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KALININGRAD EARTHQUAKE OF SEPTEMBER 21, 2004 AND SEISMIC HAZARD FORECAST IN THE BELARUSIAN-BALTIC REGION

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The paper deals with the earthquakes that took place in the Kaliningrad region (Russia) on 21 September 2004 and were felt in the territories of Poland, Lithuania, Latvia, Estonia, Belarus and Finland. Data on space and time co-ordinates and dynamic parameters of these earthquake foci available from international centers and various seismological groups are analyzed. A degree of reliability of the results obtained is discussed.

The epicentral zone of the Kaliningrad earthquakes is found within the western part of the old East European Platform (EEP). The seismotectonic map presenting the territories of Belarus and the Baltic States was considered, and the Kaliningrad-Lithuanian potential seismogenic area was analyzed. Methods used to outline possible earthquake zones when seismic zoning of the Belarusian-Baltic region was carried out were verified in practice and, actually, made possible a long-term forecast of earthquake origination in Kaliningrad.

Keywords: hazard; Kaliningrad region; seismicity; tectonics

1. Introduction

A series of earthquakes certain of which were felt in the territories of Poland, Lithuania, Latvia, Estonia, Belarus and Finland occurred in the Kaliningrad Enclave (Russia) on 21 September, 2004. The earth's surface tremor intensity in an epicenter of the major event which took place at 01:32 p.m. was estimated to be 6 on MSK scale.

The earthquakes were recorded by the seismic observation network of Belarus. This network included 2 observatories operating at Naroch and Pleshchenitsi, seismic stations at Glushkovichi in the south of Belarus, and a local seismic group at

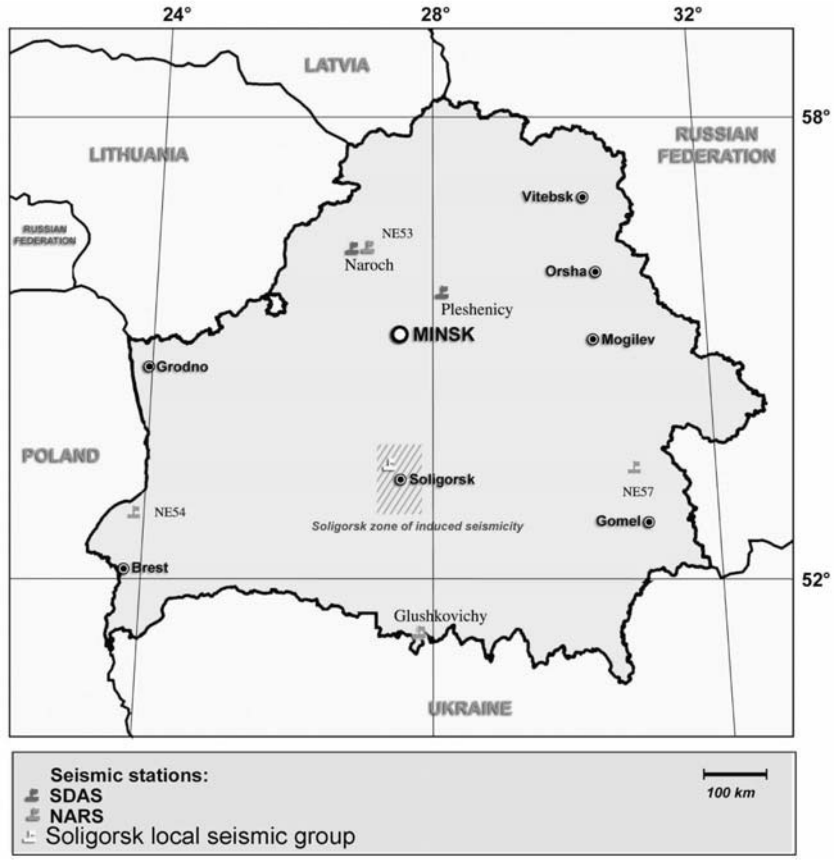

Fig. 1. Seismic network of Belarus

Soligorsk involving 4 observation points nearly the Starobin potassium salt deposit in the north-western part of the Pripyat Trout.

