Peaceful nuclear explosions in Eastern Siberia and the republic of Sakha on the base of Baikal regional seismic data

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Abstract **–** During 1976-1987 in the territory of Eastern Siberia (the Siberian platform, Chitinskaya area and Yakutia) ten peaceful nuclear explosions (PNEs) were conducted. The PNEs' magnitudes ranged from 4.8 to 5.3. Explosions were measured by regional analogue seismic station networks located in the Baikal rift system at epicenter distances from 246 to 1407 km. Regional travel times distributions for the regional seismic phases (Pn, Pg, Sn, Sg and Rg) were constructed using arrival times of 10 PNEs. Based on these data the regional velocities of seismic waves were determined: VPn = 8.31 km/s, VPg = 6.12 km/s, VSn = 4.62 km/s, VSg = 3.60 km/s. The velocities obtained are well correlated with the data known on the velocity structure of the Baikal rift system.

Keywords **–** nuclear explosion; controlled source seismology; body waves velocity; structure of the Earth

I. 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 [1]. 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) [2]. 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.) [3]. The PNEs have yields in the range of 3.2 to 15 kT [2].

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 [2, 4, 5]. However, until now, the data of the Baikal network for the treatment of PNEs have not been involved. The paper presents the first results of the treatment of seismograms obtained by BAGSR regional network.

II. REGION

The first order ancient tectonic structures of the East Siberia region considered are the Archaean-Proterozoic Siberian craton and Sayan-Baikal folded area. The Cenozoic Baikal rift system is superimposed on both ancient structures (Fig. 1). Together with the Aldan-Stanovoy mobile zone it presents an active interplate border between Eurasia and the Amurian plate. Velocity studies of the crust and the upper mantle by DSS have revealed a low velocity layer in the upper part of the crust of the Baikal rift [6]. Its position agrees with other data sets such as seismology, magnetometry and magneto-telluric sounding and is found along the whole rift system [6]. According to the DSS data [6], the area with an abnormally low velocity of seismic waves (VP=7.6–7.8 km/s, VS=4.3 km/s) on the surface of the mantle is observed over the vast territory under the Sayan-Baikal folded area. The normal mantle is located under the Siberian craton (VP=8.0–8.1 km/s, VS=4.55 km/s). The results of the inversion of the residuals of the P-wave travel times showed an decrease in the seismic wave velocities under the northeastern flank of the Baikal rift system due to the heat and mass transfer from under the Siberian Craton [7]. The results of magneto-telluric sounding show that the roof of the layer with high electrical conductivity identified within the mantle lies at 200 km depth under the Siberian craton, at 100 km depth under the southern Baikal rift and at 60 km depth in the northern rift [8, 9]. Deep sounding data [10], gravity analyses [11] and seismic tomography data integraion [12] show that the crustal thickness varies within 35–42 km under the Baikal basin, 43–55 km under uplifts of for the NE part of the rift system and 36–43 km under the Siberian craton.

III. Data

During the nuclear explosions, seismic monitoring in the study area was carried out by the Baikal Experimental-Methodical Seismological Expedition on the base of the Institute of the Earth's Crust of the Siberian branch of the Russian Academy of Science (at present – Baikal branch of the Federal Research Center "United Geophysical Service of the Russian Academy of Science"). In the period from 1976 to 1987 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 [13]. 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.

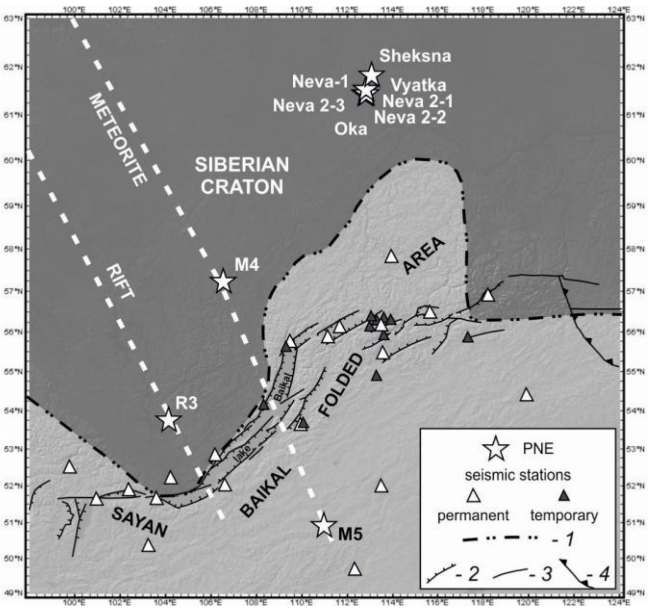

Figure 1. Baikal network (triangles) and PNEs (stars). Siberian craton is represented by dark area. The location of the long-range seismic profiles Rift and Meteorite are shown by dotted white lines. Numbers: 1 – boundary between the Siberian craton and Sayan-Baikal folded area, 2–4: faults: 2 – normal,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

In the period under review, a local temporary network of seismic stations worked in the area of the North Muisky Tunnel (the Baikal-Amur Railway). Therefore, in the region of the northeastern flank of the Baikal rift, the majority of seismic stations were concentrated – 19 points (Fig. 1). The distances from PNE's epicenters to seismic stations vary within 246–1407 km. For these events according to analog seismograms we determined the arrival times of the main regional seismic phases – Pg, Pn, Sg and Sn. The arrival times obtained were used to relocate epicenters of explosions and estimate the velocities of seismic waves.

