OCEANOLOGY, English Translation, VOL. 35, NO. 4, FEBRUARY 1996
Russian Edition: JULY - AUGUST 1995

The neotectonic evolution and geomorphology of the outer continental margin to the south of Kerch Strait

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Abstract. A detailed echo sounding 320 km long was performed in a polygon with sides of 26 and 31 km in one of the parts of the outer continental margin to the south of the Kerch Strait in June 1993 on board the R/V *Aquanaut.* Using materials of the survey, the authors prepared a bathymetric and a geomorphological scheme and review floor surface profiles illustrating the structure of the study area, characterized by expressive relief features: scarps, benches, horsts and grabens, and underwater valleys. An analysis of the initial materials obtained and the schemes presented distinctly show that neotectonics played the leading role in the origination of the floor relief in this area. It is also noted that the formation and evolution of morphostructures proceeded in subaerial conditions under the action of abrasion, denudation, and accumulation over a long period of time.

Diversity and dissimilarity of the relief in different parts of the outer continental margin of the Black Sea was repeatedly mentioned in regional investigations [*Goncharov et al.*, 1972; *Kara*, 1979], in particular, polygon investigations [*Goncharov and Yevsyukov*, 1985; *Yevsyukov*, 1985; *Yevsyukov et al.*, 1987; *Shimkus et al.*, 1980]. In many regions the underwater margin is characterized by the occurrence of marginal ramparts, terraces with steep scarps, and other contrasting relief forms most often due to processes of neotectonics.

An investigation of a small shelf part to the south of the Kerch Strait was carried out in 1971 during the cruise of the R/V *Akademik S. Vavilov*; it gave an idea of the evolution in this area of three underwater terraces bounded by variously pronounced scarps [*Shimkus et al.*, 1980]. The investigation was continued in the course of the Russian-American expedition on board the R/V *Aquanaut* in June 1993. An echo sounding survey was made in a study area with sides of 26 and 31 km following the system of mutually intersecting tacks: sublatitudinal tacks 17–31 km long and submeridional tacks 7–27 km long with intertack distances of 1–1.5 km. The total length of the sounding comprised 320 km. (The expedition was organized by the Southern Branch of the Institute of Oceanology, Russian Academy of Sciences, and the Lamont Dougherty Geological Observatory of Columbia University, New York, and was pioneered by W. Rayen and W. Pitman. It proceeded under the supervision of K. M. Shimkus. High-frequency seismic profiling was also carried out along the major part of the route using American equipment (colored displayed data recording, Datasonic); bottom samples were taken with the help of a single-pass tube with a large diameter, and other studies were done.)

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Depths were recorded by the ship NEL5 sonic depth finder. Most (75%) of the survey was done between of 0–200 m, and the rest between 0–1000 m. The sonic depth finder operated stably within these regimes, and relief records of good quality were obtained. A Magnavox satellite navigation system coordinated the ship and controlled tacks, which provided a high-accuracy survey in the polygon.

A detailed processing of the materials obtained resulted in the preparation of the bathymetric (Figure 1) and geomorphological (Figure 2) schemes and review floor profiles (Figure 3). These documents visually reflect the relief structure of the study area under consideration, and it is worth noting that its morphology essentially differs from that of other Black Sea areas.

In compiling the geomorphological scheme, morphostructural indications were accepted as the base, which provided a possibility of differentiating the coastal shallow water and outer (sunken) shelf parts, as well as the upper part of the continental slope in this area. Each of these morphostructures is complicated by smaller morphological elements.

The shelf is morphologically not uniform. It is characterized by a relatively flat surface, and the depths smoothly increase from 50 to 100–120 m toward the south. However, gently sloping ridges and hollows with amplitudes of 8–12 m are observed here. Hollows correlate with channels of large valleys of the continental slope. There are also three scarps bounding underwater terraces in the shelf, and these scarps are likely to be genetically different.

