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ROCKY SHORE GEOMORPHOLOGY: A CASE STUDY ON THE CAPE SCHITU (WESTERN BLACK SEA COAST IN ROMANIA)

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Abstract. A rocky shore developed on porous-cavernous limestone was investigated in an environment with microtide, with temperate continental climate typical for Western Black Sea, on a waves-dominated coast. Rocky shore is represented by a sequence of 3 benches under which a shore platform with 2 steps is developed. All processes are controlled by lithology and structure of limestone, by the wave action and weathering. Present-day processes affecting rocky terrain are weathering, abrasion, washing the surface. Weathering is favoured by cavernous fractured porous nature of limestone. Abrasion acts effectively on the ground prepared weathering. By washing away the surface rock debris the ground is prepared for further weathering.

Keywords: shore platforms, rock control, limestone weathering, littoral karst, the Black Sea.

AIMS AND BACKGROUND

The problems of the rocky shores geomorphology in general and of the shore platform, in particular, focused the attention of many geomorphologists in the last 20 years[1–8].

The main analysed issues are: rocky shore morphology, long-term morphogenetic processes that generate a certain morphology, present-day geomorphologic processes carried out on rocky shore with or without the formation of offshore platform, the value of the rocky shore as geomorphic sites[2,4–6,9,10]. Most studies refer to the rocky shore in macrotide areas, from which a certain approach to all problems appears.

At the same time, attention and protection of coastal environment of the Black Sea can be observed[11–14].

We present below the results of research on a rocky terrain on the western coast of the Black Sea of Romania. Microtidal regime, temperate continental climate and geology conditions confer specific traits of interest for understanding the rocky coastline in general.

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EXPERIMENTAL

Research of the rocky shore at the cape Schitu followed current geomorphology methods and techniques: cross-shore profiles, mapping the relief forms at appropriate scales (1:1000, 1:5000 and 1:10 000), analyses of aerial photographs and satellite images, photography on successive metrics of certain directions, landforms and microforms diagnosis[1,15]. A detailed monitoring of relief and microrelief change on rocky shore was made in the period 2006–2010 (Ref. 16).

RESULTS AND DISCUSSION

STUDY SITES

The cape Schitu is located at 43° 56′ 22.11″N latitude and 28°38′ 16.75″E longitude on the Romanian Black Sea coast, the coastal arch Mangalia (Fig. 1).

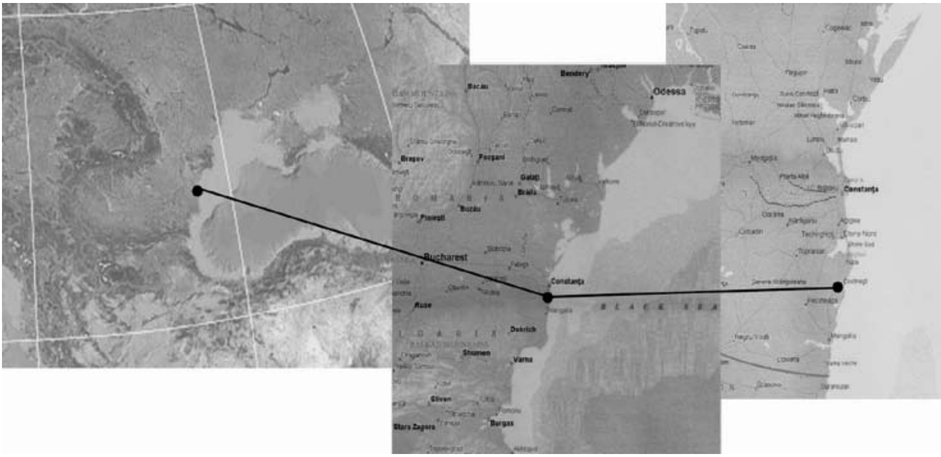

Fig. 1. Location of the studied region

ENVIRONMENTS

Lithology. Rocky shore is developed on Sarmatian limestones. These limestones are oolite siliciclastic and shelly siliclastic type and they are organised in quasi-horizontal layers (Fig. 2).

Rock mass properties are characterised by: (i) a porous cavernous general character, with numerous cavities with very different sizes, from a few millimetres to 30–40 cm; (ii) the presence of many linear discontinuities, with a rich network of joints and fractures oriented parallel to the outer edge of benches, and also orientated transversal, or oblique, forming a disordered network of joints. This geological specific has a dominant role in controlling the processes that affect the benches and generate shore platform.

