Regional Seismological Observation Network in Yakutia

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5

Operational Procedures of Contributing Agencies

5.1 Regional Seismological Observation Network in Yakutia

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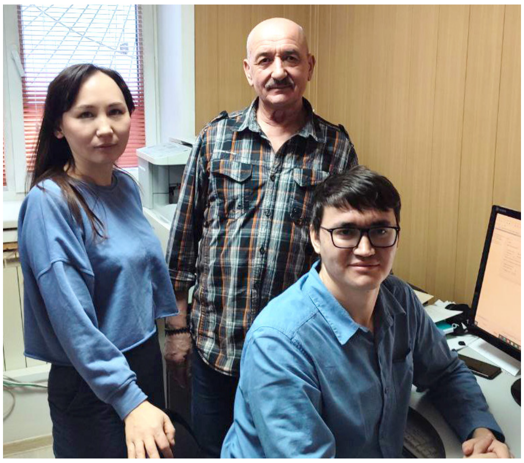

Team of Yakutia Branch of GS RAS

The article gives a brief history of the development of instrumental seismic observations in the territory of the Republic of Sakha (Yakutia). We describe the current state of seismic observations and data processing in the Yakutia Branch of the Geophysical Survey of the Russian Academy of Sciences (GS RAS), ISC agency code YAGSR, as well as the results of the seismic activity monitoring on the territory of Yakutia for the last 66 years. The article also describes the organizational structure of the data collection centre at central seismic station Yakutsk (YAK) and presents the configuration and development of the seismic observation network in Yakutia.

5.1.1 Introduction

The first seismological studies in the Republic of Sakha (Yakutia) began in Tiksi (1956) and Yakutsk (1957) (see Fig. 5.1). The first seismogram recordings had already showed that the territory of Yakutia is seismically active, as seismic stations recorded not only earthquakes from known seismically active regions of the globe (Kamchatka, Kurils, Japan, etc.), but also local seismic events. This was especially evident following two catastrophic earthquakes (Nyukzhinsky and Olekminsky), which took place in the South of the republic in the Olekma river region in 1958 (*Imaev et al.*, 2000), a year after the seismic station in Yakutsk had been opened. Instruments clearly recorded ground motions associated to the two events, making it possible to determine the coordinates of their epicentres reliably for the first time (see Fig. 5.2).

The MS 6.3 Nyukzhinsky earthquake (*International Seismological Centre*, 2024a) occurred on 5 January, 1958, and had an intensity at the epicenter of 9 points (MSK-64 scale). The event generated landslides, rockfalls and expanding ground cracks, which were found in the area most affected. In the village closest to the epicenter, Ust-Nyukzha (40 km epicentral distance), the earthquake was felt with an intensity of 7-8. Its macroseismic effects have been observed in Yakutia, Buryatia, Transbaikalia, and the Amur region over an area of about 800,000 – 900,000 km^2 (*Imaev et al.*, 2000).

The second large event, the MS 6.4 Olekminsky earthquake (*International Seismological Centre*, 2024b), occurred in the Olekma river region on 14 September 1958, where the intensity at the epicenter reached 9 points on the MSK-64 scale. In the zone of strongest impact, tensile cracks were revealed in the ground, rockslides occurred and trees fell down. In the village of Ust-Nyukzha, macroseismic effects corresponding to the intensity 7 were observed. The total area of perceptible shaking in Yakutia, Buryatia, Transbaikalia and the Amur region amounted to more than 500,000 km^2 (*Imaev et al.*, 2000).

5.1.2 A Brief History of Instrumental Seismological Observations in Yakutia

In 1964, a network of five seismic stations was running in Yakutia (Yakutsk, Tiksi, Ust-Nera, Chulman and Ust-Nyukzha), and additional seismic stations were installed in Chagda in 1968 and Batagay in 1975. By 1980 the seismic network included 12 stations, and reached 22 by 1990. Following this, due to difficulties in financing, their number was gradually reduced by half. All stations during the second half of the 20th century were equipped with domestic devices: SKM-3 seismographs and GK-VII galvanometers, designed for analogue recording of earthquakes on photographic paper. From 1999 to 2006, the seismic observation network was considerably extended with new digital devices of domestic manufacture (Seismic Distributed Acoustic Sensing (SDAS), Obninsk), which were installed in Aldan (1999), Chulman (2000), Tynda (2001), Batagai (2001) and Ust-Mai (2006).