The locations of seismic station are shown in Fig. 1.

2. Parameters of the seismic observation network

The main parameters of the seismic observation network are given in Table I.

International data centers and various seismological groups determined space and time co-ordinates and dynamic parameters of foci of these earthquakes. The information on three major events is presented in Table II.

Figure 2 presents fragments of wave patterns of the Kaliningrad earthquakes recorded by seismic stations of Belarus.

The reliability of the result of location of earthquake epicenters depends mainly on a body of relevant information obtained from seismic observation points involved in seismic monitoring.

Table I. Monitoring network of seismic stations of Belarus

Station		Date	Co-ordinates			Equipment			
Name	Code	Opening	$\varphi°$, N	$\lambda°$, E	h, m	Instrument type	Component	$V_{\max}$	$\Delta T_{\max}$, c
Minsk	MNK	03.01.1963	54.50	27.88	196	CCM-CKM	N	7900	1.04–1.57
							E	8800	1.11–1.64
							Z	10174	1.15–1.53
						CCM-CKD	N	480	1.71–13.9
							E	490	1.74–11.0
							Z	560	1.24–13.6
		05.06.2002				SDAS	N,E,Z		0.5–10
Soligorsk	SOL	01.01.1983	52.84	27.47	–436	CKM	N	30800	0.37–0.87
							E	8300	0.30–0.59
							Z	25500	0.45–1.12
	PKN 1	20.05.2003	52.84	27.47			N,E,Z		
	PKN 2	20.05.2003	52.75	27.52			N,E,Z		
	PKN 3	20.05.2003	52.80	27.43			N,E,Z		
	PKN 4	20.05.2003	52.79	27.63			N,E,Z		
Naroch	NAR	01.10.1989	54.90	26.78	189	CCM-CKM	N	15900	0.71–0.88
							E	8700	0.79–1.12
							Z	19200	0.78–1.03
						CCM-CKD	N	1300	1.13–8.81
							E	900	2.10–10.5
							Z	1300	2.23–10.1
						CCM-CD	N	100	3.18–27
							E	80	3.40–22
							Z	160	2.95-33
						CCM-KPTS	N	100	2.45–29
							E	80	4.11–18
							Z	160	3.14–26
		07.07.1995				CSD-20	N,E,Z		0.1–10
		28.11.2002				SDAS	N,E,Z		0.5–10
Glushkovichi	GLSH	25.04.2002	51.54	27.80	100	CSD-20			0.1–10

The allocation of the spatial temporal sources position data of Kaliningrad earthquakes in Centre of Geophysical Monitoring, National Academy of the Sciences of Belarus (CGM NASB) was carried out according to the nearest monitoring network data. The information was obtained from the seismic stations in Belarus, Poland, Lithuania, Czech Republic and Slovakia.

A "classic" for seismologists three-layer crust consisting of sedimentary, "granitic"

