

## Results and prospects of seismological observations in the central part of the Baikal rift

© 2021 Ts.A. Tubanov<sup>1,2</sup>, P.A. Predein<sup>1,2</sup>, L.R. Tsydyпова<sup>1,2</sup>, D.P.-D. Sanzhieva<sup>1,2</sup>, N.A. Radziminovich<sup>1,3</sup>, A.D. Bazarov<sup>1,2</sup>

<sup>1</sup>BuD GS RAS, Ulan-Ude, Russia; <sup>2</sup>GIN SB RAS, Ulan-Ude, Russia; <sup>3</sup>IEC SB RAS, Irkutsk, Russia

Received March 10, 2021

**Abstract** This article reports the results of detailed seismological observations in the Central Baikal region conducted by the local network of seismological stations of the Buryat Division of the Geophysical Survey of the Russian Academy of Sciences. The local network was created in the 1990s. A crucial feature of the network is the combination of seismic monitoring both in the passive mode (the study of natural seismicity) and in the active mode, with a controlled vibration source of seismic waves. The study area covers the Lake Baikal region and adjacent territories characterized by high seismic activity. Here occurred several catastrophic earthquakes including the strongest one during the period of instrumental observations – the Middle Baikal' 1959 earthquake. Recently here occurred the Kudarinsky earthquake on December 9, 2020 with  $m_b=5.4$ . For more than twenty years the network of observations has been expanding, the equipment has been upgrading. A significant amount of seismological material has been accumulated. Broadband data was processed by the receiver function method. The Moho and the lithosphere-asthenosphere boundaries for stations of the network are determined. Shear seismic wave attenuation characteristics are obtained and the possibility of energy classification of Baikal earthquakes by coda-waves total oscillations is shown.

**Keywords** seismicity, Baikal rift, deep structure, method of receiver functions, attenuation of seismic waves.

**For citation** Tubanov, Ts.A., Predein, P.A., Tsydyпова, L.R., Sanzhieva, D.P.-D., Radziminovich, N.A., & Bazarov, A.D. (2021). [Results and prospects of seismological observations in the central part of the Baikal rift]. *Rossiiskii seismologicheskii zhurnal* [Russian Journal of Seismology], 3(4), 38-57. (In Russ.). DOI: <https://doi.org/10.35540/2686-7907.2021.4.03>

### References

- Aki, K. (1980). Scattering and attenuation of shear waves in the lithosphere. *Journal of Geophysical Research: Solid Earth*, 85(B11), 6496-6504.
- Aki, K., & Chouet, B. (1975). Origin of coda waves: source, attenuation, and scattering effects. *Journal of Geophysical Research*, 80(23), 3322-3342.
- Anan'in, L.V., Mordvinova, V.V., Gots', M.F., Kanao, M., Suvorov, V.D., Tat'kov, G.I., & Tubanov, Ts.A. (2009). Velocity structure of the crust and upper mantle in the Baikal Rift Zone from the long-term observations of broadband seismic stations. *Doklady Earth Sciences*, 428(7), 1067.
- Aranovich, Z.I., Kirnos, D.P., & Fremd, V.M. (Resp. Eds.). (1974). *Apparatura i metodika seismometricheskikh nabludenii v SSSR* [Equipment and methods of seismometric observations in the USSR]. Moscow, Russia: Nauka Publ., 245 p. (In Russ.).
- Bisztricsány, E. (1959). On the determination of earthquake magnitudes. *Annales Universitatis Scientiarum Budapestinensis de Rolando Eotvos Nominatae. Sectio Geolog.*, 39-51.
- Borovik, N.S. (1988). [Seismic regime according to the regional and local observation systems in the Baikal region]. In *Issledovaniia po poiskam predvestnikov zemletriasenii v Sibiri* [Research on the search for earthquake precursors in Siberia] (pp. 109-115). Novosibirsk, Russia: Nauka Publ. (In Russ.).
- Dantsig, L.G., & Dergachev, A.A. (1990). [Characteristics of weak earthquake foci in the Baikal region]. In *Seismichnost' Baikal'skogo rifta: prognosticheskie aspekty* [Seismicity of the Baikal rift: prognostic aspects] (pp. 17-22). Novosibirsk, Russia: Nauka Publ. (In Russ.).
- Dergachev, A.A. (1982). [Methods and results of determining the absorption of seismic waves in the central part of the Baikal rift zone]. *Geologiya i geofizika* [Geology and Geophysics], 23(6), 94-101. (In Russ.).
- Dobrynina A.A., Sankov, V.A., Déverchère, J., & Chechel'nitsky, V.V. (2017). Factors influencing seismic wave attenuation in the lithosphere in continental rift zones. *Geodynamics & Tectonophysics*, 8(1), 107-133. (In Russ.)
- Dobrynina, A.A., Chechel'nitskii, V.V., & San'kov, V.A. (2011). Seismic quality factor of the lithosphere of the southwestern flank of the Baikal rift system. *Russian Geology and Geophysics*, 52(5), 555-564.
- Dobrynina, A.A., Predein, P.A., Sankov, V.A., Tubanov, T.A., Sanzhieva, D.P., & Gorbunova, E.A.