5.1.3 Current Status of Instrumental Seismic Observations

At present, the Yakutia Branch of GS RAS carries out seismicity monitoring in Yakutia and neighboring regions based on a system of instrumental observations. The system includes 20 seismic stations, located in the North and North-East (7 stations), in the centre of the region (3 stations), in the West (3 stations) and in South Yakutia (7 stations) (Tab. 5.1, Fig. 5.1).

This regional network covers an area of over 4,107,735 km^2. In addition to Yakutia, the network's area of responsibility also includes a small part of the Amur Region (about 2,500 km^2), Khabarovsk Territory (80,000 km^2) and part of the Krasnoyarsk Territory (240,000 km^2) (Fig. 5.1). The seismic network is capable of registering local and regional events of magnitude $Mw \geq 2.0$–3.0. Continuous observations from the network stations are sent to the data collection and processing centre in a near real-time regime (*Shibaev et al.*, 2007). The Yakutsk station has access to the internet through a dedicated optical communication channel at a speed of 40 Mb and a backup satellite channel. Station Tiksi has internet

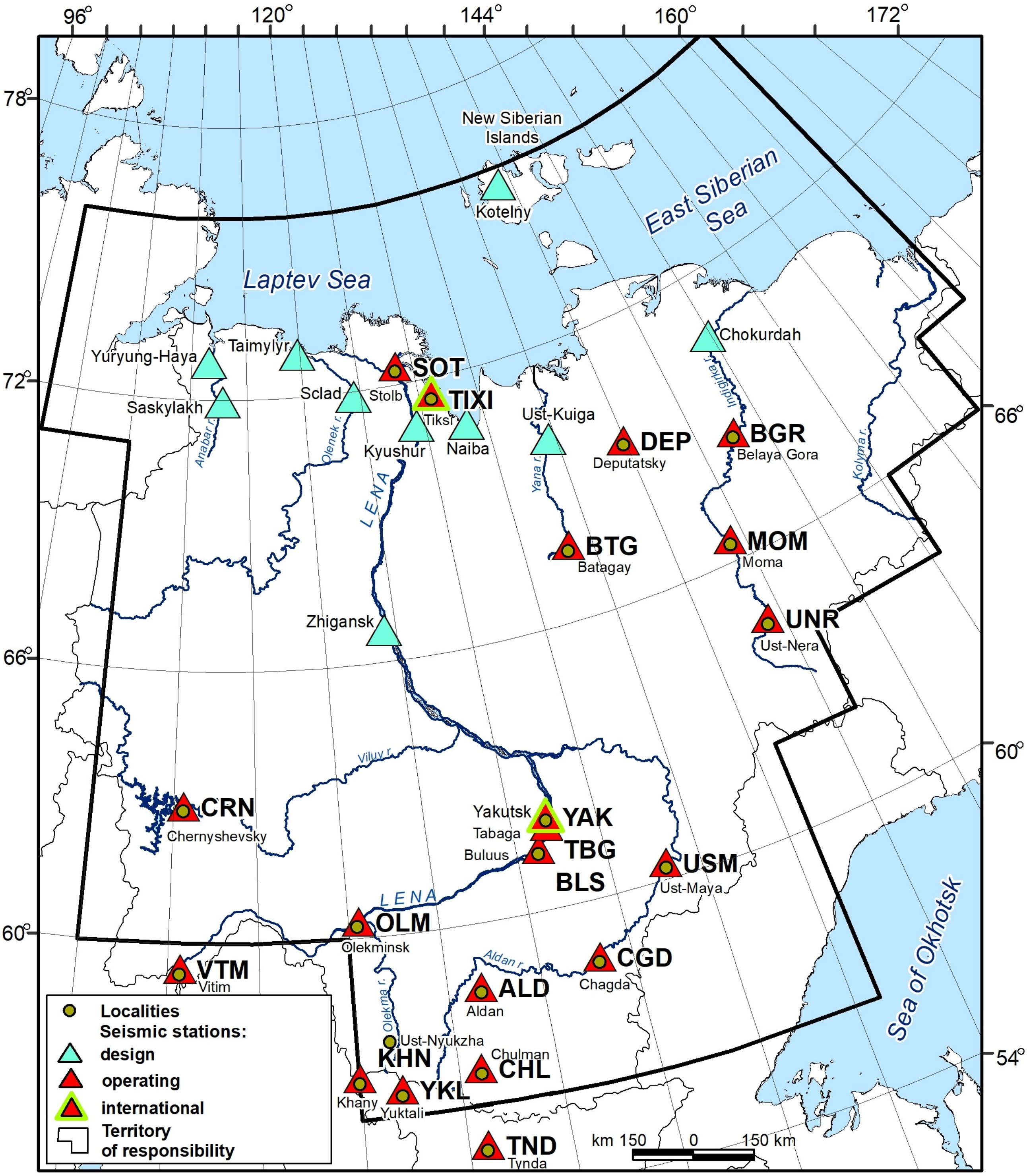

Figure 5.1: *Map of active (red triangles) and planned (cyan triangles) seismic stations in Yakutia.*

access via an ADSL modem and a backup satellite channel. Two more stations of the regional network (Chagda and Vitim) transmit data via satellite communication channels. The remaining stations of the regional network transmit data to the data collection server in Yakutsk through the network of the Megafon mobile operator.

Seismic data collection is carried out by the Yakutsk central reference station. It further sends digital data to the GS RAS (in Obninsk), local events to the Siberian branch of the GS RAS (in Novosibirsk) and Yakutsk ministry of emergency.

