

# Practice of Detailed Seismic Zoning of the Northwest Caucasus Taking into Account the Results of Paleoseismological Studies

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**Abstract**—A new generalization of Northwest Caucasus seismic hazard data is presented taking into account the influence of paleoseismological studies on the seismic hazard level. An attempt has been made to use data on paleoearthquakes for direct seismic hazard assessment by comparing, in accordance with the recurrence law, the magnitude of a strong earthquake with the estimated number of weak seismic events. A fundamentally new seismotectonic base (map of possible earthquakes source (PES) zones) has been prepared for compiling detailed seismic hazard maps of the region. Based on the map of PES zones, seismic impacts are calculated on a probabilistic basis. On the compiled maps, the northwestern and central segments of the Greater Caucasus look like a seismic hazardous area, where the level of seismic effects reaches 8.5 points on maps A and B. At the same time, compared to data from GSZ-97 maps, the results look more differentiated and overall appreciable decrease the level of seismic hazard in the region. The work is important from a methodological aspect in light of seismic risk management of this densely populated and actively developed Russian territory.

**Keywords:** recurrence law, PES zones, seismic hazard maps, paleoearthquakes, seismic activity, seismic shaking, seismic mode

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## INTRODUCTION

In recent years, an increase in the number of paleoseismological studies has been noted (Nikonov, 1991; Nikonov and Reisner, 2002; *Paleoseismology*, 2009; Rogozhin et al., 2014). As a result, paleoseismic dislocations have been identified that may be associated with strong earthquakes that occurred in the distant past. Rough dating of such seismic events is done by radiocarbon, thermoluminescent, and other methods, and their magnitudes are also very approximately estimated from the offset amplitude the horizons of young sediments and paleosols. A significant amount of paleoseismological studies have been carried out in the past 10–15 years in the Northwest and Central Caucasus (Rogozhin et al., 2014).

Until now, data on strong paleoearthquakes obtained from analyzing paleoseismic dislocations have been used only to refine estimates of the maximum magnitude ( $M_{\max}$ ) identified in the research area of possible earthquakes source (PES) zones (Nikonov

and Reisner, 2002; Rogozhin et al., 2014). This study, using the example of the Northwest Caucasus, attempted to apply paleoearthquake data for direct seismic hazard assessment by comparing, in accordance with the law of recurrence, the magnitude of a strong paleoearthquake with the estimated number of weak seismic events with a magnitude of  $M_S = 3.3$ . This magnitude is used as a reference when assessing the seismic activity of the territory (*Seismicheskoe...*, 1980).

The study was carried out with the methodology of the new SP 408.1325800.2018 “Detailed Seismic Zoning and Seismic Microzoning for Spatial Planning.”

## ANALYSIS OF THE REGIONAL SEISMIC REGIME

The considered territory of the Northwest and, partially, the Central Caucasus has a trapezoidal shape with coordinates of the peaks of 42.5°–45.5° N, 37.0°–41.0° E. To analyze the seismic regime, the

**Table 1.** Distribution of number of events in catalog by year and magnitude

Years	Magnitude $M_S$												$N_0$
	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
BCE	0	0	0	0	0	0	0	0	0	1	1	1	3
0–1000	0	0	0	0	0	0	0	0	2	0	0	0	2
1001–1500	0	0	0	0	0	0	0	0	0	0	1	1	2
1501–1700	0	0	0	0	0	0	1	0	0	0	0	0	1
1701–1800	0	0	0	0	2	0	1	1	0	0	0	1	5
1801–1850	0	0	1	0	5	0	2	2	0	0	0	0	10
1851–1900	0	0	0	0	6	7	3	4	1	1	0	0	22
1901–1950	0	0	0	4	12	11	10	8	4	0	1	0	50
1951–1960	0	0	1	0	5	3	8	1	2	0	0	0	20
1961–1970	0	28	7	52**	22	8	1	2	1	0	1	0	122
1971–1980	0	1	0	68	18	9	5	0	1	0	0	0	102
1981–1990	0	0	23	47	17	8	2	0	0	0	0	0	97
1991–2000	12	26	83	87	35	9	3	0	0	0	0	0	255
2001–2005	3	34	97	25	15	1	2	1	0	0	0	0	178
2006–2010	10	19	70	30	9	1	0	0	0	0	0	0	139
2011–2015	244	259	130	54	13	10	4	1	0	0	0	0	715
2016–2018	61	46*	37	30	12	4	0	0	0	0	0	0	190
$N_0$	330	413	449	397	171	71	42	20	11	2	4	3	1913
$N_{com}$	0	305	334	393	141	53	35	17	9	0	0	0	1287

Periods of completeness observations are highlighted.  $N_0$ , the total number of events of corresponding magnitude.  $N_{com}$ , number of events of corresponding magnitude during completeness observations.

\* By 2016, inclusive.