Fig. 2. Structure of the rocky shore

Sea level. In the west coast of the Black Sea tides are mixed and they have maximum amplitude of 0.20 m. The annual variations of the Black Sea level present significant seasonal oscillations[17]: in winter the levels are moderate but with high-amplitude oscillations; in spring the levels are at highest, with moderate oscillations; in summer the levels are low with moderate oscillations; during fall the lowest values are recorded (Fig. 3*a*).

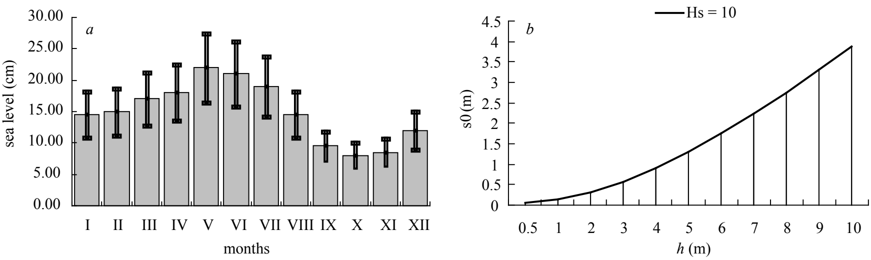

Fig. 3. Sea level variations recorded by the tide graph from Constanta – average multi-annual values 1933–2009 (*a*); level super-ascensions due to east wind at 10 m isobaths (*b*)

Against this recorded general background of tide gauge from Constanta local oscillations caused by wind appear episodically. Level super-ascensions due to winds from the east can reach a maximum of 4 m at the 10 m isobath (Fig. 3*b*) and 3 m at water line[18]. In periods of maximum level growth all benches are completely flooded. The multi-annual average (for the period 1933 to 2009) of rocky shoreline flooding duration is 12 days per year for higher bench, 38 days per year for medium bench and 120 days per year for lower bench. Flooding process is discontinuous in time. In the last 4 years (2006–2010) only 14 days have been recorded for entirely flooding of the three benches. During periods of flooding cracks and cavities are filled with sea water. Then an intense evaporation of water follows during the periods of emersions, generating specific weathering processes.

Weather conditions. Synthetic data have been used to characterise the climatic conditions in the studied region[19–21]. Mean value of solar radiation is 132.5 kcal/cm^2. Average annual air temperature is 11.7ºC, with relatively small variations of seasonal averages: winter – 3.5ºC, spring – 10.1ºC, summer – 21.2ºC, and autumn – 13.1ºC. The average annual number of days with frost (calculated for the period 1961–2000) is 62.8 days, most of them in December (14.4 days), January (20 days) and February (15 days). During the analysed period (2006–2010) 28 days with freesing of water on rocky shore in the winters of 2006 and 2010 have been recorded. Precipitation has an annual average of 406.9 mm and they are distributed relatively uniform during the year: winter – 93.2 mm, spring – 99.6 mm, summer – 105.3 mm, autumn – 108.8 mm. Annual average wind speed is 4–6 m/s with highest frequency from the northern, north-eastern and eastern sectors (Fig. 4*a*). Wind accelerations are specific for winter and autumn periods, the lowest frequency occurring in summer[20] (Fig. 4*b*).

Wave conditions. Most waves are caused by winds from east and north-east, plus by the south-east winds (Fig. 4*c*). During storms the waves wash entirely the rocky shore, causing abrasion and sheet flood.