Over the last ten years, work has been carried out to equip seismic stations of Yakutia with digital equipment. Stations Yakutsk (YAK) and Tiksi (TIXI) were included into the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). The stations are equipped with broadband seismometers (STS and Trillium, Tab. 5.1), providing seismic wave recordings in the frequency range of 0.003 - 5.0 Hz. In addition, these stations are also equipped with short-period transducers extending the frequency range to higher frequencies of up to 40 Hz. The 120-140 dB dynamic range of the instruments allows them to record waveforms from the local earthquakes with magnitudes of 1-2 to 7-8 on the Richter scale in the near-field distances without distortion.

Table 5.1: *Seismic stations of the Yakutia Branch of the GS RAS (YAGSR) network in 2022.*

	Name	**Code**	**Starting Date**	**Lat / deg**	**Lon / deg**	**Elev. / m**	**Site condition**	**Equipment**
1	Aldan	ALDR	01/10/1999	58.61	125.41	662	Large gravel, clay, permafrost	CME-6211, Baikal-8
2	Batagay	BTGS	12/03/1975	67.656	134.625	127	Clay, gravel, permafrost	CME-6011, Baikal-8
3	BelayaGora	YBGR	12/08/2011	68.532	146.193	36	Clay, permafrost	KS-2000, Baikal-8
4	Buluus	BLSR	27/03/2012	61.36	129.03	90	Pebble	CME-6211, Baikal-8
5	Vitim	VTMR	16/06/2003	59.44	112.55	188	Loams	CMG-3ESPC, CD-24
6	Deputatsky	DEPR	27/08/2003	69.39	139.9	320	Permafrost	CME-6011, Baikal-8
7	Moma	MOMR	05/03/1983	66.467	143.217	192	Lay, gravel, permafrost	KS-2000, Baikal-8
8	Olekminsk	OLMR	11/06/2010	60.376	120.463	45	Sand, permafrost	CME-6211, Baikal-8
9	Stolb	SOTR	13/08/2021	72.403	126.812	50	Siltstones, permafrost	CME-6011, Baikal-8
10	Tabaga	TBGR	24/06/2003	61.821	129.637	98	Permafrost	Baikal-8 until 06/22, then Centaur
11	Tiksi	TIXI	02/03/1956 15/08/1995 (IRIS)	71.649	128.867	50	Dolomites, quartzites, permafrost	STS-1, STS-2, since 2023 Trillium Compact Q330
12	Tynda	TNDR	20/06/2001	55.147	124.721	530	Pebbles, clay	CME-6011, Baikal-8

