Physics of the Earth and Planetary Interiors xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Seismicity and S-wave velocity structure of the crust and the upper mantle in the Baikal rift and adjacent regions

Alena Seredkina [a,b,*], Vladimir Kozhevnikov [a], Valentina Melnikova [a,b], Oksana Solovey [a]

[a] Institute of the Earth's Crust, SB RAS, Irkutsk, Russia
[b] Diamond and Precious Metal Geology Institute, SB RAS, Yakutsk, Russia

ARTICLE INFO

Article history:
Received 23 September 2016
Received in revised form 28 October 2016
Accepted 28 October 2016
Available online xxxx

Keywords:
Rayleigh waves
Surface-wave tomography
Mantle structure
Seismicity
Seismotectonic deformations
Baikal rift

ABSTRACT

Correlations between seismicity, seismotectonic deformation (STD) field and velocity structure of the crust and the upper mantle in the Baikal rift and the adjacent areas of the Siberian platform and the Mongol-Okhotsk fold belt have been investigated. The 3D *S*-wave velocity structure up to the depths of 500 km has been modeled using a representative sample of Rayleigh wave group velocity dispersion curves (about 3200 paths) at periods from 10 to 250 s. The STD pattern has been reconstructed from mechanisms of large earthquakes, and is in good agreement with GPS and structural data. Analysis of the results has shown that most of large shallow earthquakes fall in regions of low *S*-wave velocities in the uppermost mantle (western Mongolia and areas of recent mountain building in southern Siberia) and in zones of their relatively high lateral variations (northeastern flank of the Baikal rift). In the first case the dominant STD regime is compression manifested in a mixture of thrust and strike-slip deformations. In the second case we observe a general predominance of extension.

1. Introduction

The spatial patterns of seismicity and earthquakes nucleation are largely controlled by rock mechanics, which can be inferred implicitly from seismic wave velocities. Such studies allow tracing back correlations between the crust and upper mantle structure and seismicity in different tectonic provinces. The current activity of the Earth's interior and the origin of seismic structures have important implications for seismic hazard and geodynamics of active regions.

The investigated area (80°E – 132°E, 40°N – 60°N) consists of different tectonic units (Fig. 1), with the Baikal rift being located in the center. In the north there is the Paleozoic West-Siberian plate and the stable Precambrian Siberian platform which inner parts are weakly affected by modern tectonic movements. The Mongol-Okhotsk fold belt comprises besides the seismoactive Baikal rift regions of recent mountain building in southern Siberia and western Mongolia and folded structures of Transbaikalia, central and eastern Mongolia characterized by moderate orogenesis and sparse seismicity (Barth and Wenzel, 2010; Radziminovich et al., 2012). To the south we considered the eastern Tien-Shan, the Tarim basin and the northern parts of the China-Korean platform.

Although velocity structure, seismicity, and stress-strain patterns of the Central Asian lithosphere have been largely investigated separately using different methods (Molnar et al., 1995; Yunga, 1996; Yanovskaya and Kozhevnikov, 2003; Calais et al., 2003; Kuznetsova et al., 2004; Melnikova, 2008; Kozhevnikov and Solovei, 2010; Koulakov, 2011; Rebetsky et al., 2012; Kozhevnikov et al., 2014; Karagianni et al., 2015), there are quite few papers that consider their relations (Krylov and Ten, 1995; Kopnichev and Sokolova, 2003; Lei and Zhao, 2009; Robert et al., 2010; Zhang et al., 2011; Liu and Zhao, 2014; Romano et al., 2014; Wei and Zhao, 2016). Furthermore, most of these studies are concerned with only megathrust earthquakes and limited to the crustal depths giving no information on the mantle structure. The latter is undoubtedly significant as it controls the processes in the crust.

In this article we discuss qualitative correlations between seismicity and upper mantle velocity structure of the Baikal rift and adjacent regions. The seismicity pattern was compared with the 3D shear wave (*S*-wave) velocity structure modeled to the depth of 500 km from the data on Rayleigh wave dispersion. Crustal seimotectonic deformation (STD) field was reconstructed from earthquake focal mechanisms.

* Corresponding author at: Institute of the Earth's Crust, SB RAS, Lermontova St., 128, Irkutsk 664033, Russia.
E-mail address: ale@crust.irk.ru (A. Seredkina).

http://dx.doi.org/10.1016/j.pepi.2016.10.011
0031-9201/

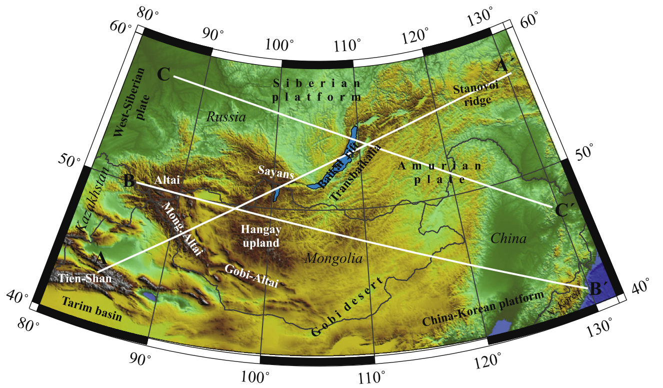

Fig. 1. The study area and the profiles along which the vertical *S*-wave velocity sections were calculated.

1.1. Velocity structure

The S-wave velocity structure was studied on the basis of Rayleigh wave group velocity maps calculated by the authors earlier (Kozhevnikov et al., 2014). The initial dataset consist of records at the LHZ channels of the IRIS broadband digital stations of 145 large ($M \geqslant 5.5$) teleseismic earthquakes occurred between 1991 and 2009 (Fig. 2). The epicentral distances varied approximately from 1500 to 16000 km, so the fundamental Rayleigh wave mode was determined at periods from 10 to 250 s. Rayleigh wave group velocities in this period range are sensitive to depths up to 500 km (Ritzwoller and Levshin, 1998; Yanovskaya, 2015).