The upper scarp is from 3 to 11 m high, and its edge is located at depths of 53–71 m (Figure 2). It is distinctly

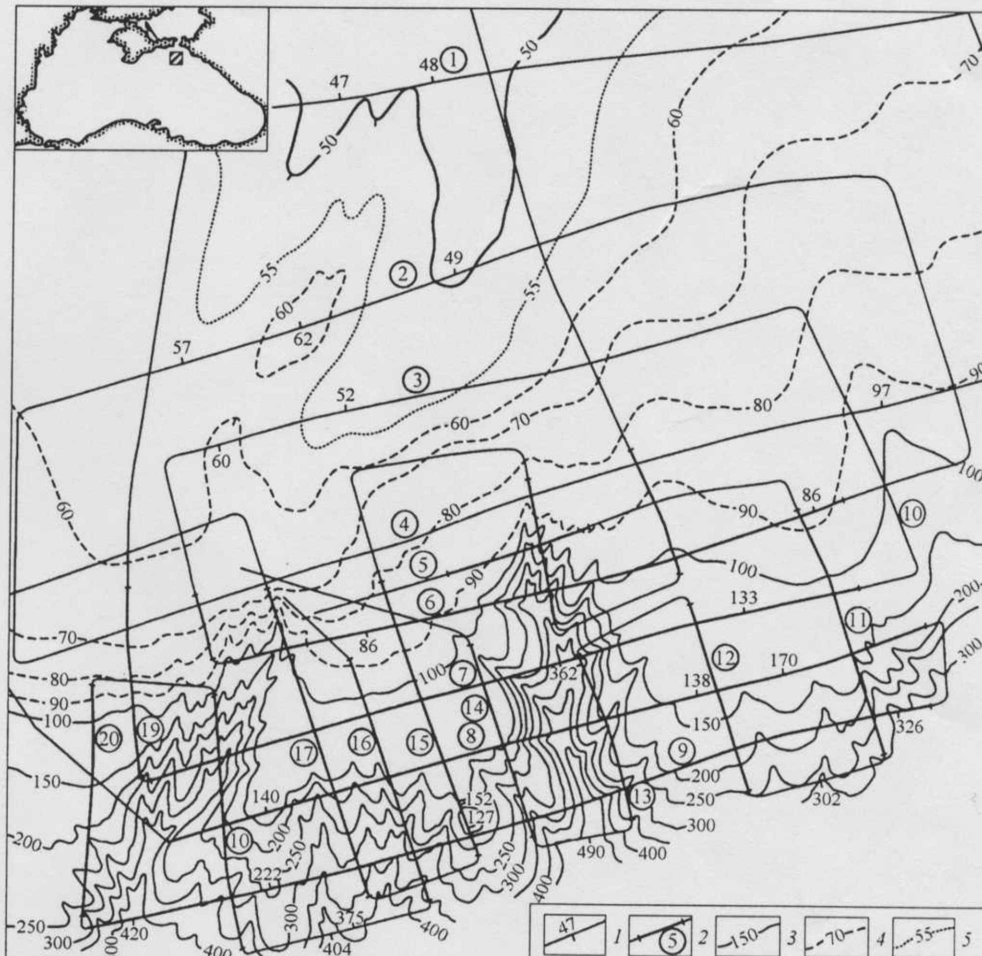

Figure 1. Bathymetric chart of the Kerch shady area: 1, sonic depth finder profiles and depth marks; 2, illustrated sonic depth finder profiles and their numbers. Isobath spacings: 3, 50 m apart; 4, 10 m apart and 5, 5 m apart. The location of the study area is shown in the inset map.

traceable in each profile. However, the scarp disappears in two parts approximately in the center of the polygon. It is likely that this scarp is leveled by young sediments. The middle scarp is more extensively pronounced in the western part of the polygon. Its height is 4–7 m, and the edge is at depths of 82–93 m. It is typical that the upper and middle scarps sink along the courses toward the southwest and east, respectively. Similar scarps are revealed in other regions of the Black Sea shelf as well [*Goncharov and Yevsyukov*, 1985; *Shimkus et al.*, 1980]; they are most likely to be of an abrasion genesis and could be formed during the periods of recent glacial eustatic fluctuations of the Black Sea level. Different directions of sinking (distortion) are due to neotectonic processes. Deeper locations of the edges of the upper and middle scarps which are spatially related to the upper reaches of valleys in the middle polygon part also may be explained by the latter.