Continued on next page

	Name	Code	Starting Date	Lat / deg	Lon / deg	Elev. / m	Site condition	Equipment
13	Ust-Maya	USM	08/04/2006	60.367	134.458	170	Clay, permafrost	KS-2000, Baikal-8
14	Ust-Nera	UNR	21/11/1961	64.566	143.228	485	Loams, permafrost	CME-6211, Baikal-8
15	Khany	KHNR	11/12/2005	56.921	119.979	690	Granitic gneisses	KS-2000, Baikal-8
16	Chagda	CGD	01/08/1968	58.752	130.609	195	Pebbles, clay, permafrost	CM3-KB, Baikal 11
17	Chernyshevsky	YCRN	14/07/2011	63.021	112.486	319	Pebbles, clay	KS-2000, Baikal-8
18	Chulman	CLNS	01/07/1963	56.837	124.893	745	Sandstone	CMG-3ESPC, CD-24
19	Yuktali	YKLR	04/07/2004	56.5915	121.654	417	Loams	CMG-3ESPC, CD-24
20	Yakutsk	YAK	04/10/1957 31/08/1993 (IRIS)	62.031	129.68	91	Sandstone, permafrost	STS-1, STS-2, Q330

The Yakutia Branch of GS RAS uses the Seismic Data Processing System WSG (`http://www.gsras.ru/new/soft/WSG/`), designed to analyse seismic signals and obtain estimates for hypocenter parameters of seismic events, both from the records of a single station as well as multiple stations. To store processing results, a SQL-compatible database with an ODBC driver is used. The authors of the program are Akimov Andrey Petrovich and Krasilov Sergey Alexandrovich (*Akimov and Krasilov*, 2020). In the processing routine we use the IASPEI-91 (*Kennet and Engdahl*, 1991) and Baikal (*Golenetsky*, 1990) travel time curves.

Integrated processing of the instrumentally-recorded data from the territory of Yakutia and neighboring regions, is performed by the instrumental observation interpretation and processing group of the Yakutia Branch of the GS RAS in the city of Yakutsk, as the digital earthquake records arrive from the local seismic stations (in near real-time). After a preliminary assessment of the records' quality, fixing of gaps in recorded data, analysing the operation of the individual channel components (EW, NS, UD) and timing, as well as assessing background interference (noise), the data is transferred to a group of regional stations to add to their processing procedures. The result of the this data-processing workflow provides the annual catalogue and map of earthquake epicenters in Yakutia (Fig. 5.2), which is sent to the Geophysical Service of the Russian Academy of Sciences in the city of Obninsk.

5.1.4 General Characteristics of the Observed Seismicity

As a result of seismic monitoring, it has been established that earthquakes on the territory of Yakutia are concentrated along two extended seismic belts: the Arctic-Asian belt in the north-east, and the Baial-Stanovoy belt in the south (Fig. 5.2) (*Imaev et al.*, 2000).

The Arctic-Asian earthquake belt traces across the Arctic Ocean, northeast Yakutia, the Sea of Okhotsk and the Kamchatka peninsula to the Aleutian island arc, and connects seismicity manifestations in the

