

**THE SARMATIAN CARBONATE TEMPESTITES FROM  
KALIAKRA CAPE (NE BULGARIA)  
– A REAL RISK TO ITS STABILITY**

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**Abstract**

This study presents the results of 227 tested specimens of the Sarmatian age taken from the rock complexes that build Kaliakra Cape: these are carbonate tempestites, as well as the limestones from the Karvuna Formation lying above them. Sedimentological and geotechnical tests have been performed.

The micropetrographic analysis of the carbonate tempestites is also presented, including slightly consolidated conglomerates and hard limestones between them. It was found that the matrix of conglomerates is composed mainly of micritic peloids. Their size is about and below 0.2 mm. No cement is found, which is why the porosity is significant. Peloidal limestone has low values of bulk density – an average value of 1.95 g/cm<sup>3</sup>. There is a significant difference in compressive strength and velocity of seismic waves obtained in both directions – crosswise and parallel to the layering.

Studies of collapses in the caves in the area show that they occur in friable peloidal limestones, and the disturbances follow the formation. This is also confirmed by the laboratory tests of samples showing lower strength indicators, namely in the direction of the layering. The data thus obtained provide valuable information on the geotechnical parameters of the main varieties in which the

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rock deformations are developed, which can be used in the analysis of slope stability.

**Key words:** carbonate tempestites, physico-mechanical properties, Sarmatian, Kaliakra Cape, NE Bulgaria

**Introduction.** Kaliakra Cape (NE Bulgaria) has a complex structure due to the presence and action of many faults [1–4]. The front part of the cape is 57 m above sea level. At the base, the Bessarabian (Sarmatian) limestones with *Nubeculaia novorossica* with a thickness of 16 m [5] are revealed, which are referred to the Odartsi Formation [6]. Above them are several stromatolite-thrombolite horizons (also belonging to the Odartsi Formation) with a total thickness of about 9 m, of which only the upper two horizons are described [7]. An 11-meter interval composed of carbonate tempestites was studied above [8]. Limestones (about 14 m) are observed above them, which have not been collected due to the steep and unstable nature of the cliff. In the upper part of the section a second interval (at the memorial plaque of Admiral Ushakov), composed of carbonate tempestites, with a thickness of 3 m [9] was studied. They are covered by the Khersonian (Sarmatian) *Mactra* limestones, which are attributed to the Karvuna Formation [6]. The studied tempestites accumulate in the time interval early Bessarabian-middle Khersonian, or between the limestones of the Odartsi Formation and the limestones of the Karvuna Formation (Fig. 1a, red rectangle). The carbonate tempestites (storm sediments) are the subject of this study. The main goal is to make a geotechnical characterization of the rock massif in the vicinity of Kaliakra Cape, including determining the main physical and mechanical properties of the rock complexes that build the cape. The cape is affected by rock deformations, mainly rocktoppling, and in the lower parts – by rockfalls.

**Material and methodology.** A micropetrographic analysis of 10 thin sections was applied for the sedimentological examination of the carbonate tempestites from the interval at the memorial plaque of Admiral Ushakov. The observations were made with a Zeiss Axioscope 40 transmission light-microscope, and the microphotographs with a ProgRes GT3 digital camera. The following physico-mechanical parameters were determined: compressive strength, tensile strength, and point load index. The test specimens were sonicated with an ultrasonic apparatus Mark III of James Instruments to determine the velocities of the seismic waves  $V_p$  and  $V_s$ . The tests were performed in the natural and water-saturated conditions of the test specimens. The compressive and tensile strengths were determined by using a press with a range of 0 to 600 kN. Tensile strength was obtained by the so-called method of “repeated cutting of rock sample beams” [11, 12]. It is determined by the expression  $\sigma_t = P/A$  [MPa], where  $P$  is the maximum destructive force and  $A$  is the cross-sectional area of the test specimen. Additionally, the strength of the point load has been determined. The method consists of loading to failure, by applying point loading, to rock samples of regular (cu-