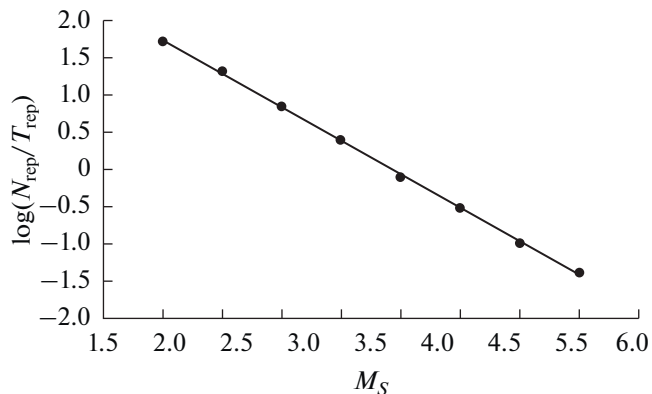
\*\* Since 1962.

Caucasus Earthquake Catalog from 1250 BC the end of 2018 was used, which was compiled at GS RAS (Obninsk). The catalog is constantly updated with current seismological information from the Operational Seismological Catalog and Catalog of the Urgent Reporting Service of the GS RAS (Obninsk).

After cleaning from aftershocks, the catalog in the coordinates indicated above totaled 1913 events in the magnitude range  $1.3 \leq M_S \leq 7.2$ . Table 1 presents the distribution of the number of events in the catalog by years and magnitudes.

In accordance with the above data, the lowest completeness magnitude was identified as  $M_S = 2.0$  (from 2011 to 2016 inclusive). Data on  $M_S = 2.0$  for 2017–2018 are not yet available, since GS RAS processes small-magnitude events with a lag. Since there was also no guarantee that all high-magnitude events ( $M_S \geq 6.0$ ) were recorded in the past without gaps, we limited ourselves to  $M_S = 5.5$  as the upper boundary of the magnitude completeness catalog.

In Table 2, events of the earthquake completeness catalog are separated by number of events in the corresponding magnitude ranges, taking into account the period of their complete observation. From the data in Table 2, using the linear orthogonal regression method, we constructed an unnormalized graph of the earthquake recurrence frequency (Fig. 1), which gives an idea of the average recurrence period of the corresponding magnitudes throughout this territory.



**Fig. 1.** Recurrence graph of earthquakes in Northwest Caucasus in magnitude range  $2.0 \leq M_S \leq 5.5$ .

**Table 2.** Distribution of number of events by magnitude in completeness catalog

$M_S$	Years	$T_{\text{com}}$ , years	$N_{\text{com}}$	$N_{\text{com}}/T_{\text{com}}$	$\log(N_{\text{com}}/T_{\text{com}})$
2.0	2011–2016	6	305	50.83333	1.70615
2.5	2001–2016	16	334	20.875	1.31963
3.0	1962–2018	57	393	6.894737	0.83852
3.5	1962–2018	57	141	2.473684	0.39334
4.0	1951–2018	67	53	0.791045	–0.10180
4.5	1901–2018	118	35	0.29661	–0.52781
5.0	1851–2018	168	17	0.10119	–0.99486
5.5	1801–2018	218	9	0.041284	–1.38421

$T_{\text{com}}$ , period of completeness observations of corresponding magnitude;  $N_{\text{com}}$ , number of events of corresponding magnitude during completeness observations.

In analytical form, the recurrence graph is as follows:

$$\log(N/T_{\text{com}}) = -(0.900 \pm 0.009)M_S + 3.532 \pm 0.056; \quad (1)$$

$$R_c = 0.9997.$$

Hereinafter,  $R_c$  is the linear correlation coefficient.

It should be noted that in recent decades (since the end of the 1980s), the slope of the recurrence graph for the study area has hardly changed (Lutikov and Chebkasova, 1991; Lutikov et al., 2013).

### SEISMIC ACTIVITY

For detailed knowledge of earthquake recurrence of various magnitudes in this territory, a matrix of seismic activity  $A_{3,3}$  was constructed, which is an analog of seismic activity  $A_{10}$  (*Seismicheskaya...*, 1979), also used with the matrix  $M_{\text{max}}$  for calculating seismic shaking. Calculations were carried out for cells  $10'$  ( $0.167^\circ$ ) in latitude and  $15'$  ( $0.25^\circ$ ) in longitude. Recall that seismic activity is defined as

$$A_0 = (1 - 10^{-b})/10^{-b(M_{\text{min}} - M_0)}(T_0 S_0)/(TS)N_S, \quad (2)$$

where  $b$  is the slope of the recurrence graph (in this case  $b = -0.900$ );  $M_{\text{min}} = 2.0$  is the smallest completeness magnitude (level of completeness);  $M_0 = 3.33$  – magnitude of earthquakes, which corresponds to the calculated activity  $A_0$ ;  $S$ —area of the averaging site;  $T$ —the period of completeness observation of earthquakes;  $S_0$ —adopted in accordance with  $A_0$  area standardization unit (in this case  $S_0 = 1000 \text{ km}^2$ );  $T_0$ —unit of time (1 year);  $N_S$ —total number of earthquakes of various magnitudes  $M \geq M_{\text{min}}$  observed over time  $T$  on the square  $S$ .

In fact, seismic activity  $A_0$  reflects the average number of earthquakes with magnitude  $M_0$  per year in an area of  $1000 \text{ km}^2$ . The resulting seismic activity matrix, which was used to calculate the seismic shock  $B_j$ , is given in Table 3.