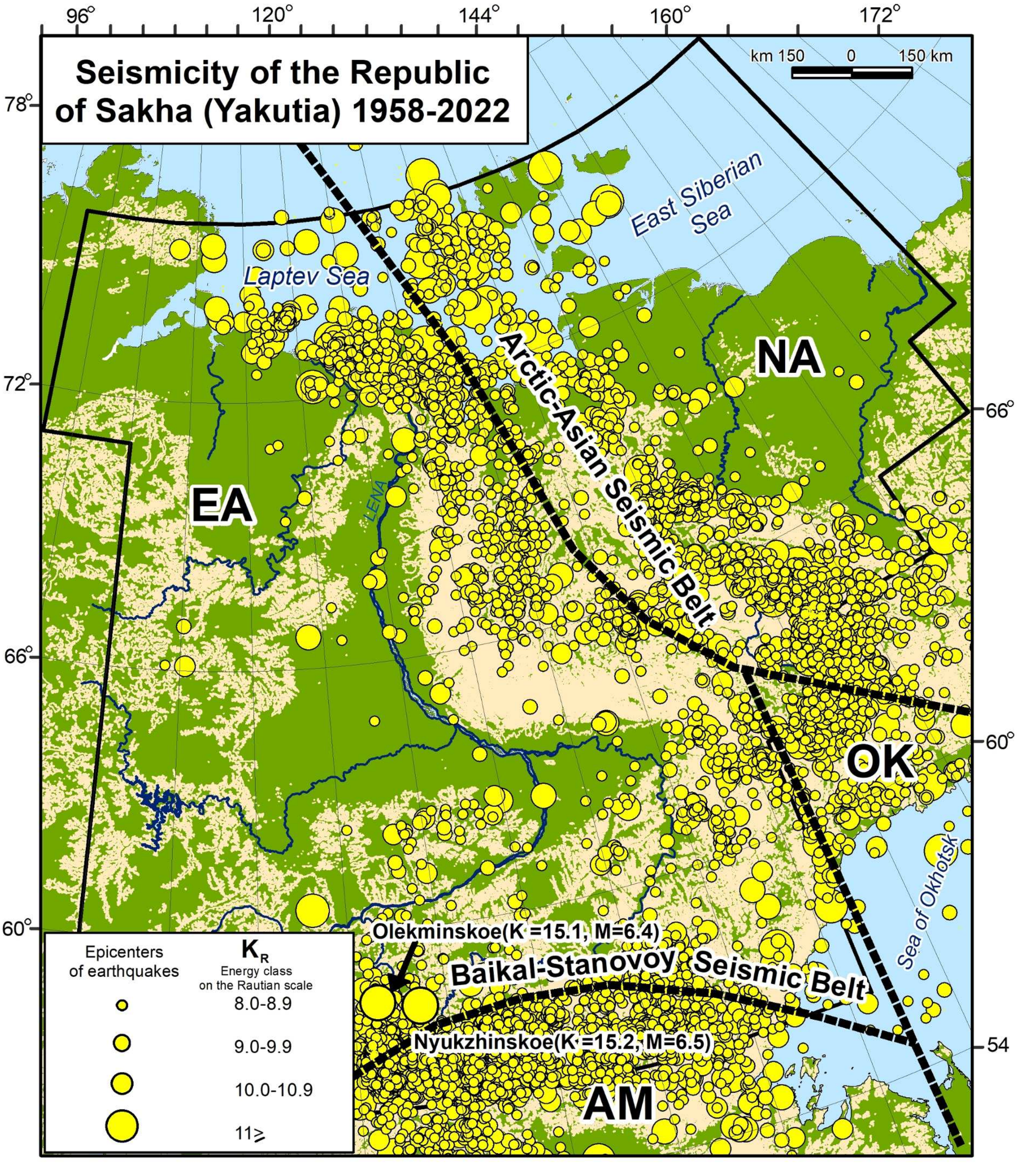

Figure 5.2: *Map of seismic activity on the territory of the Republic of Sakha (Yakutia). Dotted lines show the boundaries of lithospheric plates and blocks traced by seismicity (circles) of the Arctic-Asian belt in the northeast and Baikal-Stanovoy belt in the south (*Imaev et al., 2000*). NA - North American, EA - Eurasian, OK - Okhotomorskaya, AM - Amurskaya lithospheric plates. See Section 5.1.4 for information on energy class K_R.*

