Journal of Asian Earth Sciences 62 (2013) 146–161

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

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

Seismicity of the Baikal rift system from regional network observations

N.A. Radziminovich [a,*], N.A. Gileva [b], V.I. Melnikova [a], M.G. Ochkovskaya [a,b]

[a] Institute of the Earth's Crust SB RAS, Lermontov Street 128, Irkutsk 664033, Russia
[b] Baikal Division of the Geophysical Survey of SB RAS, Lermontov Street 128, Irkutsk 664033, Russia

ARTICLE INFO

Article history:
Available online 7 November 2012

Keywords:
Baikal rift
Regional seismic network
Seismicity

ABSTRACT

In the paper we report the state-of-the-art of seismicity study in the Baikal rift system and the general results obtained. At present, the regional earthquake catalog for fifty years of the permanent instrumental observations consists of over 185,000 events. The spatial distribution of the epicenters, which either gather along well-delineated belts or in discrete swarms is considered in detail for different areas of the rift system. At the same time, the hypocenters are poorly constrained making it difficult to identify the fault geometry. Clustered events like aftershock sequences or earthquake swarms are typical patterns in the region; moreover, aftershocks of $M \geqslant 4.7$ earthquakes make up a quarter of the whole catalog. The maximum magnitude of earthquakes recorded instrumentally is $M_{LH}7.6$ for a strike-slip event in the NE part of the Baikal rift system and $M_{LH}6.8$ for a normal fault earthquake in the central part of the rift system (Lake Baikal basin). Predominant movement type is normal faulting on NE striking faults with a left lateral strike-slip component on W–E planes. In conclusion, some shortcomings of the seismic network and data processing are pointed out.

1. Introduction

The Baikal rift system (BRS) is an intracontinental rift consisting of a number Cenozoic basins linked by topographic highs. It extends for approximately 1500 km from northern Mongolia in the southwest to southern Yakutia in the northeast (Fig. 1). The structural setting of the rift is controlled by its position between the Precambrian Siberian craton and the Sayan-Baikal and Mongolia–Okhotsk mobile belts. According to Logatchev and Florensov (1978), Baikal rifting started in the Middle Eocene with the formation of the Southern Baikal basin that is the oldest and deepest basin of the BRS. The thickness of Cenozoic sediments is up to 7 km there (Hutchinson et al., 1992). Other basins have the sedimentary layers with thickness less than 4 km. The rift basins are structurally half grabens with steep northern or north-western sides bordered by master faults. A remarkable feature of the BRS is absence of the present day active volcanism. Late Cenozoic volcanic fields are located off the rift basins and their mountain shoulders.

There are some discrepancies in the crust thickness estimates. For the rift basins they vary from 34–36 km (Gao et al., 2004; Puzyrev et al., 1973; Zorin et al., 2002) to 40–42 km (Suvorov et al., 2002; ten Brink and Taylor, 2002; Nielsen and Thybo, 2009). The depth to the Moho discontinuity beneath the Siberian platform and the Sayan-Baikal fold belt is considered to be 38–42 km and 45–50 km correspondingly. According to that, the estimates of the amount of crust thinning beneath the BRS range from a few km to 10 km. In the work by Nielsen and Thybo (2009) no thinning has been revealed at all. Contradictory results have been obtained also for the state of the upper mantle beneath the BRS. Some studies suggested low seismic velocities such as 7.6–7.8 km/s (Puzyrev et al., 1973; Gao et al., 2003; Achauer and Masson, 2002; Brazier and Nyblade, 2003; Tiberi et al., 2003; Zhao et al., 2006), whereas others evidenced them to be normal, i.e. 8.0–8.2 km/s (ten Brink and Taylor, 2002; Nielsen and Thybo, 2009).

From a geodynamic point of view, the BRS separates the Eurasian plate and Amurian microplate diverging at 3–4 mm year^{-1} (Calais et al., 1998; Sankov et al., 2009). Recent geodynamic interpretations imply effects from the India-Asian collision, the Pacific plate subduction and coeval movement of the Amurian plate in a SE direction (Zonenshain and Savostin, 1981; Barth and Wenzel, 2010).

