The Present State of the Kola Peninsula Broadband Seismic Network

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Abstract: This paper provides information about the main parameters of spatial broadband seismic network in the Kola region (the northeastern part of the Fennoscandian Shield). Since 2021 the seismic network has been expanded by five seismic stations and currently consists of nine stations located on the territory of the Russian Federation. Configuration of the network allows to broaden the scope of research of the Kola region lithospheric structure significantly. The prospects of integrating the newly installed stations into the automated regional seismic monitoring network are considered. The analysis of seismic noise in the places of installation of new seismic stations was carried out. It was shown that the data provided by the new broadband stations increases the accuracy of seismic events location in the research area.

Keywords: Arctic, Kola region, Fennoscandia, seismic network, location, technogenic seismicity, earthquakes.

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1. Introduction

Arctic Region' exploration requires deepening the knowledge about its geological structure, tectonics and seismicity. The Kola region is one of the key regions of the Arctic zone of the Russian Federation (AZRF) with developed civil and industrial infrastructure and also with the largest mining complex in Europe.

One of the fundamental issues related to deep geodynamics is the genesis of large polymetallic deposits that are currently being mined within Kola Peninsula, and the features of their spatial distribution. A combination of geological and geochemical data links ore genesis to plume-lithospheric processes [*Bayanova et al.*, 2019]. Presumably, determining the characteristics of these mineral deposits' origin will lead to a new vision of the circumstances of their formation.

The Kola Peninsula is an area of low tectonic activity. The main tectonic process, as for the entire Baltic Shield, is considered to be the process of slow and differentiated uplift, accompanied by the emergence of new or revival of former disjunctive dislocations [*Lukk et al.*, 2019]. Natural earthquakes that occasionally occur within the Kola Peninsula are a consequence of this process. Along with natural, technogenic seismic events also occur in the region [*Morozov et al.*, 2022]. It is worth mentioning, that the intensity of technogenic events is comparable to the intensity of the natural events in terms of energy emitted.

Developing the Kola Peninsula seismic network allows to deepen our knowledge of the lithospheric structure of the region. This adds to the understanding of Fennoscandia geological evolution in general [*Thybo et al.*, 2021] and, hopefully, of the numerous ore deposits' origin within the Kola region. In addition, the new seismic data provides the opportunity to research local seismicity, especially in proximity to large mining operations, which is crucial to Kola's mining industry.

This paper demonstrates the technical capabilities of the extended broadband seismic network within the Kola region. The technical characteristics, the quality of the data obtained, as well as the stations' distribution make it possible to study the lithosphere effectively and locate various seismic events.

2. Characteristics of the Kola Region Seismic Network

Seismic monitoring on the Kola region territory and adjacent areas of Fennoscandia is performed by Kola Branch of the Geophysical Survey of the Russian Academy of Sciences (KB GS RAS). Prior to 2021 the regional seismic monitoring network consisted of 5 seismic stations and a seismic array comprised of 9 short-period seismometers with an aperture of 1 km. Additionally, the data collected by Norwegian and Finnish seismic networks is jointly analyzed by the regional information processing center of the KB GS RAS.

The analysis of the network configuration (Figure 1) prior to 2021 reveals an extremely heterogeneous distribution of seismic stations over the territory under observation. This complicates the ability to research of the lithospheric structure of the Kola region's western part (as well as in the areas containing large ore deposits – "Pechenga" and "Kovdor"). This also hindered the local focal zones' research.