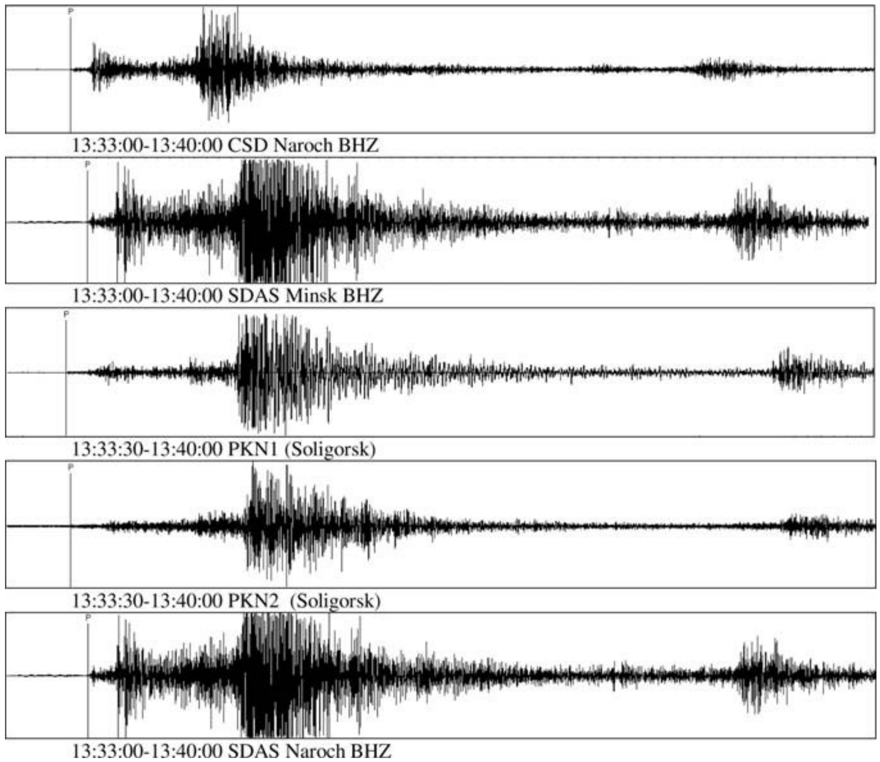

Fig. 2. Fragments of records of Kaliningrad earthquake at 01:32 p.m.

and "basaltic" layers, separated horizontally deposited gradient borders was taken as a model. As a result of the analysis of the crust structure in various western regions of EEP averaged velocity profile of the region was obtained, which naturally should be observed with a certain error estimate.

The zone of creep speeds has thickness of about 2 km and the average stratal compressional speed of $V_P = 4.5$ km/s and transverse velocity of $V_S = 2.3$ km/s. Further long the speed rapidly increases up to $V_P = 5.9 - 6.0$ km/s; $V_S = 3.3 - 3.4$ km/s. Any substantial speed increase within the borders of "granitic" layer is not observed, however, in the depth of about 20 km compressional speed and transverse velocity start growing according to the parabolic law and rich up to 6.6 and 3.8 km/s respectively, which characterizes "basaltic" layer. A rapid parabolic speed increase up to $V_P = 8.0$ km/s and $V_S = 4.6$ km/s is also observed at the bottom of the crust at the average depth of about 43 km.

The epicentral zone of the Kaliningrad earthquake is confined to the western part of the old East European Platform (Belarusian-Baltic region) and is adjacent to the Baltic Sea. Generally, this region is a single seismotectonic feature which exhibits the similar geological evolution and common present-day geodynamic conditions.

In spite of a rather poor seismic activity of this region, rather important seismic events with magnitudes $M = 4.0 - 5.0$ (e.g. Aronov et al. 2003, 2004, Boborikin

Table II. Main parameters of the Kaliningrad earthquakes of September 21, 2004

	GMT		Lat. N	Long. E	H km	M_s	m_b	I_o
GS RAS	11 05	04.96	54.838	20.129	21	4.1	4.9	4–5
	13 32	31.33	54.840	20.172	17	4.3	5.1	5–6
	13 36	33.76	54.868	19.99	0.5	3.0	–	3–3.5
CGM NASB	11 05	09.54	54.762	20.683	10	4.1	4.9	4–5
	13 32	35.92	54.800	20.774	10	4.3	5.1	5–6
	13 36	31.54	54.569	20.402	10	3.0	–	–
EMSC	11 05	04.2	54.69	20.23	10		4.4	–
	13 32	29.2	54.77	19.94	10		5.0	–

