depths is linearly approximated).

4. TOMOGRAPHIC INVERSION RESULTS

At first there were obtained the preliminary results of earthquake hypocenters from the one-dimensional model, and then there were performed three iterations of tomographic inversion. Root-mean-square misfits of P- and S-wave travel times after each of the iterations are presented in Table 2. After the third iteration, the misfits reduced to 0.22 s (for P-waves) and 0.30 s (for S-waves).

Tomographic inversion produced the three-dimensional distribution of P- and S-wave velocity anomalies shown on horizontal (Fig. 4) and vertical (Figs 5, 6) sections. The figures show that most of the P- and S-wave velocity anomalies correspond well to each other. The dots in Fig. 4, 5 and 6 stand for the refined locations of sources (after inversion); the vertical sections (see Fig. 5; Fig. 6) show the sources in a 7-km wide layer around corresponding sections (refined epicenters for the whole catalogue are shown in Fig. 2). Table 3 presents the distribution of sources along the depth. It can be seen that most of the earthquakes occur at depths of 10–22 km and coincide with the estimates reported in [Radziminovich, 2010; Suvorov, Tubanov, 2008]. The Selenga River delta exhibits the concentration of earthquakes with hypocenter depths to 30 km. An earthquake near Zarechye (ZRHB) station occurred at a depth of >60 km (see Fig. 2).

5. RESULTS AND DISCUSSION

Fig. 7 presents a comparison between the results obtained for velocity anomalies and reliably identified faults [Lunina, 2016].

Anomalous area 1 shown in Fig. 7 is located northwest of the Selenga River delta. According to the seismic data [Hutchinson et al., 1992], there lies the subsided block of the acoustic basement with a sediment thickness of about 7.5 km. On the southeast, this area is bounded by the Baikal-Buguldeika fault – a normal-fault [Lunina, 2016] which is considered active since it is confined to both seismicity and gas hydrate structures [Khlystov et al., 2016, 2018]. The fault separates area 1 from the adjacent low-rate block (from S-velocity anomalies) which is characterized by low seismicity (in accordance with the regional catalog data over the period 1960–2021); there is also located the Posolsk Bank. A new result is that the area shows an anomalously low Vp/Vs ratio (1.56–1.65) as compared to the surrounding rock (1.70–1.75) (Fig. 7, c). Therefore, it can be concluded that the blocks on either side of the Baikal-Buguldeika fault not only move relative to each other but also differ in their physical composition.

Area 2 is located northeast of the intersection between the Delta and Fofanov faults and elongated towards the Olkhon Island (Fig. 7). According to the seismic tomography data, there lies a high-velocity rigid crustal block at a depth of about 20 km which is presumably composed of the rocks different from the host rock in composition.

This anomalous block and seismicity distribution thereabout can be seen clearly in the vertical section along Profile 5 (see Figs 5, 6). The block is ~80–100 km long and ~20 km wide and lies at depths of 15 to 35 km. Seismicity is mostly concentrated on the boundary between the low- and high-wave-velocity areas at depths of 15 to 20 km.

Seismicity (hypocenter) distribution analysis shows that there occurs a complex interaction between this block and adjacent structures (Fig. 7). Seismicity is concentrated along the southeastern margin of the rigid block. There is a clearly defined arc structure similar to the Baikal-Buguldeika fault mentioned above. It has a submeridional strike and is formed by the southern Delta fault and Fault 5 in Fig. 7

Table 1. Initial Velocity Model

Depth, km	Vp, km/s	Vs, km/s
–2	5.14	2.99
5	5.67	3.40
10	6.03	3.54
15	6.20	3.60
20	6.34	3.67
30	6.49	3.82
40	7.13	4.15

Table 2. Average misfits of arrival times (s)

