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SEISMOTECTONICS AND SEISMIC HAZARD OF THE NORTH-WESTERN CAUCASUS (SOUTHWEST OF RUSSIA)

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ABSTRACT

Several earthquakes with a magnitude $M > 5$ (1879-10-09, M =6.0; 1966-07-12, M = 5.5; 1970-11-07, M = 5.1; 2002-11-09, M = 5.0) and intensity in VII-VIII (in values of MSK-64 scale) occurred within the Northwest Caucasus. The most active areas are the Anapsky and Sochinsky seismic areas, on the territory of which large industrial and resort cities, such as Novorossiysk, Anapa, Gelendzhik, Tuapse, Sochi, are located.
The analysis of the seismic-generating structures of the North-Western Caucasus is based on the structure of the consolidated Earth's crust, developed on the results of interpretation of geological and geophysical materials. It is shown that the seismic-generating structures of the Anapsky and Sochinsky seismically active areas are high-density rigid blocks of the crystalline crust. The Anapsky seismically active area, in addition, is controlled by the Crimea and West-Caucasus deep faults. Sochinsky seismically active area, controlled in its continental part by the same block of crystalline crust, is limited by the Northwest and the Black Sea deep faults. The most seismically dangerous is the area corresponding by the Anapa seismic-generating block. The earthquakes of the Anapsky seismic area are caused by the movement of the seismic-generating block in the north-east direction, at the same time the seismic-generating block Sochi does not undergo similar stresses.

Keywords: North-Western Caucasus; earthquake; seismically active area; crystalline crust, seismic hazard

1. INTRODUCTION

Large industrial and resort cities: Novorossiysk, Sochi, Gelendzhik, Anapa and Tuapse are situated on the Black Sea coast of Russia of southern slope of the North-Western segment of the Greater Caucasus orogen. The North-Western Caucasus, which is the object of our research, according to the values of the map "General Seismic Zoning of the Territory of the Russian Federation" (GSZ-97A) belongs to the zone of seismic affects intensity (I_o) to VIII in values of MSK-64 scale (fig. 1). Earthquakes with magnitudes $M > 5$ are projected in the nearest 10 years in the area of cities Anapa – Novorossiysk – Krymsk (Akopian et al., 2017), seismic events with intensity I_o to IX are possible in the area according to the forecast (Ulomov et al., 2007).
The North-Western segment orogeny of the Greater Caucasus belongs to the Crimea-Caucasus seismic zone of the Mediterranean Sea seismic belt. Strong ancient earthquakes with I_o = VIII–X are known in the North-Western Caucasus and adjacent Kerch Peninsula, including catastrophic Panticapaeon earthquake in 63 BC (M = 6.4), which destroyed a number of cities on both sides of the Kerch Strait; Anap earthquake in 800 BC (M = 6.5); Kerch earthquake in 275 AD (M = 6.4); Low-Kuban earthquake in 1879 (M = 6.0).
In the XX and XXI centuries the earthquakes with $M > 5$ took place, among them Anap (1966-07-12), Low-Kuban-2 (2002-11-09), Sochi (1970-04-12 and 2012-12-10) and in the East of our research area Teberda (1905, M = 6.4, I_o = VII–VIII) and Chkhalta (1963, M = 6.4, I_o = IX) earthquakes.
The global level of seismic-generating stresses formation of the North-Western sector of the orogen of the Greater Caucasus is determined by its position within the Mediterranean mobile belt and associated with the movement of the Arabian plate towards the Eurasian, what generates the processes

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of the interaction between the Eastern-Black Sea and Scythian plates. The northern boundary of the Eastern-Black Sea plate is usually identified with the system of thrust faults of the southern slope of the Greater Caucasus orogen. The western boundary is drawn both along the Western-Crimean (Odessa-Sinop) fault (Kazmin et al., 2004), and Salguero-October fault (Patalaha et al., 2003) from the city Alushta to the coast of Turkey (near the city Bafra). The North-East Anatolian fault is taken as the eastern border of the Eastern-Black Sea plate and the North Anatolian fault – as the southern border (McKenzie, 1974; Vardapetyan, 1979; Kazmin et al., 2004). The thesis that sub-oceanic crust of the Eastern-Black Sea plate subducts under the Scythian plate is put in the basis of the most existing geodynamic models of the interaction of the Eastern-Black Sea and the Scythian plates (Kazmin et al., 2004; Patalaha et al., 2003; Piip et al., 2011; Gobarenko et al., 2016).

