ISSN 0001-4338, Izvestiya, Atmospheric and Oceanic Physics, 2019, Vol. 55, No. 11, pp. 1726–1733. © Pleiades Publishing, Ltd., 2019.
Russian Text © The Author(s), 2019, published in Geofizicheskie Protsessy i Biosfera, 2019, Vol. 18, No. 4, pp. 158–166.

Time Variations in Earthquake Focal Mechanisms of the Racha-Dzhava Seismic Zone

L. A. Shumlianskaya[a] and V. Yu. Burmin[b, *]

[a]*Subbotin Institute of Geophysics, National Academy of Sciences of Ukraine, Kiev, 03860 Ukraine*
[b]*Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, 123242 Russia*
**e-mail: burmin@ifz.ru*

Abstract—In this publication we consider how local seismicity in the Racha-Dzhava seismic zone of the Caucasus changed in time under the influence of large earthquakes that occurred in 1971–2011. In order to divide the whole studied period into time intervals within which the total energy released by local earthquakes was summed up, we use the averaged focal mechanisms (obtained from the first *P*-waves arrivals) of earthquakes presented in the Seismological Bulletins of the Caucasus. The averaged focal mechanisms were built according to the method of K. Aki, in the terms of which a set of weak local earthquakes with a close distribution of the first *P*-waves arrivals are considered one large earthquake. The change in averaged focal mechanisms with time is revealed; this is associated with a change in tectonic stresses within the Racha-Dzhava zone. We also compare the changes in directions of tectonic stresses and the influence of strong earthquakes. It is shown that one of the factors of an abrupt and short-term change in a stress state and in a local seismicity level is an impact of distant strong and catastrophic earthquakes. The results can be interesting for understanding some aspects of local seismic activity and the causes of changes in the stress field and the activity of seismic process in the Racha-Dzhava seismic zone.

Keywords: earthquakes, earthquake mechanisms, Racha-Dzhava seismic zone

DOI: 10.1134/S0001433819110136

INTRODUCTION

The studies of paleostresses using the method of cataclastic analysis of the Greater Caucasus meganticlinorium show significant reorientations of the principal stress axes near the Anapa and Dzhiginka fault zones (Marinin and Sim, 2015). Similar results were obtained for the Northwestern Caucasus (Marinin, 2013). Other publications also show a change in the stress state of the geological medium over time (Rebetskii and Alekseev, 2014). However, the reasons for such changes have not been considered up to the present. This publication shows that one of the factors for an abrupt and short-term change in the stress state is the impact of strong and catastrophic earthquakes.

In order to investigate the time variation in the Racha-Dzhava seismic-zone tectonic stress field, we studied the averaged focal mechanisms of weak earthquakes. The method for determining averaged focal mechanisms is that a set of the first arrivals of signs of body waves from various earthquakes is used. In this case, it is believed that all the arrivals belong to one focus. This method is especially effective if a small number of recording stations is available (Aki, 1966; Zverev et al., 1976; Misharina and Solonenko, 1977). A summation of the first arrival signs is possible, provided that the seismic process is associated with a long-term shift along faults and fractures and its duration is from several months to several years (Kocharyan, 2016).

We used the averaged mechanisms not only to track the changes in the directions of compression vectors in time, but also to distinguish time intervals within which the energy released by local earthquakes is summed up. In our opinion, the results allow us to have insight into what changes the directions of compression forces and what causes the seismic process activity both for the Racha-Dzhava seismic zone and for the region of the Caucasus as a whole.

STUDY AREA

The study area is an underthrust zone where the continental microplates of the Southern and Northern Caucasus interact, leading to the tectonic stratification of alpine formations into various south-verging allochthonous and parautochthonous thrust strata. Large linearly stretched tectonic units correspond to the axis of the alpine marginal sea basin. The alpine cover was compressed in the underthrust zone and is shifted southward. During the continental stage of alpine tectogenesis, intense lateral compression has been caused by the Arabian Plate indentation into the structures of the southern margin of Eurasia. The modern geodynamic activity is confirmed by GPS data, according to which the Southern Caucasian block moves to the north at a rate of up to 29 mm/yr. To compare, the North Caucasian microplate motion rate is as low as 0–6 mm/yr (Babaev et al., 2017).

