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Velocity of seismic waves in the earth's crust and upper mantle of the Siberian platform and Baikal folded region according to underground nuclear explosions

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1. Introduction

During 1976–1987 in the Former USSR in the territory of Irkutsk and Chita area (the Eastern Siberia) and Sakha republic (Yakutia) ten peaceful nuclear explosions (PNE) were conducted (Fig. 1, Table). The explosions in the territory of Irkutsk and Chita area were conducted for scientific applications. They were included in the superlong profiles of deep seismic sounding (DSS) "Rift" and "Meteorite" (3 PNEs) [Pavlenkova & Pavlenkova 2006]. All the rest explosions localized in the south-west of the Republic of Sakha had commercial applications (an increase in oil production, the construction of oil storage facilities, etc.) [Mackey et al. 2005]. PNEs were measured by the regional seismic station network located in the Baikal rift system and surroundings (FDSN code is BAGSR). A number of works studied the explosions in the Republic of Sakha ("Sheksna", "Oka", "Neva-1, 2-1, 2-2, 2-3", "Vyatka") based on the data of the Yakutia regional seismic station network [Mackey et al. 2005, 2011, Burkhard et al. 2016].

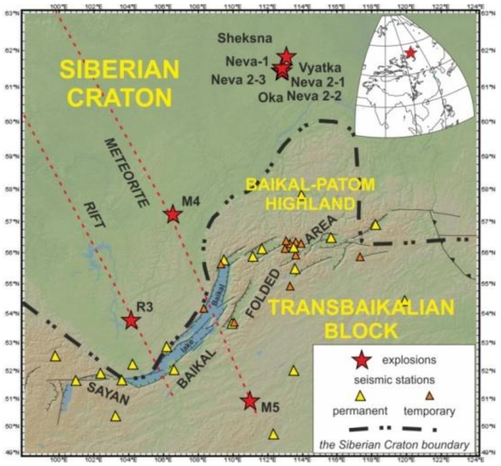

Fig. 1. Baikal network (triangles) and PNEs (stars). Siberian craton is represented by dark area. The location of the long-range seismic profiles Rift and Meteorite are shown by dotted white lines. Numbers: 1 – boundary between the Siberian craton and Sayan-Baikal folded area, 2–4: faults: 2 – normal, 3 – strike-slip, 4 – reverse and thrust.

Table. PNEs location and energy

DATE	ORIGIN TIME	LAT	LO	MB	YIELD	EVNAME
1976310	11/05/76 04:00:00.0	61.4580	112.8660	5.3	15	PNE:Oka
1977222	08/10/77 22:00:00.1	50.9550	110.9820	5.0	8.5	PNE:Meteorite-
1977253	09/10/77 16:00:00.2	57.2510	106.5510	4.8	7.6	PNE:Meteorite-
1978281	10/08/78 00:00:00.0	61.5500	112.8500	5.2	15	PNE:Vyatka
1979280	10/07/79 21:00:00.2	61.8500	113.1000	5.0	15	PNE:Sheksna
1982211	07/30/82 21:00:00.0	53.8000	104.1500	5.0	8.5	PNE:Rift-3
1982283	10/10/82 05:00:00.2	61.5500	112.8500	5.3	15	PNE:Neva-1
1987188	07/07/87 00:00:00.0	61.5000	112.8500	5.1	15	PNE:Neva 2-1
1987205	07/24/87 02:00:00.0	61.4500	112.8000	5.1	15	PNE:Neva 2-2
1987224	08/12/87 01:30:00.5	61.4500	112.8000	5.0	3.2	PNE:Neva 2-3

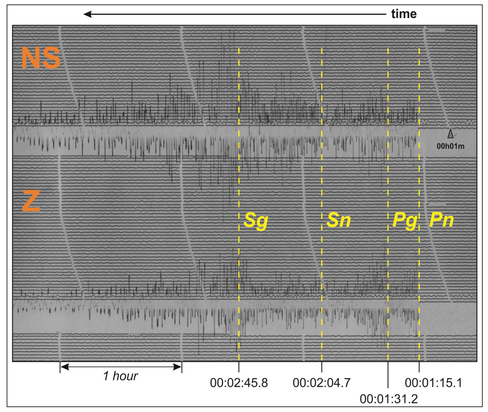

Fig. 2. "Neva 2-1" seismogram (seismic station Nelyaty, epicentral distance 579 km) displaying regional seismic phases observed: Pn, Pg, Sn and Sg.