- (2019). Spatial variations of seismic wave attenuation in the South Baikal basin and adjacent areas (Baikal rift). *Geodynamics & Tectonophysics*, 10(1), 147–166. (In Russ.)
- Dobrynina, A.A., Sankov, V.A., & Chechel'nitsky, V.V. (2016). New data on seismic wave attenuation in the lithosphere and upper mantle of the northeastern flank of the Baikal rift system. *Doklady Earth Sciences*, 468(1), 485–489.
- Farra, V., & Vinnik, L.P. (2000). Upper mantle stratification by P and S receiver functions. *Geophysical Journal International*, 141, 699–712.
- Goldin, S.V. (2004). Dilatancy, repacking, and earthquakes. *Izvestiya. Physics of the Solid Earth*, 40(10), 817–832.
- Gol'din, S.V., Dyad'kov, P.G., & Dashevskii, Y.A. (2001). The South Baikal geodynamic testing ground: strategy of earthquake prediction. *Russian Geology and Geophysics*, 42(10), 1484–1496.
- Gusev, A.A., Chebrov, D.V., Potanin, M.E., & Tishkin, V.R. (2015). [Spectral code-magnitude for Kamchatka earthquakes]. In *Problemy kompleksnogo geofizicheskogo monitoringa Dal'nego Vostoka Rossii. Trudy Piatoi nauchno-tekhnicheskoi konferentsii* [Problems of integrated geophysical monitoring of the Russian Far East. Proceedings of the Fifth Scientific and Technical Conference] (pp. 337–343). Petropavlovsk-Kamchatsky, Russia: KB GS RAS Publ. (In Russ.)
- Haskell, N.A. (1962). Crustal reflection of plane P and SV waves. *Journal of Geophysical Research*, 67, 4751–4767.
- Havskov, J., & Ottemoller, L. (2010). *Routine data processing in earthquake seismology: With sample data, exercises and software*, Springer Science & Business Media, 347 p.
- Kennett, B.L.N. (1991). IASPEI91 Seismological Tables, Canberra, Australia: Australian National University, 167 p.
- Kobeleva, E.A., Gileva, N.A., Khamidulina, O.A., & Tubanov, Ts.A. (2020). [The Baikal region and Transbaikalia. Results of seismic monitoring of various regions of Russia]. In *Zemletriaseniia Rossii v 2018 godu* [Earthquakes in Russia in 2018] (pp. 44–50). Obninsk, Russia: GS RAS Publ. (In Russ.)
- Kochetkov, V.M., Borovik, N.S., Misharina, L.A., Solonenko, A.V., Anikanova, G.V., Solonenko, N.V., Mel'nikova, V.I., & Gileva, N.A. (1987). *Angarakanskii roi zemletriaseniia v Baikal'skoi riftovoi zone: Usloviia vozniknoveniia i osobennosti razvitiia* [Angarakan earthquake swarm in the Baikal rift zone: Conditions of occurrence and features of development]. Novosibirsk, Russia: Nauka Publ., 80 p. (In Russ.)
- Kochetkov, V.M. (1988). [On the state and prospects of development of works on the creation of scientific bases for earthquake forecasting]. In *Issledovaniia po poiskam predvestnikov zemletriaseniia v Sibiri* [Research on the search for earthquake precursors in Siberia] (pp. 3–8). Novosibirsk, Russia: Nauka Publ. (In Russ.)
- Kochetkov, V.M., Borovik, N.S., Solonenko, A.V., & Misharina, L.A. (1985). [Detailed seismological studies in the Severo-Muysky district]. In *Geologiya i seismichnost' zony BAM. Seismichnost'* [Geology and seismicity of the BAM zone. Seismicity], 6, 123–180. (In Russ.)
- Kondorskaia, N.V., & Shebalin, N.V., (Eds.) (1977). *Novyi katalog sil'nykh zemletriaseniia na territorii SSSR s drevneishikh vremen do 1975 g.* [A new catalog of strong earthquakes on the territory of the USSR from ancient times to 1975.]. Moscow, Russia: Nauka Publ., 536 p. (In Russ.)
- Kopnichev, Yu.F. (1991). [New data on the structure of the upper mantle of the Baikal rift system]. *Doklady Akademii nauk* [Doklady of Academy of Sciences], 325(5), 944–949. (In Russ.)
- Kosarev, G.L., Makeeva, L.I., & Vinnik, L.P. (1987). Inversion of teleseismic P-wave particle motions for crustal structure in Fennoscandia. *Physics of the Earth and Planetary Interiors*, 47, 11–24.
- Lee, W.S., & Sato, H. (2006). Power-law decay characteristic of coda envelopes revealed from the analysis of regional earthquakes. *Geophysical research letters*, 33(7), 4.
- Levi, K.G., Babushkin, S.M., Badardinov, A.A., Buddo, V.Y., Larkin, G.V., Miroshnichenko, A.I., Sankov, V.A., Ruzhich, V.V., Wong, H.K., Delvaux, D., & Colman, S. (1995). Active Baikal Tectonics. *Russian Geology and Geophysics*, 36(10), 143–154.
- Logachev, N.A. (2003). History and Geodynamics of the Baikal Rift. *Russian Geology and Geophysics*, 44(5), 373–387.
- Lunina, O.V. (2016). The digital map of the Pliocene–Quaternary crustal faults in the Southern East Siberia and the adjacent Northern Mongolia. *Geodynamics & Tectonophysics*, 7(3), 407–434. (In Russ.)
- Mel'nikova, V.I., Gileva, N.A., Imaev, V.S., Radziminovich, Y.B., & Tubanov, T.A. (2013). Features of seismic activation of the Middle Baikal region, 2008–2011. *Doklady Earth Sciences*, 453(2), 1282–1287.
- Mitchell, B.J. (1981) Regional variation and frequency dependence of  $Q\beta$  in the crust of the United States. *Bulletin of the Seismological Society of America*, 71(5), 1531–1538.
- Mordvinova, V.V., & Artemyev, A.A. (2010). The three-dimensional shear velocity structure of lithosphere in the southern Baikal rift system and its surroundings. *Russian Geology and Geophysics*, 51(6), 694–707.
- Mordvinova, V.V., Kobelev, M.M., Treussov, A.V., Khritova, M.A., Trynkova, D.S., Kobeleva, E.A., & Lukhneva, O.F. (2016). Deep structure of the Siberian