Iteration No	dtP, s	dtS, s
1	0.29	0.49
2	0.22	0.31
3	0.22	0.30

Table 3. Depth distribution of seismicity after tomographic inversion

Depth, km	Number of events
0–10	65
10–22	593
22–40	167
>60	1

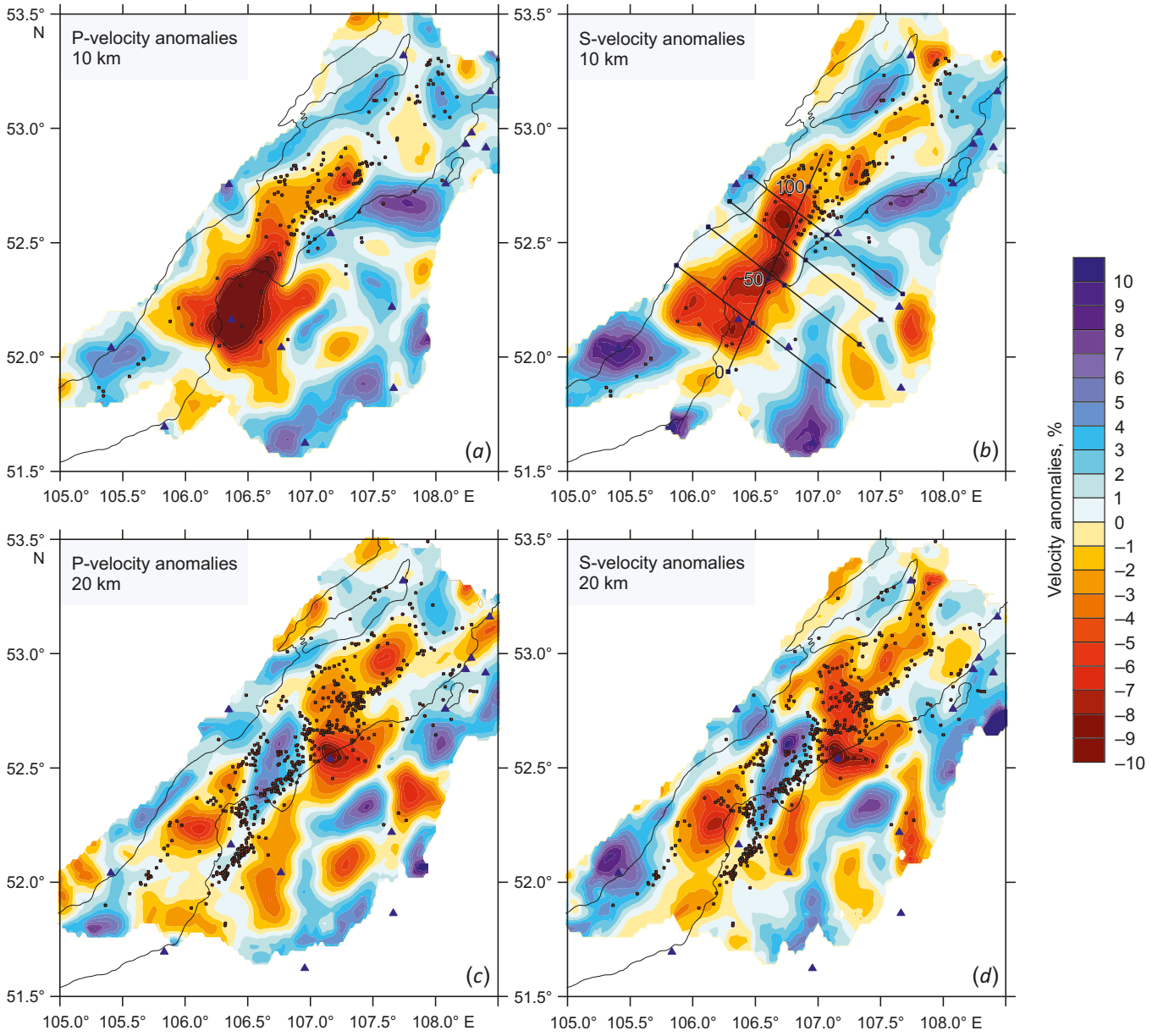

Fig. 4. P- and S-velocity anomalies from tomographic inversion.
Horizontal sections at depths of 10 km (*a, b*) and 20 km (*c, d*); dots denote the events at corresponding depths; triangles denote seismic-station locations. The location of the profiles for constructing vertical sections is indicated in the fragment (*b*).