Note: GMT – Greenwich mean time; Lat. – latitude; Long. – longitude; H – hypocenter depth; M_s – surface wave magnitude; m_b – body wave magnitude; I_o – seismic intensity score in epicentral zone; GS RAS – Geophysical Service of the Russian Academy of Science; CGM NASB – Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus; EMSC – European Mediterranean Seismological Center, France

et al. 1988, 1995, Nikonov and Sildree 1988, Kondorskaya and Ulomov 1990, 1995, Nikulins 1998) took place within its limits. Seismic manifestation in the region are probably associated with several large seismoactive tectonic features situated there: a recent forming rift within the Gulfs of Bothnia and Finland in the Baltic Sea, the Pripyat-Donets aulacogen, zones of junction of the old East European Craton and the young West European Platform (Teisseire-Tornquist zone) and of the Russian Plate and the Baltic Shield.

At the end of the past centure investigations were performed to assess the seismic hazard in the Belarusian-Baltic region (e.g. Aizberg et al. 1999, Garetsky et al. 1997). These works were based on methodical approches aimed at identification (outlining) of Zone of Probable Occurrence Earthquake Foci (hereinafter referred to as "PEF zones") in poorly seismoactive regions (e.g. Reisner et al. 1991, Reisner et al. 1993 or Reisner and Ioganson 1993, Nikulin et al. 2004). Investigations based on geological-geophysical, seismological and tectonic data resulted in a seismotectonic map compiled for the territory of Belarus and the Baltic States (e.g. Aizberg et al. 1999), where 18 seismoactive and potentially seismoactive PEF zones were distinguished, and their quantitative parameters were determined, among them linear and areal sizes, seismotectonic potential value $M_{\max}$, minimum depth of probable earthquake foci.

Among PEF zones distinguished in the region the Kaliningrad-Lithuanian potentially seismoactive zone was outlined. The term "potential" was used to signify that no data on seismicity manifestation within this PEF zone were available despite obvious geological and geophysical evidences of a neotectonic active geological structure existed there.