- platform – Central Asian mobile belt transition zone from teleseismic data. *Geodynamics & Tectonophysics*, 7(1), 85-103. (In Russ.).
- Mosegaard, K., & Vestergaard, P.D. (1991). A simulated annealing approach to seismic model optimization with sparse prior information. *Geophysical Prospecting*, 39, 599-611.
- Nielsen, C., & Thybo, H. (2009). No Moho uplift below the Baikal Rift Zone: Evidence from a seismic refraction profile across southern Lake Baikal. *Journal of Geophysical Research*, 114, 22.
- Pavlenko, O.V., & Tubanov, T.A. (2017). Characteristics of radiation and propagation of seismic waves in the Baikal Rift Zone estimated by simulations of acceleration time histories of the recorded earthquakes. *Izvestiya, Physics of the Solid Earth*, 53(1), 18-31.
- Predein, P.A., Dobrynina, A.A., Tubanov, Ts.A., & German, E.I. (2017). CodaNorm: A software package for the body-wave attenuation calculation by the coda-normalization method. *SoftwareX*, 6, 30-35.
- Puzyrev, N.N. (Ed.) (1993). *Detal'nye seismicheskie issledovaniia litosfery na P- i S-volnakh* [Detailed seismic studies of the lithosphere at P- and S-waves]. Novosibirsk, Russia: Nauka Publ., 199 p. (In Russ.).
- Radziminovich, N.A., & Miroshnichenko, A.I. (2020). The Ust'-Barguzin Transfer Zone (Central Baikal): Seismological evidence on the transtensive stress field of the crust. *Doklady Earth Sciences*, 493(2), 636-639.
- Rautian, T.G., & Khalturin, V.I. (1978). The use of the coda for determination of the earthquake source spectrum. *Bulletin of the Seismological Society of America*, 68(4), 923-948.
- Rautian, T.G., Khalturin, V.I., Zakirov, M.S., Zemtsova, A.G., Proskurin, A.P., Pustovitenko, B.G., Pustovitenko, A.N., Sinel'nikova, L.G., Filina, A.G., & Shengeliia, I.S. (1981). *Eksperimental'nye issledovaniia seismicheskoi kody* [Experimental studies of the seismic code]. Moscow, Russia: Nauka Publ., 142 p. (In Russ.).
- Sanzhieva, D.P.-D., Predein, P.A., Tubanov, Ts.A., & Bazarov, A.D. (2019). [The database of seismological data of the Srednebaikalsky region of the Baikal rift zone for 2001–2013]. Certificate of State registration of a database RF, no. 2019621509. (In Russ.).
- Sato, H., & Fehler, M.C. (2009). Attenuation of high-frequency seismic waves. In *Seismic wave propagation and scattering in the heterogeneous earth*, Springer, Berlin, Heidelberg, 109-148.
- Song, Y., Krylov, S.V., Yang, B., Cai, L., Dong, S., Liang, T., Li, J., Xu, X., Mishenkina, Z.R., Petrik, G.V., Shelud'ko, I.F., Seleznev, V.S., & Solov'ev, V.M. (1996). Deep seismic sounding of the lithosphere on the Baikal – Northeastern China international transect. *Russian Geology and Geophysics*, 37(2), 1-13.
