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Seismicity and deep tectonics of the Black Sea depression and its margins

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Abstract. Seismicity has been detected within the central "granite-free" part of the Black Sea depression, which earlier was considered aseismic. The seismicity defines specific zones in the depression and its margins. In the depression, epicenters are grouped into diagonal linear chains separating large blocks. The vertical distribution of seismicity has allowed us to distinguish four main levels in the Black Sea tectonosphere, which differ in elastic and strength properties: sedimentary layers, brittle crystalline crust, plastic upper mantle, and deeper mantle which is considerably more homogenous. At various levels, structures show azimuthal discordance. The plastic upper mantle appears to be connected with the asthenosphere. It is most uplifted under the "granite-free" part of the Black Sea depression and is apparently responsible for its formation. A mantle asthenolith (or asthenolithes) probably occur there.

The Black Sea region is known to be an area of active tectonics and seismicity [*Boll. Geof. Teor. Appl.,* 1988; *Nauka,* 1975, 1989; and others]. Since these processes are interrelated, it is essential to study the spatial and temporal distribution of seismic sources and the energy they release, to reveal seismic inhomogeneities and simulate velocity models for better understanding of deep structure and the processes in the tectonosphere in the region analyzed.

The central, deepest part of the Black Sea depression was believed to be aseismic. Thus when estimating seismic risk, only continental slope and on-shore tectonic structures were considered as zones of strong earthquake generation [*Medvedev,* 1968].

Recently, a large amount of work has been done to generalize seismologic observations in the Black Sea region for the instrumental period since 1927 [*Pustovitenko et al.,* 1990]. These data indicate that the central part of the Black Sea also has active seismicity, although not as high as at its margins. Seismic zoning of the region has been performed based on active seismicity, and regularities in the vertical distribution of earthquake sources and the energy released have been determined. In combination with other data, we can make some tectonic conclusions.

Seismic zoning. Figure 1 shows that the bulk of the epicenters and most of the released energy for the period considered are attributed to the boundaries of the Black Sea marginal zones, that is to the Black Sea depression. Seismic processes also occur in the central "granite-free" part of that structure. Some major zones can be recognized in the Black Sea depression and its margins from the common seismicity manifestations, namely the central Black Sea "granite-free" zone (A), Crimean (southern shore)-Caucasian zone (B), North Anatolian (C), Sea of Marmara (D), Scythian (E), and Vrancea (F). In the center of zone A, there is a bridge incorporating a thin granitic layer (A') which connects the shores of Crimea and Turkey in a northwesterly direction and corresponds to the Andrusov swell [*Moskalenko and Malovitskiy,* 1974; *Tugolesov et al.,* 1985]. In the light of new data [*Chekunov et al.,* 1990; *Pustovitenko et al.,* 1988], the northern boundary of the Crimean-Caucasian zone (B) can be drawn from the western Kuban depression along the southern Azov fault north of Cape Kazantip at the Kerch peninsula, toward Sudak-Alushta-Yalta-Sevastopol, that is considerably north of its earlier assumed position. The Crimea mountain structure is considered to be an uplifted marginal part of the aseismic Scythian plate (E) located north of the former [*Chekunov,* 1990]. West of the Odessa submeridional fault [*Chekunov and Garkalenko,* 1969], the Crimean (the southern shore) zone cannot be traced.

The southern part of zone B and northern part of zone C are beneath the Black Sea, forming its shelf and continental slope. Seismic activity of the Sea of Marmara region (D) seems to be related to its structure and is a component of the North Anatolian zone. This area