Fig. 1. *a* – Location of research area and summary stratigraphic column of the vicinities of Kaliakra Cape [10]; *b* – Lithostratigraphic column of the interval composed of carbonate tempestites at the plaque of Admiral Ushakov; *c* – Close view of the boundary between carbonate tempestites and *Maetra* limestone (Karvuna Formation)

bic or cylindrical) and irregular shape. The device used UTR-0580 is made of a load frame with a capacity of 50 kN with a hydraulic loading mechanism activated by a jack. After the test, the uncorrected point load strength index  $I_s$  is determined, which depends on the size  $D$ . A corrected point load strength index ( $I_{s(50)} = F \times I_s$ ) is calculated, which in turn is recalculated for size  $D = 50$  mm. The factor correcting the sample size is determined by the equivalent diameter  $D_e$ .

**Description of the studied interval. Package 1.** About 2 m of the conglomerate pebbles in a grained matrix (Fig. 1*b*). Most of the conglomerate clasts

are rounded, less often semi-rounded. They vary in size from  $1 \times 1$  to  $30 \times 15$  cm. Most of them are composed of light beige limestones. Single clasts are black in colour and do not exceed  $5 \times 4$  cm. There is no sorting and in some places the matrix has a larger quantity and these are the so-called “unsaturated conglomerates”. Low-angle hummocky cross-stratification is observed in the uppermost 20 cm of the package.

**Package 2.** Total thickness is 1 m (Fig. 1b). A harder limestone with a thickness of 20 cm occurs at the base; two layers with a thickness of about 2–3 cm are traced in it, in which small rounded clasts with a maximum size of  $1.0 \times 0.5$  cm are observed. It is followed by a hard limestone, with a positive relief and a thickness of 3 cm. Next is a friable limestone with a negative relief and a thickness of 7 cm, there are rounded clasts with a maximum size of  $1 \times 1$  cm, and also black, more angular lithoclasts. Above this layer, a hard limestone with positive relief and thickness of 2 cm is present; next are: a limestone with a total thickness of 40 cm, at its base there are single rounded clasts; hard fine-layered limestone with a positive relief and a total thickness of 25 cm; friable (softer) limestone with a negative relief and a thickness of 5 cm. The samples taken from the friable limestone were referred to sample no. 1, and those from the hard limestone – to sample no. 2.

**Package 3.** *Maetra* limestones (Karvuna Formation [6]) (Fig. 1b, c) – up to the last outcrops of the cape. They contain large quantities of *Maetra bulgarica* and are highly karstified. The samples taken from these limestones are referred to sample no. 3.

**Micropetrographic examination.** The studied interval is composed of carbonate tempestites (conglomerates and hard limestones). Under a microscope, it was found that the matrix of the conglomerates is composed mainly of micrite peloids (Fig. 2a). Their size is about and below 0.2 mm and well-rounded micrite clasts with sizes from 0.2 to 0.5 mm are observed. There are single superficial ooids and cortoids. Rare bivalve fragments (less than 1.0 mm in size) are present, which are almost completely dissolved. No cement is observed, due to which the porosity is significant (see geotechnical data). The light beige conglomerate clasts and grains are composed mainly of micrite limestones. Black conglomerate pebbles and grains are composed of very small peloids located in a dark micritic matrix. In hard limestones, micrite peloids also predominate (Fig. 2b), with sizes varying from about and slightly below 0.2 mm. They have a predominantly spheroidal shape. Single ostracod fragments and shells are found. These limestones are cemented and their porosity is lower (see geotechnical data). There are two types of cement: blocky and poikilotopic.

**Geotechnical investigation.** A total of 227 test specimens were examined, 67 of which were from sample no. 1, 71 from sample no. 2 and 89 from sample no. 3. The results are presented in tabular form (Tables 1 and 2). The specimens from sample no. 1 were taken from different parts of the slope between the