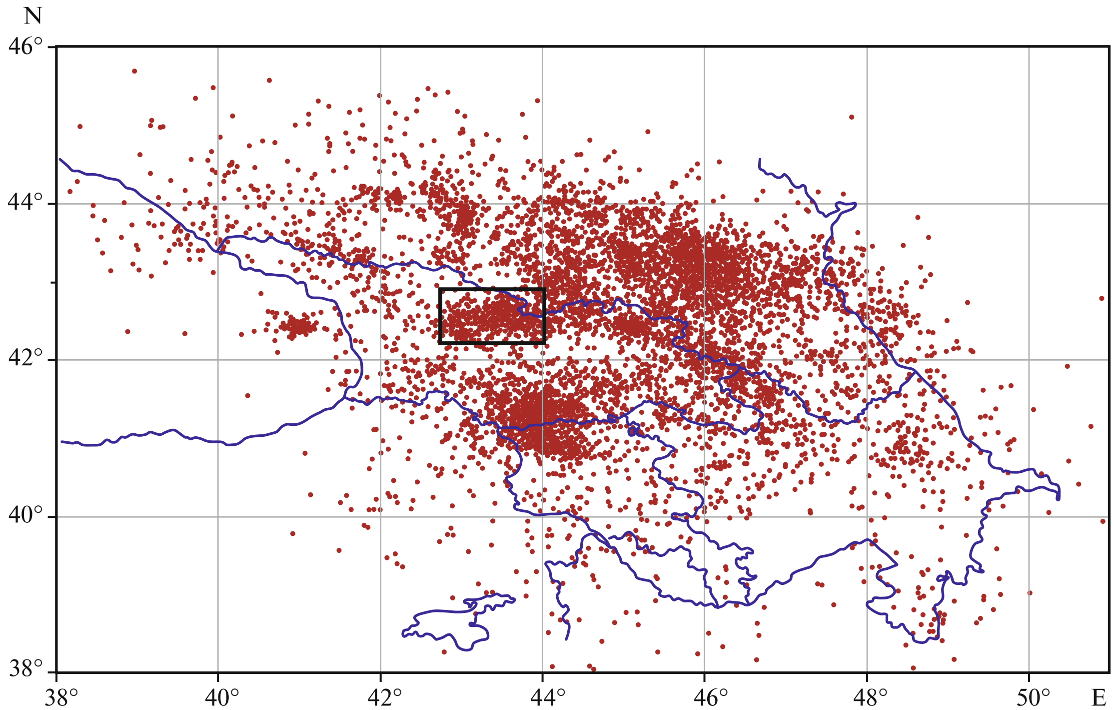


Fig. 1. Seismic cluster of the Racha-Dzhava seismic zone (marked with a rectangle) on the map showing the distribution of earthquake epicenters in the Caucasus, after (Burmin et al., 2019).

The main reasons for seismic activity in the Caucasus region are, first, compression under the influence of the indenting Arabian Plate and, second, stresses emerging from the differences in topological levels of tectonic blocks (Kangarli et al., 2018). Such a difference in motion rate produces a differentiated stress field and additional conditions for local seismicity to occur. The earthquake foci are confined to the intersections between fractures and faults, as well as to the planes of deep tectonic faults with lateral displacements along unstable contacts between tectonic units. Based on the focal mechanisms of seismic events, chiefly subvertical planes of normal dips and strike-slips were determined. Moreover, it was found that the earthquake foci, as a rule, are confined to the intersections between fractures trending along the "main Caucasian" and "cross-Caucasian" directions.

In order to analyze the time variation in focal mechanisms of the Caucasus earthquake, we selected the Racha-Dzhava seismic zone (Fig. 1), where low-energy local seismic events are concentrated. These events are confined to the intersection of two transverse (NE-striking) faults, namely, the Tskhinvali–Kazbek deep fault in the east and the Rioni–Ossetian fault in the west, with the perpendicular faults that separate the Greater Caucasus folded system (from west to east) into the Svaneti, Racha, and Kartli transverse segments.

In 1991, the Racha-Dzhava earthquake with $M = 7.2$ and epicentral shaking intensity of VIII, which appeared to be the strongest in the history of seismological observations in the Caucasus, occurred in this zone, being accompanied by a large number of aftershocks (Aref'ev et al., 1993; Papalashvili et al., 1997; Aref'ev, 2003; Belousov, 2009; Tatevossian and Aptekman, 2011; Vakarchuk et al., 2013; Burmin, 2016). The mainshock had an oblique (reverse-dip) thrust mechanism along a NW-striking plane gently inclined to the northeast. According to the distribution of surface dislocations and epicenters of the aftershocks, the source of the Racha-Dzhava earthquake spatially coincides with the Racha–Lechkhumi segment of the Kakheti–Lechkhumi suture zone, which is the largest tectonic unit on the Southern slope of the Greater Caucasus. The Racha–Lechkhumi suture zone separates the Dzirula ledge, corresponding to the middle massif of the Georgian block, on south, from the folded zone of the Southern slope of the Greater Caucasus on north (Rogozhin, 2009).

STUDY METHOD

There are several methods for studying the stress state of the geomedium from the set of weak earthquakes. C. Richter (1958) proposed determining focal mechanisms by the distribution of the first arrival signs of *P*-waves observed at one station from multiple earthquake foci surrounding this station.

Another approach (Aki, 1966; Zverev et al., 1976; Misharina and Solonenko, 1977), which is used in the present study, implies the analysis of stresses by determining focal mechanisms of earthquakes from the distribution of the first arrival signs of *P*-waves, which were recorded at several stations from groups of earthquakes united on a territorial basis. It is also assumed that the first arrival signs correspond to one earthquake focus.