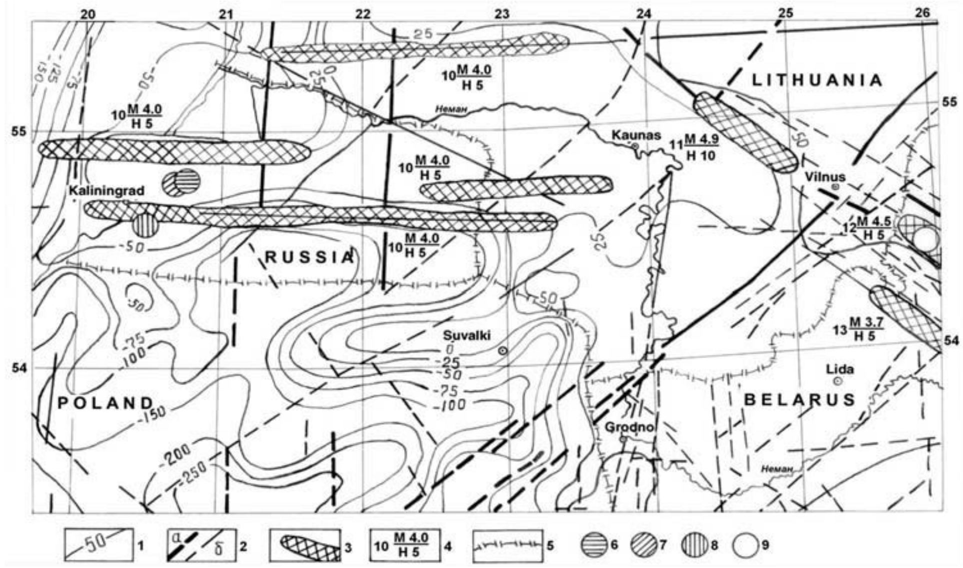

Fig. 3. Fragment of the seismotectonic map of the Belarusian-Baltic region with epicenters of the Kaliningrad earthquakes of 21 September, 2004. 1 – isobase of total amplitude of vertical Neotectonic movements (m); 2 – active faults: a – of the first order (superregional), b – of the second and smaller orders (regional and local). Solid lines show activated sections of ancient faults, broken lines show recent rupture disturbances; 3 – PEF zones (10 – Kaliningrad-Lithuanian zone; 10.1 – Northern subzone, 10.2 – Central subzone, 10.3 – Southern subzone); 4 – PEF zone parameters: numerator (M) shows maximum magnitude values, denominator (H) – minimum depth to the earthquake hypocenter with $M_{\max}$ for the given zone; fraction is prefixed by a figure which is conventional number of a zone (Aizberg et al. 1999); 5 – interstate boarder. Epicenters of earthquakes of 21 September, 2004 according to data of: 6 – GS RAS; 7 – CGM NASB; 8 – EMSC; 9 – epicenter of earthquake of 1908. Note: SDAS – Seismic Digital Automatic Station, made in Russia; NARS – a separate station of Network of Autonomous Recording Stations, made in the Netherlands

3. The Kaliningrad-Lithuanian PEF zones

The Kaliningrad-Lithuanian PEF zones is described by high seismotectonic potential and divided into three subzones.

1. *Northern subzone* is distinguished from a complex of geological and geophysical evidences as a neotectonic active geological structure. It is slightly pronounced in the Moho discontinuity. There are displacements along the fault zone in the basement surface and in the sedimentary cover. This zone is identified as a tectonic dislocation active in Neogene-Quaternary time and responsible for differentiated variation of rock thickness in the upper part of the sedimentary cover.

   It is revealed in the recent relief as a lineament zone governing changes of linear landforms. Elevated heat flow values (up to 90 mW/m^2) are recorded along the fault zone; $M_{\max} = 4.0$; $H = 5$ km.

2. *Central subzone.* A belt of fault was distinguished from geological and geophysical data. It is slightly pronounced in the Moho. The subzone is evident in the basement and cover as small-amplitude shifts along faults. It is distinguished as a part of the active regional fault, which is responsible for linear landforms, is shown as a lineament zone in the cosmotectonic map. This structure corresponds to a linear gradient zone of neotectonic deformations found between isobases +25 m and −75 m. All the above features permit this subzone identification as a neotectonic active geological structure, $M_{\max} = 4.0$; $H = 5$ km.

3. *Southern subzone* is composed of several latitudinal rupture dislocation distinguished from geological and geophysical evidences. It is shown in the basement and cover as small-amplitude shift in the Moho. The faults under consideration are found in a zone of rather severe neotectonic deformation in the neotectonic map and are distinguished as lineament responsible for linear landforms — in the cosmotectonic map. The information cited above relates the southern subzone to neotectonic active geological structure, $M_{\max} = 4.0$; $H = 5$ km.

Epicenters of the Kaliningrad earthquakes are located within the Southern subzone and they are shown in Fig. 3.

Possible approaches to quantitative solution of the determination of maximum probable magnitudes $M_{\max}$ of earthquakes for the EEP condition can be found in different papers (e.g. Grachev 2000). The method advanced is based on a possibility of estimation of the deformation rate dependent on tectonic processes along with using the seismic regime parameters.

Investigations described in this paper suggest that the region of the Kaliningrad earthquakes is also related to a zone with $M_{\max} = 4.0$ according to a diagram of geodynamic zoning.

Methodical approaches used to distinguish PEF zones, when the territory of the Belarusian-Baltic region was divided into seismotectonic zones, were substantiated in actual practice and, in fact, provided an opportunity to make a long-term forecast of the Kaliningrad earthquakes. However, as the magnitude of this earthquakes was well above the forecasted values obtained when the seismotectonic map of Belarus and the Baltic states (Garetsky et al. 1997) and the diagram of the geodynamic zoning (e.g. Grachev 2000) were compiled, some additional investigations are required to assess the PEF zone parameters using the seismicity data recently available for this region.

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