A number of publications, as well as the website of the International Seismological Center, give the coordinates and depths of the PNEs determined in a various ways: geodetical [1], seismical (using teleseismic data obtained by different seismological agencies of the World [14]), search of places of explosions (mines) in the locality [4], and for PNEs included in the superlong profiles of deep seismic sounding "Rift" and "Meteorite" – also according to archival data [2]. For each explosion there are 6 to 9 different definitions of the parameters of the source. Coordinates of the epicenter and depth, origin time and magnitude of the events can vary greatly (differences in coordinates can be several degrees, and depths range from 0 to 38.3 km). In present work, the reconstruction of PNE epicenters was carried out using the HYPOICENTER software [15]. We used the velocity models for the Siberian craton and Sayan-Baikal folded area obtained as a result of the DSS according to the superlong profiles "Rift" and "Meteorite" [2].

For the explosions in the territory of the Sakha Republic, relocalization was carried out according to the data of all stations in the network, and also taking into account the seismic wave arrival times only at the stations located in the northeastern flank. In calculating, the depths of the hypocenters were fixed to the depths given in [1]. For the relocalization of the epicenters of the PNEs "Meteorite-4" and "Meteorite-5", the number of seismic phases use was equal to 9 and 19, for the events in the territory of the Sakha Republic – from 26 to 52 phases. The deviation in the origin time varies from 0.5 to 5.2 seconds, the displacement of the coordinates of the epicenter in some cases can reach ~40 km.

The total of 190 seismograms registered at the distances from 246 to 1407 km were processed and 540 seismic wave arrival times were obtained: 161 – Pg, 139 – Pn, 108 – Sg and 132 – Sn. These times were used to construct regional travel time curves and determine the velocities of seismic waves in the crust and upper mantle of the region (Fig. 2). According to the results obtained, the velocities of seismic waves in the crust are VPg = 6.12±0.02 km/s и VSg = 3.60±0.02 km/s, and in the upper mantle – VPn = 8.31±0.02 km/s, VSn = 4.62±0.04 km/s.

IV. Discussion

Significant variations of the origin times and errors in determining of the epicenters obtained during the relocalization of PNEs according to the data of the Baikal regional seismic station network can be explained both by the one-sided location and remoteness of seismic stations and by the unsatisfactory velocity model of the medium chosen for calculations. The comparison of the real travel times of seismic waves from PNEs in the territory of the Sakha Republic with theoretical ones has shown that for P waves in the crust there is a delay in the arrival times, whereas for the upper mantle for P and S waves, on the contrary, earlier arrival times are observed. For the Sg waves, the theoretical and observed arrival times coincide. This also indicates that the actual velocity structure on the path from the epicenters of PNEs to the Baikal rift system may differ significantly from the model chosen. The problem of choosing a good velocity model is complicated by the fact that the source-receiver path passes through two tectonic structures – the consolidated Siberian craton and the Sayan-Baikal fold area, that is characterized by a high degree of heterogeneity. A possible solution to the problem of choosing a valid velocity model can be the inversion of the seismic wave arrival time residuals from the PNEs using the coordinates and depths of explosions certified on the terrain according to the data [16].

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 (VPn=8.31 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”) [2]. The velocities of the transverse S waves in the upper mantle correspond to the results of inversion of the receiver functions – VS=4.4–4.5 km/s [7]. 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 [3] and Pn=8.27 km/s, Pg=6.20 km/s, Sn=4.67 km/s and Sg=3.55 km/s [5]. It can be seen that the values of the velocities of S-waves in the upper mantle obtained in this work for the same events at the stations of the Baikal region are much lower ~ 1.1–1.6 %; for P-waves velocities are higher ~ 0.5%, while in the srust, on the contrary, velocity of S-wave is higher – 0.2–1.4 %, and velocity of P-wave is lower: ~ 0.6–1.3 %. Such a spatial distribution of the velocities of seismic waves satisfactory agrees 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 – VPg=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 – VPg=5.8–6.7 km/s [12].

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 [6]. 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 [17]. 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 [18].

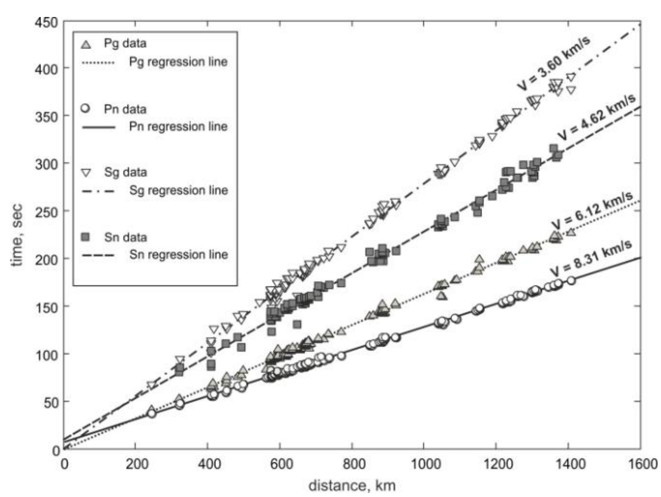

Figure 2. Travel time curves based on the Eastern Siberia PNEs.

V. CONCLUSIONS

As a result of the processing of analogue seismograms of PNEs recorded by the Baikal regional seismic station network at the distances from 246 to 1407 km, the data on the arrival times of seismic waves Pn, Pg, Sn and Sg were obtained. The relocalization of nuclear explosion epicenters using regional velocity models was made. 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.

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