*Russian Geology and Geophysics © 2020, V.S. Sobolev IGM, Siberian Branch of the RAS*
*Vol. 61, No. 9, pp. 1056–1064, 2020 DOI:10.15372/RGG2019165* *Geologiya i Geofizika*

# The 9 November 2002 Earthquake in the Northeast of the Russian Plate (Komi Republic)

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Received 18 May 2018; received in revised form 29 December 2018; accepted 10 October 2019

**Abstract**—The East European Platform (EEP) is characterized by a rather weak seismicity. The south of the Komi Republic is the most seismically active territory in the northeast of the EEP. The 1939 Sysola earthquake (grade 7), one of the strongest earthquakes in the European north of the 20th century, occurred there. Many world's seismic stations recorded an earthquake in the Priluzsky region of the republic on 9 November 2002, but it was not thoroughly studied and is not considered in literature. In this work we recalculate the parameters of the earthquake hypocenter, substantiate its tectonic nature, construct its focal mechanism, and describe its tectonic position. For processing, we used data on 86 seismic phases from 58 stations with epicentral distances from 5.9 to 57°, azimuth angles from 1.5 to 341.7°, and the maximum azimuthal gap of 70°. The following parameters of the hypocenter were obtained: $t_0$ = 06 h 47 min 17.9 s, 59.93° N, 49.76° E, $R_{minor}$ = 7.7 km, $R_{major}$ = 10.7 km, $Az_{major}$ = 20°, $h$ = 16 km, and $M_s$ = 3.4/5. The earthquake is localized in the upper crust and is confined to the zone of the junction of the eastern slope of the Sysola arch and the western flank of the Kirov–Kazhim aulacogen of the Volga–Ural anteclise of the Russian Plate. We have established a strike-slip fault focal mechanism of the earthquake, which corresponds to the latest stress field of the region. The estimated axis parameters (value, azimuth, plunge) are as follows: $T$ = 0.707, 90.0, 0; $N$ = 0, 0, 39.792; and $P$ = –0.707, 180.0, 50.208. The plane parameters (strike, dip, slip) are estimated at 327, 57, –140° for the first plane and 213, 57, –40° for the second plane. The recorded seismic events in the northeast of the Russian Plate indicate that the platform area is not seismically passive. The performed research shows that recent seismotectonic processes are related to the structure and state of the Earth's crust within the platform.

*Keywords:* earthquake; weak seismicity; magnitude; bulletin; focal mechanism; East European Platform

## INTRODUCTION

The East European Platform (EEP) is characterized by weak seismicity. Until recently, written records existent over the historical period were the main source of information on the platform seismicity. However, high urbanization and the presence of critical and hazardous entities and large industrial centers make it necessary to trace every manifestation of seismicity in platform areas more attentively. Owing to rare manifestations of tectonic activity, each recorded earthquake is a unique event needing a thorough study.

The development of instrumental observation networks in the northern EEP, with the active cooperation of the Federal Research Center Geophysical Survey of the Russian Academy of Sciences (FRC GS RAS), made it possible to estimate manifestations of the present-day weak seismicity of the platform and to use these data for geological–tectonic and geodynamic reconstructions (Starovoit, 2005). The significance of such reconstructions was repeatedly emphasized by Yu.K. Shchukin (2001, 2007). He pointed out that the information on the tectonic activity of the platform remains fragmentary, not covering the whole recent geodynamics of the platform.

Southern Komi is the most seismically active territory in the northeastern EEP. It was struck by one of the largest earthquakes in the European north in the 20th century – the 1939 Sysola earthquake (grade 7) (Nikonov and Chepkunas, 2009) and the 2008 (Noskova, 2019) and 2011 (Noskova and Mikhailova, 2017) earthquakes with $M_L$ = 3.2 and 2.6, respectively.

On 9 November 2002, at 06:47 (UTC), seismic stations worldwide recorded an earthquake in the southern Komi Republic, with $M_s$ = 3.4–3.9, according to different seismological centers. This earthquake was recorded by a representative network of seismic stations, but it was not thoroughly studied and is not considered in literature. It is common in

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seismology to refine the focal parameters of earlier recorded earthquakes, because data obtained at different seismological centers and published in bulletins on an ongoing basis are preliminary and only from local stations. As a rule, more detailed studies are made later, when it becomes possible to use records from seismic stations of other networks, refined velocity models, and new research approaches.

The goal of the present work is to recalculate the hypocentral parameters of the earthquake, to construct its focal mechanism, and to describe its tectonic position. This requires the solution of the following problems: (1) collection of waveforms with earthquake records; (2) their processing with the use of the same velocity model, the same approach, and all now-available original data and bulletins from Russian and non-Russian seismic stations, and (3) comparison of the obtained coordinates with those provided by other seismological services.

## ORIGINAL DATA AND METHODS OF CALCULATION

In 2002, seismic observations at the Syktyvkar (SYK) station in the Komi Republic were still made using PC-II analog equipment involving photographic paper recording with a galvanometer based on SKM-3M short-period seismometers. Analog recording was stopped on 14 October 2002. In 2003, the Syktyvkar geophysical observatory was equipped with a SDAS digital seismic station, which had been developed by Geotekh+ research and production enterprise in cooperation with the GS RAS. Therefore, seismic records from the Syktyvkar station, which was the closest to the earthquake epicenter, are missing.