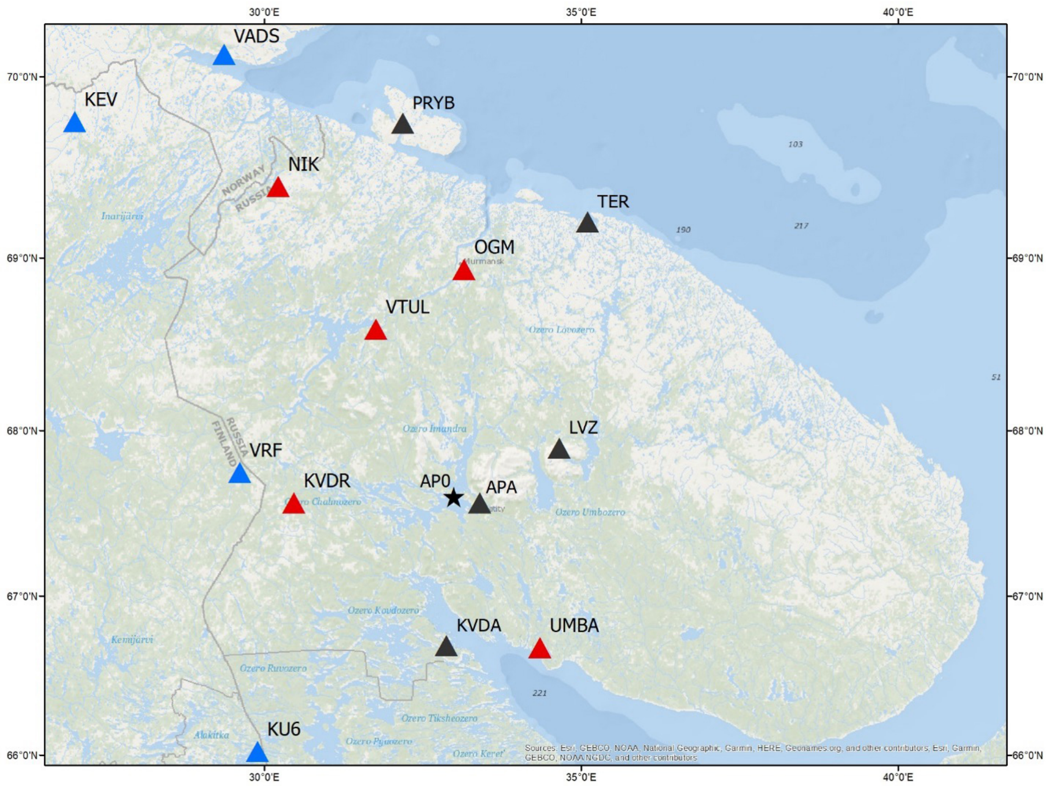

Figure 1. A map seismic stations' distribution within the Kola region. The black triangles represent stations prior to 2021. The black star represents the Apatity seismic array. The red triangles represent the new broadband seismic stations. Blue triangles represent permanent broadband stations of foreign services.

In 2021 the Russian science foundation (RSF) (https://rscf.ru/project/21-17-00161/) project named "Development of a spatial structural-dynamic model of the interaction of near-surface geological forms and geophysical processes with deep inhomogeneities of the earth's crust and upper mantle of the central and arctic parts of the Kola Peninsula" was initiated. It was aimed at studying the lithosphere's structure of the central and Arctic parts of the Kola Peninsula and to investigate possible links between the genesis of deposits and plume-lithospheric processes. As a part of this project, five new broadband stations have been installed – "Nickel" (NIK), "Verkhnetulomsky" (VTUL), "Kovdor" (KVDR), "Ogni

Murmanska” (OGM) and “Umba" (UMBA). The location and technical characteristics of seismic stations are shown in Figure 1 and in Table 1, respectively.

Table 1. Main characteristics of new seismic network

Name	Code	Lat	Lon	freq. range (Hz)	Start time
Nickel	NIK	69.24	30.13	0.03–50	06.2020
Verkhnetulomsky	VTUL	68.35	31.45	0.03–50	06.2021
Teriberka	TER	69.20	35.10	0.03–50	12.2013
Lovozero	LVZ	67.89	34.65	0.002–10	1991
Apatity	APA	67.56	33.40	0.01–50	1991
Kovda	KVDA	66.69	32.87	0.03–100	07.2018
Umba	UMBA	66.67	34.34	0.03–100	05.2021
Kovdor	KVDR	67.56	30.47	0.008–100	12.2021
Ogni Murmanska	OGM	68.93	33.14	0.03–100	10.2022

The seismic network’s configuration and equipment used provides the opportunity to study the lithosphere of the Kola region. It makes possible to carry out a comparative analysis of the structure of the Earth’s crust and the upper mantle of the largest tectonic elements – the Murmansk, Kola and Belomorsky megablocks (Figure 2). In addition, there is an opportunity to study Khibino-Lovozersky tectonic cluster and the areas of the largest iron ore and copper-nickel deposits of “Kovdor” and “Pechenga” in detail in order to identify their origins. Results of the conducted research are presented in [*Adushkin et al.*, 2021; *Goev*, 2022].

