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THE FIRST FINDINGS ON THE ORIGIN OF ALVEOLAR DISINTEGRATION AT THE WESTERN SHORES OF GELİBOLU PENINSULA

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ABSTRACT.- Various specific disintegration types, characterized by alveolar disintegration, were observed in Cape Büyükkemikli, at the northern side of Suvla Bay and western side of Gelibolu Peninsula. Field observations and analytical data indicate that alveolar disintegration, which developed over Oligocene sandstones, is dominant at carbonate-cemented sandstones, with fine to medium texture and rich in biotite and plagioclase. Alveolisation ideally develops over the surfaces of sandstone layers, which are dipping towards the sea with an angle of 33-40°. Furthermore, it is understood that disintegraton over sandstone is related to micropore and microfracture zones and supported by the biogenic origined formations along the intratidal zone. Salt disintegration is effective within the wave wash zone as a result of evaporation conditions during the periods of May-June. Besides, ellipsoidal disintegration cells and tafoni formations are abundant over frontal walls, which receive the impact of south sector winds with right angle. The edges of polygonal fracture zones, hardened by iron oxide infillings delimits alveolisation.

Key words: Alveol, salt disintegration, biogenic disintegration, intratidal zone, Gelibolu Peninsula.

INTRODUCTION

Alveolar disintegration is a technical term used for honeycomb weathering patterns developed especially over sandstones, depending on wind erosion, exfoliation, freezing-thawing, salt disintegration and precipitation. This specific disintegration process, dominated over sandstones, is represented by honeycomb weathering pores and their 1-m or larger equivalents which are known as tafoni formations, formed under the control of geomorpological, geological, climatological and especially at the shore regions by hydrodynamical and biological factors. The first observations related to their formations were done by Darwin (1839) and Dana (1849) in Australia, and a variety of definitions such as honeycomb weathering, stone lattice rather than alveolar disintegration were made. The definitions and theories were studied in detail by Mustoe (1982), Turkington and Phillips (2004) and Turkington and Paradise (2005).

According to previous studies, alveolar disintegration may develop over different rock types such as diorite, tuff, agglomerate and sandstone, under different climatic conditions. There are so many examples of alveolar disintegration over sandstone as it is the most frequent and important (Scherber, 1927; Bouchart, 1930; Rondeau, 1965; Mustoe, 1982; Kelletat, 1980; Mellor el al., 1997; McBride and Picard, 2004; Turkington and Paradise, 2005). The most accepted idea so far is that the alveolisation occurs on the control of salt disintegration (Evans, 1970; Bradley et al, 1978; Mc Greevy, 1985; Cooke et al, 1993). Yet there is debate over the origin of alveolar disintegration, there is still no study on Turkish shores related to this subject.

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At this study, alveolar disintegration observed at the Cape Büyükkemikli, located at the northern side of the Suvla Bay and western side of the Gelibolu Peninsula, were considered with a multidisciplinary approach. Alveols and tafonis at the alveolar disintegration zones (Figure 1) over

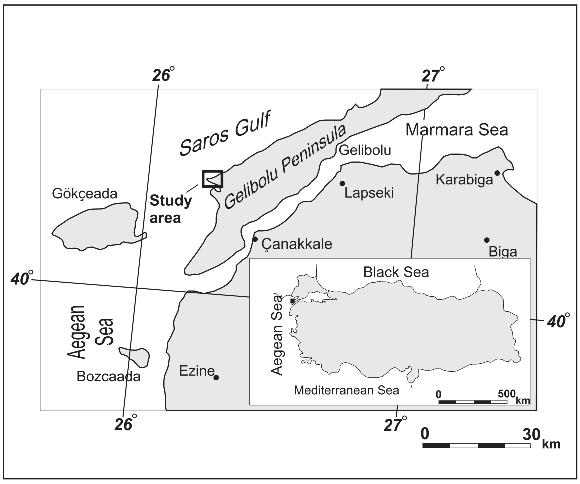


Figure 1- Location map of study area

Oligocene sandstones cover a wide region from the shore line to 15-m-altitude. Over the region, where alveols different in shape and size developed, the morphometric properties of alveols and tafonis, petrographical features of sandstones, and the systematics of joint and fractures over sandstones were studied. Besides, it was attempted to determine the colonial features of macroendolitic and surface fauna, which have settled into alveol and tafoni pores, considering bioerosion arising from the relation between the microscopic epilite and endolites as the primary producers of bioerosional community. The study was concentrated on the relation of alveolar disintegration to sea water and salt brine, the impact of climatic components over the sandstone disintegration, the density of cyanobacteria over sandstone, and the effect of various physical and chemical factors such as temperature, pH and salinity over the disintegration process. The study includes the preliminary results of ongoing research about the geomorphological, petrographical, structural, biological and sea water/salt brine which are effective on the disintegration developing on the study area.