In general, the territory is characterized by moderate or low seismic activity: its maximum values are noted in the west and east of the study territory and are, respectively,  $A_{3,3} \approx 0.129$  and  $A_{3,3} \approx 0.099$ .

### PARAMETERIZATION OF PALEOEARTHQUAKES

The results of paleoseismological studies in recent years in the Northwest Caucasus are summarized in the monograph (Rogozhin et al., 2014). For seismic hazard calculations, paleoseismic dislocations (PD) were used, identified at the northwestern end of the Greater Caucasus mountain structure between the cities of Novorossiysk and Tuapse on the Novorossiysk, Kuznetsovskii, and Babichevskii active faults (Fig. 2) Typical signs of the source of a severe earthquake reaching the surface (seismotectonic faults) were found in the zones of the Kuznetsovskii and Babichevskii active faults. They have a similar tectonic position, forming the tectonic sides of the suture-depression zone of with a common Caucasian trend, extending in the axial part of the Northwest Caucasus. Based on the amplitudes of seismotectonic displacements, estimates of  $M_w = 6.5$ – $6.7$  were obtained for them.

Thus, to reconstruct the chronology of earthquakes, we used the results from relatively remote areas of the Northwest Caucasus. They were obtained in trenches dug either in the zones of active faults or within the limits of secondary-type seismic dislocations. All dates used were calibrated to calendar years using the latest version of the CALIB 7.1 software (Reimer et al., 2013).

Absolute datings of seismotectonic faults was obtained in the Babichevskii fault zone. There are traces of four paleoearthquakes, of which the last two are dated. For this, layers of paleosols buried as a result of seismotectonic slip were used, which allows us to consider them as event horizons marking the age of paleoearthquakes.

**Table 3.** Seismic activity matrix  $A_{3,3}$  in geographic coordinate system

N, hail.	East, city													
	37.25	37.50	37.75	38.00	38.25	38.50	38.75	39.00	39.25	39.50	39.75	40.00	40.25	40.50
42.83	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.003
43.00	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.009	0.022
43.16	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.004	0.003	0.002	0.003	0.01	0.022
43.33	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.006	0.026	0.052	0.033	0.029	0.03	0.013
43.49	0.002	0.001	0.001	0.001	0.001	0.002	0.007	0.015	0.06	0.105	0.07	0.053	0.055	0.027
43.66	0.001	0.007	0.007	0.001	0.001	0.001	0.011	0.026	0.053	0.086	0.073	0.059	0.099	0.074
43.82	0.001	0.007	0.007	0.004	0.005	0.009	0.023	0.037	0.048	0.066	0.076	0.057	0.075	0.055
43.99	0.003	0.001	0.007	0.011	0.005	0.015	0.047	0.073	0.062	0.042	0.058	0.042	0.007	0.006
44.15	0.017	0.011	0.017	0.023	0.018	0.016	0.03	0.053	0.042	0.03	0.035	0.027	0.065	0.057
44.32	0.06	0.079	0.053	0.03	0.018	<b>0.01</b>	0.003	0.014	0.03	0.032	0.018	0.012	0.067	0.059
44.48	0.12	0.118	0.052	0.02	<b>0.009</b>	<b>0.007</b>	0.001	0.01	0.021	0.012	0.001	0.005	0.009	0.01
44.65	0.129	0.07	0.013	<b>0.007</b>	<b>0.017</b>	0.023	0.01	0.003	0.005	0.003	0.009	0.011	0.007	0.012
44.81	0.083	0.028	0.011	<b>0.002</b>	0.008	0.016	0.01	0.001	0.002	0.009	0.015	0.008	0.003	0.006
44.98	0.038	0.022	0.023	0.007	0.001	0.008	0.008	0.001	0.003	0.01	0.007	0.003	0.003	0.001
45.14	0.014	0.02	0.018	0.009	0.003	0.008	0.009	0.001	0.001	0.001	0.001	0.003	0.003	0.003
45.31	0.011	0.01	0.002	0.003	0.003	0.001	0.008	0.008	0.004	0.004	0.003	0.003	0.001	0.003

Cells with paleoseismic dislocations are in bold.

In the Novorossiysk fault zone, traces of repeat abrupt subsidence of the near-fault basin (pull-apart basin structures), marked by the appearance of layers with an admixture of coarse-grained material in a 2-m section of marsh paleosols, have been dated. The use of these dates in paleoseismic reconstructions is based on the assumption that there is a close relationship between the tectonic subsidence occurring here and activations of the largest seismogenic structure in the region.

At a distance of 1.7 km south of the Kuznetsovskii fault, the rear suture of the currently stable large block landslide was studied in detail, which has all the signatures of a gravitational–seismotectonic structure. In the section of the rear seam, several colluvial wedges, debris horizons, and deluvial fans were revealed that buried paleosol horizons and reflect several phases of impulsive landslide activation. The landslide activation phases that occurred approximately 9500–9000, 7500–7000, 6000–5500, 3000–2500 years ago obviously resulted from strong seismic events and can be included in paleoseismic reconstructions.

Table 4 shows the age and coordinates (CPS) of these paleoseismic dislocations.