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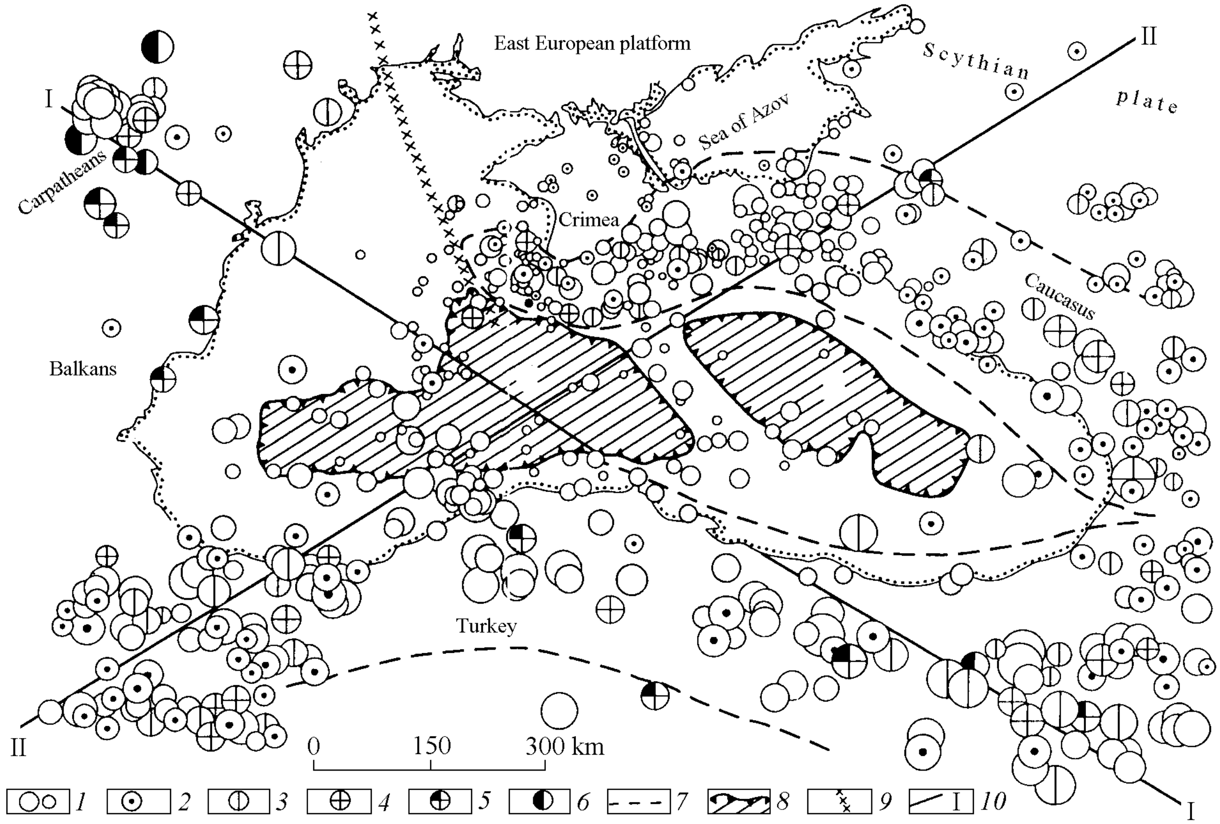

Figure 1. Map of the Black Sea region, seismic zones and profiles: 1, earthquake foci (size of the circles is proportional to magnitude); 2–6, focal depth, in km: 2, 0–15; 3, 15–30; 4, 30–50; 5, 50–100; and 6, 100–150; 7, contours of seismic zones; 8, "granite-free" part of the Black Sea depression; 9, Odessa fault; and 10, position of profiles I–I and II–II (Figure 3). Letters indicate zones described in the text.

seems to be influenced by the large Aegean asthenolith which is located to the south [*Chekunov,* 1988]. The Vrancea active seismic region with deep sources (F) is close to the Black Sea; however, it, as well as the entire Carpathean arc, is related genetically to the deep processes of Pannonea.

Seismicity of the Black Sea deep basin. The Black Sea basin epicenters are not randomly spaced; they tend to be grouped in linear chains and large spots (places where these lineaments intersect), forming large clusters (Figure 2). Elongated seismic lineaments have a diagonal NW and NE orientation, marking and dividing the entire Black Sea depression into several blocks. The largest and most pronounced blocks (II and IV) are almost symmetrical with respect to the center of the depression and have close linear dimensions (about 150×150 km). Dimensions of other blocks (I and III) are approximately by 1.5 or 2 times less and their geometry is not so expressed. There are no recorded intrablock earthquakes with $K > 10$ in the region analyzed. The highest density of seismic energy occurs in the western part of the depression.