Digital records from 22 stations in and outside Russia (Fig. 1) were obtained and analyzed. The epicentral distances were 5.9–21.2°, and the azimuth angle was 22–341°. Original digital data from seismic networks abroad were obtained from GEOFON (GEOFON…, 1993), IRIS (Incorporated…), and NORSAR (Norwegian…) electronic resources.

We took wave onsets at 37 seismic stations from the 9 November 2002 earthquake bulletin by the International Seismological Centre (United Kingdom) (International…). Also, we used the *P*- and *S*-wave phases from the Amderma (Kola Branch of the GS RAS), FINESS Array Site C1, and Moravský Beroun stations and the *S* wave from the Arti, Arkhangelsk, Pulkovo, Storozhevoe, Kislovodsk, Kurchatov, and Spitsbergen Array stations. The location of all the stations used to refine the hypocentral parameters is shown in Fig. 2. The seismic bulletin of the 9 November earthquake is presented in Table 1. In total, we took 86 seismic phases at 58 stations with epicentral distances of 5.9 ($D_{min}$) to 57° ($D_{max}$) and azimuth angles of 1.5–341.7°; the maximum azimuthal gap (Gap) at these stations is 70°. Note that the use of the Amderma station in the processing of records permitted reducing the azimuthal gap by 13° compared to that in the ISC bulletin.

Preliminary determination of the hypocentral parameters based on original digital data was carried out with the WSG program complex (Krasilov et al., 2006) by minimization of misties. The final determination of the hypocentral parameters was performed by improved generalized beamforming (Ringdal and Kvaerna, 1989) with the NAS (New Association System) program (Fedorov et al., 2018). This program carries out association and more precise determination of coordinates and time in the vicinity of the precalculated hypocenter. The program chooses a circle of large radius (250 km in the present paper) around the point of origin. A more precise location is searched for in this circle, and it is covered with overlapping circles of smaller radii, which form a grid. The rating function $R(c, t)$ is calculated for each of these smaller circles to estimate the hypothesis that the event took place in the cell $c$ at the moment $t$. The grid is reduced several times. Every time three-quarters of the cells with the lowest ratings is removed from the grid. Each remaining cell is divided into four parts, for which the ratings are recalculated.

This search is done for a set of fixed depths (in this paper, 0–100 km with increments of 5 km). Finally, the preliminary location of the event is the cell with the maximum rating. The time $t_0$ at which the rating function reached its maximum is considered the estimated focal time. Only the phases which made a nonzero contribution to this maximum rating are regarded as associated with the located event. This approach permits automatically ignoring phases with unrealistic (erroneous) arrival times. This is very important in the use of the arrival times of seismic phases measured at stations which are "noisy" or far away from the epicenter, when erroneous determination of the arrival times is highly probable.

At the second stage, the location is specified by minimization of the mistie of the estimate of focal time from so determined times and their weighted values, and locations of the confidence region (error ellipse) are constructed. The confidence region appears instead of the true location point, because the values important for the location are unclear. First, the wave arrival times at the station are measured with errors whose interval will be denoted as $(-\Delta t_{arrival}, +\Delta t_{arrival})$. In other words, we presume that the measurement errors of the arrival times lie in this interval with a high probability (for example, 95%). Second, the velocity model that we use to calculate the traveltimes is also imprecise. If we assume that the apparent velocity in some case, according to the model, is equal to $v$, then the true apparent velocity lies in the interval $[v - \Delta v, v + \Delta v]$ with the same high probability (95%).

Thus, along with the known phases and coordinates of the sensors, the calculation of the confidence interval requires estimates of errors of the velocity model $\Delta v$ and measurements of the arrival times $\Delta t$ for different types of waves. In the present study, the errors of the velocity model are taken to be 0.15 km/s, and the measurement errors of the arrival times are equal to 0.3 s.