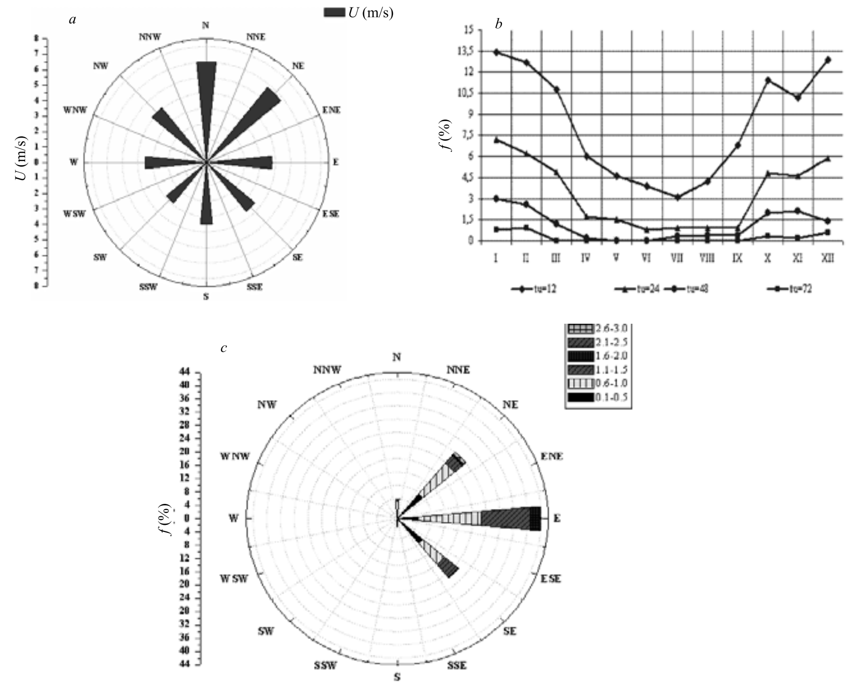

Fig. 4. Weather conditions: wind rose (*a*); monthly frequency of wind accelerations (*b*); frequency of wave birth on different high levels from different directions (*c*)

General geomorphological context. The cape Schitu is the ending of South Dobrudja tableland towards Black Sea (Fig. 5). General geomorphologic profile made between the cliff edge and –30 m isobath (Fig. 6) expresses the following sequence of coastal landforms: (i) loess cliff cut between 20–25 m and 3–5 m above mean sea level; (ii) rocky shore developed on limestones between 3–5 m and –2 ... –4 m, (iii) two submerged levels developed on inner shelf from –15 m and –25 m, up to 5 km to sea, –5 m isobath is located at a distance of 0.325 km, and the –10 m one, at 0.625 km. This profile that surveys the contact between South Dobrudja tableland and inner shelf indicates a very low extensions – only 250 m – of the active shore. It is obviously a land formed in the last 1800–2000 years. At the same time bottom topography is favourable to the attack of the high-energy waves coming from the east upon the shore.

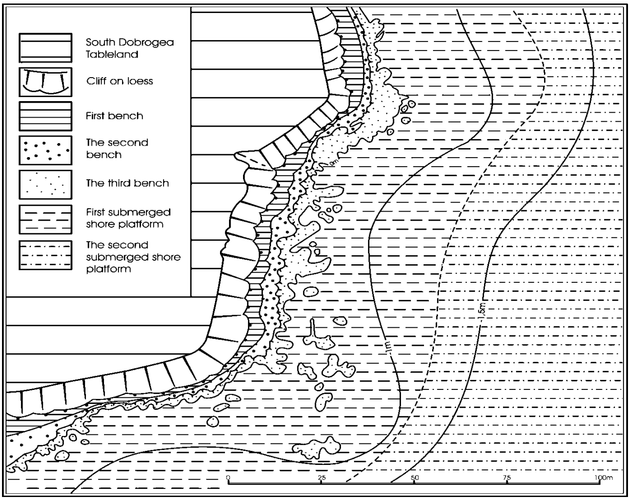

Fig. 5. General geomorphologic map at the cape Schitu

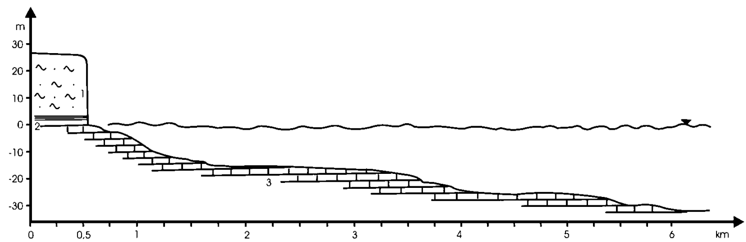

Fig. 6. General geomorphologic profile from the cape Schitu to inner shelf: 1 – loess; 2 – clay; 3 – Sarmatian limestone

Morphology. Relief developed on limestone under the loess cliffs at the cape Schitu is composed of a succession of 3 benches, continued with the shore platform (Fig.7*a*). Upper bench (B_1) is presented as a well marked step at 3–4 m above mean sea level and it has the smallest extension (approx. 380 m²). Medium bench (B_2) has an extension of approx. 3200 m² at 1.8–2.5 m above mean sea level. Lower bench (B_3) has the largest extension (approx. 11000 m²) and is situated at 0.7–1 m above mean sea level. B_3 presents, on its outer edge, B_2 erosion of the ramparts that are similar with the ramparts from other platforms of the shore[6,22–25]. Shore platform is developed from –0.3 m and it continues as an internal step up to –0.8 m (PT_1), under which there is an external step up to –2 m (PT_2). Several witnesses of erosion from B_3 and even from B_2, like ramparts appear on the shore platform. On the shore platform there are blocks of limestone and holes resulted from opening of large cavities and caves in the mass of the rock. All these give a discontinuous character of the shore platform.