- Suvorov, V.D., Mordvinova, V.V., Tat'kov, G.I., & Tubanov, Ts.A. (2011). [Velocities of shear waves in the Earth's crust of the Baikal rift according to the DSS data, receiver functions and nearby earthquakes]. In *Dinamika fizicheskikh polej Zemli* [Dynamics of physical fields of the Earth] (pp. 90-108). Moscow, Russia: Svetoch Plus Publ. (In Russ.).
- Suvorov, V.D., & Tubanov, Ts.A. (2008). Distribution of local earthquakes in the crust beneath central Lake Baikal. *Russian Geology and Geophysics*, 49(8), 611-620.
- Tat'kov, G.I. (2009). [Geophysical monitoring of the stress-strain state of natural and technical systems. Dr. geol. and mineral. sci. diss. abs.]. Irkutsk, Russia, 43 p. (In Russ.).
- Tat'kov, G.I., & Tubanov, Ts.A. (2004). [Development of the seismic process and near-real-time monitoring of the zone of the 1999 South Baikal earthquake]. *Vestnik Buriatskogo Universiteta* [Bulletin of the Buryat University], 3(3), 35-46. (In Russ.).
- Tat'kov, G.I., Tubanov, Ts.A., Bazarov, A.D., Tolochko, V.V., Kovalevskii, V.V., Braginskaia, L.P., & Grigoriuk, A.P. (2013). [Vibroseismic studies of the lithosphere of the Baikal rift zone and adjacent territories]. *Otechestvennaia geologiya* [Domestic geology], 3, 16-23. (In Russ.).
- Tikhonov, A.N., & Arsenin, V.Ia. (1979). *Metody resheniia nekorrektnykh zadach* [Methods for solving incorrect problems]. Moscow, Russia: Nauka Publ., 288 p. (In Russ.).
- Tsumura, K. (1967). Determination of earthquake magnitude from total duration of oscillation. *Bulletin of the Earthquake Research Institute. University of Tokyo*, 45, 7-18.
- Tsydyanova, L.R., Tubanov, Ts.A., Predein, P.A., & Sanzhieva, D.P.-D. (2013). [Selenga Network of seismological and vibroseismic observations]. In *Materialy VIII mezhdunarodnoi seismologicheskoi shkoly "Sovremennye metody obrabotki i interpretatsii seismologicheskikh dannykh"* [Proceedings of the VIII International Seismological Workshop "Modern Methods of Processing and Interpretation of Seismological Data"] (pp. 342-345). Obninsk, Russia: GS RAS Publ. (In Russ.).
- Tubanov, Ts.A., Sanzhieva, D.P.-D., Gileva, N.A., & Suvorov, V.D. (2019). [Hodographs of seismic waves of earthquakes in the north-east of the Baikal Rift]. *Estestvennye i tekhnicheskie nauki* [Natural and Technical Sciences], 12, 160-164. (In Russ.).
- Tubanov, Ts.A., Suvorov, V.D., & Gileva, N.A. (2018). [On the influence of lateral velocity inhomogeneities on the accuracy of estimating the depth of nearby earthquakes]. *Estestvennye i tekhnicheskie nauki* [Natural and Technical Sciences], 12, 114-117. (In Russ.).
- Vinnik, L.P. (1977). Detection of P to SV in the mantle. *Phys. Earth planet. Inter.*, 15, 39-45.