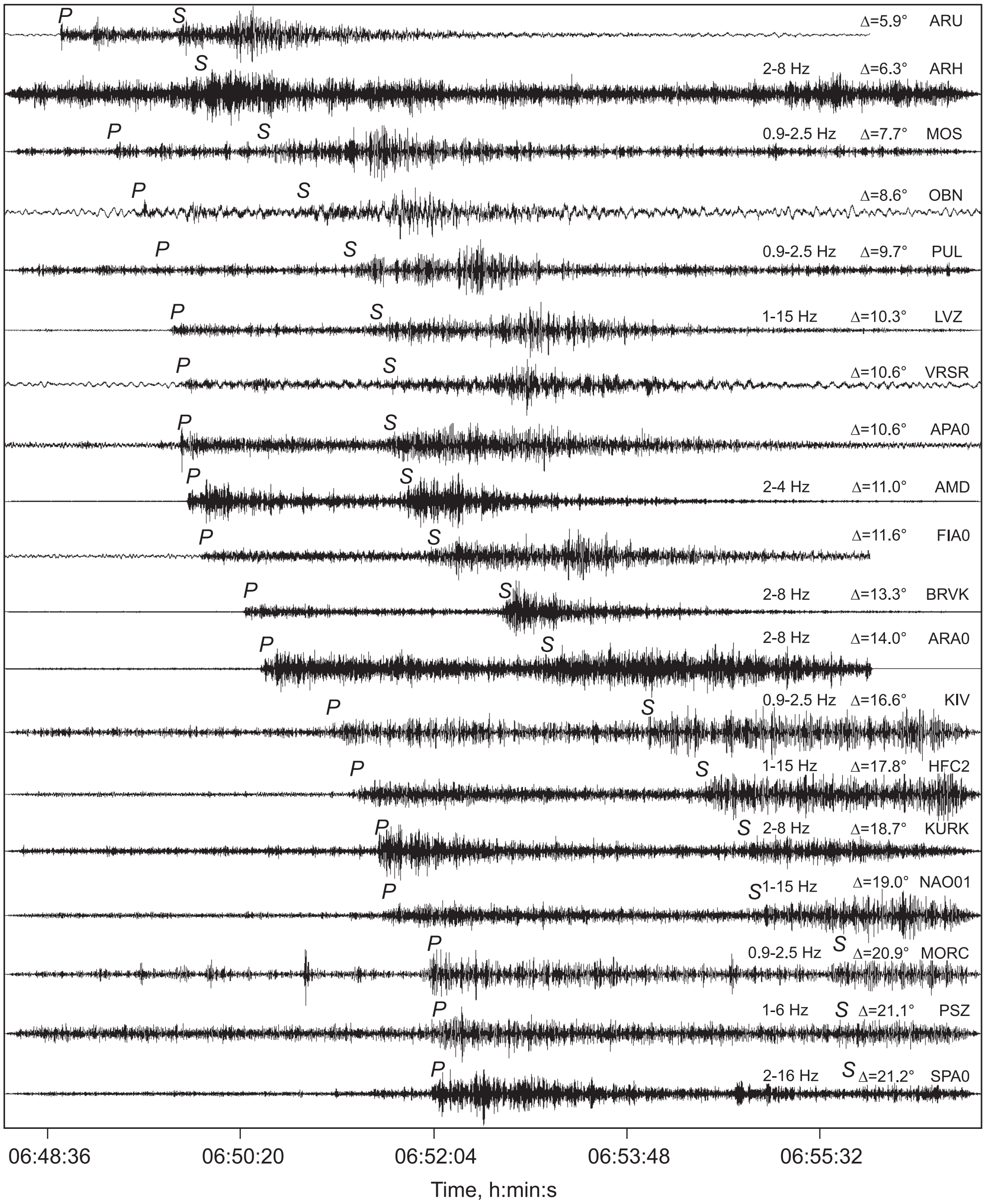



**Fig. 1.** Fragments of records of the vertical component of the 9 November 2002 earthquake, ordered according to the arrival time of the first phase.

The NAS program is a part of NSDL (New System for Detection and Location), which is used to organize automatic monitoring of regional seismic activity with an arbitrary grid of seismic stations or with individual stations. The system was approved at non-Russian and Russian research organizations, including branches of the GS RAS (Asming et al., 2017, 2018). The efficiency of the algorithm for calculating the hypocentral parameters in the NAS program was demonstrated by location of two nuclear explosions executed in the northern part of European Russia on 18 July 1985 and 6 September 1988 and two nuclear explosions executed on Novaya Zemlya on 2 November 1974 and 24 October 1990 (Morozov et al., 2018a). The approach described above helped to update the focal parameters of earthquakes in the northern Russian Plate of the EEP (Morozov et al., 2018b) and in the Barents–Kara region (Morozov et al., 2018a) as well as technogenic events in the Pechora coal basin (Noskova and Asming, 2018).

The parameters of the hypocenters were calculated using a velocity model for the East European (Schueller et al., 1997) supplemented by deep layers of the AK-135 model (Kennett et al., 1995). The local magnitude $M_L$ (MWA) was determined by the method implemented in the WSG program. It is based on the average calibration function for Northern Eurasia (Gabsatarova, 2006). The focal mechanism for the 9 November 2002 earthquake was determined from the signs of the first arrivals of *P* waves with the FA2011 program, developed by A.V. Lander (Ivanova et al., 2011).

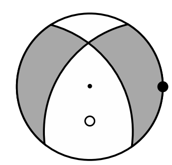
**Table 1.** Bulletin of the 9 November 2002 earthquake