Table 1. Time intervals for constructing the averaged focal mechanisms of earthquakes of the Racha-Dzhava zone

Ord. nos.	Interval	Number of events per interval	Total energy, J	Number of months in the interval	Average energy per month, J
1	Jan. 4, 1971–Apr. 14, 1971	56	1.45951×10^{27}	3	4.86504×10^{26}
2	Apr. 26, 1971–Mar. 23, 1972	98	4.66073×10^{29}	10.9	4.2759×10^{28}
3	**Apr. 6, 1972–Nov. 10, 1972**	**16**	$\mathbf{8.26616 \times 10^{21}}$	**8.1**	$\mathbf{1.02051 \times 10^{21}}$
4	Nov. 11, 1972–June 16, 1973	8	1.37448×10^{19}	7.03	1.95516×10^{18}
5	June 27, 1973–July 12, 1974	10	1.7408×10^{20}	12.5	1.39264×10^{19}
6	July 15, 1974–Jan. 17, 1978	84	5.1342×10^{28}	30.04	1.70912×10^{27}
7	**Jan. 18, 1978–Dec. 31, 1978**	**44**	$\mathbf{3.49687 \times 10^{25}}$	**12.5**	$\mathbf{2.7975 \times 10^{24}}$
8	**Jan. 1, 1979–May 16, 1980**	**55**	$\mathbf{2.60289 \times 10^{27}}$	**15.43**	$\mathbf{1.6869 \times 10^{26}}$
9	May 23, 1980–Dec. 1, 1981	21	2.46903×10^{23}	8.26	2.98914×10^{22}
10	Jan. 6, 1982–Jan. 23, 1982	13	2.73144×10^{21}	0.54	5.05823×10^{21}
11	Feb. 26, 1982–Dec. 22, 1982	6	8.2586×10^{17}	9.86	8.37586×10^{16}
12	Apr. 14, 1983–Oct. 21, 1984	23	1.12214×10^{24}	18.03	6.22373×10^{22}
13	Jan. 11, 1985–Dec. 6, 1988	185	1.81674×10^{32}	46.56	3.90193×10^{30}
14	**Dec. 7, 1988–Dec. 31, 1989**	**72**	$\mathbf{2.09276 \times 10^{27}}$	**12.7**	$\mathbf{1.64784 \times 10^{26}}$
15	**Jan. 1, 1990–Dec. 31, 1990**	**247**	$\mathbf{2.58107 \times 10^{31}}$	**12**	$\mathbf{2.15089 \times 10^{30}}$
16	**Jan. 1, 1991–Dec. 31, 1991**	**69**	$\mathbf{2.16618 \times 10^{26}}$	**12**	$\mathbf{1.80515 \times 10^{25}}$
17	**Jan. 1, 1992–Dec. 31, 1992**	**120**	$\mathbf{2.55393 \times 10^{30}}$	**12**	$\mathbf{2.12828 \times 10^{29}}$
18	**Jan. 1, 1993–Dec. 31, 1993**	**66**	$\mathbf{6.85769 \times 10^{27}}$	**12**	$\mathbf{5.71474 \times 10^{26}}$
19	**Jan. 1, 1994–Dec. 31, 1994**	**106**	$\mathbf{9.26547 \times 10^{29}}$	**12**	$\mathbf{7.72123 \times 10^{28}}$
20	**Jan. 1, 1995–Dec. 31, 1995**	**50**	$\mathbf{4.96544 \times 10^{26}}$	**12**	$\mathbf{4.13787 \times 10^{25}}$
21	**Jan. 1, 1996–Dec. 31, 1996**	**74**	$\mathbf{4.14022 \times 10^{27}}$	**12**	$\mathbf{3.45019 \times 10^{26}}$
22	**Jan. 1, 1997–Dec. 31, 1997**	**64**	$\mathbf{7.59691 \times 10^{26}}$	**12**	$\mathbf{6.33076 \times 10^{25}}$
23	**Jan. 1, 1998–Dec. 31, 1998**	**75**	$\mathbf{7.45553 \times 10^{27}}$	**12**	$\mathbf{6.21295 \times 10^{26}}$
24	**Jan. 1, 1999–July 8, 1999**	**94**	$\mathbf{9.82164 \times 10^{28}}$	**7.3**	$\mathbf{1.34543 \times 10^{28}}$
25	Jan. 14, 1999–Dec. 31, 2000	348	2.27432×10^{34}	23.5	9.67795×10^{32}
26	**Jan. 2, 2001–Dec. 31, 2001**	**298**	$\mathbf{6.45754 \times 10^{33}}$	**12**	$\mathbf{5.38128 \times 10^{32}}$
27	**Jan. 1, 2002–Dec. 31, 2002**	**651**	$\mathbf{1.8249 \times 10^{34}}$	**12**	$\mathbf{1.52075 \times 10^{33}}$
28	**Jan. 1, 2003–Dec. 31, 2003**	**428**	$\mathbf{1.32487 \times 10^{35}}$	**12**	$\mathbf{1.10406 \times 10^{34}}$
29	**Jan. 1, 2004–Dec. 31, 2004**	**348**	$\mathbf{1.52294 \times 10^{34}}$	**12**	$\mathbf{1.26911 \times 10^{33}}$
30	**Jan. 1, 2005–Jan. 14, 2006**	**369**	$\mathbf{2.81312 \times 10^{34}}$	**12.05**	$\mathbf{2.33454 \times 10^{33}}$
31	Jan. 15, 2006–Oct. 6, 2006	468	5.34208×10^{34}	8.7	6.14033×10^{33}
32	**June 12, 2006–Feb. 10, 2008**	**531**	$\mathbf{1.35806 \times 10^{36}}$	**18.9**	$\mathbf{7.18552 \times 10^{34}}$
33	Feb. 13, 2008–Jan. 16, 2009	192	3.49648×10^{31}	11.03	3.16997×10^{30}
34	Feb. 2, 2009–June 2, 2009	312	1.65927×10^{33}	4	4.14818×10^{32}
35	July 1, 2009–Nov. 28, 2009	1158	6.57674×10^{38}	3.1	2.12153×10^{38}
36	**Nov. 29, 2009–Dec. 25, 2010**	**714**	$\mathbf{1.81191 \times 10^{37}}$	**12.86**	$\mathbf{1.40895 \times 10^{36}}$
37	Dec. 26, 2010–Aug. 2, 2011	616	1.9723×10^{36}	7.93	2.48714×10^{35}
38	Aug. 2, 2011–Sept. 29, 2011	150	1.00401×10^{30}	1.9	5.28425×10^{29}
39	Oct. 2, 2011–Dec. 27, 2011	145	1.17781×10^{30}	1.96	6.00922×10^{29}