- Vinnik, L.P., Oreshin, S.I., Tsydyпова, L.R., Mordvinova, V.V., Kobelev, M.M., Khritova, M.A., & Tubanov, T.A. (2017). Crust and mantle of the Baikal rift zone from P- and S-wave receiver functions. *Geodynamics & Tectonophysics*, 8(4), 695-709. (In Russ.).
- Zeng, Y., Su, F., & Aki, K. (1991). Scattering wave energy propagation in a random isotropic scattering medium: 1. Theory. *Journal of Geophysical Research: Solid Earth*, 96 (B1), 607-619.

### Information about authors

**Tubanov Tsyren Alekseevich**, PhD, Director of the Buryat Division of the Geophysical Survey of the Russian Academy of Sciences (BuD GS RAS), Ulan-Ude, Russia; Head of the Laboratory of Geological Institute of Siberian Branch of Russian Academy of Sciences (GIN SB RAS), Ulan-Ude, Russia. E-mail: ttsyren@gmail.com

**Predein Petr Alekseevich**, Engineer of the BuD GS RAS, Junior Researcher of the GIN SB RAS, Ulan-Ude, Russia. E-mail: crmpeter@gmail.com

**Tsydyпова Larisa Rinchinovna**, PhD, Engineer of the BuD GS RAS, Researcher of the GIN SB RAS, Ulan-Ude, Russia. E-mail: laraMGU@yandex.ru

**Radziminovich Natalia Anatolievna**, PhD, Engineer of the BuD GS RAS, Researcher of the Institute of the Earth's Crust of the Siberian Branch of the Russian Academy of Sciences (IEC SB RAS), Irkutsk, Russia. E-mail: nradzim@crust.irk.ru

**Sanzhieva Darima Purba-Dorzhiyevna**, Engineer of the BuD GS RAS, 2nd category Engineer of the GIN SB RAS, Ulan-Ude, Russia. E-mail: gindarima@mail.ru

**Bazarov Artem Dambievich**, PhD, Engineer of the BuD GS RAS, Researcher of the GIN SB RAS, Ulan-Ude, Russia. E-mail: adbazarov@yandex.ru