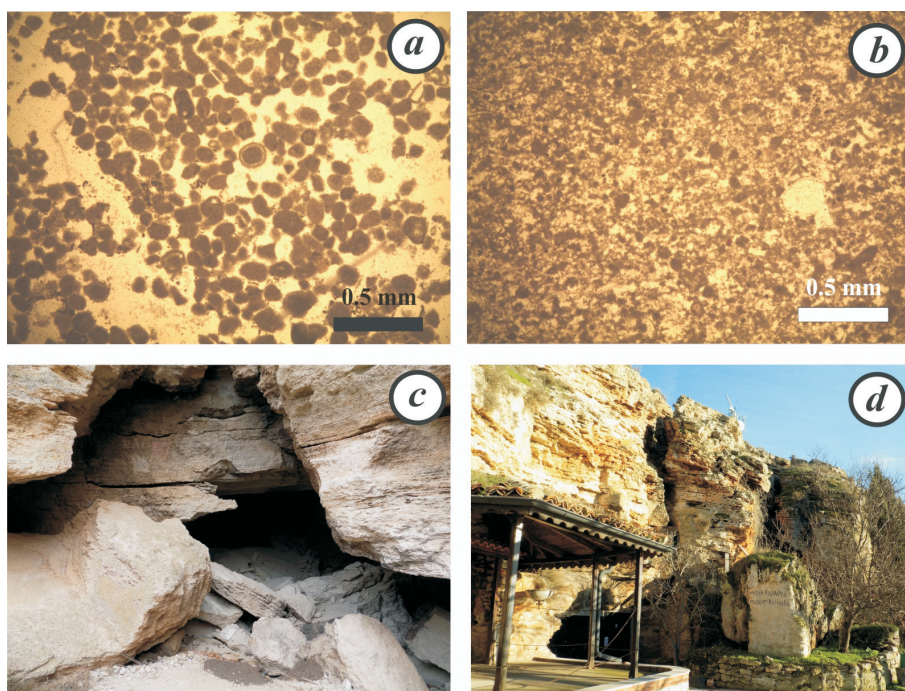


Fig. 2. *a* – Microphotograph of the peloidal matrix of the carbonate conglomerate (Package 1), plane polarized light; *b* – Microphotograph of the peloidal limestone (Package 2), plane polarized light; *c* – Demolishing the ceiling of the Tamnata Peshtera (“the Dark Cave”) occurred on 13 September 2018; *d* – Historical Museum, Kaliakra Cape and the dangerous rock slope close to it

Historical Museum and the memorial plaque of Admiral Ushakov, incl. and from the cave called Tamnata Peshtera (“the Dark Cave”) (Fig. 2*c*), located next to the Historical Museum (Fig. 2*d*). Sample no. 2 was taken from the thin layers at the memorial plaque of Admiral Ushakov, and the specimens from the Karvuna Formation – sample no. 3 were taken from different sections of the slope at the edge of the rock crown above the Historical Museum or south of it. The strength indicators are tested in two directions – in the direction of layering and across it. Water-saturated test specimens were tested after immersing in water more than 72 hours.

**Package 2** – peloidal limestone (sample no. 1). It is most characterized by a strong variation in bulk density – from 1.79 to 2.20 g/cm<sup>3</sup>, with an average of 1.95 g/cm<sup>3</sup>. High values of the mineral density are typical – on average 2.83 g/cm<sup>3</sup>, high porosity – from 6.9 to 35.4% and high water absorption – from 6.9 to 20.7%. There is a significant difference in the velocities of the seismic waves obtained in both directions – crosswise and in the direction of layering. At water saturation, a significant reduction of 2 to 3 times the compressive strength (crosswise and longitudinal to the layering), as well as the transverse waves Vs in the

T a b l e 1

Average values of physical parameters of rock samples taken at Kaliakra Cape area

Sample no.	Bulk density $\rho_n$ g/cm <sup>3</sup>	Mineral density $\rho_s$ g/cm <sup>3</sup>	Porosity n %	Water absorption $W_{abs}$ %
1	1.95	2.83	26.09	14.19
2	2.33	2.76	11.97	5.31
3	2.41	2.74	7.08	3.07

tests performed across the layering (Table 2).

**Package 2** – hard limestone (sample no. 2). The bulk density of this layer, located among the peloid limestones, varies from 1.99 to 2.52 g/cm<sup>3</sup>, average value is 2.33 g/cm<sup>3</sup>. The mineral density varies widely from 2.69 to 2.95 g/cm<sup>3</sup> (7 tests), averaging 2.76 g/cm<sup>3</sup>. The porosity is slightly lower – it varies from 7.1 to 19.7%. The water absorption is from 2.9 to 10.3%. There is a significant difference in the propagation of seismic waves between the values obtained crosswise and in the direction of layering. Lower indicators are established in the direction of the layering.