| Code | International name of station, country | Latitude | Longitude | Distance | Azimuth | Arrival time | | International Seismological Centre (ISC) | Present paper |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *P* wave | *S* wave | | |
| | | deg | | | | h:min:s | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| AMD | Amderma, Russia | 69.7607 | 61.6782 | 11.0 | 22.1 | 06:49:51.30 | 06:51:49.71 | – | + |
| APA | Apatity, Russia | 67.5690 | 33.4050 | 10.4 | 323.3 | 06:49:44.70 | 06:51:37.50 | + | + |
| APA0 | Apatity Array Site A0, Russia | 67.6061 | 32.9923 | 10.6 | 323.3 | 06: 49:46.55 | 06:51:39.87 | + | + |
| ARA0 | ARCESS Array Site A0, NORSAR, Norway | 69.5349 | 25.5059 | 13.9 | 323.4 | 06:50:30.47 | 06:52:57.69 | + | + |
| ARC2 | ARCESS Array Site C2, NORSAR, Norway | 69.5383 | 25.5228 | 13.9 | 323.4 | 06:50:30.93 | 06:52:58.40 | – | + |
| ARE0 | ARCESS Array Site E0, NORSAR, Norway | 69.5348 | 25.5056 | 13.9 | 323.4 | 06:50:30.90 | – | + | + |
| ARHR | Arkhangelsk, Russia | 64.5505 | 40.5148 | 6.3 | 321.0 | – | 06:49:58.02 | – | + |
| ARU | Arti, Russia | 56.4293 | 58.5615 | 5.8 | 123.2 | 06:48:43.10 | 06:49:45.84 | + | + |
| BGCA | Bogoin, Central African Republic | 5.1761 | 18.4242 | 57.1 | 216.7 | 06:57:19.10 | – | + | + |
| BRVK | Borovoye, Kazakhstan | 53.0581 | 70.2828 | 13.2 | 112.3 | 06:50:21.17 | 06:52:39.71 | + | + |
| CLL | Collm, Sachsen,Germany | 51.3076 | 13.0026 | 22.0 | 263.0 | 06:52:14.00 | 06:56:06.00 | + | + |
| DOMB | Dombås, Norway | 62.0423 | 9.0641 | 19.4 | 293.3 | 06:51:42.11 | – | + | + |
| DPC | Dobruška/Polom, Czech Republic | 50.3501 | 16.3221 | 20.9 | 257.4 | 06:52:04.10 | – | + | + |
| EIL | Eilat, Israel | 29.6698 | 34.9511 | 31.5 | 204.5 | 06:53:41.05 | – | + | + |
| FIA0 | FINESS Array Site A0, Finland | 61.4436 | 26.0771 | 11.6 | 287.5 | 06:49:58.47 | 06:52:02.69 | + | + |
| FIC1 | FINESS Array Site C1, Finland | 61.4384 | 26.0596 | 11.6 | 287.5 | 06:49:58.59 | 06:52:03.36 | – | + |
| HFC2 | Hagfors New Array Site C2, Sweden | 60.1334 | 13.6945 | 17.7 | 286.3 | 06:51:20.20 | 06:54:28.47 | – | + |
| HFS | Hagfors, Sweden | 60.1334 | 13.6945 | 17.7 | 285.8 | 06:51:18.55 | 06:54:26.68 | + | + |
| ILAR | Eielson Array, Alaska, United States | 64.7713 | -146.8866 | 52.7 | 8.6 | 06:56:48.11 | – | + | + |
| INK | Inuvik, Canada | 68.3065 | -133.5254 | 50.0 | 1.5 | 06:56:25.92 | – | + | + |
| KAF | Kangasniemi, Finland | 62.1128 | 26.3061 | 11.5 | 290.2 | 06:49:57.30 | – | + | + |
| KEV | Kevo, Finland | 69.7553 | 27.0067 | 13.6 | 325.1 | 06:50:26.80 | – | + | + |
| KHC | Kašperské Hory, Czech Republic | 49.1309 | 13.5782 | 23.1 | 258.0 | 06:52:21.20 | – | + | + |
| KIV | Kislovodsk, Russia | 43.9553 | 42.6863 | 16.5 | 198.0 | 06:51:05.23 | 06:53:58.86 | + | + |
| KK31 | Karatay, Array, Kazakhstan | 43.1034 | 70.5115 | 20.9 | 133.8 | 06:52:02.23 | – | + | + |
| KONO | Kongsberg, Norway | 59.6491 | 9.5982 | 19.8 | 286.2 | 06:51:41.21 | 06:55:32.76 | + | + |
| KSP | Książ, Poland | 50.8428 | 16.2931 | 20.7 | 258.4 | 06:52:02.00 | – | + | + |
| KTK1 | Kautokeino, Norway | 69.0117 | 23.2371 | 14.4 | 319.6 | 06:50:35.18 | 06:53:11.91 | + | + |
| KURK | Kurchatov, Kazakhstan | 50.7154 | 78.6202 | 18.6 | 106.7 | 06:51:32.98 | 06:54:49.03 | + | + |
| LOF | Lofoten, Norway | 68.1310 | 13.5420 | 17.4 | 312.5 | 06:51:22.43 | – | + | + |
| LVZ | Lovozero, Russia | 67.8979 | 34.6514 | 10.3 | 326.8 | 06:49:43.03 | 06:51:33.51 | + | + |
| MK31 | Makanchi Array, Kazakhstan | 46.7937 | 82.2904 | 23.0 | 110.2 | 06:52:22.99 | – | + | + |
| MKAR | Makanchi Array Beam Reference Point, Kazakhstan | 46.7936 | 82.2903 | 23.0 | 110.2 | 06:52:21.57 | – | + | + |
| MLR | Muntele Roşu, Romania | 45.4908 | 25.9450 | 20.1 | 234.5 | 06:51:51.08 | – | + | + |
| MNK | Minsk, Belarus | 54.5021 | 27.8833 | 12.9 | 254.0 | 06:50:19.00 | – | + | + |
| MOL | Molde, Norway | 62.5700 | 7.54800 | 20.0 | 295.3 | 06:51:49.95 | – | + | + |
| MOR8 | Mo i Rana, Norway | 66.1713 | 14.4411 | 16.8 | 306.1 | 06:51:09.56 | – | + | + |
| MORC | Moravský Beroun, Czech Republic | 49.7768 | 17.5425 | 20.7 | 255.2 | 06:52:01.22 | 06:55:41.37 | – | + |
| MOS | Moscow, Russia | 55.7383 | 37.6250 | 7.7 | 241.8 | 06:49:07.49 | 06:50:31.64 | + | + |
| NAO01 | NORSAR Array Site 01A01, Norway | 60.8442 | 10.8865 | 18.9 | 289.6 | 06:51:35.94 | 06:54:54.90 | + | + |
| NOA | NORSAR Array, Norway | 61.0397 | 11.2147 | 18.9 | 289.6 | 06:51:30.14 | 06:54:50.50 | + | + |
| NSS | Namsos, Norway | 64.5300 | 11.9670 | 17.8 | 300.5 | 06:51:21.94 | – | + | + |
| NUR | Nurmijärvi, Finland | 60.5090 | 24.6490 | 12.4 | 282.7 | 06:50:09.30 | – | + | + |