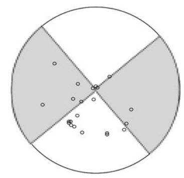
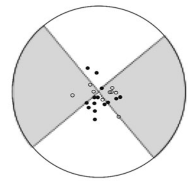
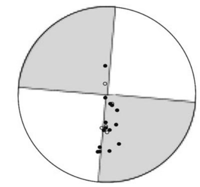
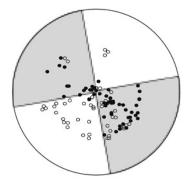
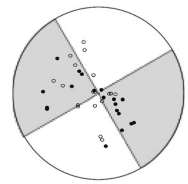
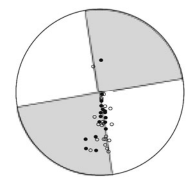
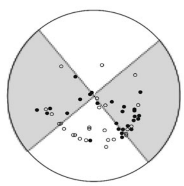
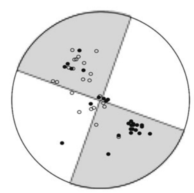
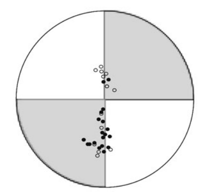
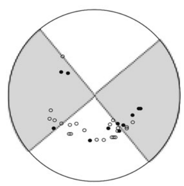
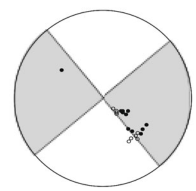
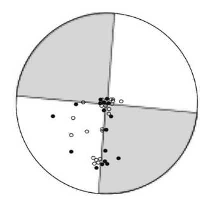
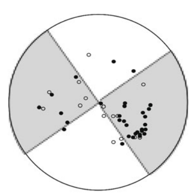
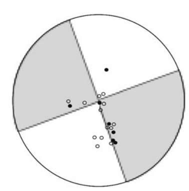
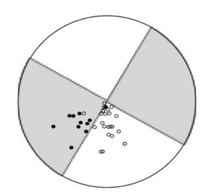
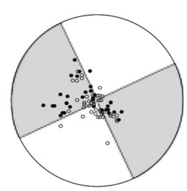
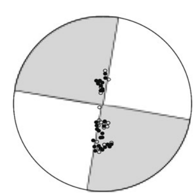
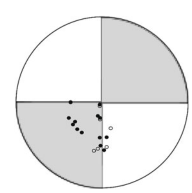
Intervals not containing the arrival signs of *P*-waves are in boldface. For the time period after 2011, the arrival signs are not provided in seismological bulletins.

INITIAL DATA

In order to construct the compression vectors, we used averaged focal mechanisms obtained from the first arrival signs of *P*-waves from weak earthquakes, which had been recorded in the Racha-Dzhava zone by the seismological agencies of the Russian Academy of Sciences, Armenia, Georgia, and Azerbaijan. The hypocenters of earthquakes for the period of 1971–2016 were taken for processing; the coordinates of hypocenters were obtained in (Burmin et al., 2019). Unfortunately, signs of the first arrivals are not provided for all events in the seismological bulletins; in this respect, we had to exclude significant periods of time from consideration.

The time intervals for constructing the averaged focal mechanisms were distinguished by changing the azimuthal distribution of the first arrival signs relative to the fault planes of the previous averaged focal mechanism (Shumlyanskaya and Burmin, 2016). Thus, 39 spatiotemporal intervals were identified, for which 18 averaged focal mechanisms were constructed. Table 1 shows the time intervals for constructing the averaged focal mechanisms.

Table 2. Time changes of averaged focal mechanisms of earthquakes in the Racha-Dzhava zone for the time period of 1971–2011

Interval	Averaged focal mechanism	Interval	Averaged focal mechanism	Interval	Averaged focal mechanism
Jan. 4– Apr. 14, 1971 (1)*		Jan. 6– Jan. 23, 1982 (10)		Feb. 13, 2008– Jan. 16, 2009 (33)	
Apr. 26, 1971– Mar. 23, 1972 (2)		Feb. 26– Dec. 21, 1982 (11)		Feb. 2, 2009– June 2, 2009 (34)	
Nov. 11, 1972– June 1, 1973 (4)		Apr. 14, 1983– Oct. 21, 1984 (12)		July 1– Nov. 28, 2009 (35)	
June 27, 1973– July 12, 1974 (5)		Jan. 11, 1985– Dec. 08, 1988 (13)		Dec. 26, 2010– Aug. 2, 2011 (37)	
July 15, 1974– Jan. 17, 1978 (6)		Jan. 14, 1999– Dec. 31, 2000 (25)		Aug. 2– Sept. 29, 2011 (38)	
May 23, 1980– Feb. 1, 1981 (9)		Jan. 15– Oct. 6, 2006 (31)		Oct. 2– Dec. 27, 2011 (39)	

* Parenthetical numerals are time intervals corresponding to those in Table 1.