The angular coefficient of the earthquake recurrence curve connected with the fractional character of the geophysical medium was estimated from the data for the period from 1933 through 1984. The first version considered only those earthquakes which fall strictly within the inner part of the depression with no "granitic" layer. The second one considered the nearby epicenters at a distance of up to 20 km from the depression boundaries, as epicenter coordinates and the boundary itself are determined with error.

The earthquake recurrence curve has a low angular coefficient ($\gamma = 0.22$), which is half the typical value of the same curve for the seismic events of the continental slope near Crimea ($\gamma = 0.44$). This shows that the medium in the inner part of the Black Sea depression is less fractionated, and the accumulated energy may be released only by larger discontinuities. It has been shown by *Polyakova* [1985] that earthquakes with $M > 7$ originate in regions with low γ. Based on the

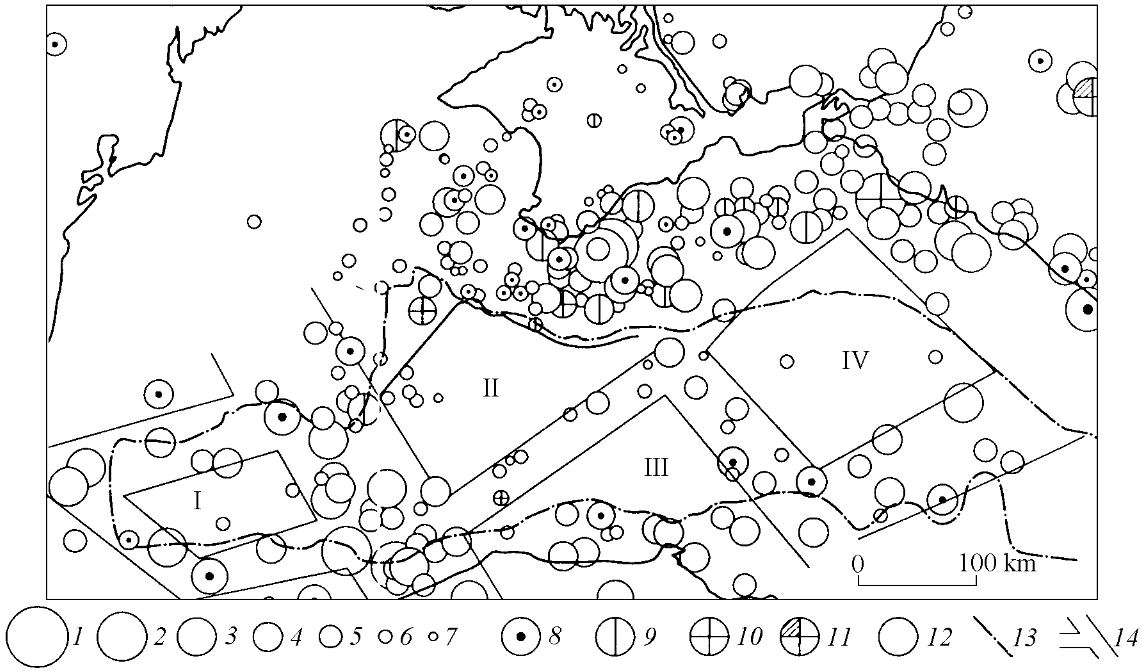

Figure 2. The Black Sea earthquake epicenters: 1–7, epicenters of earthquakes from 1900 through 1986: 1, $M \geq 7.5$; 2, $6.5 \leq M \leq 7.4$; 3, $5.5 \leq M \leq 6.4$; 4, $4.5 \leq M \leq 5.4$; 5, $3.5 \leq M \leq 4.4$; 6, $2.5 \leq M \leq 3.4$; and 7, $1.5 \leq M \leq 2.4$; 8–12, focal depth, in km: 8, 0–15; 9, 15–30; 10, 30–50; 11, 50–100; and 12, depth is not determined; 13, contour of the area with no "granite" layer; 14, seismic lineaments. Roman figures are explained in the text.

data, the occurrence of strong earthquakes in the Black Sea depression, events which would exceed the known Crimea earthquakes with $M = 6.8$, and the structures they may be related to can be estimated. The occurrence of large blocks in the Black Sea basin bounded by elongate seismic lineations about 200 km long suggests the possible generation of sources with $M \approx 7 - 7.5$.