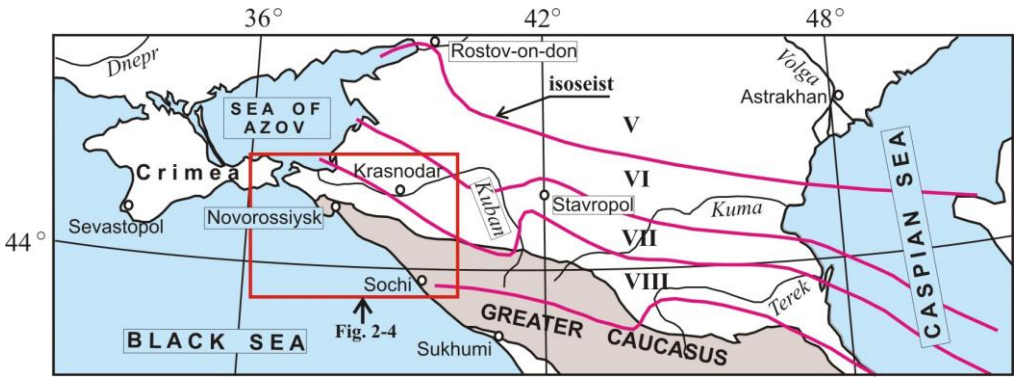

Figure 1. The simplified map showing the intensity I_o of the seismic influence (in the values of the MSK-64 scale) of the North-Western segment of the Greater Caucasus in accordance with the map of the "General Seismic Zoning of the Territory of the Russian Federation" (GSZ-97A), our study area is indicated by the red box

In accordance with the first scheme of plate tectonics of the Black Sea-Caspian region, proposed by McKenzie (1974), the movement of the Arabian plate to the north caused the formation of a number of the small plates within the southern flank of the Eurasian plate. Subsequent builds from the position of the plate tectonics of the Black Sea-Caspian region mainly broached the problems of the situation of the plate boundaries and the process of their interaction. Vardapetyan (1979) has substantiated the borders of the Black Sea and Small-Caucasus microplates, bordering in the north with the Eurasian plate, and in the south with the Anatolian and the Arabian plates by the feature of the distribution of the strong earthquakes within the Caucasus region. The Black Sea plate was divided further into Eastern-Black Sea and Western-Black Sea microplates (Patalaha et al., 2003; Kazmin et al., 2004). Some authors (Kazmin et al., 2004) believe that the Eastern-Black Sea microplate moves northward and rotates clockwise. There was suggested a general northern and even north-eastern motion of the Eastern-Black Sea and Western-Black Sea microplates with provision for the north-eastern direction of the Adriatic plate movement (Entin et al., 2010). The sections of the deep structure of the joint area between the Eastern-Black Sea and the Scythian microplates are based on DSS interpretation results of the seismic profiles 28–29, DOBRE-2, DOBRE-5. The capacity of the Earth's crust was evaluated and the deep faults were marked out on results of the interpretation of these materials, however, the available schemes of the interpretation of the deep structure are many-valued (Baranova et al., 2008; Starostenko et al., 2010).

The analysis of the available materials has showed that the actual problem for the North-Western Caucasus is the development of the seismotectonic model as the basis of the detailed seismic zoning and earthquake prediction. The location of the northern boundary of the Eastern-Black Sea plate is one of the key questions of this problem, which reviewed by the results of the analysis of the gravity field.

2. THE SEISMOTECTONIC MODEL OF THE NORTH-WESTERN CAUCASUS

2.1 The boundaries of the Eastern-Black Sea and the Scythian plates by the results of the gravitational field analysis

The gravitational field of the North-Western Caucasus in accordance with the scheme of zoning of the gravitational field (Stogny G., Stogny V., 2017) is presented by the flanks of the two anomalous regions: the Black Sea and the Scythian in regional plan (fig. 2). The Scythian anomalous region tectonically corresponds to the Scythian plate, including the Indol-Kuban sedimentary basin, which appears as Indol-Kuban minimum with amplitude more than 25 mGal.