The lower scarp is a peculiar morphological boundary between a comparatively shallow water part of the shelf and the outer sunken part. The height of the scarp is 16–27 m, and the edge is located at depths of from 85 to 115 m. In two parts this scarp is destroyed by the intensively progressing upper reaches of large valleys and their "tributaries." A distinct morphological manifestation (a height above 25 m, a steepness of 13°–17°,

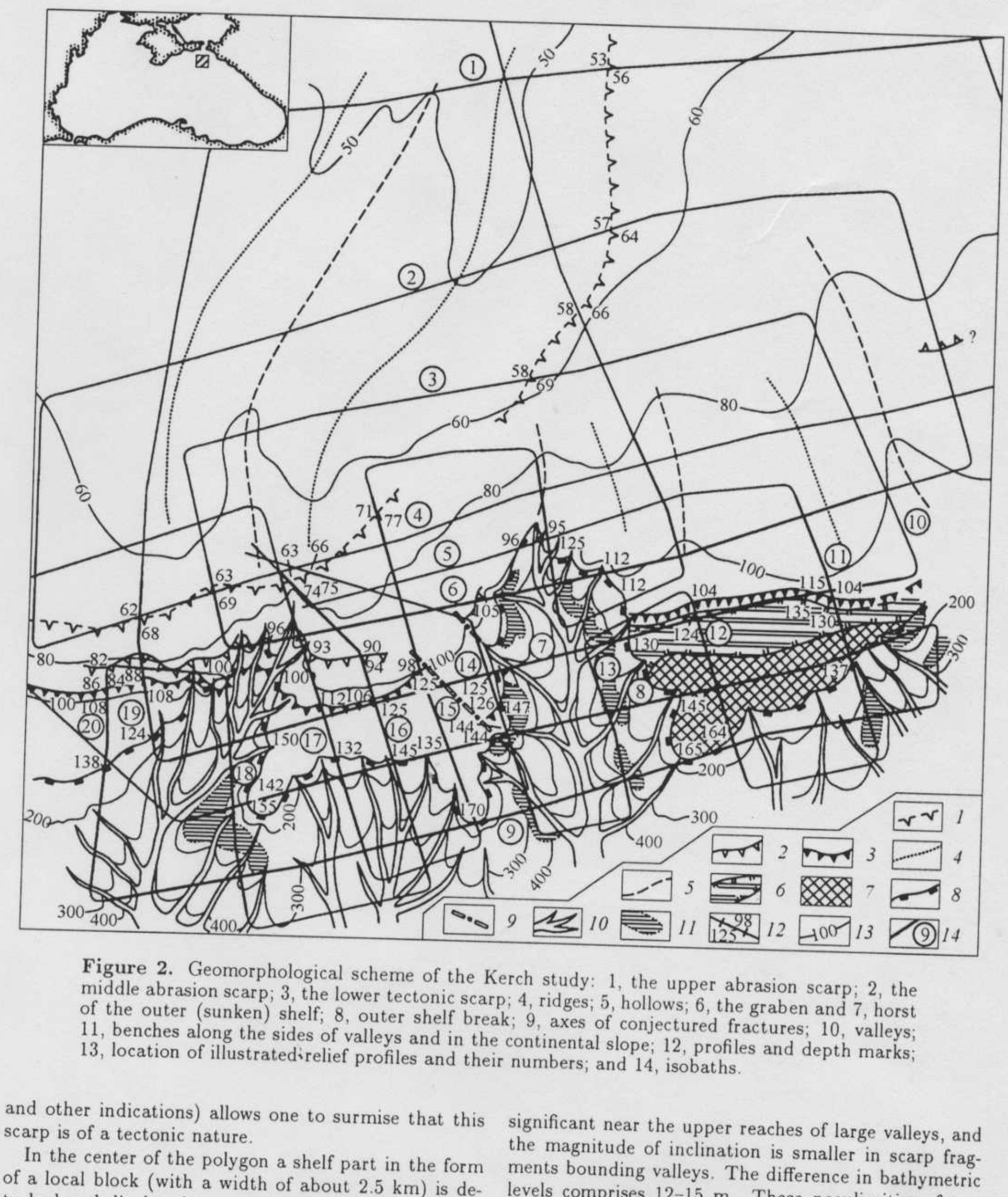

Figure 2. Geomorphological scheme of the Kerch study: 1, the upper abrasion scarp; 2, the middle abrasion scarp; 3, the lower tectonic scarp; 4, ridges; 5, hollows; 6, the graben and 7, horst of the outer (sunken) shelf; 8, outer shelf break; 9, axes of conjectured fractures; 10, valleys; 11, benches along the sides of valleys and in the continental slope; 12, profiles and depth marks; 13, location of illustrated relief profiles and their numbers; and 14, isobaths.

and other indications) allows one to surmise that this scarp is of a tectonic nature.

In the center of the polygon a shelf part in the form of a local block (with a width of about 2.5 km) is detached and displaced toward the southeast over a distance above 3 km. The outer part of the block sank by more than 25 m. The flank parts are bounded by fractures with the axes coinciding with valley channels.

A general sinking of the tectonic scarp along the eastern direction is distinctly seen. It is also typical that this inclination is not uniform along the course. It is insignificant near the upper reaches of large valleys, and the magnitude of inclination is smaller in scarp fragments bounding valleys. The difference in bathymetric levels comprises 12–15 m. These peculiarities of tectonic scarp morphology are indicative that the region under consideration is subjected to nonuniform neotectonic subsidence both along the latitudinal and submeridional fracture systems.

Another morphological indication points to the nonuniformity mentioned: the tectonic scarp in lips bounding valleys consists of two smaller scarps (Fig-