RESULTS

Table 2 presents the averaged focal mechanisms constructed for 18 selected time intervals from Table 1. In order to construct the earthquake focal mechanisms, 3893 events, for which the first arrivals signs of *P*-waves had been provided in the bulletins, were used. All foci were located in the Earth's crust.

During the interval under consideration (1971–2011), the focal mechanism type (pure strike-slip) has not changed. In addition, the average total energy released per month was calculated for each time interval (Fig. 2).

The data given in Table 2 show that the obtained directions of the compression vector coincide with the

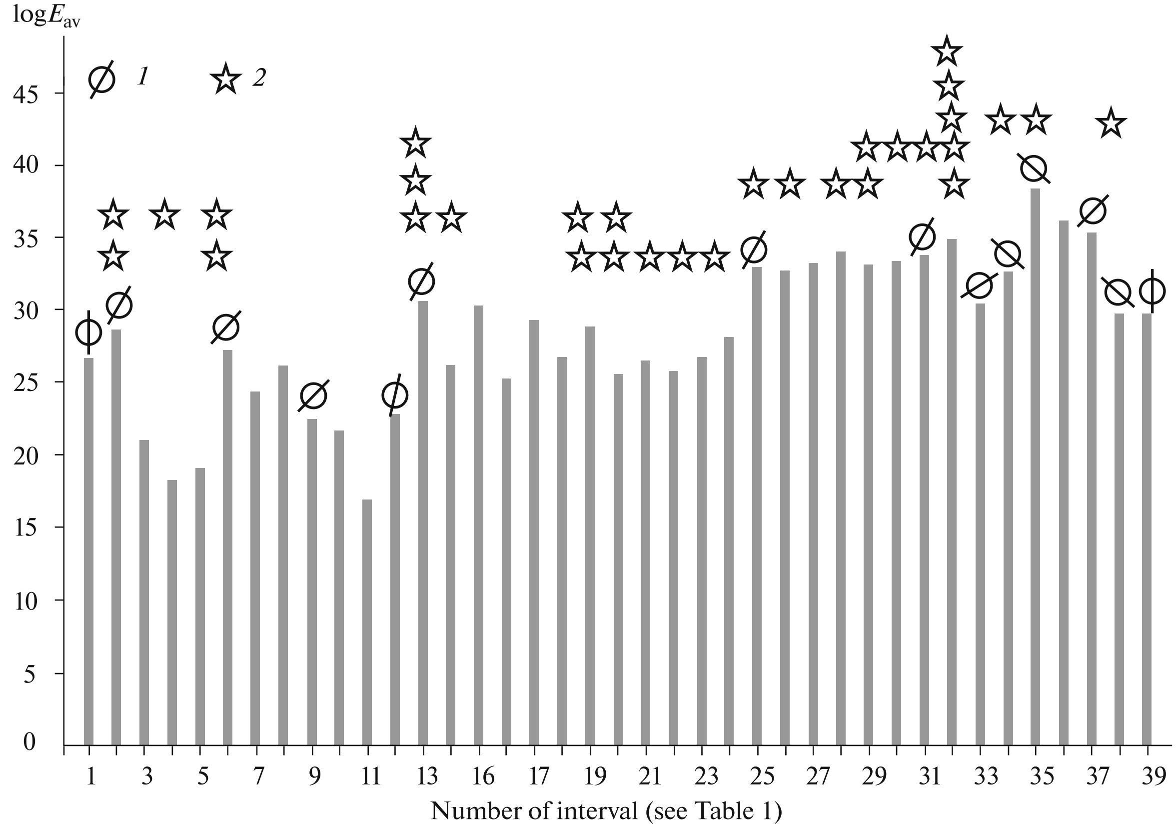


Fig. 2. Coincidence of the changes in direction of compression vector (*1*) in time with strong and catastrophic earthquakes (*2*) in comparison with monthly total energy E_{av} released during local earthquakes within the considered time interval (see Tables 1, 3).

distribution of vectors of horizontal stress components for the Caucasus region (Babaev et al., 2017), according to which the western and central parts of the Greater Caucasus suffer a NE–NW shortening. Despite the occurrence of the strong earthquakes in the immediate vicinity of the Racha-Dzhava zone, this direction demonstrated minor changes with time. However, the considered time intervals demonstrate a correlation between the sharp change in the direction of the compression vector (up to 90° in the counterclockwise direction) and distant strong and catastrophic earthquakes with $M_w \geq 8$ after 2007. The list of these earthquakes is given in Table 3.

Let us compare the averaged focal mechanisms of local earthquakes with those of the mainshock and aftershocks of the Racha earthquake of April 29, 1991, which is the strongest in the region with M_w = 6.9 (based on the data from the International Seismological Centre).