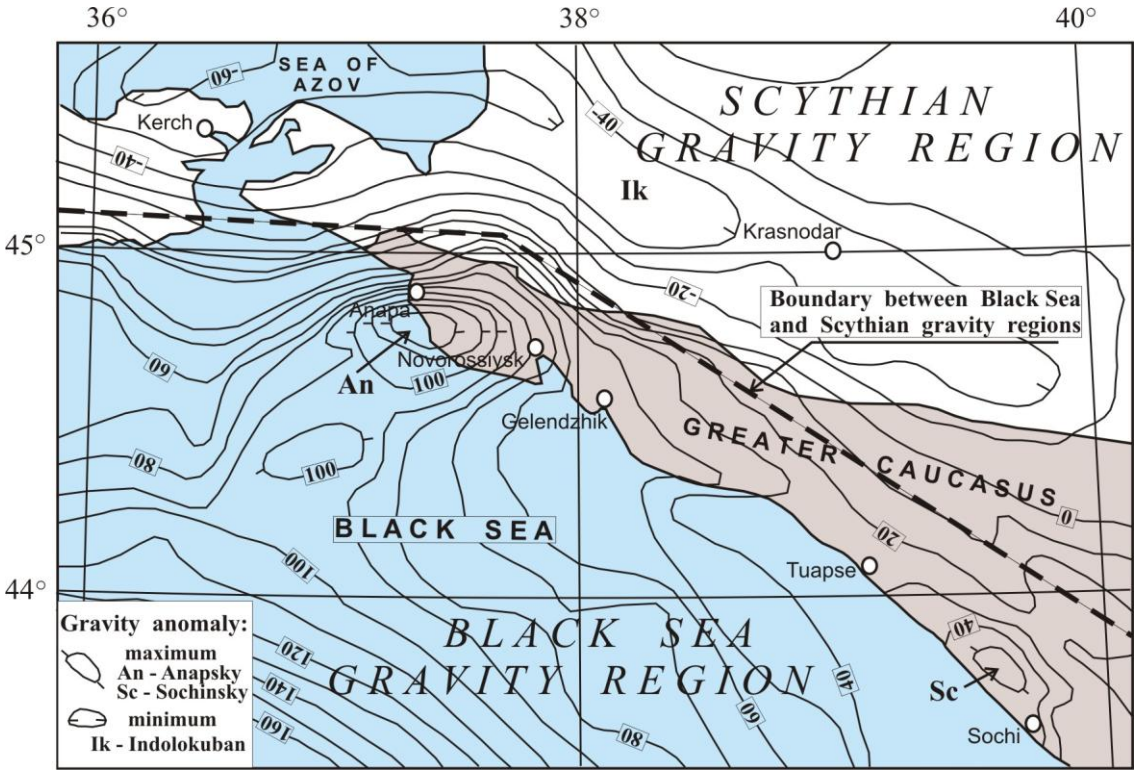

Figure 2. The scheme of the gravity regions and anomalies of the north-western segment of the Greater Caucasus (the map of the Bouguer gravimetric anomalies, units are given in mGal)

The Black Sea gravity region covers the area of the Eastern-Black Sea depression, the Mountain Crimea and the southern slope of the north-western segment of the Greater Caucasus orogen. The north-eastern gravitational step of the Black Sea anomalous area corresponds to the southern wing of the north-western segment of the Greater Caucasus orogen. The Novorossiysk local gravitational maximum with the amplitude 60 mGal and the Sochi local gravitational maximum with the amplitude to 15 mGal stand out in borders of the Black Sea anomalous area (fig. 2).

There are several points of view on the nature of these local gravity anomalies. Buriyanov and Soloviev (1996) explained the gravitational maxima of the northern and western frame of the Black Sea depression by the intrusive bodies that embedded on the periphery of the Black Sea. According to another point of view (Baranova et al., 2008) with the fact that these intense gravitational anomalies in the plan are limited by isobath 200 m, their nature is partly associated with the edge effect.