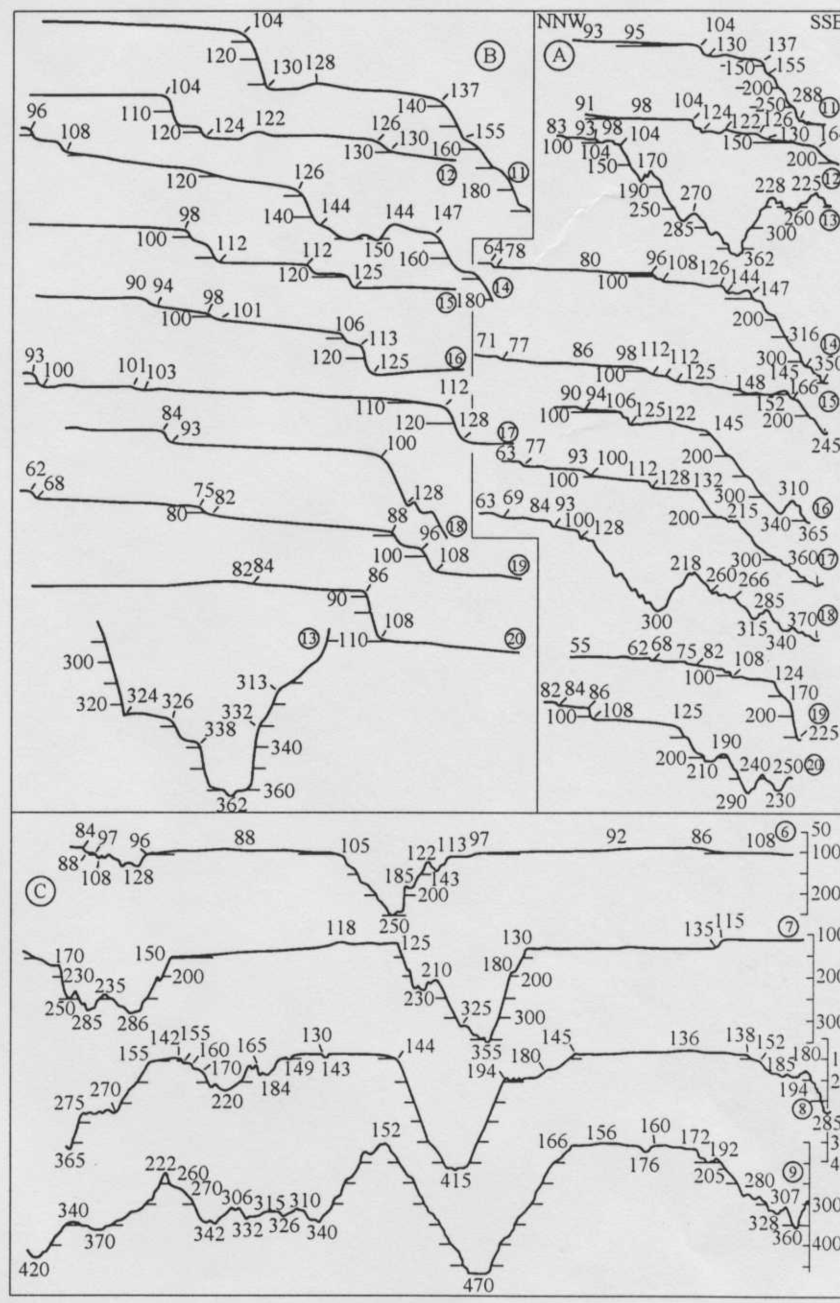

Figure 3. Review profiles of the floor relief: (a) submeridional profiles and (b) their enlarged fragments; (c) sublatitudinal profiles.

ure 3b, profiles 12, 15, 16, and 19), which distinctly demonstrates an increase in tectonic activity along the eastern direction.

The width of the outer (sunken) part of the shelf sharply changes in plan. This shelf part is almost absent in the upper reaches of valleys, and it is widened up to 4–6 km between them. The shelf break is very meandering in plan (Figure 2). Its bathymetric location is also very different; it is at a depth of 95–100 m in the upper reaches of valleys and sinks down to 150–170 m in distal parts of scarps bounding valleys (Figures 3a–3c).

The sunken shelf of the eastern part of the polygon is represented by horst-graben structures (Figures 2 and Figure 3b, profiles 11 and 12). The bottom of a graben (with a width of 1.5–2 km) filled by sediments is characterized by a varying (from plane to ridge, hilly) surface. In this area the tectonic nature of the third scarp is clear, and it marks the northern boundary of the shelf outer part. The almost flat surface of a horst (with a maximum width of 4 km) is inclined toward the southwest along the channel of a large valley.

The outer margin of the shelf in the central part of the polygon is represented by a variously pronounced narrow ridge rise (Figure 3a, profiles 14–16). It is likely to be a relic of a horst which previously extended along the overall shelf margin and on the surface of which a marginal accumulative rampart was formed at a later time. Its comb part is located at a depth of 143–147 m. This morphostructure is absent in the eastern part of the sunken shelf, which may be explained by its more intense neotectonic sinking. We also mention that the marginal rampart or the series of such ramparts in the Caucasian, Bulgarian, and other shelf parts occur at depths of 70–90 m and 86–96 m, respectively [*Goncharov and Yevsyukov*, 1985; *Yesin et al.*, 1990]. These parts of the shelf experience less significant neotectonic singing.

The mentioned peculiarities of the structure and spatial arrangement of the shelf break are indicative of a manifestation of intense neotectonic movements in its margin. A tectonic "eating" of the break takes place in connection with this, and it is most active in the upper reaches of underwater valleys, where sublatitudinal sinkings give way to submeridional sinkings. The latter are traceable far to the north of the shelf break and, as is shown above, are represented by gently sloping hollows with an amplitude of 8–12 m.