2. Data

During the nuclear explosions, seismic monitoring in the study area was carried out by the Baikal Experimental-Methodical Seismological Expedition. The network consisted of 20 permanent and 12 temporary analog seismic stations (Fig. 1). The network stations were equipped with short-period and long-period equipment: seismometers SKM and SKD [Equipment 1974]. The registration of seismic events was conducted in a continuous mode with the fixation on photographic paper, the sweep speed was 1 and 2 mm/s.

The distances from the epicenters of the nuclear reactor to seismic stations vary between 173–1407 km. On seismograms, the direct and reflected from the Moho P- and S-wave are well distinguished, and also a train of surface waves is recorded at a number of stations (Fig. 2). In total for 10 explosions, 213 seismograms were processed and 582 values of arrival times of seismic waves were obtained: 154 - Pg, 175 - Pn, 132 - Sg and 121 - Sn. The arrival times obtained were used to estimate regional travel time curves and evaluate the velocities of seismic waves (Fig. 3).

3. Results

The regional travel time curves for Pg, Pn, Sg and Sn seismic phases are shown on Fig. 3. According to the results obtained, the velocities of seismic waves for whole region in the crust are V_{Pg} = 6.12±0.03 km/s и V_{Sg} = 3.58±0.02 km/s, and in the upper mantle – V_{Pn} = 8.25±0.03 km/s, V_{Sn} = 4.57±0.03 km/s.

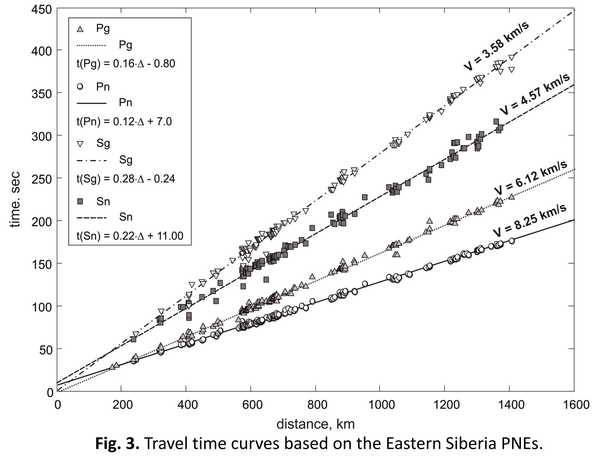

Fig. 3. Travel time curves based on the Eastern Siberia PNEs.

In addition to determining the average seismic wave velocities for the entire region, the average seismic wave velocities in the crust and upper mantle were also obtained for three large blocks: the Siberian platform, the Baikal-Patom highland and the Transbaikalian block (Fig. 4).

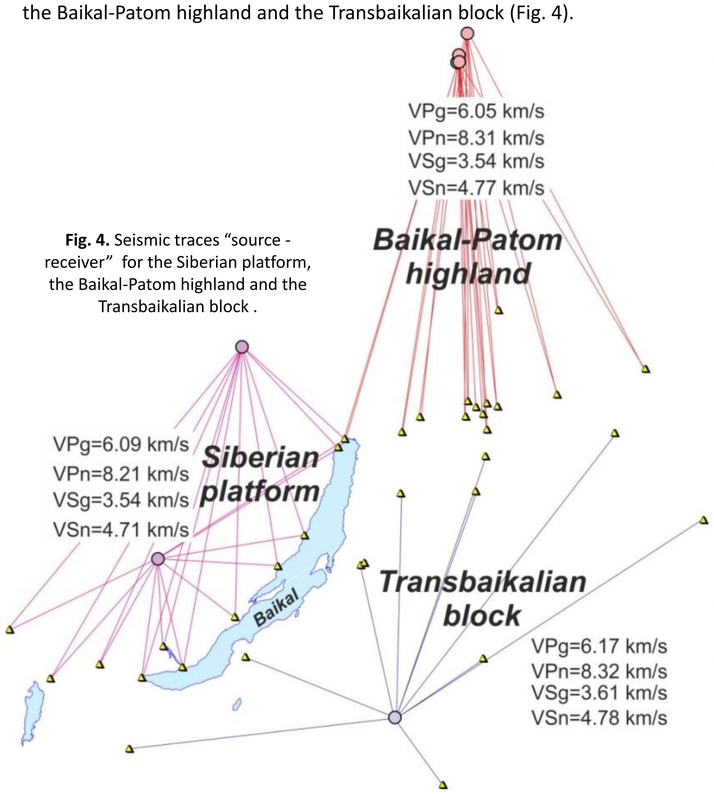

Fig. 4. Seismic traces "source - receiver" for the Siberian platform, the Baikal-Patom highland and the Transbaikalian block .