The structure of the low-frequency component of the gravitational field is explained by the dense inhomogeneities of the consolidated layer of the Earth's crust (Stogny G., Stogny V., 2017). The tectonic scheme of the crystalline Earth's crust of the Crimean-Caucasus region was developed according to the results of analysis of the gravitational field.

2.2 The seismotectonic model of the North-Western Caucasus and seismic hazard assessment

Epicenters of the earthquakes in the North-Western Caucasus are concentrated within two seismically active areas: Anapsky and Sochinsky (fig. 3). The analysis of the tectonic structure of the crystalline crust and earthquake epicenters of the Greater Caucasus north-western segment allows to remark the coincidence of the Anapsky and Sochinsky seismically active areas to local objects – high-density

blocks of the consolidated crust and deep faults that limit them. The role of transverse faults in the formation of the North-Western Caucasus seismicity is also quite significant and the ability of these faults to produce earthquakes of destructive power is assumed (Gabsatarova et al., 2016).

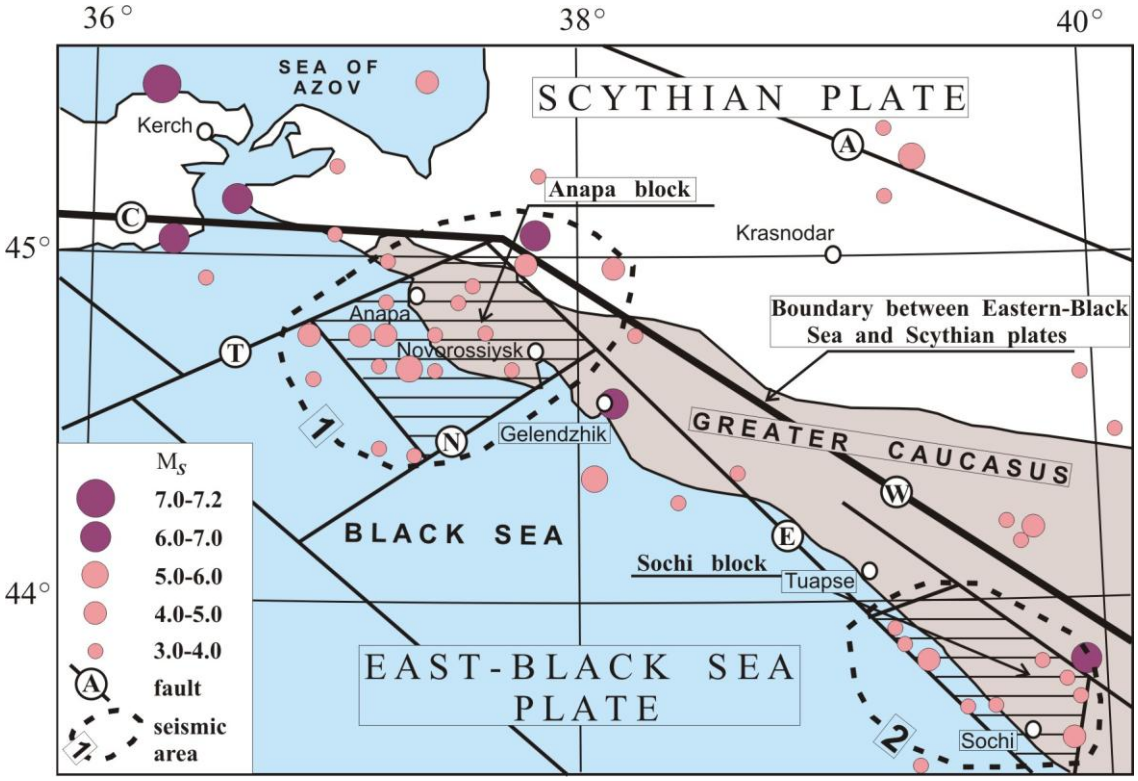

Figure 3. The main seismically active units of the Greater Caucasus north-western segment (faults: A – Azov, C – Crimea, E – East-Black Sea, N – Novorossiysk, T – Taman, W – West-Caucasus; seismic areas: 1 – Anapsky, 2 – Sochinsky; episenters: lilac – historical earthquakes, before 1900; rosy – instrumental earthquakes, after 1900)