**Table 1.** (*continued*)

| Code | International name of station, country | Latitude | Longitude | Distance | Azimuth | Arrival time | | International Seismological Centre (ISC) | Present paper |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *P* wave | *S* wave | | |
| | | deg | | | | h:min:s | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| OBN | Obninsk, Russia | 55.1138 | 36.5687 | 8.5 | 241.2 | 06:49:22.10 | 06:50:52.75 | + | + |
| OJC | Ojców, Poland | 50.2195 | 19.7984 | 19.4 | 252.9 | 06:51:43.70 | 06:55:08.80 | + | + |
| PRU | Průhonice, Czech Republic | 49.9883 | 14.5417 | 22.0 | 258.6 | 06:52:17.40 | – | + | + |
| PSZ | Piszkéstető, Hungary | 47.9184 | 19.8944 | 20.9 | 248.4 | 06:52:02.84 | 06:55:42.31 | + | + |
| PUL | Pulkovo, Russia | 59.7728 | 30.3222 | 9.7 | 277.3 | 06:49:32.49 | 06:51:17.84 | + | + |
| SPA0 | Spitsbergen Array Site A0, NORSAR, Norway | 78.1777 | 16.3700 | 21.0 | 341.7 | 06:52:02.86 | 06:55:46.21 | + | + |
| SUW | Suwałki, Poland | 54.0125 | 23.1808 | 15.5 | 258.6 | 06:50:53.03 | – | + | + |
| SVE | Sverdlovsk, Russia | 56.8271 | 60.6319 | 6.5 | 114.7 | 06:48:52.70 | – | + | + |
| TRO | Tromsø, Norway | 69.6325 | 18.9281 | 16.0 | 319.4 | 06:50:59.08 | – | + | + |
| VOR | Voronezh, Russia | 51.7311 | 39.2000 | 10.1 | 219.3 | 06:49:42.00 | – | + | + |
| VRAC | Vranov, Czech Republic | 49.3082 | 16.5935 | 21.5 | 254.9 | 06:52:08.34 | – | + | + |
| VRSR | Storozhevoe, Russia | 51.2150 | 39.1900 | 10.5 | 218.7 | 06:49:45.18 | 06:51:39.01 | + | + |
| ZAL | Zalesovo, Russia | 53.9366 | 84.7981 | 19.7 | 92.4 | 06:51:46.17 | – | + | + |
| ZRNK | Zerenda, Kazakhstan | 52.9508 | 69.0041 | 12.7 | 115.3 | 06:50:14.28 | 06:52: 27.52 | + | + |
| CHKZ | Chkalovo, Kazakhstan | 53.6761 | 70.6152 | 12.9 | 110.1 | 06:50:17.77 | 06:52:32.45 | + | + |

**Table 2.** Parameters of the focal mechanism of the 9 November 2002 earthquake

| $t_0$, h:min:s | Principal stress axes | | | | | | Nodal planes | | | | | | Diagram (double couple) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *T* | | *N* | | *P* | | $NP_1$ | | | $NP_2$ | | | |
| | PL | AZM | PL | AZM | PL | AZM | STK | DP | SLIP | STK | DP | SLIP | |
| 06:47:17 | 0 | 90 | 40 | 0 | 50 | 180 | 327 | 57 | –140 | 213 | 57 | –40 |  |

Note. *T*, *N*, *P*, Stress axes: extension, intermediate, and compression, respectively; PL, plunge, deg; AZM, azimuth, deg; $NP_1$, $NP_2$, nodal planes; STK, strike, deg; DP, dip, deg; SLIP, slip, deg.

## DISCUSSION

The following preliminary parameters were obtained by processing of data from seismic stations with the WSG program: $t_0$ = 06 h 47 min 17 s, 59.954° N, 49.698° E, depth $h$ = 16 km, and $M_s$ = 3.4/5. The final update was carried out with the NAS program for a depth of 16 km: $t_0$ = 06 47 min 17.9 s, 59.931° N, and 49.762° E; parameters of the error ellipse: $R_{minor}$ = 7.66 km, $R_{major}$ = 10.74 km, and $Az_{major}$ = 20°.

We calculated the focal mechanism of the earthquake from the signs of the first arrivals of *P* waves with the FA2011 program. The signs were determined using seismic records from ten stations, with expansional waves recorded at seven stations (APA0, AMD, PR1R, PR2R, FIA0, FIC1, and ARC2) and compressional waves at three (ARU, BRVK, and VRSR). Records from the Romanovo (PR1R) and Dobryanka (PR2R) stations (Mining Institute of the Ural Branch of the Russian Academy of Sciences) were preserved only as text files (μm/s). Therefore, they did not take part in the calculation of coordinates but were used to determine the directions of the first movement. We obtained a probable solution for a focal mechanism with strike-slip fault movement along both planes (Table 2). The axis parameters (value, azimuth, plunge) are as follows: $T$ = 0.707, 90.0, 0; $N$ = 0, 0, 39.792; and $P$ = –0.707, 180.0, 50.208. The plane parameters (strike, dip, slip) are estimated at 327, 57, –140° for the first plane and at 213, 57, –40° for the second.