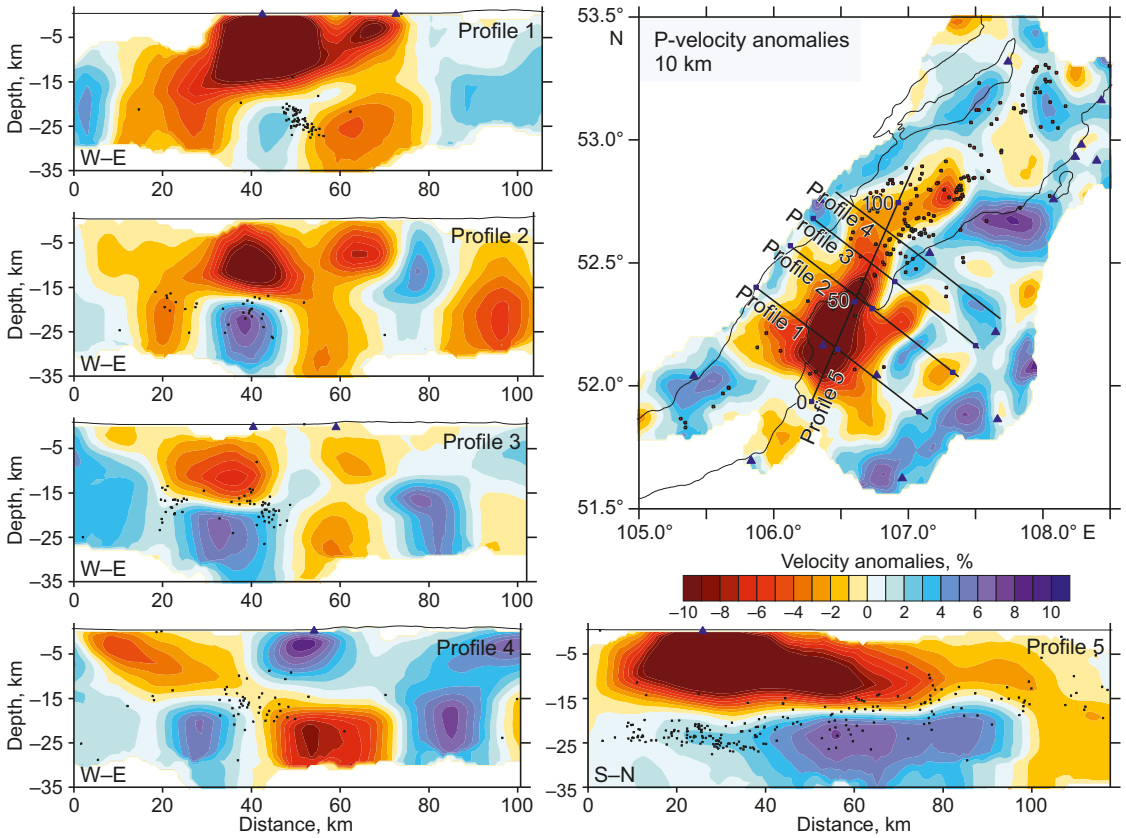

Fig. 5. P-velocity anomalies from tomographic inversion (vertical sections). Dots denote the events near the section (within a 7-km layer); triangles denote seismic-station locations. Vertical section lines are shown in the upper right panel.