Anapsky seismically active area is corresponded to the eponymous block of the Earth's crust and the node of the Crimean and West Caucasian deep faults intersection. The main part of earthquakes hypocenters is localized in the depth interval 10–35 km. The following earthquakes occurred within the Anapa block: Low-Kuban-1 (1879-10-09, M = 6.0, I_o = VII–VIII), Anapa (1966-07-12, M = 5.5, I_o = VII), Low-Kuban-2 (2002-11-09, M = 5.0, I_o = VI–VII). The Anapa earthquake (1966-07-12) epicenter is located in the sea at a distance of 10–15 km from the coast, the intensity of the shock in the cities Anapa and Novorossiysk was VI. The long axis of the isoseismic zone has a north-eastern strike.

The Low-Kuban-2 earthquake (2002-11-09) epicenter was located within the epicentral area (VII–VIII) of the Low-Kuban-1 earthquake (1879-10-09). The Low-Kuban-2 earthquake was felt on a large territory of the Krasnodar Region with intensity from V–VI to II (fig. 4). The isoseist V covers the territory where the cities Anapa, Novorossiysk and Krymsk are located. The isoseismic zone stretch is similar to the strike of the Anapa seismogenerating block of the Earth's crust.

Sochinsky seismically active area is controlled by the same name block of consolidated crust. The block is bounded by the Northwest and the Black Sea deep faults in the continental part. Earthquakes with M < 5 are characteristic for it. The earthquake (1970-11-07, M = 5.1, I_o = VII–VIII), which was felt with the force IV–V in Sochi, is necessary to remark among the powerful earthquakes.

The North-Western Caucasus seismicity in the lithospheric plate tectonics concept is explained by the subduction process of the Eastern-Black Sea plate under the Scythian plate (Kazmin et al., 2004; Gobarenko et al., 2016). The subduction model was developed on the basis of the oceanic or sub-oceanic type of the Earth's crust of the East-Black Sea depression. The thin high-speed Earth's crust of the East-Black Sea plate has rheological properties like to the crust of the East European Platform

(Yanovskaya et al., 2016) and is a thin continental crust formed as a result of strong extension of the continental crust without significant change of the underlying mantle. The conditions of the Eastern-Black Sea and Scythian plates interaction should be considered within the framework of interaction between two plates of the continental type on the basis of these data. The boundary of the Eastern-Black Sea and the Scythian plates (fig. 3) corresponds to the boundary between the East-Black Sea and the Scythian anomalous gravitational regions (fig. 2). The continental part of the Eastern-Black Sea plate is divided into blocks whose movements at the level of different layers of the Earth's crust lead to the formation of tectonic stress fields in the lithosphere and their discharge through earthquakes.