The tectonic eating of the shelf margin is not uniform in different parts of the polygon under consideration. The variable width of the sinked shelf part as well as the different depth of incision of underwater valleys in its margin, where the factor of erosion plays an essential role in the relief formation in addition to tectonics mentioned, are indicative of this fact.

The continental slope is studied only to a depth of 500 m. This part of the floor is represented by an extremely dismembered relief, which is primarily formed by channels of two large valleys (by convention the eastern and western valleys) with numerous "tributaries," which is typical of other regions of the basin as well [*Yevsyukov et al.*, 1986; *Yevsyukov and Kara*, 1989; *Yesin et al.*, 1990].

The eastern valley penetrates into the shelf over a distance of 10–12 km by its upper reaches. Its cross section is variably asymmetric along the course. The valley sides have a medium steepness of 10°–14°; they are complicated by scarps 50–70 m high and benches up to 1 km in width. A meandering channel with an incision depth of 10–15 m is traceable in the narrow (the first hundreds of meters) bottom; it is formed of suspension flows (Figure 3b, profile 13; Figure 3c, profiles 6–8). The bottom is widened up to 1–1.2 km at depths above 400 m, and the suspension channel becomes less pronounced in this area.

The western valley, asymmetric in the cross section, intrudes into the shelf over a distance of 4–6 km by its upper reaches. It has a plethora of tributaries, as the eastern valley does. Scarps and bench stairs located at different bathimetric levels occur along its sides.

The morphological structure of valleys points to neotectonic movements intensively proceeding in this area and active erosion processes. Talweg of valleys and their large tributaries mark the location and course of the meridional network of fractures dissecting the continental slope.

The origination and evolution of the relief of the polygon under consideration is due to differentiated neotectonic movements and abrasion and erosion-accumulative processes.

To see this, the presence of the steep and comparatively young scarp, its displacement along fractures together with a shelf part toward the southeast, the horst-graben structure of the sunken shelf part, the step-structure of slopes of valleys, and other morphological indications show that neotectonics played the leading role in their formation. It is probable that large fractures are submeridionally oriented. They dissect the continental slope and are likely to extend within the shelf, thus determining the location of hollows. Some fractures led to the formation of large valleys in the continental slope. It can be also surmised that their relative age is comparatively young (Pleistocene?). It is likely that the fracture along which the sublatitudinal tectonic scarp was formed is more ancient. It was formed in the shelf margin (which resulted in its neotectonic sinking) and subsequently destroyed by a series of submeridional fractures along which the formation of large valleys of the continental slope took place.

The outer deltas of the Danube and Kuban were under formation in the region of the study area in the period of glacieustatic regressions and transgressions of the Pleistocene. Vast areas covered by a thick layer of outer-delta deposits forming progradation bodies were discovered in the central and western parts of the studied polygon by a high-frequency seismic profiling. The third terrace scarp in these areas marks the outer margin of a progradation accumulative structure, and from distinct seismic records it is evidently of a tectonic nature. By and large, underwater terraces with pronounced scarps occur predominantly in an area where loose outer-delta deposits accumulate, and they were formed as a consequence of Upper Pleistocene tectonic subsidence and abrasion-accumulative processes.

The shelf near Kerch became exposed in the course of the last glacial epoch and regression maxima. The valleys of the Don and Kuban worked their way in it, and the mouths of these rivers went right to the shelf margin [*Shimkus et al.*, 1975; *Shcherbakov and Chistyakov*, 1981]. During these periods intense erosion-accumulative processes in the upper part of the continental slope proceeded under the action of suspension flows. The latter were caused by a delivery of a great mass of solid river discharge right to the slope. It is most likely that the basic network of underwater valleys was formed in the course of this period.

Erosion incisions of large river valleys and their tributaries occurred in the outer-delta layer formed during the process of regression. Many of these channels were partially or completely buried under a younger blanket of sediments in the course of a transgression. Slightly noticeable hollows marking the location of these channels have survived in the floor relief in places.

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(Received March 21, 1994.)