The mainshock and all aftershocks had focal mechanisms of a reverse-dip type. The reverse-dip occurred along a NW-striking (azimuth 300°) plane gently (35°) dipping to the northeast. This mechanism closely matches the idea of the main tendencies of the Greater Caucasus geological evolution, namely, underthrusting of the Dzirula massif basement beneath the anticlinorium of the Greater Caucasus Range (Aref'ev, 2003).

We compared the directions of compression vectors obtained from the averaged focal mechanisms (see Fig. 2) with the directions of stress axes of the 1991 Racha earthquake (Fig. 3). We can see that until 2007 the direction of compression vector by the averaged focal mechanisms coincides with the direction of stresses that caused the mainshock of the Racha earthquake. It confirms the long-term regional character of underthrusting of the Dzirula massif basement beneath the Greater Caucasus Range, which is associated with the northward indentation of the Arabian Plate (Rogozhin, 2009).

CONCLUSIONS

The results of studying the time variation in the direction of compression vectors in the Racha-Dzhava seismic zone for the time period of 1971–2011 show that the directions azimuths of these compressional stresses are changing with time. Compression forces are produced by the general compression setting throughout the entire continental stage of alpine tectogenesis, which was caused by indentation of the Arabian Plate into the structures of the southern margin of Eurasia.

Table 3. Strongest earthquakes in the world, 1971–2011 (https://earthquake.usgs.gov/earthquakes/)

Time interval no. in Table 1	Magnitude	Region of the epicenter location	Date	Time (hh:mm:ss)	Focal depth, km
38	9.1	Japan	Mar. 11, 2011	05:46:24	29.0
36	8.8	Chile	Feb. 27, 2010	06:34:11	22.9
35	8.1	Samoa	Sept. 29, 2009	17:48:10	18.0
32	8.4	Indonesia	Sept. 12, 2007	11:10:26	34.0
32	8	Peru	Aug. 15, 2007	23:40:57	39.0
32	8.1	Solomon Islands	Apr. 1, 2007	20:39:58	24.0
32	8.1	Kuril Islands	Jan. 13, 2007	04:23:21	10.0
32	8.3	Kuril Islands	Nov. 15, 2006	11:14:13	10.0
31	8	Tonga	May 3, 2006	15:26:40	55.0
30	8.6	Indonesia	Mar. 28, 2005	16:09:36	30.0
29	9.1	Andaman Islands	Dec. 26, 2004	00:58:53	30.0
29	8.1	North of the Macquarie Island	Dec. 23, 2004	14:59:04	10.0
28	8.2	Japan	Sept. 25, 2003	19:50:06	27.0
26	8.4	Peru (near the southern coast)	June 23, 2001	20:33:14	33.0
25	8	Papua New Guinea	Nov. 16, 2000	04:54:56	33.0
23	8.1	Balleny Islands	Mar. 25, 1998	03:12:25	10.0
21	8.1	Indonesia	Feb. 17, 1996	05:59:30	33.0
20	8	Mexico	Oct. 9, 1995	15:35:53	33.0
20	8	Chile	July 30, 1995	05:11:23	45.6
19	8.3	Kuril Islands	Oct. 4, 1994	13:22:55	14.0
19	8.2	Bolivia	June 9, 1994	00:33:16	631.3
14	8	Macquarie Island	May 23, 1989	10:54:46	10.0
13	8	Alaska	May 7, 1986	22:47:10	33.0
13	8	Mexico	Sept. 19, 1985	13:17:47	27.9
13	8	Chile	Mar. 3, 1985	22:47:07	33.0
6	8.3	Indonesia	Aug. 19, 1977	06:08:55	25.0
6	8	Kermadek Islands	Jan. 14, 1976	16:47:33	33.0
4	8	Philippines	Dec. 02, 1972	00:19:52	60.0
2	8.1	Papua New Guinea	July 26, 1971	01:23:22	40.0
2	8	Papua New Guinea	July 14, 1971	06:11:30	40.0

Unfortunately, we do not have a complete picture of how focal mechanisms of earthquakes of this region changed, since the data on first arrival signs of *P*-waves are fragmentary and incomplete. According to the data, two periods with different characters of the compression vectors can be distinguished. The time division between these periods is year 2007, after which the largest number of distant earthquakes with a magnitude of more than 8 occurred.

Before 2007, the compression vectors vary in the SW–NE direction within the range of 45°. After 2007, a change in the behavior of compression stress directions was observed: the southeastern and northwestern directions appeared and they were perpendicular to the directions obtained from all the averaged focal mechanisms in the previous time interval. A sharp change in the behavior coincides with an increase in the total energy released by local seismic events (the trend can be seen in Fig. 2).

Our study results show that there are several sources determining the changes in geodynamic setting of the Racha-Dzhava zone. At the global level, the geodynamic setting persists for long periods of time comparable with geological eras in duration, and that is reflected in the directions of compression vectors. At the local level, the character of changes is affected by local factors such as the topology of geological layers, the sizes of tectonic blocks, and the compositions of these blocks.