Distribution of sources and energy with depth. It is clear from Figure 3 that earthquake sources in zone A reach a depth of 15 km. As the sedimentary thickness there is 10–15 km [*Nauka,* 1975], it is clear that fractioning occurs only in the uppermost in crystalline crust, in the basalt layer. In the places where a granitic layer appears (zones B and C), and also in subzone A' (the

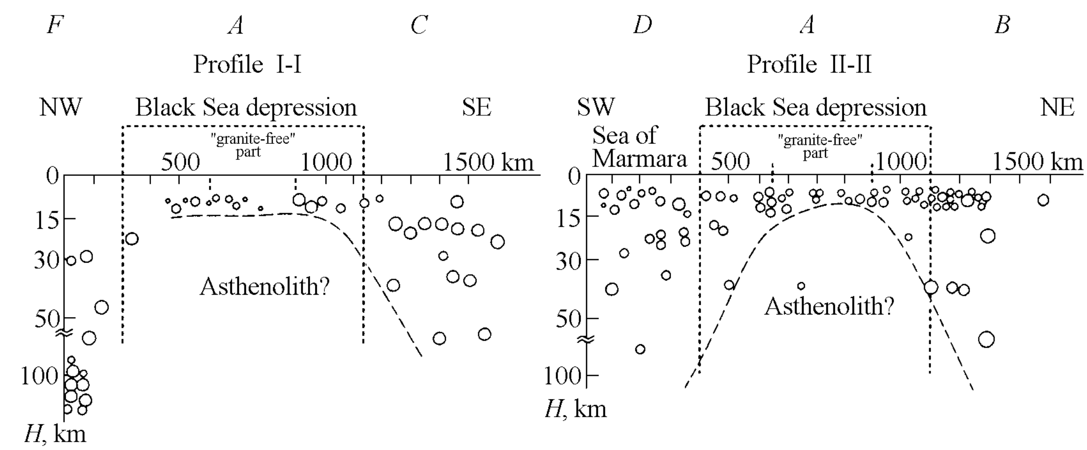

Figure 3. Earthquake epicenter distribution with the depth along profiles I–I and II–II (Figure 1). Bold dashed line is the contour of the supposed asthenolith. For other notations see Figure 1.

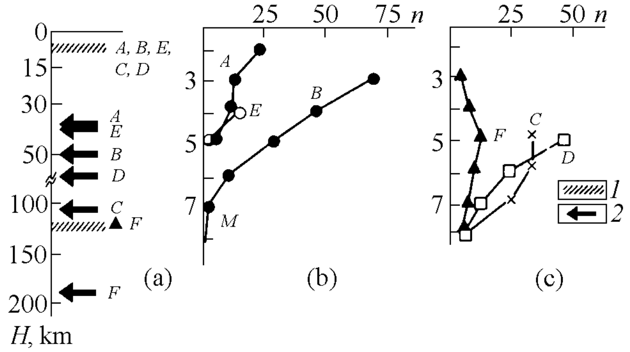

Figure 4. Distribution of seismicity (a) and magnitudes (b, c) of earthquakes by zone: 1, maximum of released energy and 2, maximum depth of seismicity. $AF-$ seismicity zones according to Figure 1. M is magnitude, H is depth, n is number.

Andrusov swell), seismic activity and maximum source depth increase.

In zone B, and more distinctly in zones C and D, the maximum source depth increases to 50–100 km, respectively. The deepest sources have been recorded in the Vrancea zone (down to 190–200 km). So, the "granite-free" part of the Black Sea depression is surrounded on the north, east and southwest by deeply diving active seismic zones.

Energetically, there are no magnitudes over 5 in zones A and E; values are generally less than 4 (Figure 4). The same picture can be observed in zone B, but there are many values of 5–6 and in some cases even 7. The opposite situation can be observed in zones C, D and F, where sources with $M = 5$ and over, up to 8, have greater energetic input.