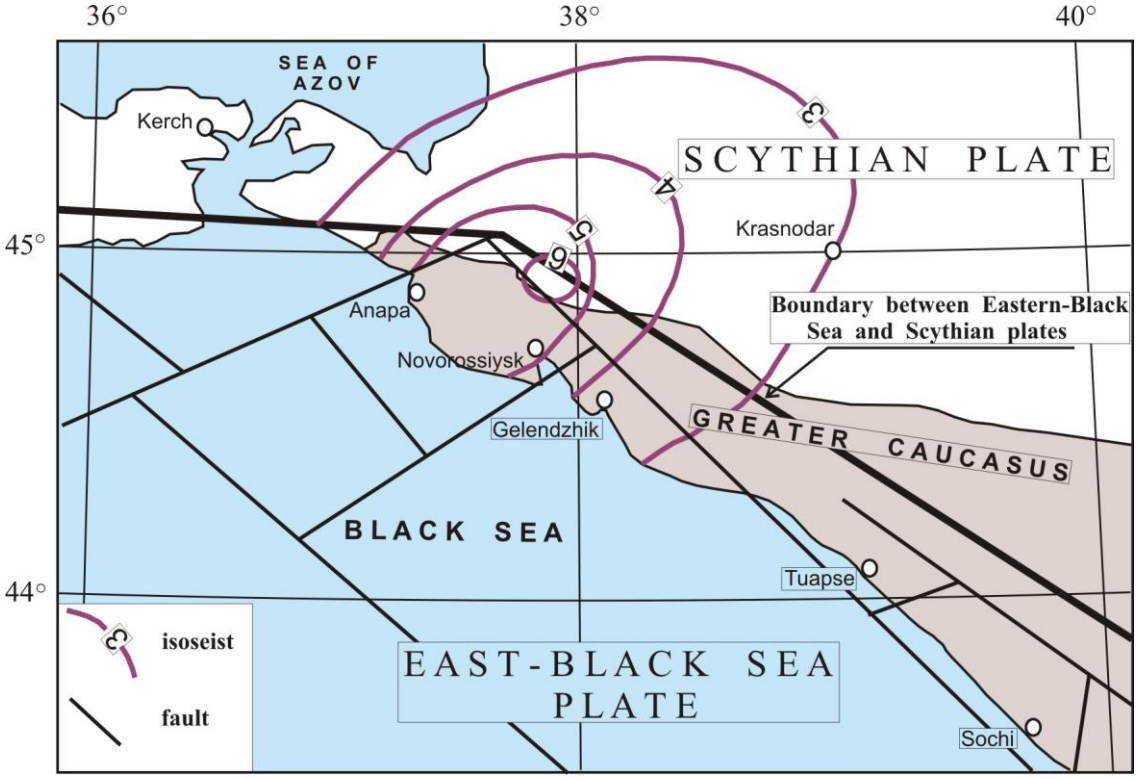

Figure 4. Map of isoseist of the Low-Kuban-2 earthquake (2002-11-09) according to (Malovichko et al., 2012) on the scheme of the main tectonic elements of the North-West segment of the Greater Caucasus

The Anapa block, which moves in a north-eastern direction and "is pressed" into the basement of the Scythian plate, is the most unstable one. The Sochi block does not experience similar stresses and its seismic hazard is less than for Anapa block. The seismogenerating structures of the Sochi block are the faults that limit it.

3. CONCLUSIONS

The basis of the seismotectonic model of the North-Western Caucasus which was developed by us is the interaction of the Eastern-Black Sea and the Scythian plates of continental or sub-continental type, the boundary between which corresponds to the boundary between the East-Black Sea and the Scythian anomalous gravitational areas.

The spatial distribution of earthquake epicenters of the Eastern-Black Sea lithospheric plate has a nodal character. Within its boundaries the Anapsky and Sochinsky seismically active regions of the Black Sea coast of Russia are the most seismically active. Earthquakes with $M > 5$ occurred mainly within the Anapsky seismically active area: Low-Kuban-1 (1879-10-09, $M = 6.0$), Anapa (1966-07-12, $M = 5.5$) and Low-Kuban-2 (2002-11-09, $M = 5.0$). Hypocenters of the earthquakes are localized mainly in the depth interval 10–35 km.

The seismogenerating structures of the Anapsky and Sochinsky seismically active regions are the same name blocks, marked out in the contours of local gravitational maxima. According to our interpretation, they are high-density rigid blocks of granulites of the crystalline crust of the northern flank of the Eastern-Black Sea plate. Anapsky seismically active area, in addition, is controlled by a node of the West Caucasian and the Crimean deep faults intersection. The tectonic pattern permit to assume that the Anapa block "is pressed" in the north-eastern direction, while the transverse faults of the north-eastern strike of the North-Western Caucasus have a common strike with the Kerch-Azov fault system.

These faults limit the Anapa and Sochi seismogenerating blocks are seismically active. The role of transverse faults in the North-Western Caucasus seismicity formation is quite significant and the ability of these faults to produce devastating earthquakes is assumed. The territory of the Anapa block (cities Anapa, Novorossiysk, Krymsk) is the most seismically risky on the base of the developed seismotectonic model of the North-Western Caucasus.

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