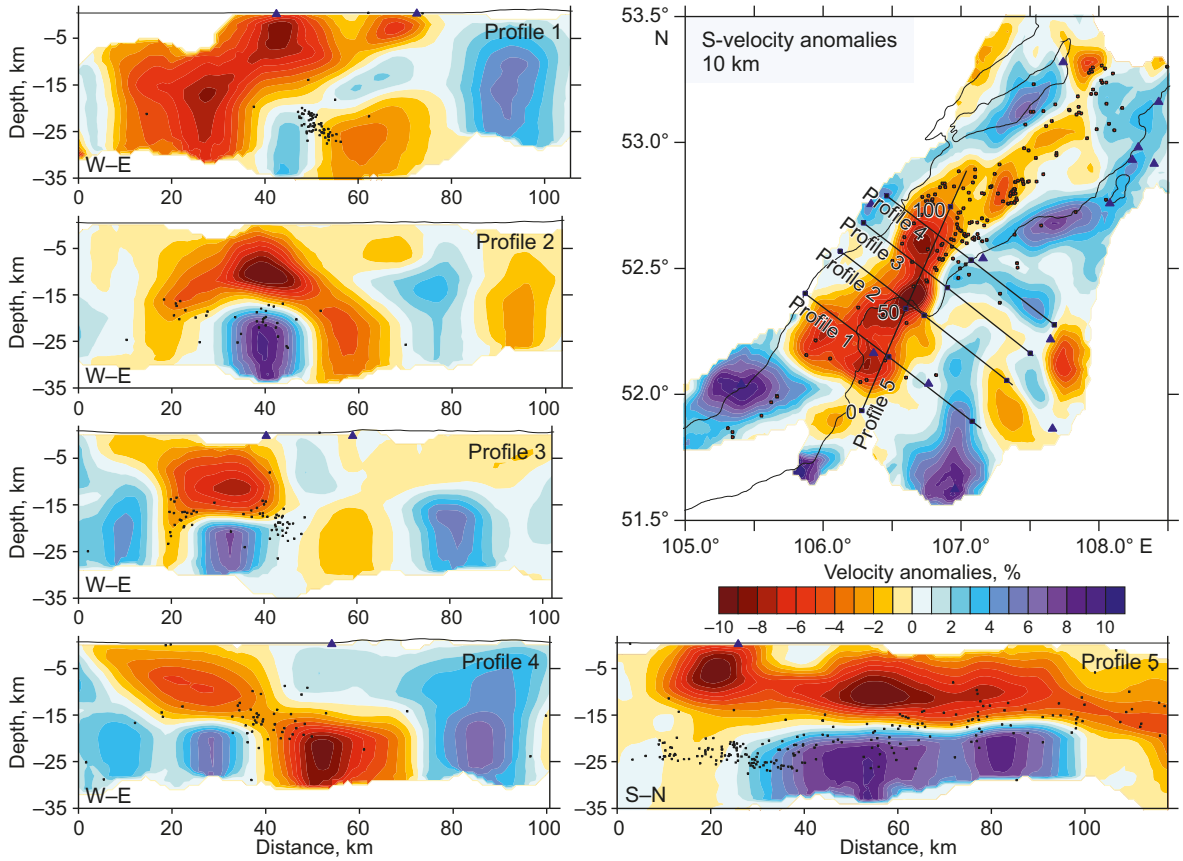

Fig. 6. S-velocity anomalies from tomographic inversion (vertical sections).