In all zones except the Vrancea one, the total released energy decreases with depth. The largest amount of energy has been released in the uppermost 15-km layer, with the maximum in zones B, C and D, and the margins of the Black Sea depression. Decrease in total energy with depth can be explained by decreases in brittle properties, particularly in zones A and E. In the case of the Scythian plate, decreases may be explained by the quiet nonactive character of the stabilized platform, whereas in the central part of the Black Sea, they may indicate anomalous rapid increase of plasticity in the active deep asthenolith, according to the model of *Chekunov* [1987].

Deep structural plan. Figure 1 shows the strikes of the seismogenic zones. A sublatitudinal elongation is the principal one at the diagonal orientation of some segments. Assuming deep sources, this tendency probably is preserved to a depth of 100 km and then changes to the SW-NE one (Figure 5). There, differentiation of seismic wave velocities also decreases [*Gobarenko and Nesterov,* 1990], suggesting increasing homogeneity with depth.

Tectonosphere stages. Concepts of multilevel tectonics are now being developed actively [*Chekunov,* 1987; *Khain,* 1990; and others]. For the tectonosphere as a whole, these ideas are based mainly on theoretical suppositions that the rhyolitic properties of the geological medium change as the latter varies compositionally in the thermodynamic environment at great depth. Experimental data, in the combination with data obtained by other techniques and geological material, support these simulations and allow us to distinguish four principal tectonosphere levels in the Black Sea region. They are:

1. Sedimentary. Its thickness and inner structure are well revealed by geological and geophysical techniques and by drilling. Earthquakes are caused mainly by motions of consolidated basement due to processes at deeper levels. Several smaller structural-compositional sublevels can be distinguished within the sedimentary

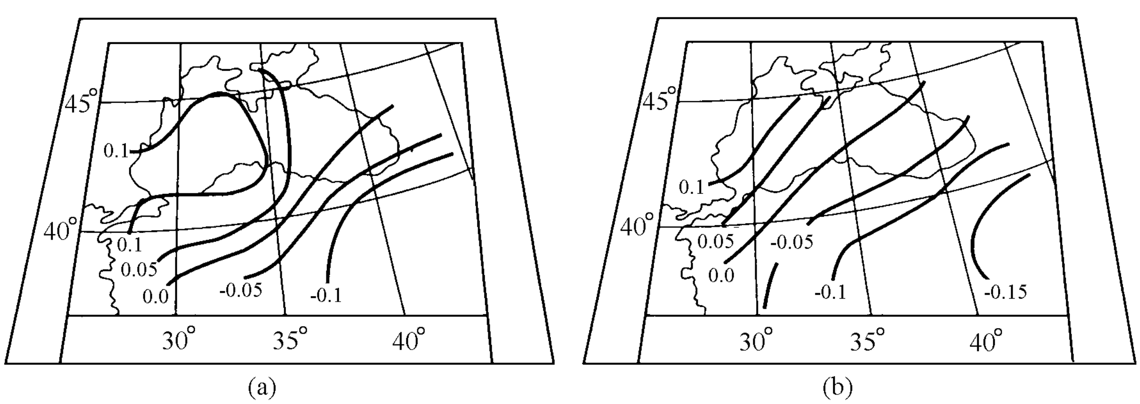

Figure 5. Velocity inhomogeneities in the upper mantle of the Black Sea at the depths of: (a) 50 and (b) 150 km [*Gobarenko and Nesterov,* 1990]. Isolines have corrections for seismic wave velocity, Δv km/s (with respect to the Jeffreys standard profile).

complex. They are characterized by brittle and plastic deformations which are not considered in the present work.

2. The upper, more brittle layer in crystalline crust. Most of the earthquakes with intermediate and small intensity originate here. Their total energy, however, dominates the total seismic activity of the region.