4. Discussion

In general, the velocities of seismic waves in the crust and upper mantle of the region, obtained in the present study, are in good agreement with the results of studies of the velocity structure of the Baikal rift system and surroundings. In particular, the obtained velocities of P waves in the upper mantle (V_{Pn}=8.25 km/s) are in satisfactory agreement with the velocities at the Moho boundary (8.0 km/s) determined from the results of the DSS in the Baikal rift system (superlong profiles "Rift" and "Meteorite") [Pavlenkova & Pavlenkova 2014]. The velocities of the transverse S waves in the upper mantle correspond to the results of inversion of the receiver functions – V_S=4.4–4.5 km/s [Mordvinova 2009]. The lower values of the velocities in the mantle of the Baikal rift system relative to the Siberian craton reflect the results of the manifestation of active deformations of the lithosphere in the zone of the modern interplate boundary between Eurasia and the Amurian lithospheric plate.

According to the PNEs records obtained on the Yakutia seismic station network (Neva serial), in the earlier works, the P and S wave velocities in the crust and upper mantle of the Siberian Craton were calculated: Pn=8.313 km/s, Pg=6.158 km/s, Sn=4.695 km/s and Sg=3.594 km/s [Mackey et al. 2005] and Pn=8.27 km/s, Pg=6.20 km/s, Sn=4.67 km/s and Sg=3.55 km/s [Burkhard et al. 2016] (Fig. 5).

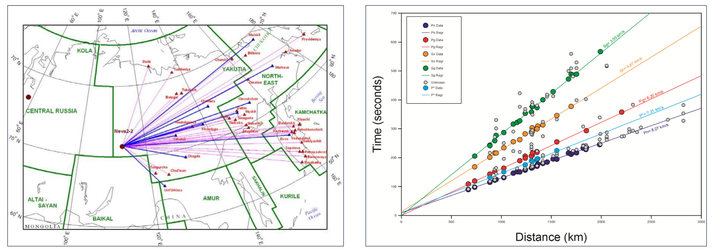

Fig. 4. Seismic traces "source - receiver" for Yakutian PNEs (left) anf travel time curves (right).

It can be seen that the values of the velocities of seismic waves in the upper mantle obtained in this work for the same events at the stations of the Baikal region are much lower: ~0.2–0.8 % for P waves and ~ 0.4–2.7 % for S waves, while in the srust, on the contrary, they are higher – 0.6–1.3 %. Such a spatial distribution of the velocities of seismic waves agrees well with the SibCrust model: for the territory of the Siberian craton the P wave velocities in the upper mantle are equal to ~8.2 km/s, the average crust is characterized by lower P wave velocities (down to 5.2 km/s), in a crystalline crustal basement – V_{Pg}=6.6 km/s; for the Sayan-Baikal folded area, the seismic velocities in the mantle are reduced to 8.1 km/s, while in the crust and basement, on the contrary, an increase in seismic wave velocities is observed – V_{Pg}=5.8–6.7 km/s [Cherepanova et al. 2013] (Fig. 6) .

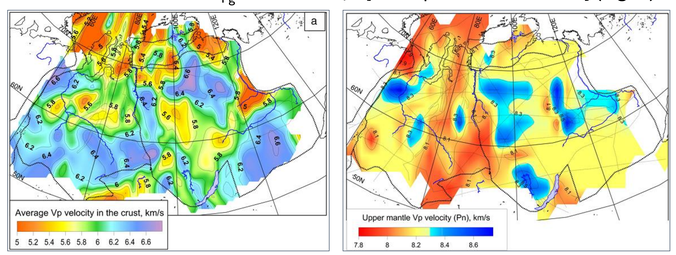

Fig. 5. Seismic wave velocities in the crust (left) and in the upper mantle (right) according to the SibCrust model [Cherepanova et al., 2013]

Low velocities of seismic waves indicate the presence of low-velocity anomalies in the region under the crust. Earlier, the presence of anomalously low velocities of seismic waves under the Moho in the Baikal rift system was noted according to the deep seismic sounding data [Krylov et al. 1981]. Also, the layer of high attenuation of seismic waves under the crust of the northeast flank of the Baikal rift system has been detected by the seismic quality factor calculations [Dobrynina et al. 2016]. The presence of such a layer was associated with the possible partial melting of matter under the crust of the northeast flank of the Baikal rift system [Pospeev 2012].

Conclusion

As a result of the processing of analogue seismograms of PNEs recorded by the Baikal regional seismic station network at the distances from 173 to 1407 km, the regional travel time curves of the direct and reflected from Moho P and S waves are constructed, which can be used later to localize regional earthquakes and industrial explosions in the north of the region. The velocities of seismic waves in the crust and upper mantle were determined. According to the data obtained, low velocities in the upper mantle and high in the crust are well traced.