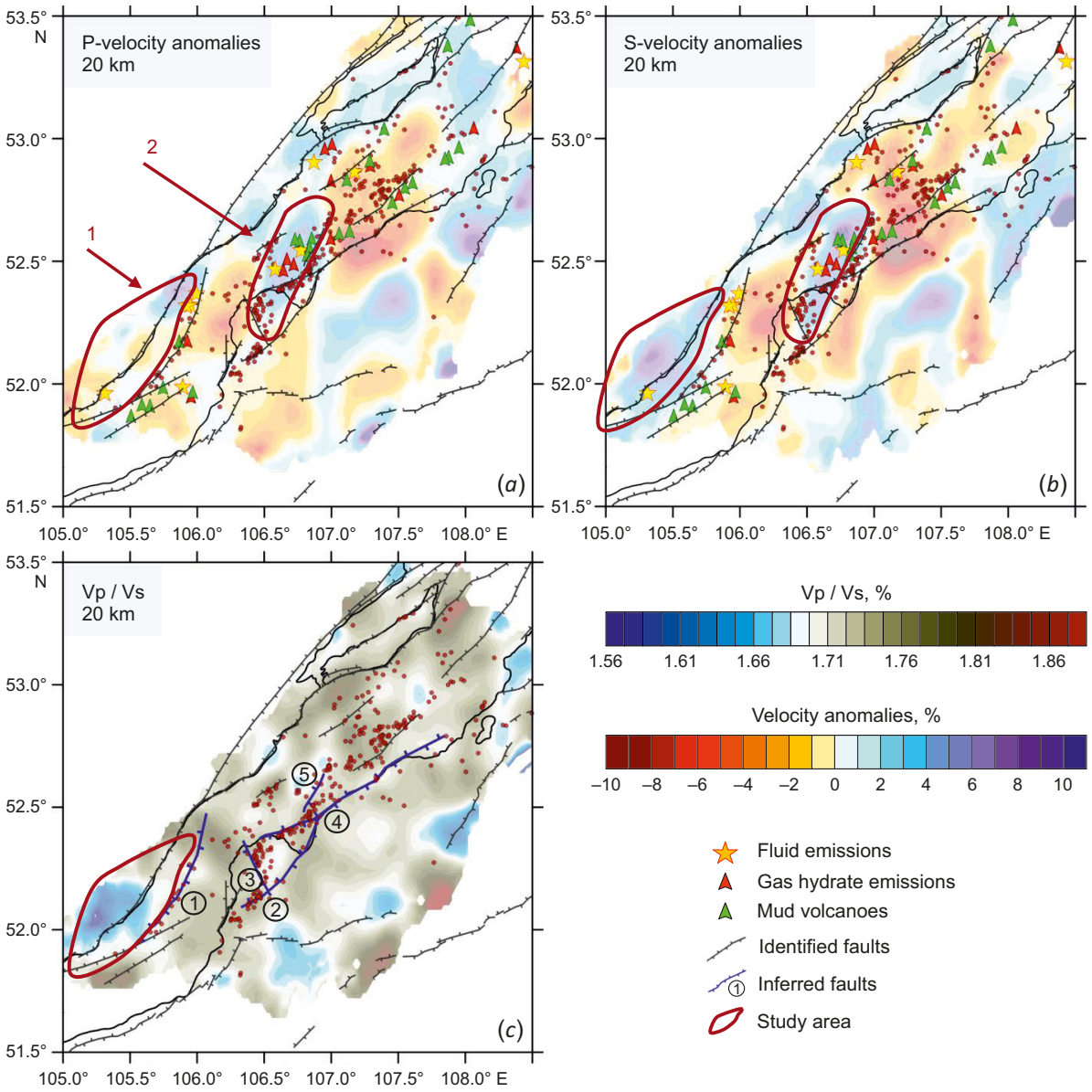

Fig. 7. Interpretation of the results of tomographic inversion.
Vp (*a*) and Vs (*b*) anomalies and the Vp/Vs ratio (*c*) at a depth of 20 km; the dots stand for seismicity around 20-km depth. The lines show the reliably identified Pliocene-Quaternary faults [Lunina, 2016]. Numbers in circles correspond to the faults: 1 – Baikal-Buguldeika, 2 – Delta, 3 – Fofanov, 4 – Sakhalin-Enkhaluk, 5 – unnamed. The discussed regions are shown by red contours.

which continues into the Baikal water area and is traced by exposed gas hydrates and underwater volcanic eruptions [Khlystov et al., 2018]. There also lies the Kukui Canyon – the longest canyon on the Baikal bottom – whose complex tortuous shape can be partially attributed to the fault pattern [Khlystov et al., 2016].

Not all southeastern margin of the high-velocity block is seismically active. Seismicity is only observed for the southern Delta fault. This appears to be related to the Sakhalin-Enkhaluk fault cutting thorough the high-velocity block in the southwestern direction. The block seems to be fractured along this line since the seismicity is now occurring throughout the block rather than on the block margin. According to [Solonenko, 1981; Lunina et al., 2009], there are many thermal springs along this fault. Besides, seismicity is observed on the southwestern margin of the Fofanov fault.

Therefore, this implies a complex interaction between the crustal blocks therein which may have resulted from the overlapping stages in the development of the Baikal rift [Mats, 2012]. The feature of the interaction considered is emphasized by large depths of the hypocenters confined to the Delta and Fofanov faults (22–30 km), but there is almost no earthquake activity at these depths in the rest of the study area.