The most striking evidence of active tectonic processes in the BRS is a high level of seismic activity. This level is confirmed both by the known historical and instrumentally recorded earthquakes, e.g. the 1862 M7.5 Tsagan earthquake at the eastern part of the Baikal Lake and the 1957 M7.6 Muya event in the Muya basin. Formation of the regional seismic network since 1960s has allowed obtaining the epicenter map and revealing some features of seismicity. It is of special interest due to the fact that the BRS is an example of the intracontinental rifts and, therefore, is a case study for intraplate seismicity.

* Corresponding author. Tel.: +7 964 2160520, +7 3952 426900; fax: +7 3952 426900.
E-mail address: nradzim@crust.irk.ru (N.A. Radziminovich).

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http://dx.doi.org/10.1016/j.jseaes.2012.10.029

In the paper, we present a brief review of results obtained by the regional seismic network. We consider its development, spatial seismicity distribution, seismic patterns, and present-day stress field derived from earthquake focal solutions. Some of these points have been already covered in a number of papers as well as in annual reports issued by Geophysical Survey of the Russian Academy of Sciences (e.g. Solonenko and Treskov, 1960; Misharina, 1961; Golenetskii, 1977, 1990; Solonenko and Solonenko, 1987; Kochetkov et al., 1987; Melnikova and Radziminovich, 1998; Deverchere et al., 1991, 2001; Radziminovich et al., 2005, 2006a, Radziminovich, 2010; Melnikova et al., 2007, 2010 and many others). Nevertheless, revising and summarizing data over the period of instrumental observations and for the whole BRS may be useful for researchers who deal with seismotectonic and geodynamic studies in the region and for officials responsible for the hazard mitigation as well.

2. Materials

2.1. Seismic network development

The history of the instrumental earthquake observations in the Baikal region began as early as 1901 when the first seismic station was installed in Irkutsk. It was equipped by an Omori–Bosh pendulum and a Miln pendulum. During the following years similar stations were deployed in several other settlements in the southern Baikal area. Since 1912 new sensors with galvanometric recording developed by B.B. Golitsyn were put into operation that resulted in significant improvement of observation quality. Further improvements were connected with timing as with the development of radio transmission, time signals provided a more stable clock reference. However, a real advance came in the end of the fifties spurred on by the occurrence of several large ($M > 6.5$) earthquakes, namely the 1950 M_{LH}7.0 or Mw6.9 Mondy earthquake, 1957 M_{LH}7.6 or Mw7.2 Muya earthquake, and 1959 M_{LH}6.8 Middle Baikal earthquake (Fig. 1), Table 1). The barest necessity of further expansion of the network was recognized, and already in 1961 it consisted of fifteen stations operating over the whole region including its northern part. Thus, the beginning of 1960s is considered as commencement of permanent instrumental seismological observations in the Baikal region. It should be noted that in this paper we take into consideration also the large earthquakes of the 1950s because they were recorded and processed already instrumentally. Review of the history of seismological observations in the BRS for that period can be found in the papers by Golenetskii (1977, 1990).

The great role of A.A. Treskov should be emphasized here. A.A. Treskov was the head of the Irkutsk seismic station during 1926–1963 and the chairman of the Siberian and Far East Seismological Commission. Besides the network development, A.A. Treskov contributed to the location methods, earthquake energy estimates, and study of the Earth's crust and mantle structure. He initiated the first seismogeological investigations of large earthquakes including the Mondy and Muya events, and the 1957 M8.3 Gobi-Altai earthquake in Mongolia (Florensov and Solonenko, 1963). Research and educational activity of A.A. Treskov gives grounds to believe that he is an originator of the Siberian seismological school.

With time the number of stations has been increasing up to 20–24 and sometimes it increased due to temporary local network deployment. The stations were gradually reequipped with modern three-component short-period SKM-3 seismographs and long-period SKD ones widely used in the former USSR. Recording was done on photographic paper with time marks monitored from radio signals. On the whole, the time period of 60–90s was an important milestone in the regional network configuration.