The group velocity dispersion curves were calculated using a frequency-time analysis procedure (Levshin et al., 1989), and finally a set of dispersion curves was obtained for about 3200 paths crossing the study area in different directions (Fig. 2). Measurements with close path endpoints were grouped to estimate the uncertainties of group velocity determinations. The standard deviations of the dispersion curve within each group were averaged over all groups. The average measurement uncertainty is in the range 0.02–0.05 km/s, with minimum values relating to the periods from 30 to 175 s.

Lateral variations of group velocities were mapped using 2D tomography technique developed for spherical surface (Yanovskaya et al., 2000; Yanovskaya, 2001, 2015). Altogether, we obtained 18 maps of the Rayleigh wave velocity variations with respect to the average velocities for the periods 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 125, 150, 175, 200, 225, 250 s. Resolution was estimated by calculating the radius of the averaging circular area R (Yanovskaya, 2001) mainly depending on path coverage of the investigated area. Synthetic tests show that values of the radius are comparable with inhomogeneity sizes estimated by checkerboard approach (Yanovskaya, 2015). Example maps of the group velocity variations with resolution for the periods 30, 50, 100 and 200 s are shown in Figs. 3 and 4.

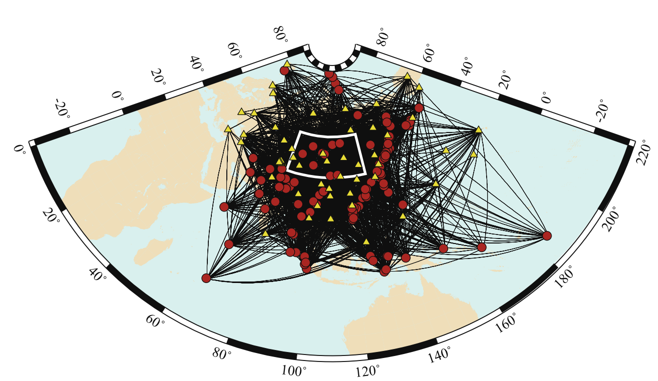

Fig. 2. Map of seismic paths (black lines), stations (triangles) and earthquake epicenters (circles) used in this study. White line contours the study area.

The resolution is the best for the Mongol-Okhotsk fold belt (R < 400 km for T = 20–100 s) and is slightly worse for the Siberian platform (Fig. 3). Note also that the resolution becomes poorer at greater periods (because the seismic paths are sparse), but remains acceptable (R < 1000 km) throughout the mapped area. A similar lateral resolution was achieved in regional studies of Asia based on surface wave data (Priestley et al., 2006; Li et al., 2013).

The obtained group velocity maps (Fig. 4) show some general trends in distribution of large-scale lateral inhomogeneities. Namely, stable regions in the north (the Siberian platform and the West-Siberian plate) are characterized by high group velocities almost in the whole period range. Low group velocities correspond to active tectonic structures of recent mountain building in southern Siberia and western Mongolia. An interesting feature of the calculated distributions is a local velocity minimum under the northeastern flank of the Baikal rift in the period range 30–175 s. At the periods more than 150 s, where velocity variations depend on the structure under the asthenosphere through lower mantle depths, they become smoother and display no evident correlations with geological structures.

In order to study the regional structure in more detail and to estimate the depths of the anomalies, the obtained group velocity maps were used to calculate vertical *S*-wave velocity patterns at different points distributed uniformly over the area. Using the group velocity maps we constructed locally averaged dispersion curves and inverted them to vertical *S*-wave velocity sections up to the 500 km depth by minimizing the misfit between the computed and measured group velocities by the conjugate gradient method. The starting model based on the PREM model (Dziewonski and Anderson, 1981) and consisted of 2 crust layers with constant velocity and 11 mantle layers with *S*-wave velocity varying linear with depth. Only *S*-wave velocities in all layers and thicknesses of the crust layers were allowed to vary since *P*-wave velocities and density cause much weaker effect on Rayleigh wave dispersion curve. Fig. 5 shows an example of the inversion results and data fit for three different regions: the Siberian platform (105° E, 58° N), the Baikal rift (113° E, 56° N) and the Hangay upland (97° E, 48° N). The dispersion curves corresponding to the calculated *S*-wave velocity patterns demonstrate good fit with the local dispersion curves. Comparison of the solutions previously obtained by the conjugate gradients and the Monte-Carlo methods demonstrated good agreement at least up to depths of 400 km (Yanovskaya and Kozhevnikov, 2003). In this paper we draw the major conclusions on lateral heterogeneity for the same depth range.

The obtained 3D *S*-wave velocity distribution was displayed as maps at depths from 50 to 500 km at every 50 km (Fig. 6) and as 2D vertical sections along some profiles crossing the main tectonic units of the area (Figs. 1 and 7). Both *S*-wave velocity maps and sections show vertical and lateral mantle inhomogeneity at all depths. The inhomogeneities appear as zones of high lateral velocity variations at the boundaries between different tectonic structures or as local velocity maximums and minimums. The most prominent velocity contrasts are concentrated in the upper mantle to the depths of 150 km, which is clearly seen in the vertical sections along three profiles (Fig. 7). As in the case of group velocity maps the stable regions in the north possess high *S*-wave velocities up to the depths of 200 km (Fig. 6). The most pronounced velocity minimum in almost the whole depth range is observed under the Hangay upland. The central part of the Baikal rift is characterized by average relative to the study area *S*-wave velocities, while local