The data in Table 4 show that the PD on the Novorossiysk and Babichevskii faults are close (~2 km) to each other, while the PD on the Kuznetsovskii fault are ~73 km from them. At the same time, comparing the dates of the subsurface, it can be concluded that up to errors in estimating the age of PD on the Novorossiysk fault, which are 7927–7674, 6308–6120, and

4870–4650 years in age, can be considered close to the PD on the Kuznetsovskii fault (block landslide) with ages of 8600, 6840, and 5210 years. The same applies to PD with an age of 2980 years on the Kuznetsovskii fault and 3000–2500 years on the Babichevskii fault.

Thus, most likely that during the Holocene four strong earthquakes (seismic activations) could have occurred here, encompassing the axial part of the Northwest Caucasus with a length of approximately 73 km.

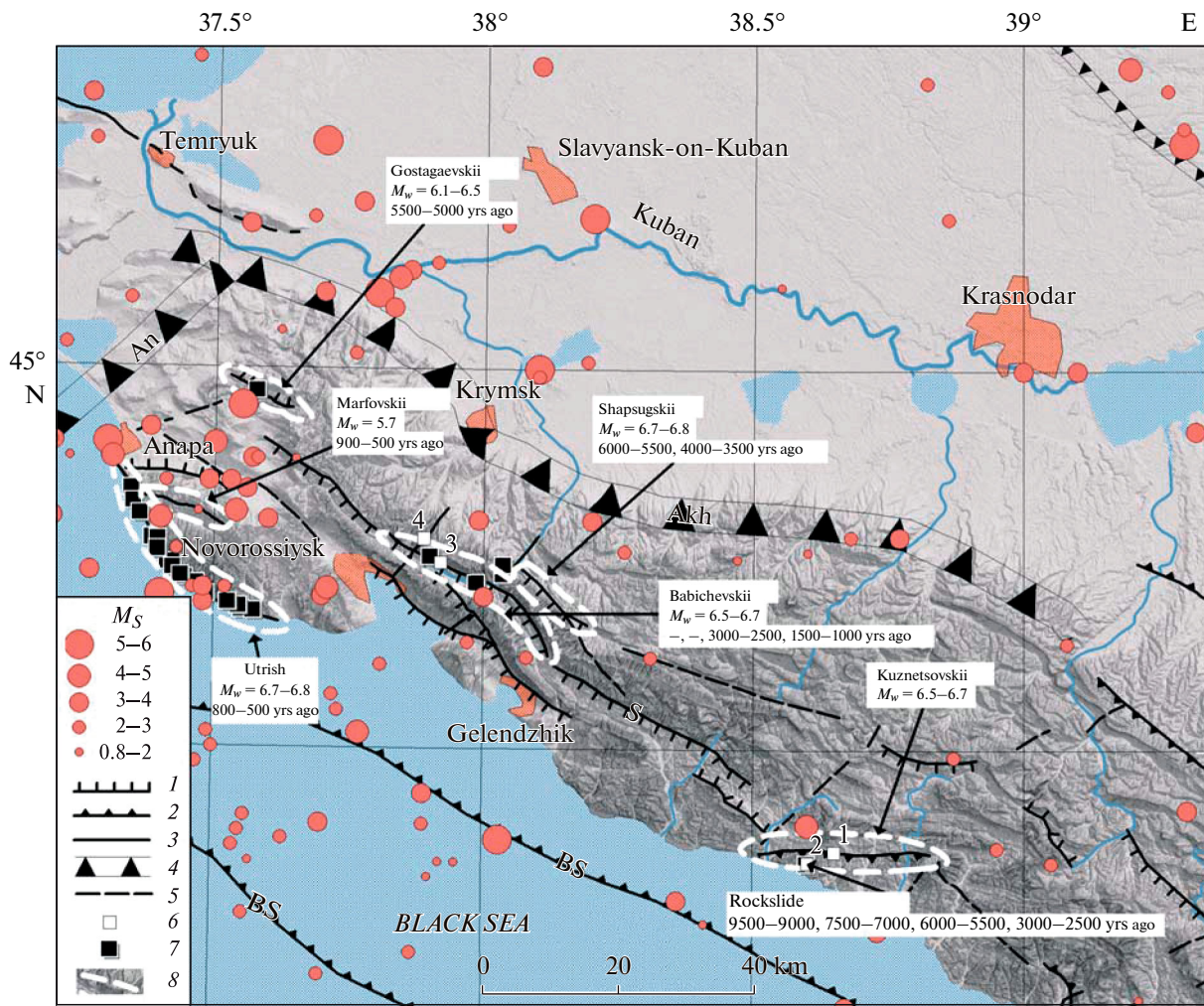
Previously, for earthquakes in the Caucasus, macroseismic data were used to estimate the extent of the source from the magnitude  $M_S$ . The dimensions of sources were estimated by N.V. Shebalina's method (1974) for 36 earthquakes in the magnitude range  $4.1 \leq M_S \leq 6.9$  (Nesmeyanov et al., 1996). As a result, the following correlation was obtained:

$$\log L \text{ (km)} = (0.521 \pm 0.046)M_S - 1.637 \pm 0.295; \quad (3)$$

$$R_c = 0.889.$$

In accordance with (3), a source length of 73 km approximately corresponds to an earthquake with a magnitude of  $M_S = 6.7$ . Clearly, the magnitude estimates based on the paleoseismogeological method and linear dimensions of the source coincide.

