USE OF SPATIAL MORPHOMETRIC ANALYSIS OF THE ZMIINYI ISLAND UNDERWATER SLOPE RELIEF TO REVEAL TECTONIC MOVEMENTS IN HOLOCENE

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Introduction. Keeping in mind geopolitical, military, resource, scientific, historical and cultural significance of the Zmiinyi Island and the adjacent north-western Black Sea shelf area, prevention of the island coast destruction and its infrastructure preservation are among the most urgent tasks of geological and environmental studies (Smyntyna et al, 2008). It is known (Shuiskiy et al, 2004, Mykhailov, 2009) that the factors of formation and development of coast-destroying processes influenced significantly the morphometric features of the island underwater slope, marked by abrasion benches and terraces. The same morphometric features of underwater coastal slopes are characteristic of the entire north-western Black Sea (Konikov, 2009, Kadurin et al, 2011, Shmouratko, 2016) and, as a rule, correspond to the periods of sea level stabilization at new position and formation of coastal benches. Using deformations of primary horizontal levels of abrasion benches as indicators of ancient coastlines it becomes possible in principle to assess size, sign and speed of vertical tectonic movements in a certain point (Nesmeyanov et al, 1987, Shmouratko, 2016). As the Zmiinyi Island coast destruction has been intensive in the recent decades, one of the main geological tasks for elaboration of protective measures in order to preserve the unique geological object and to develop the island infrastructure is assessment of Holocene tectonic movements' role in formation of modern underwater slope changes. For that, unlike the previously performed morphometric studies of the island's underwater slope along separate profiles (Shuiskiy et al, 2004, Smyntyna et al, 2008, Mykhailov, 2009), more detailed and spatial morphometric analysis is required. ***Purpose of the work*** has been to reveal the features of morphometric characteristics of modern relief of the Zmiinyi Island underwater slope in order to identify the stages of geological development and assess the intensity of vertical tectonic movements in Holocene.

Data & Methods. To build a detailed digital model of bottom relief with isobaths lines every 1 m, the current nautical charts and results of our own bathymetric surveys down to 30-35 m depth performed by the staff of the "Zmiinyi Island" Research Station in 2009-2015 using echo sounder have been used as the source data. Using cartographic methods (Nikolaev, 1988), bottom depths hypsometric curves have been built to establish the generalized values of abrasion benches location depths (used as indicators of ancient coastlines), map of the island underwater slope inclinations and amplitudes of abrasion benches displacement have been determined to estimate size, sign and speed of vertical tectonic movements.

Results. It is known (Tkachenko et al, 1969, Sulimov, 2001, Suchkov ey al, 2005) that the Zmiinyi Island is characterized by the only in the Black Sea section of Middle Paleozoic rudaceous rocks located as hogback homocline with layers inclination to the north-east from 8-10 to 36-45 degrees. In the eastern part of the island the homocline is complicated by a small anticlinal fold and an upcast on tectonic dislocation of submeridional strike with amplitude up to 200 m. There are two main systems of faulting on the island. One system is submeridional and it crosses the island from the north to the south. The other one is directed diagonally from south-west to north-east and the most displayed in the faulting complex in the island isthmus area (Figure 1).

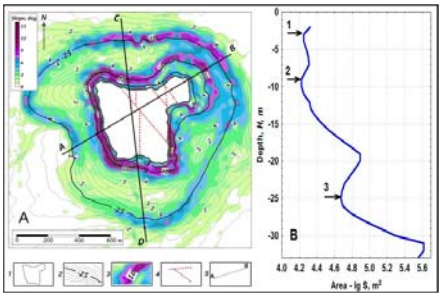

Figure 1 – Bathymetrical map with bottom surface inclinations (A) and hypsometric curve of the Zmiinyi Island underwater slope (B). A: 1 – current island contour; 2 – bathymetric lines: thickened line – isobaths corresponding to depths of an abrasion bench on hypsometric curve (B); 3 – underwater slope inclinations, degrees; 4 – faults (Tkachenko et al, 1969); 5 – profile lines. Depths of abrasion benches and their numbers is shown on B in arrows.

At that, the coasts of the Zmiinyi Island are built mainly of robust hard rock highly resistant to abrasion wave action. Abrasion is the most active in the areas with cliffs of crumbling rock with heterogeneous lithological composition, which causes the selective nature of abrasion-avalanchine denudation of the island coasts and configuration of its coastline – alternation of forelands and indentations. Comparison of the island maps of different years (Smyntyna et al, 2008) has shown that all of them display indications of structural and geological conditions influence on the coastline shape.

Analysis of underwater slope surface (Figure 1A) shows that flattened bathymetric lines repeat the coastline contour and their nearing evidences the presence of several concentric zones of relative increase of underwater slope inclination.