3. The lower, more plastic layer in the mantle. This layer is apparently related to the asthenosphere and its deep events reflect the upper boundary of its influence (Figure 3). It is most uplifted under the deep-sea "granite-free" part of the Black Sea depression, where an asthenospheric asthenolith seems to occur. It is the latter that appears to be responsible for the depression formation [*Chekunov,* 1987]. Shear and other tectonic deformations causing earthquakes originate at the lateral contacts with the upper brittle layer due to the difference in their properties and differentiated motions. In the northwestern part, the asthenolith seems to extinct, and, thus, there are no corresponding rock-fold framing of the seismoactive zone. Tectonically, that region can be considered as a pericratonic trough of the platform which is located northward.

4. The deepest, more homogeneous level. The structures this layer have NE strike which differs sharply from that in the overlying layers. The Black Sea depression "roots" cannot be traced any longer. As was already mentioned in [*Gobarenko and Nesterov,* 1990], the strike of the structures of this level coincides with the orientation of the transregional lithospheric lineaments mentioned in *Sollogub and Chekunov* [1985]. Those diagonal lineaments seem to reflect the rotational dynamics of the globe.

References

Boll. Geof. Teor. Appl., Monograph on the Black Sea, vol. XXX, no. 117/118, 324 pp., Trieste, 1988.

Chekunov, A. V., Principles of the tectonosphere structure and evolution in the southern European part of the USSR, *Geotektonika*, 5, 25–41, 1987.

Chekunov, A. V., Problems of the Black Sea depression, *Geofizicheskiy Zhurnal*, 4, 3–25, 1987.

Chekunov, A. V., Deep motives of tectogenesis, *Geofizicheskiy Zhurnal*, 5, 3–12, 1988.

Chekunov, A. V., Crimea as a part of the Black Sea fault system, *Dokl. Acad. Sci. UkSSR,* B(3), 20–24, 1990.

Chekunov, A. V., et al., Geological structure and geodynamics of the Crimea power station region, *Geofizicheskiy Zhurnal*, 3, 3–27, 1990.

Chekunov, A. V., and I. A. Garkalenko, The Odessa deep fault and its continuation onto the Russian platform and in the Black Sea, *Geofiz. Sb. AN UkSSR, 31*, 25–41, Nauk. Dumka, Kiev, 1969.

Gobarenko, V. S., and A. N. Nesterov, The upper mantle structure of the Black Sea from the P wave data, *Dokl. Acad. Sci. UkSSR,* B(6), 8–11, 1990.

Khain, V. E., The Earth's stratification and multistage convection, in *Geodynamics and Tectonosphere Evolution, Abstracts to the XXIII All-Union Tectonic Meeting,* pp. 52–53, Nauka, Moscow, 1990.

Medvedev, S. V. (Ed.), *Seismic Zoning of the USSR,* 476 pp., Nauka, Moscow, 1968.

Moskalenko, V. N., and Ya. P. Malovitskiy, Results of deep seismic sounding along transmeridional profile across the Azov and Black Seas, *Izv. Acad. Sci. SSSR Ser. Geol.,* 9, 23–31, 1974.

Nauka, *Structure and Evolution of the Black Sea Upper Mantle,* 162 pp., Moscow, 1989.

Nauka, *The Earth's Crust and the Evolution of the Black Sea Depression,* 358 pp., Moscow, 1975.

Polyakova, T. P., *Seismicity of the Central Part of the Mediterranean Belt,* 160 pp., Nauka, Moscow, 1985.

Pustovitenko, B. G., et al., Earthquake swarm of April 8-10, 1987, in the northwestern part of the Kerch peninsula (Crimea) and their possible geological-tectonic interpretation, *Geofizicheskiy Zhurnal*, 3, 37–47, 1988.

Pustovitenko, B. G., V. E. Kul'chitskiy, and A. V. Goryachun, *Earthquakes of the Crimea-Black Sea Region: Instrumental Period of Observations From 1927 Through 1986,* 190 pp., Nauk. Dumka, Kiev, 1990.

Sollogub, V. B,. and A. V. Chekunov, Principal features of the lithosphere structure within the Ukraine, *Geofizicheskiy Zhurnal*, 6, 43–54, 1985.

Tugolesov, D. A., et al., *Mesozoic-Cenozoic Tectonics of the Black Sea Deposits,* 215 pp., Nedra, Moscow, 1985.

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