Thus, with a certain degree of conditionality, we found that during the last 8000–9000 years, four strong earthquakes with  $M_S \approx 6.7$  occurred in the Northwest Caucasus. Their average recurrence period is once every 2000 years. An earthquake source with



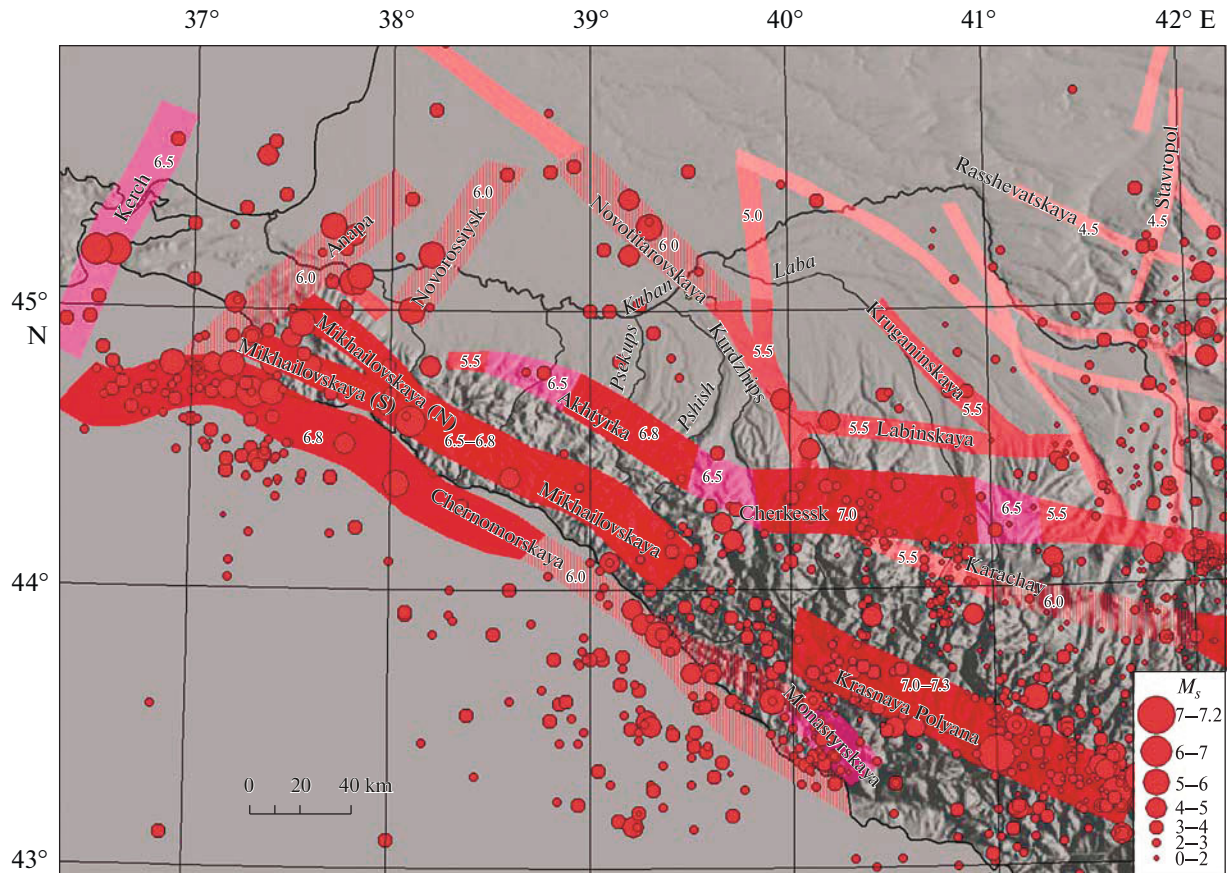
**Fig. 2.** Seismotectonic diagram of Northwest Caucasus. Epicenters of earthquakes over approximately the last 200 years and main active faults are shown. (1) Transtensional and normal faults: S, Semigorsk (triangles are directed toward downthrown wall); (2) reverse and thrust faults: BS, Black Sea (triangles are directed toward upthrown wall); (3) predominantly strike-slip faults; (4) flexure–fault zones: An, Anapa; Akh, Akhtyrskaya (triangles are pointed toward downthrown wall); (5) faults according to indirect data; (6) position of trenches discussed in text (1, Kuznetsovskii fault; 2, block landslide; 3, Babichevskii fault; 4, Novorossiysk fault zone); (7) seismic dislocation of secondary (seismic gravity) and intermediate (gravity–seismotectonic) types; (8) approximate contours of centers of paleoearthquakes reconstructed from paleoseismogeological and structural–geomorphological data with indication of their names and estimates of magnitudes and age (years ago).