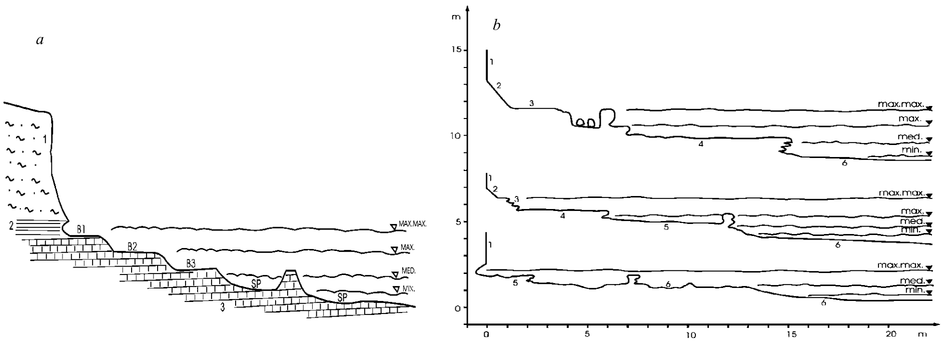

Fig. 7. Standard profile on rocky shore at the cape Schitu: 1 – loess; 2 – clay; 3 – Sarmatian limestone; B_1 (upper bench); B_2 (medium bench); B_3 (lower bench); S.P. (shore platform) (a); types of cross-sections on rocky shore at the cape Schitu: 1 – cliff; 2 – slope; 3 – higher bench; 4 – medium bench; 5 – lower bench; 6 – shore platform (*b*)

Several types of cross-sections can be observed against the synoptic profile (Fig.7*b*): (i) profile with normal extension of the 3 benches under which the shore platform exists (Fig. 7*b*), (ii) profile with a small extension of the upper bench but with the other parts well developed (Fig. 7*b*), and (iii) profile with a broad development of the lower sequence (Fig. 7*c*).

The benches appear as stage more or less well marked in relief with horizontal surface and structural character, overlapping on limestone accumulation plans. Bench contacts can be abrupt transitions, gradual transitions with secondary steps or areas of degradation with blocks and boulders (Fig. 8).

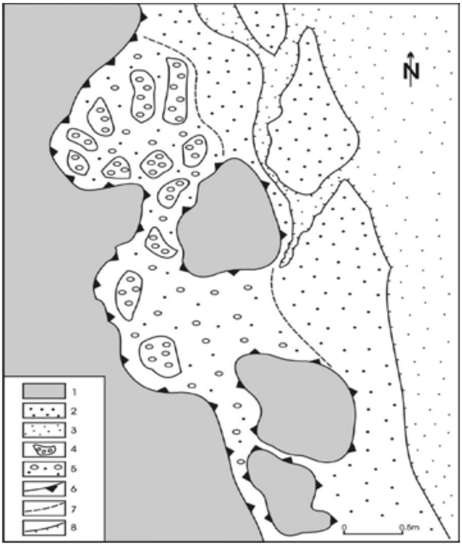

Fig. 8. Detailed geomorphologic sketch of the contact between the upper bench (B_1) and medium bench (B_2): 1 – upper bench; 2 – medium bench, 3 – lower bench; 4 – blocks and boulders; 5 – accumulation of debris resulting from weathering; 6 – outer edge of B_1; 7 – limit of sector with rock crumbs; 8 – outer edge of B_2

LITTORAL EROSION PROCESSES

In the environmental conditions presented above on benches and shore platform weathering processes, abrasion, sheet flood are present. All these processes are discontinuous in time and space.

In periods of low wave energy activity chemical and physical weathering processes prevail, being favoured by the porous nature of cavernous limestone. It is a typical cavernous weathering[26]. Rock cavities are open and modelled resulting in a wide range of coastal microforms specific to karsts.

In periods of intensive wave energy, sheet wash and abrasion processes prevail. These processes are carried out in two directions: (i) disruption by abrasion and vertical fragmentation of the benches resulting a retreat of their outer edge, and (ii) reducing the bench surface by horizontal fragmentation.