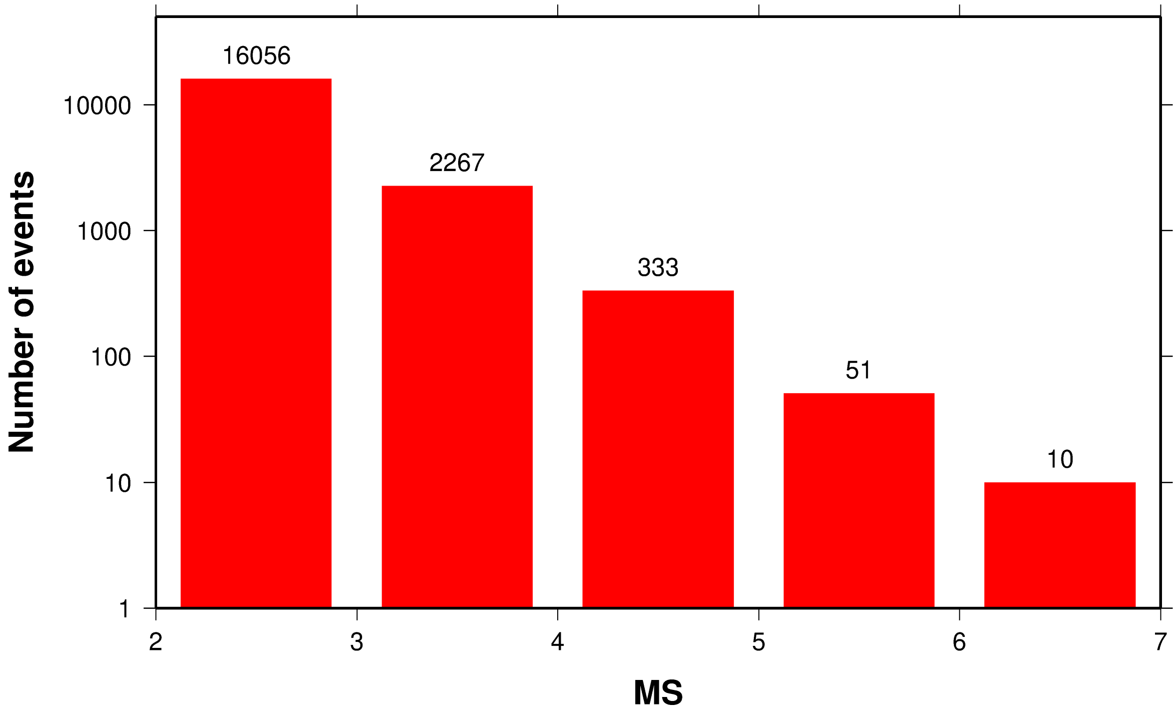

Figure 5.3: *Earthquakes recorded at seismic stations of the Yakutia Branch of the GS RAS for the time period of 1960 to 2022. Magnitudes (MS) were calculated from the Rautian energy classes (K_R), see Section 5.1.4.*

Arctic and Pacific regions. The Arctic-Asian belt separates the North American (NA), Eurasian (EA), Okhotomor (OK) and Pacific lithospheric plates, and is more than 10,000 km long (*Imaev et al.*, 2000).

The Baikal-Stanovoy belt in southern Siberia extends from Lake Baikal to the Sea of Okhotsk. It combines the Baikal rift zone and the Olekmo-Stanovaya seismic zone, which continues sub latitudinally from the Olekma River eastward to the Udskaya Bay of the Sea of Okhotsk, along a distance of over 3,000 km. This belt serves as the boundary between the Eurasian and Amur (Chinese) lithospheric plates and is reflected in the map of modern geodynamics of Northeast Asia (*Chemezov et al.*, 2007; Fig. 5.2).

Over the 66-year period of instrumental observations in Yakutia, more than 18,000 local earthquakes with MS≥2 have been recorded (Fig. 5.3), where MS was calulated from the energy class K_R (*Rautian*, 1960). Equivalent to magnitude, the energy class K_R is a measure of the size of an earthquake and was defined as $K = \log E$, where E is the released seismic energy in Joules. The relation of magnitude M and energy class K can be approximated as $K = 1.8M + 4$ (*Rautian*, 1960). More information on the relation of the energy class K_R to magnitudes mb and MS can be found in *Rautian et al.* (2007) and *Bormann et al.* (2013).

Currently, the seismic network of Yakutia annually records 1,000 - 5,000 local and regional earthquakes. Their spatial distribution covers more than 1.5 million km^2, which corresponds to almost half of the territory of the Republic of Sakha (Yakutia), and constitutes about one third of the total area of seismic risk zones in all of Russia (*Alekseev and Kozmin*, 2005).

5.1.5 Future Seismological Observation Development Project

In order to ensure an adequate level of safety for the population living in seismically hazardous areas of Russia, and reduce the casualties and material damage from natural and man-made earthquakes, as well as to ensure the functioning and further development of the federal system of seismological observations and earthquake prediction (FSSN), a federal decree on the target program "Development of the federal system of seismological observations and earthquake prediction for 2024-2028" is prepared and submitted to the Ministry of the Russian Federation. Within the framework of this program "Development of FSSN", the Yakutia Branch of the GS RAS proposes to implement the strategy of developing seismic observations in the Arctic regions of Yakutia by modernising and expanding the representative coverage area (Fig. 5.1). The installation of the additional four to ten seismic stations (planned by 2025) in the the river Lena delta region and New Siberian Islands will make it possible to monitor the low seismicity of the Arctic coast and the Gakkel mid-ocean ridge, and also increase the efficiency the Yakutia Branch of the GS RAS seismic network.

5.1.6 Conclusion

After over 60 years of operation and development of the Yakutia seismic network, some areas are still poorly covered by seismic stations, especially the Arctic regions of Yakutia. Therefore, the planned development and extension of the seismic network in Yakutia aims to equip additional stations with modern digital instrumentation, as well as to modernise the data processing center. The expansion of the seismic network of the Yakutia Branch of the GS RAS will enable the recording of smaller seismic events. In addition, with the development of the seismological network, we will be able to build 3D velocity models of the Russian Arctic.

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