$M_S \approx 6.7$  occupies six cells of matrix  $A_{3,3}$  (see Table 3). In accordance with the recurrence graph schedule (1) with an earthquake with  $M_S = 6.7$  can be matched  $N_{eq} \approx 1151$  earthquake with  $M_S = 3.3$ . Given an average recurrence period of  $T_{av} = 2016.75$  years and a fault area of  $S_s = \text{cell area} \times 6 = 2200 \text{ km}^2$ , we obtain an estimate of the seismic activity in the cells of matrix  $A_{3,3}$  (see Table 3) occupying the source of paleoearthquake with  $M_S = 6.7$ :

$$A_{3,3} = N_{eq} / (T_{av} S_s) \approx 0.259. \quad (4)$$

Of course, estimate (4) is not rigorous. However, given that earthquakes with  $M_S = 3.3$  are complete only from 1961 to 2018 inclusive, in accordance with

the law of recurrence (1), in the territory of the highlighted six cells, an average of 33 earthquakes of such magnitude could be expected. However, taking into account the onset of a possible phase of seismic quiescence, which, with an average recurrence period of events with  $M_S = 6.7$  every 2000 years, can last for decades, such events here may not be observed at all in this period. Therefore, estimate (4) can be used as the upper boundary of seismic activity taking into account paleoearthquake data. To calculate seismic shaking with allowance for the impact of paleoearthquakes, seismic activity matrix  $A_{3,3}$  was used (see Table 3), where the  $A_{3,3}$  values in the bold-highlighted cells are replaced in accordance with formula (4).



**Fig. 3.** Map of PES zones in Western Caucasus with earthquake epicenters based on instrumental and historical data. Numbers indicate  $M_{\max}$  of PES zones.

### PES ZONES

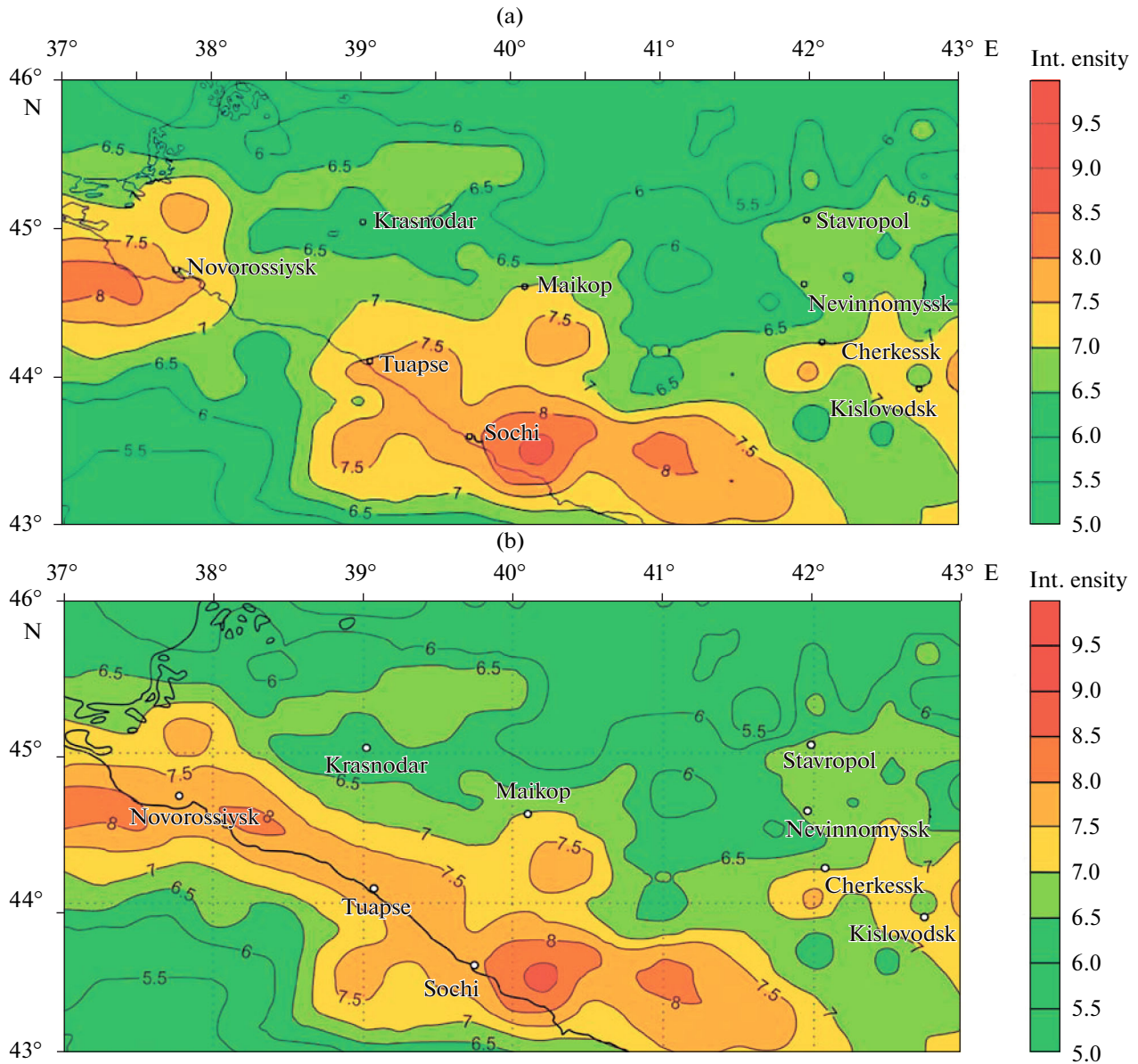
When constructing the map of PES zones for the Western Caucasus, determination and zoning of the seismic potential ( $M_{\max}$ ) were carried out based on the results of three complementary methods: paleoseismogeological, traditional, and formalized (Nesmey-

anov, 1992; Rogozhin et al., 2001; Nikonov, 1991). The calculated  $M_{\max}$  estimates were checked during seismotectonic field studies in key areas. The most important results of these studies were published earlier (Rogozhin et al., 2014). The acquired data were summarized in a map of PES zones for the Western Caucasus (Fig. 3). This map fundamentally differs