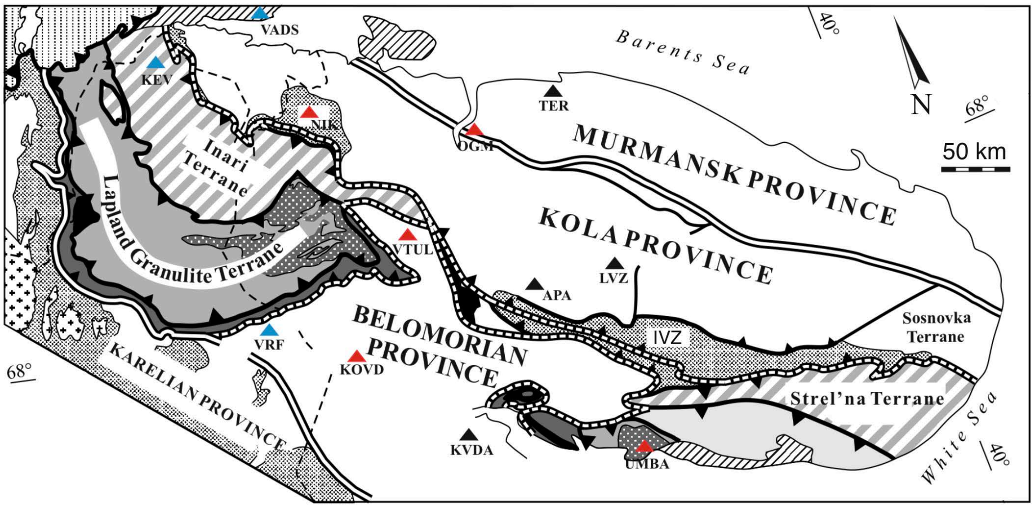

Figure 2. Tectonic scheme of the Kola region according to [*Mudruk et al.*, 2013]. The black triangles represent stations prior to 2021. The red triangles represent new broadband seismic stations. Blue triangles represent permanent broadband stations of foreign services.

The stations installed within the boundaries of the project were placed on sites with varied foundations its terms of soil type, however sites with rocky foundations were prioritized during initial planning. The recording equipment was installed directly on the rocky foundation and equipped with insulated metal cases to reduce low-frequency temperature fluctuations (Figure 3).

To assess the data quality provided by new seismic stations, evaluation of seismic noise was carried out. Data acquired by new seismic stations was analyzed, excluding

Figure 3. The seismic equipment within the insulated metal cases at stations Umba (a), Verkhnetulomsky (b), and Ogni Murmanska (c).

materials from the UMBA station, since its registration capabilities were already discussed in detail earlier in [*Fedorov et al.*, 2022]. The analysis was carried out as follows: using the vertical components of seismograms (Z) of continuous recordings within one month period, the spectral noise density was calculated and probability density graphs were derived according to [*McNamara*, 2004] (Figure 4). These graphs were compared to the model curves of the maximum (NNM curve) and minimum (LM curve) values of seismic noise calculated by the world observation network [*Peterson*, 1993]. The seismic noise levels found in the records of the new stations do not exceed the values of the NHNM high noise model.