**Package 3** – *Mactra* limestones, Karvuna Formation (sample no. 3). The

T a b l e 2

Average values of strength parameters of rock samples taken at Kaliakra Cape area  
in: a) dry conditions, b) saturated conditions

Sample no.	Unconfined compressive strength	Tensile strength	Compressive wave velocity	Shear wave velocity	Poisson ratio	Point load strength index
	UCS, MPa	$\sigma_t$ MPa	$V_P$ m/s	$V_S$ m/s	$\mu$	$I_{s(50)}$ MPa
a) dry samples						
1 $\perp$	16.36	1.32	2963	1205	0.401	0.94
1 $\parallel$	10.11	0.93	3434	1321	0.413	0.77
2 $\perp$	17.44	2.03	3864	1543	0.405	0.96
2 $\parallel$	15.29	0.73	2659	753	0.456	0.76
3 $\perp$	22.73	4.30	4311	1604	0.420	1.82
3 $\parallel$	38.32	2.49	4929	2054	0.395	1.51
b) saturated samples						
1 $\perp$	11.22	1.72	2800	1090	0.411	0.62
1 $\parallel$	7.29	2.49	3592	1381	0.413	0.26
2 $\perp$	13.70	0.57	4039	1378	0.434	0.18
2 $\parallel$	10.30	0.74	2485	821	0.439	0.21
3 $\perp$	22.75	2.31	4315	1485	0.433	1.05
3 $\parallel$	37.13	1.70	4955	2168	0.382	0.93

Note: symbol  $\perp$  means crosswise to the layering,  $\parallel$  means in direction to the layering

average value of the bulk density of these limestones is  $2.41 \text{ g/cm}^3$ , which is in the usual values for this variety [13,14]. The higher strength characteristics of the rocks are found in the direction of layering. Seismic wave velocities also show higher values in this direction (Table 2). It should be taken into account that large variations in properties are found due to the high karstification of these limestones.

**Discussion.** The initial study of rock samples shows that peloidal limestone (sample no. 1) has the lower values of physico-mechanical properties in comparison with the other two rock types. Laboratory tests of their strength indicators show values close to soft rock varieties. A minimum value of the bulk density of  $1.79 \text{ g/cm}^3$  and a maximum porosity of 35.4% is established. This material is soft, friable, and for this reason niches (caves) have been carved in it, which were used for various purposes in the Middle Ages, as there are examples in many places in the region [15]. Just here periodic problems related to slope stability, such as rocktopples or rockfalls, appear. A clear anisotropy of the strength parameters of the test specimens was found between the two spatial directions – crosswise and in direction to layering. Studies of collapses in the caves in the area show that they occur in friable peloidal limestones (sample no. 1), and the disturbances follow the formation. This is also confirmed by the laboratory tests of samples no. 1 and no. 2, showing destruction in the direction of the formation. This is clearly evident during the collapse of the arch in the Dark Cave, which occurred on September 13, 2018, which can be seen in Fig. 2c. In case of water saturation, there is a clear decrease in the strength indicators, which increases the risk of instability. During the laboratory tests it was found that the most significant is the decrease in the tests for compressive strength, tensile strength and point load index in test specimens no. 1 and no. 2.

Although hard limestone layers (sample no. 2) appear very strong on site (e.g. by a hammer blow), laboratory geotechnical tests show lower compressive strength, tensile strength and point load values. The worsened properties of these limestone layers are also confirmed by the Poisson's ratio (Table 2), which shows the worst deteriorating properties are in the direction of layering in dry samples, where the average value is  $\mu = 0.456$ . This is probably due to the presence of the thin microlayers, which help the samples to disintegrate quickly during laboratory tests.

The data thus obtained provide valuable information on the engineering geological parameters of the main varieties in which the rock deformations are developed. They can be used in the analysis of slope stability, give wider opportunities for application of different strength models. Similar approaches have been used in practice at other sites in the country [16–18], which can be successfully used for the region of Kaliakra Cape.

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