**Table 4.** Age and coordinates of paleoseismic dislocations (PD) in Northwest Caucasus

Indicator	Paleoseismic dislocation		
	Novorossiysk fault (44.78° N; 37.9° E)	Kuznetsovskii fault (44.37° N; 38.63° E)	Babichevskii fault (44.76° N; 37.9° E)
PD age	490–312	—	—
	1403–1293	—	1308–1421
	4870–4650	3322–3006	3389–3136
	6308–6120	6303–5748	—
	7927–7674	7606–7160	—
	—	9912–9409	—

\* Under Kuznetsovskii Fault, dating from block landslide 1.7 km south of Kuznetsovskii fault.



**Fig. 4.** DSZ-A map of Northwest Caucasus without (a) and with allowance (b) for paleoseismic dislocations with 10% exceedance probability in 50 years. Average recurrence period is 500 years., with points on the MSK-64 intensity scale.

from the regional map of seismic lineaments (Ulomov and Shumilina, 1999; Balasarian et al., 1999) in its detail, higher fractionality of  $M_{max}$  estimates, and confinement of PES zones to real tectonic faults of various ranks active in the Holocene.

This map laid the foundation for a new detailed seismic hazard map for the Northwest and Central Caucasus.

**SEISMIC HAZARD ASSESSMENT OF THE NORTHWEST CAUCASUS**

Based on the map of PES zones (Fig. 3), seismic hazard maps were compiled on a detailed scale for the

Northwest Caucasus in the terms and methodology described in SP 408.1325800.2018, taking into account the compilation of GSZ-97 maps A and B (Ulomov and Shumilina, 1999). Seismic hazard maps were calculated in two versions: with and without allowance for the PD described above. When calculating seismic hazard in points of the normative MSK-64 macroseismic scale (currently the new SHSI-2017 macroseismic scale is in force, which has completely inherited the intensity shaking estimates in points on the MSK-64 scale), it was deemed valid to directly use the macroseismic field equation for the Caucasus region (*Seismicheskoe...*, 1980).