According to our calculations, the earthquake occurred at a distance of 190 km from Syktyvkar, in the Priluzsky district of the Komi Republic, 29 km to the south of the mouth of the Sedka River, right tributary of the Luza River. It was felt in the neighboring populated places as weak vibrations. It should be noted that the district is not engaged in mining and there are no operating open-pit mines here. No techno-

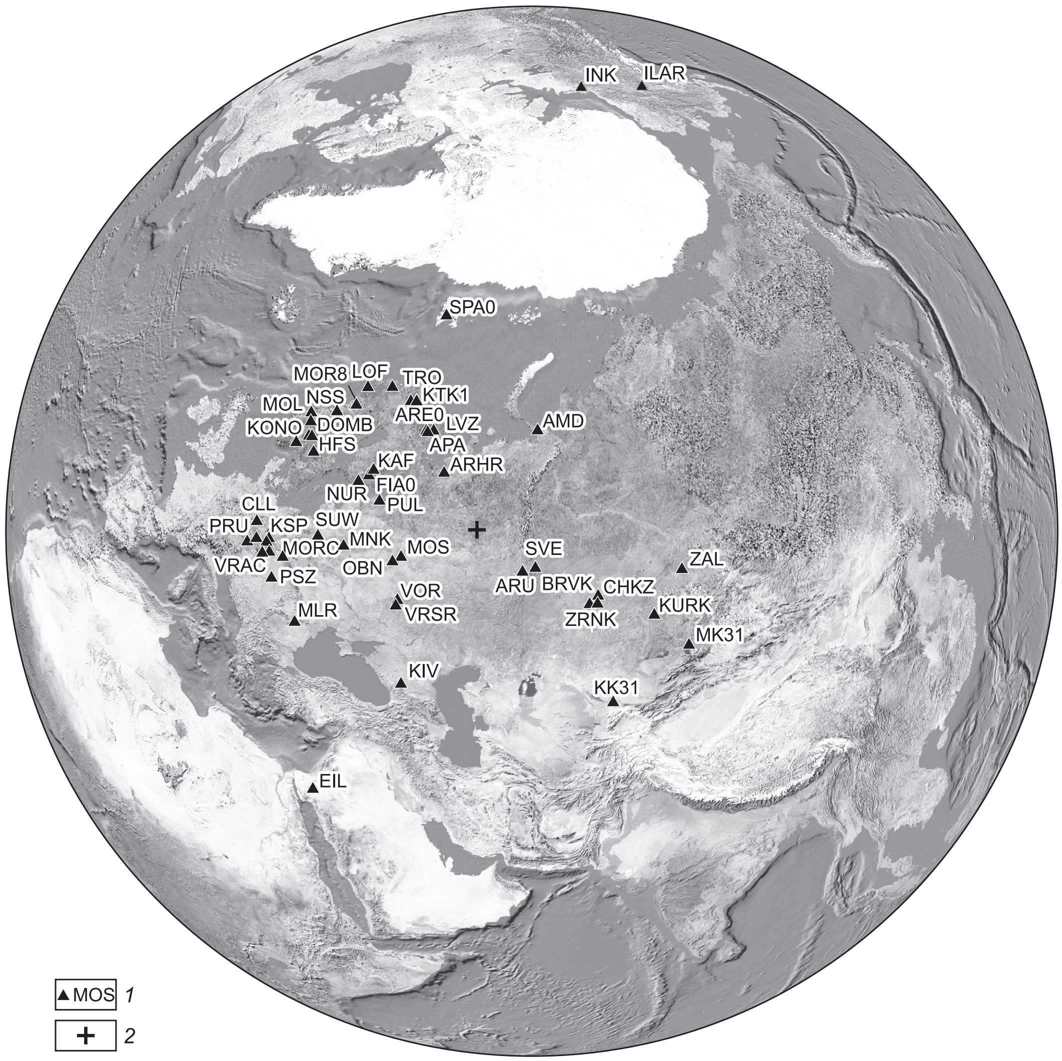



**Fig. 2.** Position of seismic stations used to relocate the 9 November 2002 earthquake. *1*, seismic station, code; *2*, position of the epicenter determined with the NAS program.

genic seismic events have been reported in the south of the republic over the entire period of instrumental observations. Also, note the strike-slip fault focal mechanism of the earthquake. So, the event was of tectonic nature.

Ten seismological centers in and outside Russia (Table 3) possess data on the focal parameters of the 9 November earthquake which were calculated based on information from different numbers of seismic stations. We determined the focal parameters of the earthquake based on all available original data and bulletins from seismic stations in Russia and abroad, using the same velocity model and approach. In total, we used 86 first-arrival times of *P* and *S* waves from 58 stations with epicentral distances of 5.9 to 57° and azimuth angles of 1.5 to 341.7°. The implemented algorithm of the NAS program makes it impossible to use the parameters of erroneous arrival times in the calculation. Thus, all conditions were provided for the most reliable calculation of the focal parameters. This is confirmed by the distribution of epicenters according to different seismological centers (Fig. 3). For example, at the Earthquake Early Alert Service of the GS RAS (Earthquake…), the parameters were calculated based on five stations, and the difference from the epicenter determined with the NAS program was 52 km. At the ISC (International…), the epicenter parameters were calculated using somewhat fewer stations (56 vs. 58), and the difference from the epicenter was already 20 km. However, unlike the parameters obtained at the ISC, the focal parameters in our work were calculated using a regional velocity model and with a larger azimuth angle and number of arrival times of seismic phases.