The revealed contrast between P- and S-velocity anomalies (sections for 20 km depth in Fig. 4) generally indicate a significant difference in composition of basement rocks in the Baikal basin. The geological studies show that the Baikal borders are composed of heterochronous rocks. For

example, on the western coast near area 1 there are outcrops of the Archean-Proterozoic migmatites and crystalline schists alternating with the Neoproterozoic sediments. The eastern coast of the Baikal is mostly composed of the Phanerozoic rocks [State Geological Map..., 2009; Gvozdkov, 1998; Grudinin, Chuvashova, 2011]. In the Selenga River delta and the Olkhon Island, there occur Upper Cretaceous–Paleogene lacustrine and alluvial deposits [Logachev, 1974; Mats, 2012, 2015]. Therefore, a wide variety of lake-bordering rocks suggests that the Baikal basement has a complex heterochronous block structure. This allows interpreting the revealed contrasts between seismic-wave velocity anomalies and their relationship as heterochronous blocks.

6. CONCLUSION

Seismic tomography method presented herein yielded the three-dimensional distribution of P- and S-velocity anomalies and provided better location estimates for hypocenters in the Central Baikal basin. The study was conducted based on the catalog of regional seismic events recorded in 2001–2012. A data set provides sufficient ray coverage of the study area and reliable identification of anomalies with horizontal dimensions from 30 km.

Northeast of the intersection between the Delta fault and the Fofanov fault, there is a high-velocity anomaly elongated towards the Olkhon Island. This anomalous area is interpreted as a rigid crustal block. This block is 80–100 km long and about 20 km wide, with a depth of occurrence from 15 to 35 km. This block is cutting through the Sakhalin-Enkhaluk fault, which provides a complex interaction between the crustal blocks therein. The feature of interaction is emphasized by large depths of the hypocenters confined to the Delta fault and the Fofanov fault, but there are almost no earthquakes that occur at these depths in the rest of the area.

In the southwest of the study area, there is a range of high S-wave velocities. Anomalously low Vp/Vs ratios imply that this anomaly is a basement block which differs from the surrounding rock in material composition. This block underwent subsidence, as can be inferred from a 7.5-km increase in the thickness of bottom sediments thereabove. In the southeast, the block is bounded by the Baikal-Buguldeika fault which presumably separates heterochronous basement blocks.

Thus, there were obtained new data on the block structure of the Earth's crust beneath the Baikal basin that might be used for constructing geological and tectonic models of the Baikal rift.

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8. CONTRIBUTION OF THE AUTHORS

Data processing, results interpretation, manuscript and graphic preparation – Eponeshnikova L.Yu.; results interpretation, manuscript revision – Duchkov A.A.; manuscript and graphic revision – Sanzhieva D.P.-D., Yaskevich S.V. All authors read and approved the final manuscript.

9. DISCLOSURE

The authors declare that they have no conflicts of interest relevant to this manuscript.

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APPENDIX 1

SYNTHETIC TESTS

Repeated testing was performed to validate the inversion results for the experimental data.

The resolution was validated through synthetic testing with chess-board anomalies. The procedure of this test is as follows. There has been created a synthetic velocity model which consists of alternating positive and negative anomalies of the prescribed size and looks like a chess board. The direct model-related problem to be solved is to calculate travel times for distribution of seismicity and location of stations from the catalog studied. After that, an inverse problem in tomography is to be solved based on the travel times obtained.

There have been conducted checkerboard tests with different sizes of anomalies in the amplitude of ±5 % for checking the horizontal resolution. Fig. 1 shows the results for anomalies with dimensions of 30×30 km. It can be seen that amplitude and shape of the anomalies with such dimensions are reconstructable to a depth of 20 km wherever the inversion is performed. A similar test for anomalies with less dimensions (25×25 km) showed that they become vague with depth. Thus, the testing results allowed concluding that the anomalies with horizontal dimensions of 30 km and greater can be determined reliably to a depth of 20 km. The vertical resolution was checked by assigning the model along the vertical segments with alternating anomalies in the amplitude of ±10 %, with a width of 30 km and change of sign at a depth of 15 km. The anomalies of such dimensions and a contract transition based on sign change at depth were also reconstructed.

Synthetic tests make it possible to choose optimal parameters for inversion performance. A sustainable solution (the absence of any other anomalies) can be based on the following parameter values: horizontal and vertical smoothing (1.0 for P-waves and 2.0 for S-waves), and amplitude damping (0.6 for P-waves and 1.0 for S-waves).