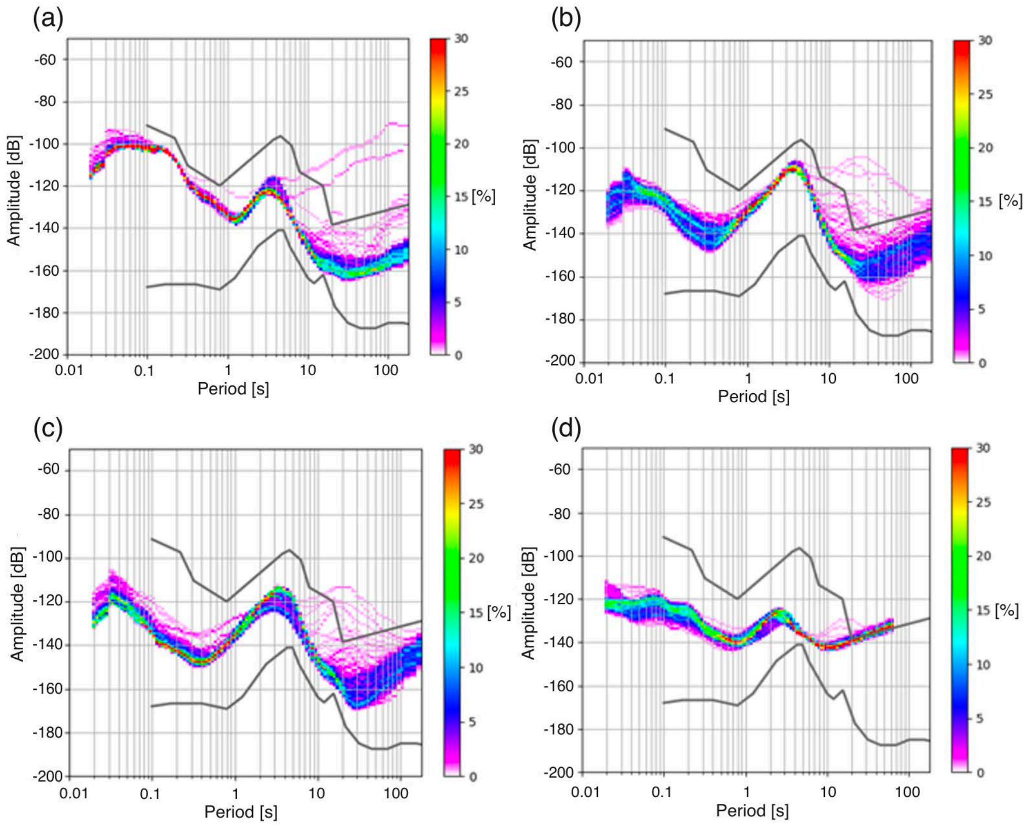

Figure 4. Power spectral density and Probability Density Function [*McNamara*, 2004] for the following station: a – KVDR, b – NIK, c – VTUL, d – OGM. Gray curves represent max and min values according to [*Peterson*, 1993].

3. Seismic Events Location Methods

Since 2016 for continuous seismic monitoring in the western sector of the Russian Federation's Arctic zone the KB GS RAS is using NSDL – an automated software package designed to detect and locate seismic events [*Fedorov et al.*, 2019]. NSDL processes data obtained by a total of 19 seismic stations of the international network located within the Kola Peninsula, in northern Norway, eastern Finland and the Spitsbergen archipelago. Data processing happens in close to real time mode. Seismic stations located on the Spitsbergen archipelago and the Kola Region are processed separately in specially allocated subsystems of the NSDL [*Asming et al.*, 2018].

The NSDL system is structurally divided into two functional parts. The first, called NSS, detects and locates regional seismic events using the data of individual stations. The second, called NAS, associates results obtained from individual stations.

The NSS program is able to analyze the data of individual seismic station (in almost real time), detect seismic events and make preliminary estimation of the epicenter coordinates using the difference in the arrival times of P- and S-waves, and their polarization.

The NAS program associates the results of data processing done by the NSS program. The program correlates the arrival time of seismic waves with registered events, locates hypocenters and compiles a database of events. The results of the NSS programs are submitted to the NAS input. These are lists of seismic events found at one station and lists of all detected phases with their azimuthal estimates obtained in cohesion with wave polarization. Association and location of hypocenters of seismic events in the NAS program is implemented by a method similar to the Generalized Beamforming method [*Ringdal and Kvaerna*, 1989]. The final catalogue is formed during the next processing stage after automated results has been reviewed by a geophysicist.

To evaluate the quality of the KB GS RAS monitoring system's automation with the inclusion of new stations installed within the frames of the RSF project, one month of data was picked – January 2023. The following chapter presents the analysis results of the automated data processing done with the new stations' data and a comparison of the results of the automated catalogues calculated by the regional network with the new stations included and excluded in the data processing.

4. Discussion

According to the automated data processing procedures described in the previous chapter, each new station was subjected to a single-station processing procedure at the first stage. The quantity of events detected by each station is presented in Table 2. The automated detector selected events with epicentral distances of 1500 km or less from the station.

Table 2. The quantity of detected seismic events during single-station processing of new stations

Station code	NIK	VTUL	KVDR	OGM
Event Number	5948	1835	611	1789

In the great majority of cases, the detected events reflect drilling and blasting operations. The results of the automated processing of singular stations were selectively validated. The average percentage of false positives detected was 22%, which is generally an acceptable result, coinciding with the results of the regional network's processing in prior years [*Fedorov et al.*, 2019].

Due to the difference in conditions, the number of detected seismic events of different stations (Table 2) varies significantly. First of all, this difference is attributed to varied levels of seismic noise (Figure 4). Additionally, the number, remoteness and intensity of ongoing drilling and blasting operations varies from station to station which also affects the number of false positives. Analysis of the data recorded by the KVDR station revealed that due to high seismic noise, this station mainly registers seismic events from the area of the

"Zhelezny" mine of the "Kovdor" deposit nearby, where industrial blasts are carried out once a week. Most of the seismic events detected by the NIK station are also the result of drilling and blasting operations. Due to the large number of technogenic interference, this station demonstrates the highest percentage of false positives – 28%. It should be noted, that at the stage of association with the other stations' data, most of the false positives are discarded and impose minimal impact on the final automated catalogue.