## TECTONIC POSITION OF THE FOCUS

Historical and instrumental seismicity near the epicentral area of the 9 November earthquake is shown in Fig. 4. The

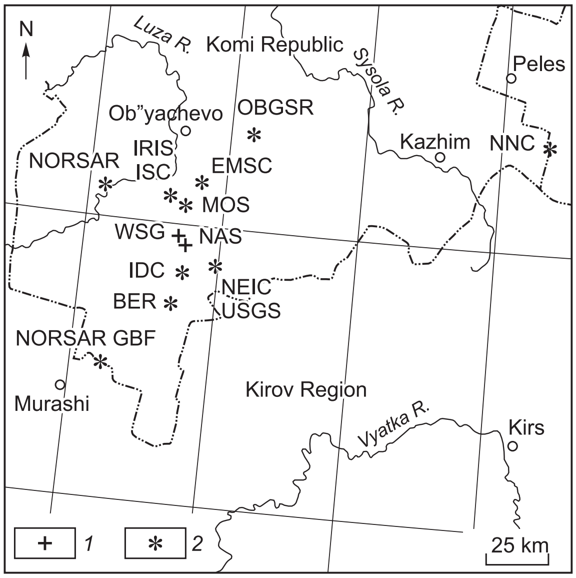



**Fig. 3.** Position of the epicenter of the 9 November 2002 earthquake, data from different seismological centers: *1*, *2*, instrumental epicenter from the seismological service in the present paper and from other seismological services, respectively.

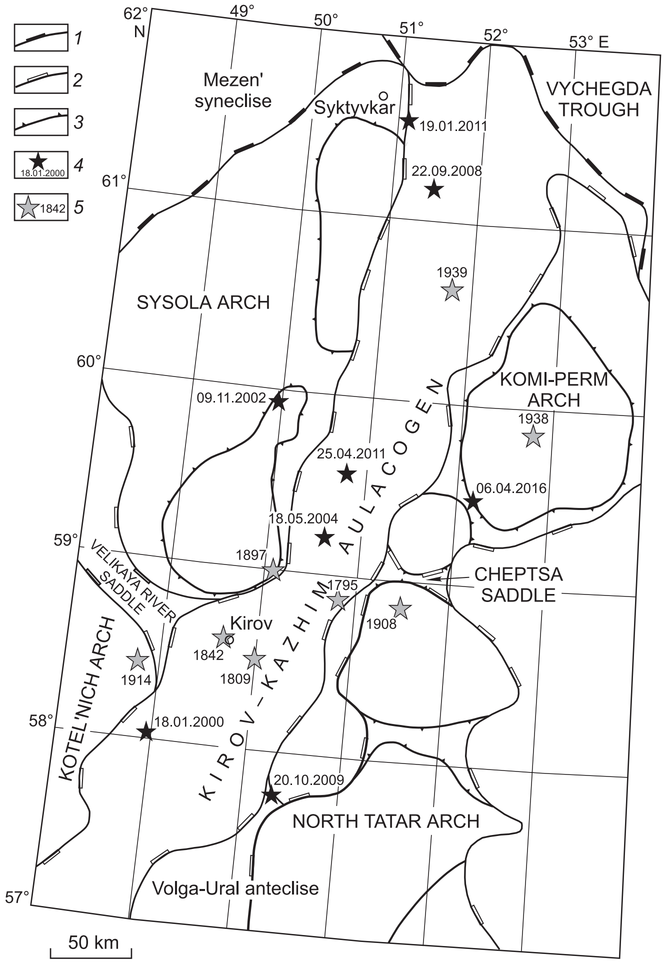



**Fig. 4.** Tectonic sketch map of the basement surface of the Kirov–Kazhim aulacogen and its framing with earthquake epicenters (Noskova and Mikhailova, 2017). *1*–*3*, boundaries of structures: *1*, superorder; *2*, first-order; *3*, second-order; *4*, *5*, epicenters of earthquakes: *4*, instrumental; *5*, historical.

seismic events in the northeastern Russian Plate are confined to the Kirov–Kazhim aulacogen and adjacent arches of the Volga–Ural anteclise of the Russian Plate. The 9 November earthquake took place within the Sysola arch, which is a large buried basement high stretching for more than 200 km from south to north and for 125–150 km from west to east. The arch surface is inclined westward from 1600 m (Sysola-1 well, –1616 m) in the eastern part, increasing to 2000 m to the west and southwest (Yakobson, 2016). The basement level in the epicentral area (–1900 m) corresponds to the Luza uplift or the Letnik salient.

The eastern slope of the Sysola arch has a benchlike junction with the western flank of the Kirov–Kazhim aulacogen. In the south, it is bounded by the Kotel'nich arch through the Velikaya River saddle, forming the Kotel'nich–Sysola system of arched uplifts, which is cut by a system of faults. In the west, the Sysola arch is separated from the Kotlas graben – a part of the Central Russian aulacogen, which marks the collisional suture zone between Fennoscandia and Volgo-Uralia (Bogdanova et al., 1996). In the northeast, the arch slope dips steeply into the area of the Vychegda trough, whose boundary is traced along large faults (Malyshev, 2002). Along the epi-Karelian basement surface, the trough is oriented northwestward along the Timan Ridge. According to geophysical data, the Timan Ridge is a thrust interpreted as a suture zone along which the Pechora Plate is overthrust onto the Russian Plate (Olovyanishnikov, 1998). In the zone of collision with the Pechora Plate, the edge of the Russian Plate experiences tangential (compression) and vertical stress. In these conditions, the territory following the plate margin will rise as if squeezed out by the approaching Pechora Plate (Zharkov, 2005). The tectonic stress calculated by us (near-E–W extension and near-N–S compression (Table 2)) might be due to the tectonic pressure of the Pechora Plate.