To estimate the reliability of identifying anomalies and the impact of random noise on the tomography results, there was a test on even and odd source numbers, with the inversion performed separately for these two independent samples from the initial catalog. The test results show a good correlation between the anomalies identified.

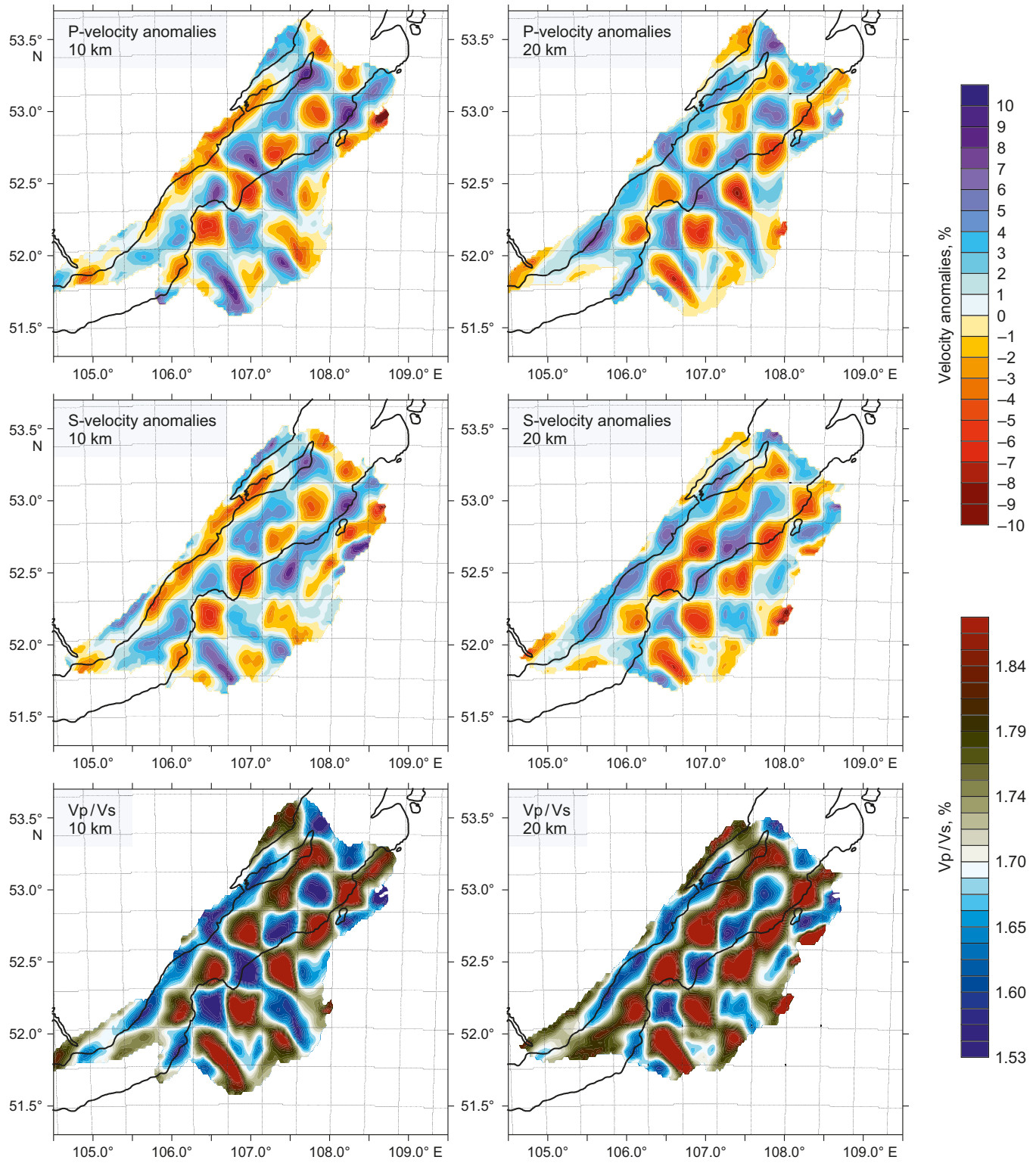

Fig. 1.1. The result of reconstructing synthetic anomalies of size 30×30 km for the study area at depths of 10 and 20 km.