The current state of the network (its ISC code is BYKL) is represented by 23 stations controlling the region shown on Fig. 1. A new stage of instrumental observations in the BRS started in 1999 as a consequence of the conversion of analogous recording into digital one (Melnikova et al., 2010). The stations are instrumented with "Baikal-10, 11" equipment developed by the Siberian Division of the Geophysical Survey RAS. Each station has three (NS, EW, Z) high-sensitivity short-period channels of seismometers SM-3 and

Table 1
Parameters of the BRS earthquakes with $M \geqslant 5.6$ since 1950.

#	Earthquake name	DD/MM/YYY	HH:MM	Lat., N	Lon., E	*M*	Magnitude type	Reference for magnitude	STK	DIP	RAKE	Reference for focal solution
1	Mondy	04/04/1950	18:18	51.77	101.00	6.9	Mw	D	100	75	0	D
2	Buteelin	06/02/1957	20:34	50.00	105.50	6.5	M_{LH}	NC	190	90	−120	VB
3	Muya	27/06/1957	00:09	56.20	116.40	7.6	M_{LH}	NC	228	60	−147	VB
4	Nyukzha	05/01/1958	11:30	56.70	121.20	6.5	M_{LH}	NC	60	42	−138	VB
5	Olekma	14/09/1958	14:21	56.73	121.03	6.4	M_{LH}	NC	32	52	−94	VB
6	Middle Baikal	29/08/1959	17:03	52.68	106.98	6.8	M_{LH}	NC	249	48	−64	B
7	Muyakan	11/11/1962	11:31	55.90	113.12	5.8	M_{LH}	NC	215	58	−78	Db
8	Tas-Yuryakh	18/01/1967	05:34	56.59	120.96	7	M_{LH}	NC	51	66	−158	B
9	Kyachta	13/05/1989	03:35	50.17	105.34	5.7	Mw	H	31	82	−155	S
10		25/10/1989	20:29	57.45	118.84	5.7	Ms	I				
11	Busiingol	27/12/1991	09:09	50.98	98.08	6.3	Mw	H	246	80	−8	H
12	Chara	21/08/1994	15:56	56.70	118.03	6.0	Mw	H	242	48	−65	MR
13	Tunka	29/06/1995	23:02	51.71	102.70	5.8	Mw	H	84	44	−40	MR
14	South Muya	13/11/1995	08:43	56.13	114.55	5.9	Mw	H	60	82	−92	MR
15	South Baikal	25/02/1999	18:58	51.64	104.82	6.0	Mw	H	249	70	−88	Ra
16	Kichera I	21/03/1999	16:16	55.83	110.34	5.9	Mw	H	200	54	−160	M
17	Kichera II	21/03/1999	16:17	55.85	110.26	5.9	Mw	H	223	44	−94	H
18	Kumora	16/09/2003	11:24	56.05	111.34	5.6	Mw	H	244	60	−74	Rc
19	Charuoda I	10/11/2005	19:29	57.37	120.77	5.8	Mw	H	90	50	−85	Rb
20	Charuoda II	11/12/2205	15:54	57.43	120.90	5.7	Mw	H	265	45	−75	H
21	Kultuk	27/08/2008	01:35	51.60	104.04	6.3	Mw	H	104	63	−47	H

Epicenters and origin times are from the catalog of the Baikal Division of GS SB RAS. Foci depths are not given being poor constrained for most events. Focal mechanisms in forms of the strike, dip and rake of a nodal plane are given mainly from the first motion regional solutions, if not they are from teleseismic body-wave inversion. For the 1989 October, 25 there is no focal solution. M_{LH} is magnitude from surface waves given in Kondorskaya and Shebalin, 1982. The references for magnitude values and focal solutions are the following: H – (Harvard) Global CMT Project (www.globalcmt.org), D – Delouis et al., 2002, Db – Doser, 1991b, I – International Seismological Center ISC (www.isc.ac.uk), NC – Kondorskaya and Shebalin, 1982, VB – Vvedenskaya and Balakina, 1960, B – Balakina et al., 1972, MR – Melnikova and Radziminovich, 1998, Ra – Radziminovitch et al., 2005, Rb – Radziminovich et al., 2006b, Rc – Radziminovich et al., 2009, M – Melnikova et al., 2007, S – Solonenko et al., 1993.