After 2007, the activation of local seismicity was observed, indicating an increase in the instability of

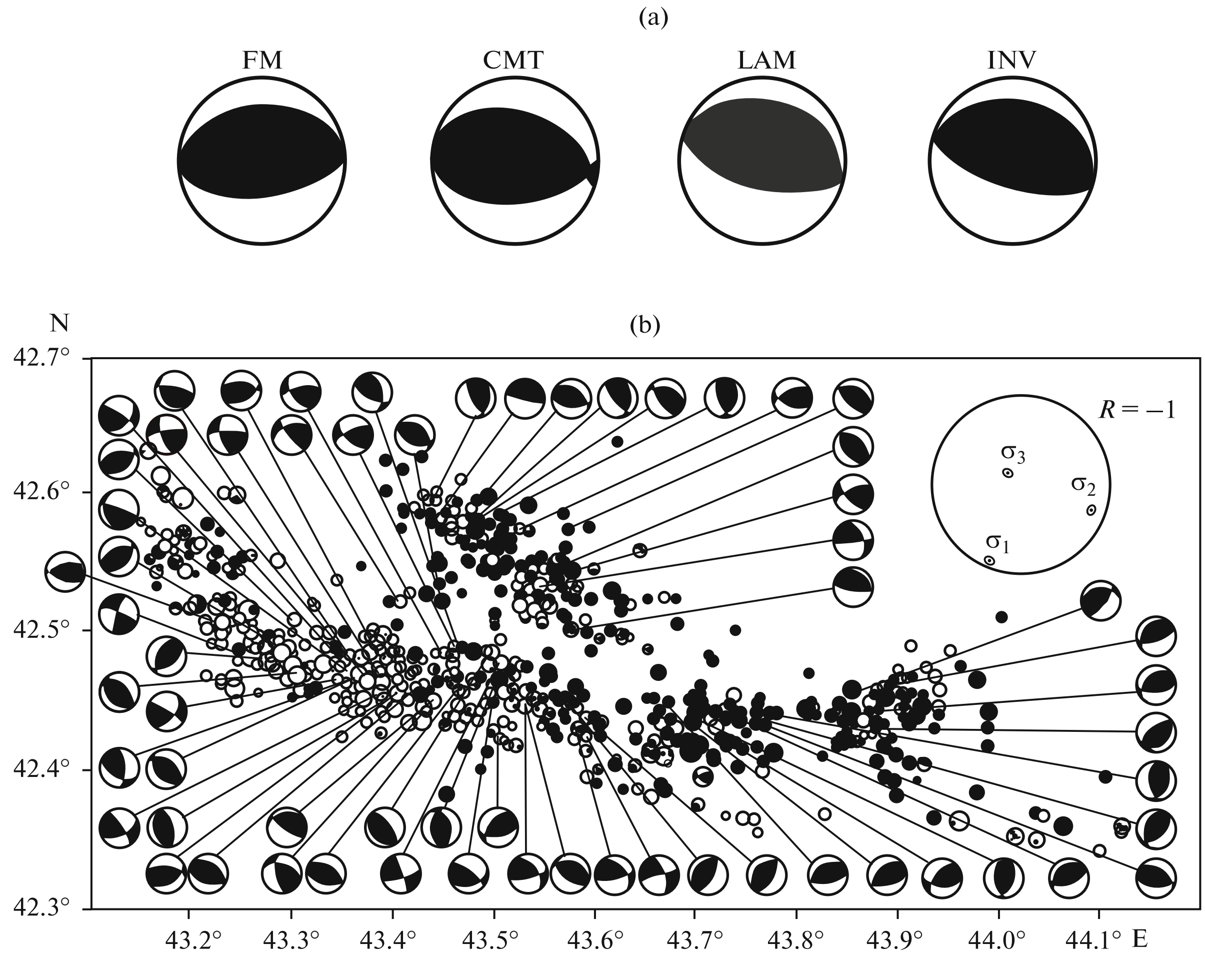


Fig. 3. (a) Versions of the mainshock mechanism of the 1991 Racha earthquake; (b) mechanisms of its aftershocks and the stress tensor, after (Aref'ev, 2003).

the region under consideration. This instability creates the conditions for short-term changes in the directions of vectors determining the stress regime of the studied region under the influence of distant strong earthquakes. The energy of these earthquakes is so large that local factors in the region stop governing.

The results of this study are interesting for understanding some aspects of local seismic activity, and the causes of changes in the stress field and the activity of seismic process of the Racha-Dzhava seismic zone, which is part of the Caucasus system.

FUNDING

This work was carried out in the framework of the state assignment project no. 0144-2019-0011 for the Schmidt Institute of Physics of the Earth, Russian Academy of Sciences.

CONFLICT OF INTERESTS

The authors claim no conflict of interest.

REFERENCES

Aki, K., Earthquake generation stress in Japan for the years 1961 to 1963 obtained by smoothing the first motion radiation patterns, *Bull. Earthquake Res. Inst., Univ. Tokyo,* 1966, vol. 44, no 2, pp. 447–471.

Aref'ev, S.S., *Epitsentral'nye seismologicheskie issledovaniya* (Epicentral Seismological Studies), Moscow: Akademkniga, 2003.