LOCAL GEOLOGICAL AND GEOMORPHOLOGICAL FEATURES OF STUDY AREA

Eocene-Oligocene units have been distributed over the study area, geology of which was previously studied by Önem (1974) and Sümengen and Terlemez (1991) and the surrounding area. Sandstones, having wide outcrops in the study area with alveolar disintegration development, were evaluated within the Korudağ formation by Kellog (1973), and are impure yellow colored, laminated, with low to medium thickness. Strike of layers is generally N50E, and dip is 38-50 SE (Plate I, Figure 1). Orthogonal and polygonal fracture systems, in which resistant crusts were developed due to calcite infillings and especially iron aggregation, are generally NE-SW and NW-SE directed (Plate I, Figure 2). Sandstone overlies massive silty-mudstone, described as Keşan formation by Gökçen (1967) and Kellog (1973), conformably. The geomorphology of study area is generally represented by low plateaus slightly descending generally towards western and southwestern direction, and broad valleys developed over clayey and silty units and small bays. Cape Büyükkemikli, composed of mainly sandstones, forms an extension of the plateau, which descends from Karakol Mountain (141 m) at the northwestern part of region towards southwestern direction and mainly composed by Upper Eocene and Oligocene sandstones, limestones, and siltstones. NW trending hillsides of NE-SW directed plateau have slopes with 20°-90°. Together with this, general slope arises 50°.

In the area, steep-cliff type shore is dominant, and small shores with siltstone ovarlain were developed. Wave action is effective over the layer as their slopes are towards southeastern direction in Cape Büyükkemikli. Thus, abrasion platforms are widely distributed in front of cliffs.

METHOD OF STUDY

Sandstones with and without alveolar disintegration were sampled to introduce driving factors for the alveolar disintegration and its origin. Standart thin sections of samples were prepared and these were classified according to Folk (1970) classification. By studying EDS (Energy Dispersive X-Ray Spectroscopy), and SEM (Scanning Electron Microscopy) analyses, mineralogical composition, cement type and abundance, and element composition effective on disintegration were studied. Furthermore, the systematic and geometry of fractures over the sandstones in the study area were examined in 22 different sampling sites. The biological species observed in the shoreline have been grouped based on their act on the shoreline morphology, and their impacts on disintegration were evaluated. The impact of sea water composition on disintegration was evaluated by the analysis of ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectroscopy) from sea water samples.

Table 1- Geochemical analysis results of seawater from the section of alveolar disintegration in the study area

Parameter	Value
T(˚C)	18.3
EC (µS/cm)	48300
pH	8.9
TDS (mg/kg)	29700
Na^{+} (mg/kg)	6915.7
K^{+} (mg/kg)	680.4
Ca^{++} (mg/kg)	403.8
Mg^{++} (mg/kg)	1095.3
Cl^{-} (mg/kg)	15862.7
SO_4^{--} (mg/kg)	2469.7

PRELIMINARY FINDINGS

Preliminary findings obtained from the study, which presents the alveolar disintegration at the study area and its promoting factors are described below

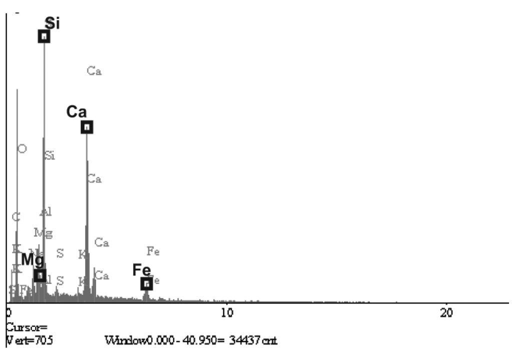
Impact of petrographic features of sandstones on alveolar disintegration

Sandstone, over which alveolar disintegration has developed, are carbonate-cemented, yellowish quartzarenite and subgreywacke, with clay and chlorite matrix, according to Folk (1970) classification. They have abundant quartz and plagioclase with minor amounts of biotite and muscovite and show a fine-medium texture with abundant serpentine, chert and metamorphic rock fragments. The impact of rock over the disintegration especially depends on its clay, plagioclase and biotite mineral abundances. As it can be concluded from the comparison of thin sections of sandstone samples with and without alveolisation, the increase of plagioclase and biotite abundance in sandstone promotes the development of alveolar disintegration. Sandstone with dominant alveolar disintegration is carbonate-cemented, fine-grained and named as quartzarenite. Rock is rich in plagioclase and has granular texture (Plate I, Figure 3). In sandstones with no alveolar disintegration, rounded or subrounded quartz grains with undulose extinction are abundant (Plate I, Figure 4). Micas are composed of muscovite cement is carbonate and rock is named as micaceous subgreywacke.