VTUL and OGM stations are characterized by lower seismic noise, much lower local technogenic interference and have the lowest percentage of false positives (10% and 12%, respectively). These stations register weak local events and even strong quarry blasts from the area of "Kovdor" and the Khibiny mountain range (130–180 km away).

At the next stage, single-station bulletins and lists of all detected phases of seismic events identified during single-station processing of new stations were combined with similar datasets of the permanent monitoring network.

Figure 5 presents a comparison of the results obtained from the data of automated processing done by the NSDL for the regional monitoring network with new stations included in processing (red circles) and without them (blue circles). The map shows automated results obtained by at least 3 seismic stations from January 1 to January 31 period of 2023 for the Kola region.

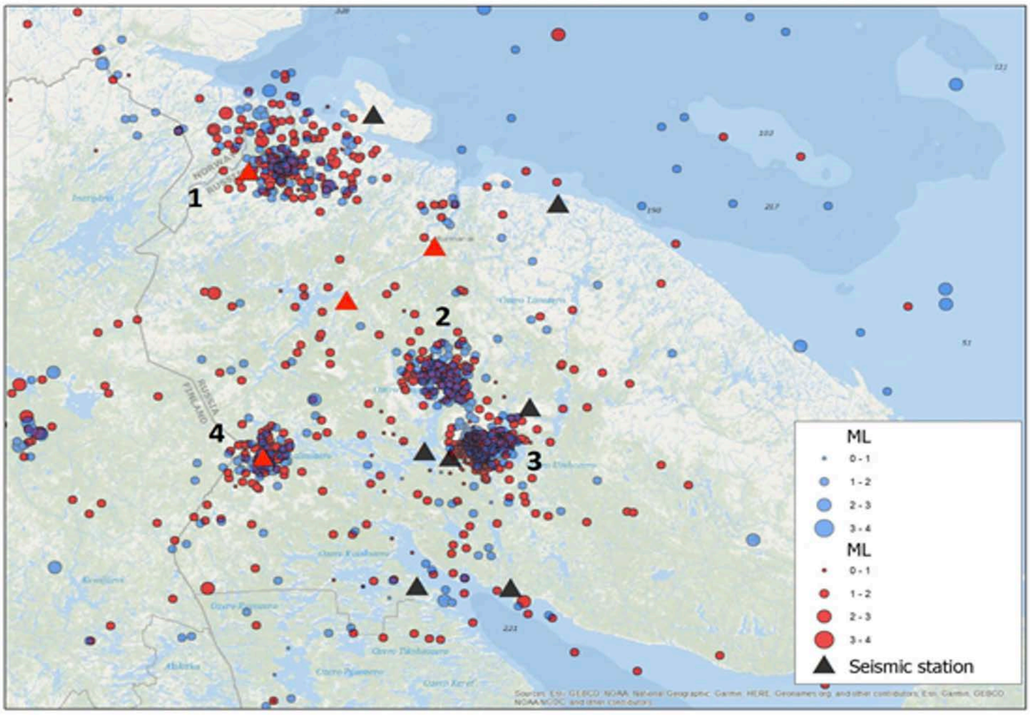

Figure 5. Comparison of the automated data processing results. Blue circles represent seismic events detected by stations of the regional monitoring network without new stations, red circles – with new stations included. The numbers indicate the areas of natural and technogenic seismicity: 1 – Mines near Zapolyarny and Kirkenes (Norway); 2 – Olenegorsky; 3 – Deposits of the Khibiny pluton; 4 – Kovdor.

The analysis of Figure 5 and Table 3 demonstrated that the inclusion of four new stations into the local monitoring network grants an increase in the number of seismic events detected and increases the accuracy of epicenters' location calculation.

5. Conclusions

The prospects of expanding the automated regional seismic monitoring network of the Kola region with five newly installed broadband stations in the region starting from 2021 were presented in this paper. It is shown that incorporating new stations into the

Table 3. Comparison of the number of detected seismic events in the main seismic zones of the Kola region according to the regional network with and without new stations

The seismogenic zone Number	Event Number with new stations	Event Number without new stations
1	214	142
2	92	72
3	1051	934
4	70	51

regional network will increase the density of stations in the western part of the Kola region and significantly improve the area coverage of the network.