Aref'ev, S.S., Pletnev, K.G., Tatevossian, R.E., Aptekman, Zh.Ya., Vasil'ev, V.Yu., Delitsyn, L.L., Romanov, A.A., Osher, B.V., Parini, I.E., Afim'ina, T.V., Shilova, N.E., Shumilina, L.S., Dzhavakhishvili, Z., Cisternas, A., Haessler, H., Rivera, L., Dorbath, L., King, J., Fuenzalida, H., Owen, T., McCormack, D., Baker, K., Langer, Ch., Maier-Rosa, D. and Smith, P., The 1991 Racha earthquake: results of field seismological observations, *Fiz. Zemli,* 1993, no. 3, pp. 12–23.

Babaev, G.R., Akhmedova, E.V., and Kadirov, F.A., Analysis of the stress-strain state of the Caucasus region (Azerbaijan) according to vectors of maximum horizontal stresses using the software from the World Stress Map project, *Geofiz. Zh.,* 2017, vol. 39, no. 3, pp. 26–39.

Belousov, T.P., *Rachinskoe zemletryasenie 1991 goda i ego proyavlenie v rel'efe Bol'shogo Kavkaza* (1991 Racha Earthquake and Its Manifestation in Topography of the Greater Caucasus), Moscow: Svetoch plyus, 2009.

Burmin, V.Yu., Aftershocks of the Racha earthquake of 29 April 1991, *Vopr. Inzh. Seismol.,* 2016, vol. 43, no. 4, pp. 87–90. https://doi.org/10.21455/VIS2016.4-6

Burmin, V.Yu., Shemeleva, I.B., Fleyfel, L.D., Avetisyan, A.M., and Kazaryan, K.S., Spatial distribution of crustal earthquakes in the Caucasus, *Vopr. Inzh. Seismol.,* 2018, vol. 45, no 1, pp. 35–44. https://doi.org/10.21455/VIS2018.1-4

Kangarli, T.N., Kadirov, F.A., Yetirmishli G.J., Aliyev, F.A., Kazimova, S.E., Aliyev, A.M., Safarov, R.T., and Vahabov, U.G., Recent geodynamics, active faults and earthquake focal mechanisms of the zone of pseudosubduction interaction between the Northern and Southern Caucasus microplates in the southern slope of the Greater Caucasus (Azerbaijan), *Geodynam. Tectonophys.,* 2018, vol. 9, no. 4, pp. 1100–1126. https://doi.org/10.5800/GT-2018-9-4-0385

Kocharyan, G.G., *Geomekhanika razlomov* (Geomechanics of Faults). Moscow: GEOS, 2016.

Marinin, A.V., Tectonophysical studies of the Semisam anticlinal (Northwestern Caucasus), *Geodynam. Tectonophys.,* 2013, vol. 4, no. 4, pp. 461–484. https://doi.org/10.5800/GT-2013-4-4-0113

Marinin, A.V., and Sim, L.A., The contemporary state of stress and strain at the western pericline of the Greater Caucasus, *Geotectonics,* 2015, vol. 49, no. 5, pp. 411–424. https://doi.org/10.1134/S0016852115040068

Misharina, L.A. and Solonenko, N.V., Focal mechanisms of earthquakes and the stress state of the crust in the Baikal rift zone, in *Rol' riftogeneza v geologicheskoi istorii Zemli* (The Role of Rifting in the Geological History of the Earth), Novosibirsk: Nauka, 1977, pp. 120–125.

Papalashvili, V.G., Varazanashvili, O.Sh., Gogmachadze, S.A., Zaalishvili, V.B., Kipiani, D.G., Makhatadze, L.H., Mukhadze, T.G., Chachava, T.N., and Aivazashvili I.V., Racha-Dzhava Earthquake on April 29, 1991, in *Zemletryaseniya v SSSR v 1991 g.* (Earthquakes in USSR in 1991), Moscow: OIFZ RAN, 1997, pp. 18–25.

Rebetskii, Yu.L. and Alekseev, R.S., The current field of tectonic stress in Central and Southeast Asia, *Geodynam. Tectonophys.,* 2014, vol. 5, no. 1, pp. 257–290. https://doi.org/10.5800/GT-2014-5-1-0127

Richter, C.F, *Elementary Seismology,* San Francisco, W.H. Freeman and Co., 1958.

Rogozhin, E.A., Seismotectonics of the central sector of Greater Caucasus as the basis of seismic monitoring and seismic hazard assessment, *Vestn. Vladikavkaz. Nauchn. Tsentra,* 2009, vol. 9, no. 4, pp. 16–22.

Tatevossian, R.E. and Aptekman, Zh.Ya, Source model and the macroseismic effect of the 1991 Racha earthquake, *Seism. Instrum.,* 2011, vol. 47, pp. 107–117.

Shumlyanskaya, L.A. and Burmin, V.Yu., Parameters of breakage planes of the Crimean–Black Sea region according to the averaged local earthquake mechanisms, *Geofiz. Zh.,* 2016, vol. 38, no. 3, pp. 100–116.

Vakarchuk, R.N., Tatevossian, R.E., Aptekman, Zh.Ya, and Bykova, V.V., The 1991 Racha earthquake, Caucasus: Multiple source model with compensative type of motion, *Izv., Phys. Solid Earth,* 2013, no. 5, pp. 58–64.

Zverev, M.S., Boldyrev, S.A., Burmin, V.Yu., and Mironova, V.I., Microearthquakes of the northern Iceland, *Fiz. Zemli,* 1976, no. 10, pp. 22–32.

Translated by N. Astafiev