Characteristic depths of location are illustrated with hypsometric curve of current underwater slope (Figure 1B), where three local minima of areas can be distinctly seen. The first of them, conventionally modern one, is located at the depth of -3.0 m and is practically adjacent to the coastal cliff, the second is at the depth of -9.0 m at the distance from 10-20 m to 100 m from the current coastline, while the third at the depth of -25 m is 200 – 500 m far from the coast. Respectively, the abrasion terraces located between the abrasion benches are also different in their widths.

According to reconstructions of paleo-geographic conditions of the Black Sea north-western shelf (Konikov, 2009, Kadurin et al, 2011, Shmouratko, 2016), in the process of Holocene transgression the sea level has established around -22…-24 m below the current one about 9.4 thousand years ago.

The next stage of the transgression came ca. 4 thousand years ago when the sea level reached the marks -6…-8 m. Transgression developed in a gradual manner, however as the sea level stabilized in the new position the new coastal bench formed actively. It is important to stress that in the relief of the north-western shelf down to 65 m depth 14 benches and terrace surfaces are distinguished (Shmouratko, 2016), among which the marks of benches -7…-9 m and -21.4…-27 m are close in marks to those defined by us on the Zmiinyi Island underwater slope. Current correspondence between hypsometric levels of coastal benches on the north-western Black Sea shelf and the island underwater slope evidences the connection of certain stages of the Black Sea geological development with forming of the island during the time of Holocene transgression. This enables us to take the age of the second coastal bench located at -9 m as 4 thousand years and of the third (-25.0 m) as 9.4 thousand years (Figure 1A, Figure 1B). Knowing the current elevation and age of an abrasion bench as an indicator of ancient coastline we can calculate relative deformations of primary horizontal abrasion benches' levels interpreting them as tectonic deformations.

Bathymetric profiles and diagrams of underwater slope inclination built based on two lines of profiles are presented on Figure 2.

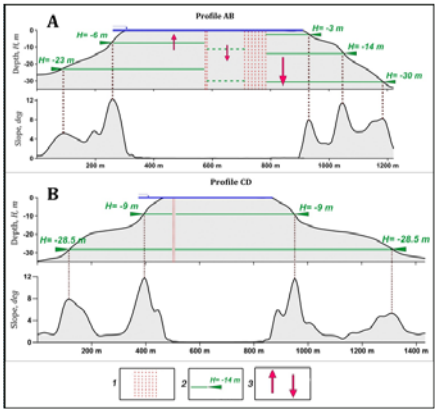

Figure 2 – Relief and inclinations of the Zmiinyi Island underwater slopes built based on profiles AB (A) and CD (B). 1 – fault zones; 2 – location and absolute marks of maximal inclinations of abrasion benches; 3 – differentiated block movements scheme.

Profile A-B (Figure 1A, Figure 2A) is orientated from south-west to north-east and crosses the diagonal fault network directed from south-west to north-east. Profile C-D (Figure 1A, Figure 2B) is orientated from north to south along one of the faults that divides the island in its middle part into eastern and western areas. Comparison between absolute marks of inclination maximal values of close in their depth second and third abrasion benches located at different sides of the island shows that the biggest displacements are in the north-eastern area (Figure 2A, Figure 2B), which is separated from the main part of the island with a narrow neck of land having vivid zone of tectonic dislocations. Based on the time of formation of, for example, the third coastal bench 9.4 thousand years ago with displacement amplitude 7 m, the tectonic subsidence speed of the north-eastern part of the island can be determined as 0.75 mm/year. With that, this speed obviously characterizes relative displacements of the north-eastern block along the fault zone under the assumption of conventional stability (immobility) of the island's western part. Most probably, the divided into separate tectonic blocks with dimensions 200 – 500 m parts of the island can have differentiated motions. This is suggested by the absolute marks of abrasion benches on the western side of the island (Figure 2B), which are 2 – 3 m higher than their statistical values (Figure 1B), as well as the absence of the first abrasion bench at the depth of -3 m on the underwater slope relief of this area.

It should be pointed out that significant tectonic subsidence with speed of ca. 1.5 mm/year was characteristic of some Black Sea north-western shelf areas during Holocene (Shmouratko, 2016). A characteristic feature of the north-western Black Sea is the strongly pronounced diagonal pattern of the fault network, which inherently controls the coastlines contour not only in the post-glacial, but also in older geological history of the region. The results of our studies (Cherkez, 1996, Kozlova,1998, Freiberg, 2011) show that significant role in the exogenous processes formation and dynamics is played by inhomogeneity of geological environment expressed in its microblock structure. The main elements of the structure are the inter-block zones – the zones of the highest engineering and geodynamical risk. Extreme gradients of speed and deformations caused by differential character of tectonic movements are typical of these zones.

Conclusion. The detailed spatial morphometric analysis enabled us to reveal the correspondence of several hypsometric levels of coastal benches between the north-western Black Sea shelf and the Zmiinyi Island underwater slope, which evidenced the connection of certain stages of geological development of the Black Sea and the island in the time of Holocene transgression, as well as assess relative deformations of primary horizontal levels of abrasion benches caused by differentiated tectonic displacements of separate blocks with linear dimensions of 200 – 500 m.

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