As shown by GPS monitoring of the territory (Ovcharenko and Balandin, 2009), the horizontal movements have directions and velocities (25–30 mm/yr to the east and 5–10 mm/yr to the north) typical of the Russian Platform. The velocities of the vertical movements are two or three times higher than those of the horizontal movements. The presence of horizontal stress and the different ranks of stress fields in the study area are confirmed in (Kopp, 2012; Kopp et al., 2014). Two competing types of fault regime with extension are shown. The epicenters of the Vyatka earthquakes were compared with data on the orientation of recent stress. The comparison showed that the linear elongated epicentral zones are associated with ENE-trending shears, mainly dextral ones, and the WNW-trending lineaments transverse to the Vyatka dislocations which must develop in the case of

**Table 3.** Principal parameters of the 9 November 2002 earthquake (06:47), according to different seismological centers and services

| Service | $t_0$, h:min:s | Hypocenter | | | Error ellipse | | Magnitude |
|---|---|---|---|---|---|---|---|
| | | N, deg | E, deg | *h*, km | $S_{major}$ | $S_{minor}$ | |
| Present paper | 06:47:17.9 | 59.93 | 49.76 | 16 | 10.7 | 7.7 | $M_s$ = 3.4/5 |
| GS RAS, Obninsk (**OBGSR**) http://www.ceme.gsras.ru/ | 06:47:15.3 | 60.35 | 50.17 | 40 | – | – | $m_b$ = 3.6/3 |
| IRIS http://ds.iris.edu/ | 06:47:13 | 60.10 | 49.60 | 23.3 | – | – | $m_b$ = 4.1 |
| EMSC http://www.webdc.eu | 06:47:12 | 60.16 | 49.82 | 2 | – | – | $m_b$ = 4.1 |
| USGS http://www.webdc.eu | 06:47:13 | 59.87 | 49.98 | 10 | – | – | $m_b$ = 4.1 |
| BER http://www.isc.ac.uk/ | 06:47:12.8 | 59.72 | 49.69 | 16 | 0.4 | 0.2 | – |
| NEIC http://www.isc.ac.uk/ | 06:47:13.9 | 59.87 | 49.97 | 10*f** | 12.3 | 6.9 | $m_b$ = 4.1 |
| MOS http://www.isc.ac.uk/ | 06:47:14.1 | 60.07 | 49.72 | 33 | 11.7 | 8.6 | $m_b$ = 4.1 |
| IDC http://www.isc.ac.uk/ | 06:47:14.6 | 59.83 | 49.75 | 0*f** | 20.5 | 14.4 | $m_b$ = 3.8 |
| NNC http://www.isc.ac.uk/ | 06:47:25.8 | 60.38 | 52.36 | | 88.4 | 12.4 | – |
| ISC http://www.isc.ac.uk/ | 06:47:13.7 | 60.10 | 49.60 | 23 | 7.4 | 5.1 | $m_b$ = 3.8 |
| NORSAR (reviewed regional bulletin November 2002) http://www.norsardata.no | 06:47:20.5 | 60.12 | 49.11 | 7 | 0.4 | 0.2 | 3.97/4 |
| NORSAR (GBF Bulletins – 2002) http://www.norsardata.no | 06:47:12 | 59.48 | 49.24 | – | – | – | 3.97/4 |

**f*, Fixed depth.

extension in the stress field with WNW compression (Kopp, 2012). This is consistent with the strike-slip fault focal mechanism of the earthquake. The dynamic layering of the latest stress field in the vertical cross-section was established. This suggests that tectonic pressure is transferred horizontally by consolidated crust (to the upper part of which the hypocenter of the 9 November earthquake is confined), including the basement. At the same time, its cover exhibits passive behavior. It almost does not transfer stress; moreover, it dispels deep horizontal stress and transforms compression into extension.

The recorded seismic events in the northeastern Russian Plate indicate that the territory is not seismically passive. Although these are mainly low-magnitude upper-crust earthquakes, they reflect recent tectonic activation of the Earth's crust.

## CONCLUSIONS

To recalculate the principal parameters of the 9 November 2002 event, the authors used a representative network of 58 stations with epicentral distances of 5.9–57°. Waveforms with an earthquake record have been obtained for 22 stations. The solution is reliable and consistent with data from other seismological services. The hypocentral depth has been determined considerably more precisely, and it shows the upper-crust character of the event. The tectonic nature of the event has been substantiated. We have established a strike-slip fault focal mechanism of the earthquake, which corresponds to the latest stress field of the region. The performed research shows that recent seismotectonic processes are related to the structure and state of the Earth's crust within the platform.

The authors are grateful to colleagues from the FRC GS RAS (Obninsk, Apatity, Voronezh, and Perm cities) for providing seismic records.

Funding research was provided by Federal Research Center of the Komi Science Centre of the Ural Branch of the Russian Academy of Sciences № AAAA-A17-117121270035-0, N. Laverov Federal Center for Integrated Arctic Research of the Ural Branch of the Russian Academy of Sciences № AAAA-A18-118012490072-7 state assignment projects, and by a project supported by the Russian Foundation for Basic Research № 19-05-00481.

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*Editorial responsibility:* V.S. Seleznev