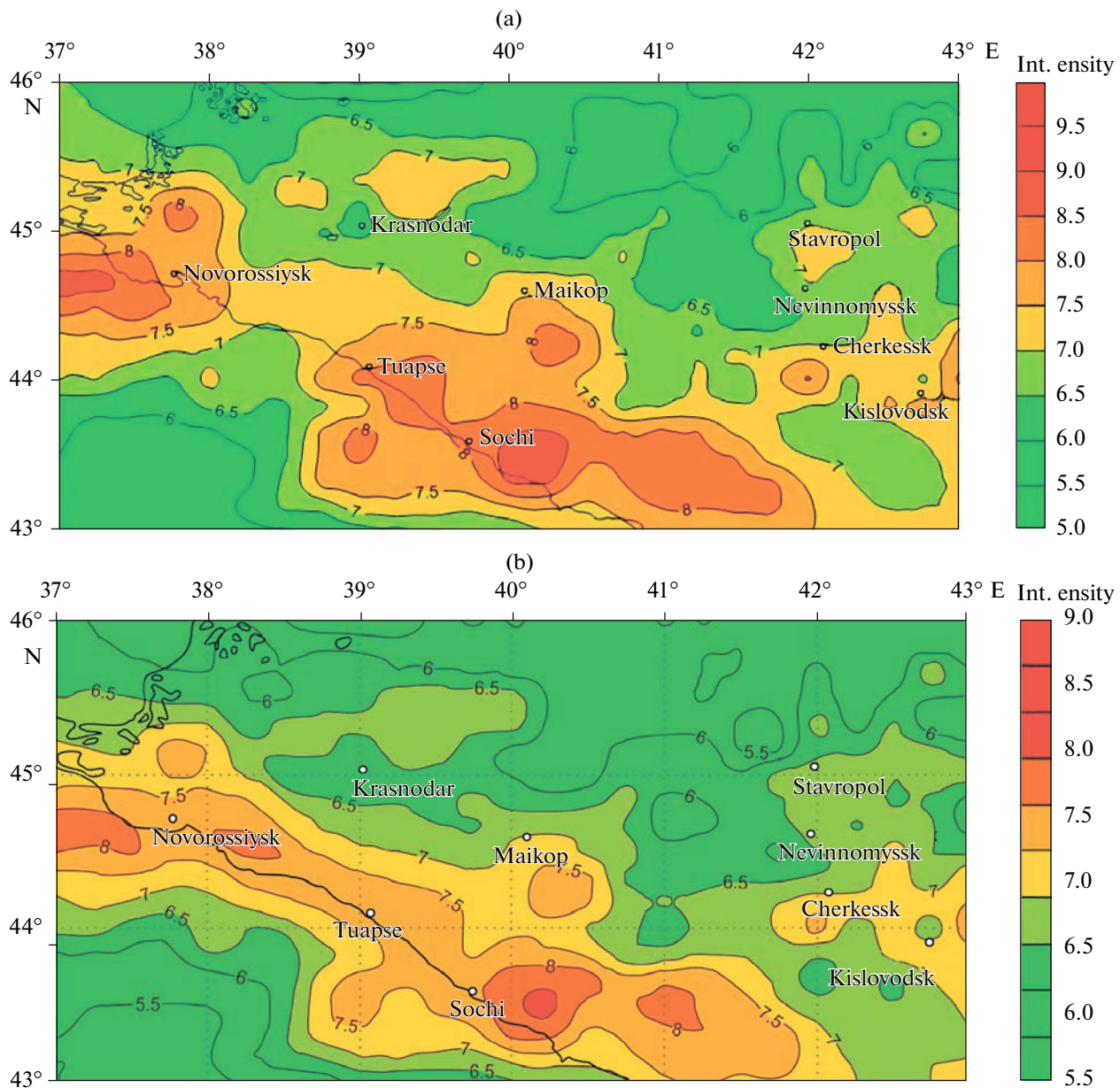


Fig. 5. DSZ-B map of Northwest Caucasus without (a) and with allowance (b) for paleoseismic dislocations with 5% exceedance probability in 50 years. Average recurrence period is 1000 years, with points on the MSK-64 intensity scale.

Let us explain the general principles for compiling these maps. Detailed scale seismic hazard maps for the region of the northwestern and central sectors of the Greater Caucasus were compiled from seismic shaking calculations (*Seismicheskaya...*, 1979) using a detailed grid with a mesh size of  $10'$  ( $0.165^\circ$ ) in latitude and  $15'$  ( $0.25^\circ$ ) in longitude. In calculations an  $M_{\max}$  matrix used, which is a digital analog of the PES zone map, as well as the seismic activity matrix (see Table 3) for the Northwest Caucasus.

The seismic shock is calculated at a specific point (a cell of the shaking matrix) by numerically integrating seismic impacts at this point from all seismic

sources (a cell of the  $M_{\max}$  matrix) in the territory under consideration, taking into account the average recurrence of earthquakes of various magnitudes in them (cells of the seismic activity matrix), from the lowest completeness up to  $M_{\max}$ . The average recurrence rate of earthquakes with magnitudes  $M \leq M_{\max}$  is determined in each cell of the  $M_{\max}$  matrix from the value of seismic activity  $A_{3,3}$  in this cell and the slope of the recurrence graph  $b$ . In calculations, the macroseismic field equation for the Caucasus was used:

$$I = 1.5M_S - 3.5 \log R + 3.0, \quad (5)$$



where  $R$  is the distance between the earthquake hypocenter and the observation point, i.e.,  $R = \sqrt{(\Delta^2 + h^2)}$ ;  $\Delta$  and  $h$  are, respectively, the epicentral distance and depth of the source, km.

Seismic shaking ( $B_I$ ) was calculated according to the program for calculating seismic shaking, which uses the  $M_{\max}$  matrix, seismic activity matrix  $A_{3,3}$ , slope  $b$  of the recurrence graph, and the average depth of the seismoactive layer, chosen in accordance with the regional depth distributions of hypocenters and from considerations of the maximum (smallest) depth of the source for the corresponding magnitudes  $M_{\max}$  (Shebalin, 1971). Figures 4 and 5 show the seismic hazard maps obtained for the Northwest Caucasus, presented in two versions: with and without allowance for PD.

## DISCUSSION

On the compiled maps (see Figs. 4, 5), the northwestern segment of the Greater Caucasus looks like a seismic hazardous area where the level of seismic impacts reaches 7.5 points on maps A and B (in terms of the GSZ-97 map). Recall that Map A is traditionally compiled for assessing seismic hazard for construction projects with normal and low criticality; and Map B is for highly critical facilities. On the maps (see Figs. 4a, 5a), a zone of low scores is clearly observed in the segment from the Novorossiysk to the Tuapse meridian, where its values are reduced compared to the neighboring segments of the meganticlinorium, up to 6.5 and 7 points, respectively. Allowance for the results of paleoseismogeological studies (see Figs. 4b, 5b) showed that in this part of the Northwest Caucasus, there is a zone of significant increase in seismic hazard level in the region compared with segments of the mobile system in the east and west (up to 7.5 and even 8 points, respectively). This seems very significant against the active economic development of the territory during the design, building, and operation of construction projects with varying degrees of criticality, in particular, high-pressure pipeline systems.

## CONCLUSIONS

The results of our studies are important from the methodological aspect. It turned out that allowance for the results of paleoseismological studies can significantly refine the seismic hazard level of a particular region. Paleoseismogeological research has been carried out for many years in conducting exploration works under the sites of nuclear facilities and pipeline routes. However, such work is not carried out in the construction of housing projects. This is very important from the viewpoint of public safety.

In light of managing seismic risk in a densely populated and actively developed territory of Russia—the

Northwest Caucasus—the obtaining of the above results is a breakthrough in terms of value.

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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