Disruption by abrasion processes affects especially the benches B_3 and B_2, forming notches up to 1.3 m deep and of 0.5–1 m high on their bases. Withdrawal of the benches outer edge is done in three phases (Fig. 9*a*): (i) primary undermining of the bench edge by abrasion, with the formation of notch and expansion of vertical cracks (joints), (ii) extension of notches and cracks, (iii) detachment and collapse of blocks. The intensity of these processes is currently limited. Thus, between 2006–2010, only a separation and collapse of two blocks with a total volume of 1.2 m^3 have occurred on an area of 15 000 m^2.

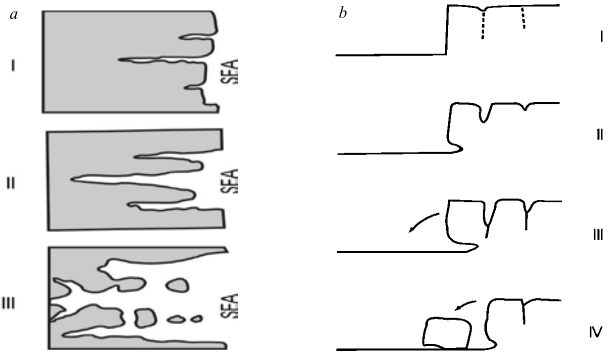

Fig. 9. Disruption of the outer edge of B_2 and B_3 benches (*a*); vertical fragmentation of the benches (*b*)

Bench vertical fragmentation process takes place on the alignment of joints oriented on the main dominant wave direction in several phases (Fig. 9*b*). In the first phase the joints are enlarged on their main direction. In phase two bays are formed that extend deep and wide. In the third phase the bench is destroyed and the process continues with undermining the upper bench. A fragmented landscape results, with witnesses from all benches (Fig. 10). Current intensity of these processes is slow. Bays with a depth of 6–8 m and width at the mouth of 3–5 m remained unchanged over the 4 years of monitoring that we carried out.

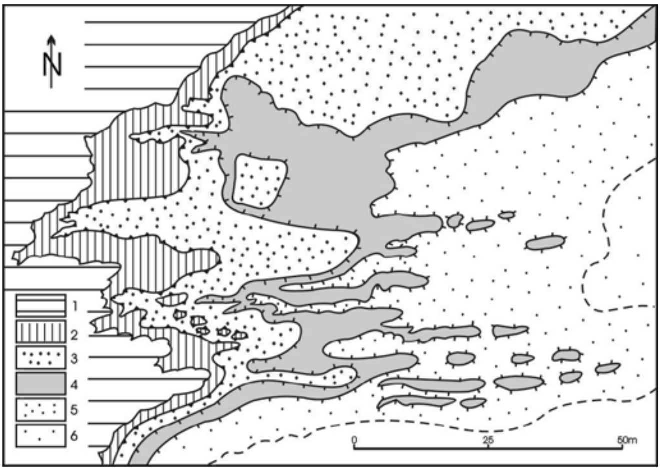

Fig. 10. Geomorphologic map of the central part of the rocky shore at the cape Schitu: 1 – South Dobrudja tableland; 2 – upper bench (B_1); 3 – medium bench (B_2); 4 – lower bench (B_3); 5 – high-shore platform (PT_1); 6 – low-shore platform (PT_2)

CONCLUSIONS

In the specific environmental conditions of the Western Black Sea shore, on porous-cavernous limestone that outcrop up to 3.5–5 m a.s.l., a rocky shore has been formed characterised by:

- a sequence of 3 benches continued with a submerged platform. Submerged coastal platform and lower bench (B_3) have a maximum extension, being under the continuous action of sea waves. Bench with median position (B_2) is affected by the storm waves wash the weathering products carried in most of the year. Upper bench (B_1) is affected only by the highest and most violent waves;
- present-day processes that affect the rocky terrain are: weathering, abrasion, sheet flood. Weathering is favoured by cavernous fractured porous nature of limestone. Abrasion acts effectively on the ground prepared by weathering. Sheet wash moves away the surface rock debris, preparing the ground for further weathering;
- performance of current processes is closely related to wave activity in general and storm waves in particular. In stormy periods all geomorphologic processes are accelerated due to abrasion and sheet wash. In 4-year period of monitoring the studied area all processes have been slow;
- the landscape is evolving into present day by: (i) abrasive attack forming notches and undermining the benches, (ii) vertical attack by deepening and developing vertical fissures and fractures, (iii) longitudinal attack with fragmentation of the benches;
- all processes are favoured by cavernous fractured porous nature of limestone and they take place discontinuously in time, short periods (2 ... 3 days) of intense processes being followed by long periods of stability.

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