Seismic noise levels were assessed for each individual station. It is shown that seismic background noise levels do not exceed the level of the high noise model for all new stations.

The automated data processing of the Kola regional monitoring network with the new seismic stations included in it was tested. The data of one month period was selected for this experiment (from January 1 to January 31, 2023). Comparison of the results of automated processing over the network with new stations and without them revealed an increase in accuracy of epicenters location calculations within key seismogenic zones of the Kola region.

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References

Adushkin, V. V., A. G. Goev, I. A. Sanina, and A. V. Fedorov (2021), The Deep Velocity Structure of the Central Kola Peninsula Obtained using the Receiver Function Technique, *Doklady Earth Sciences*, *501*(2), 1049–1051, https://doi.org/10.1134/S1028334X21120011.

Asming, V., A. Fedorov, A. Alenicheva, and Z. Jevtjugina (2018), Usage of the NSDL location system for the detailed study of the Spitsbergen archipelago seismicity, *Bulletin of the Kola Scientific Center RAS*, *10*(3), 120–131, https://doi.org/10.25702/KSC.2307-5228.2018.10.3.120-131 (in Russian).

Bayanova, T., A. Korchagin, A. Mitrofanov, P. Serov, N. Ekimova, E. Nitkina, I. Kamensky, D. Elizarov, and M. Huber (2019), Long-Lived Mantle Plume and Polyphase Evolution of Palaeoproterozoic PGE Intrusions in the Fennoscandian Shield, *Minerals*, *9*(1), 59, https://doi.org/10.3390/min9010059.

Fedorov, A. V., V. E. Asming, Z. A. Jevtjugina, and A. V. Prokudina (2019), Automated Seismic Monitoring System for the European Arctic, *Seismic Instruments*, *55*(1), 17–23, https://doi.org/10.3103/S0747923919010067.

Fedorov, I. S., S. V. Asming, A. G. Goev, and S. G. Volosov (2022), Expansion of the seismological monitoring network on the Kola Peninsula, *Russian Journal of Seismology*, *4*(1), 63–72, https://doi.org/10.35540/2686-7907.2022.1.05.

Goev, A. G. (2022), Some Features of the Mantle Transition Zone on the Kola Peninsula, *Doklady Earth Sciences*, *506*(2), 804–808, https://doi.org/10.1134/S1028334X22600402.

Lukk, A. A., V. G. Leonova, and A. Y. Sidorin (2019), Revisiting the Origin of Seismicity in Fennoscandia, *Izvestiya, Atmospheric and Oceanic Physics*, *55*(7), 743–758, https://doi.org/10.1134/S000143381907003X.

McNamara, D. E. (2004), Ambient Noise Levels in the Continental United States, *Bulletin of the Seismological Society of America*, *94*(4), 1517–1527, https://doi.org/10.1785/012003001.

Morozov, A. N., G. N. Antonovskaya, V. E. Asming, S. V. Baranov, N. V. Boldireva, N. V. Vaganova, Y. A. Vinogradov, Y. V. Konechnaya, N. N. Starkova, A. V. Fedorov, I. S. Fedorov, and S. V. Shibaev (2022), Arctic, in *Earthquakes in Russia in 2020: Annual edition*, pp. 34–38, Geophysical Survey of the Russian Academy of Sciences, Obninsk (in Russian).

Mudruk, S. V., V. V. Balagansky, I. A. Gorbunov, and A. B. Raevsky (2013), Alpine-type tectonics in the Paleoproterozoic Lapland-Kola Orogen, *Geotectonics*, (4), 13–30, https://doi.org/10.7868/s0016853x1304005x (in Russian).

Peterson, J. R. (1993), *Observations and modeling of seismic background noise*, US Geological Survey, https://doi.org/10.3133/ofr93322.

Ringdal, F., and T. A. Kvaerna (1989), Multi-channel processing approach to real time network detection, phase association, and threshold monitoring, *Bulletin of the Seismological Society of America*, *79*(6), 1927–1940, https://doi.org/10.1785/BSSA0790061927.

Thybo, H., N. Bulut, M. Grund, A. Mauerberger, A. Makushkina, I. M. Artemieva, N. Balling, O. Gudmundsson, V. Maupin, L. Ottemøller, J. Ritter, and F. Tilmann (2021), ScanArray-A Broadband Seismological Experiment in the Baltic Shield, *Seismological Research Letters*, *92*(5), 2811–2823, https://doi.org/10.1785/0220210015.