Development of alveolar disintegration is expecially related with mineral grains in sandstones and carbonate cement binding rock fragments. This situation can also be concluded from EDS analysis of rock samples. Alveolar disintegration is abundant on sandstones with high Ca^{++} content (Table 2a). Results of elemental analysis indicate the existence of iron and magnesium which are reduceing factors of dissolution. Thus in sandstones with minor Ca^{++} and abundant Mg^{++} ve Fe^{++}, the alveolisation either is stopped or is very limited (Table 2b).

When SEM images of rock samples were studied, microporosity and microfracture compo-

Table 2-a-b EPS analysis of rock samples



Elt.	Line	Intensity (c/s)	Conc		
C	Ka	8.42	0.000	wt.%	
O	Ka	61.55	0.000	wt.%	
Na	Ka	5.03	2.121	wt.%	
Mg	Ka	11.65	3.644	wt.%	
Al	Ka	26.15	7.454	wt.%	
Si	Ka	121.04	34.978	wt.%	
S	Ka	4.44	1.480	wt.%	
K	Ka	2.84	0.875	wt.%	
Ca	Ka	126.33	40.589	wt.%	
Fe	Ka	12.30	8.859	wt.%	
			100.000	wt.%	Total

a

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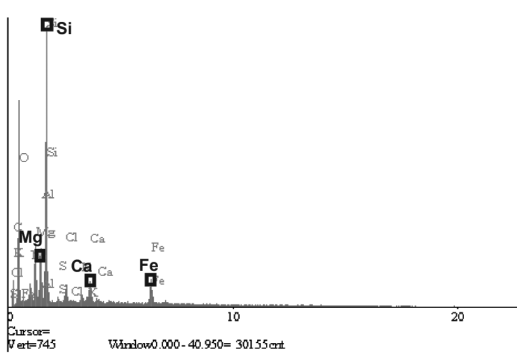

Elt.	Line	Intensity (c/s)	Conc		
C	Ka	2.24	0.000	wt.%	
O	Ka	59.66	0.000	wt.%	
Na	Ka	7.70	3.527	wt.%	
Mg	Ka	23.86	8.529	wt.%	
Al	Ka	25.40	9.019	wt.%	
Si	Ka	130.05	47.651	wt.%	
S	Ka	1.91	0.877	wt.%	
Cl	Ka	13.42	5.883	wt.%	
K	Ka	5.33	2.297	wt.%	
Ca	Ka	15.79	6.935	wt.%	
Fe	Ka	17.98	15.280	wt.%	
			100.000	wt.%	Total

b

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sition of sandstones are seen also effective over the progress. When SEM images of sandstones with dominant alveolar disintegration were examined, it can be observed that rock is rich in microporosity and microfractures (Plate II, Figure 1). Pore size is generally around 50-100 µm and fractures connecting the ellipsoidal pores have length varying between 100-400 µm. Sand stones without alveolisation, on the other hand, are rich in micaceous flakes and have dense carbonate cement (Plate II, Figure 2).

Relation of sea water and brine salt with alveolar disintegration

Relation of alveolar disintegration and crystallized salt produced under the strong evaporation conditions in dry season which creat a pressure on the rock surface and alveol walls is the most accepted theory (Evans, 1970; Bradley et al., 1978; Mc Greevy, 1985; Cooke et al., 1993; Rodriguez-Navarro et al., 1999). Observations in the study area indicate that in the dry season (July-August 2006) sea water spilled with waves can reach upto 5 m height. Indeed, within the mentioned altitudes on the sandstone beds, in the fractures and alveols salt concentration is observed. In order to explain brine salt during the disintegration, some geochemical analyses were carried out.

Results of ICP analysis of the sample recovered from sea water indicate that NaCl known as hygroscopic, is the main component which is transported by waves and may cause important chemical reactions (Andrews et al., 2004). Results of ICP analysis are shown in table I regarding development of alveolar disintegration, the following reaction can be proposed:

$$H_2SO_4 \text{ (aer)} + NaCl \text{ (aer)} \rightarrow HCl \text{ (g)} + NaHSO_4$$

According to this, sea water may affect aerosol formation in various degrees. This condition will create an acidic environment in which disintegration rate increases. In order to prove the reaction, PHREEQC software (Parkhurst and Appello, 1999) is used, by this way, distribution and concentration of chemical substances are determined. Calculations are performed on the basis of physical and chemical parameters such as T (°C), pH and average major element concentrations. As a result, Na^+ ve Cl^- are found as both seperate ions and ion couples (NaCl°) and in that form they are the main component of the reaction which causes the formation of acidic media which results the alveolar disintegration.

Morphological and morphometric features of alveolar disintegration types

In the study area, many samples which are discussed in the literature are observed (rounded, ellipsoidal, turtleback, tendril, tafoni, etc.).

Among the formed structures, ellipsoidal disintegration cells under the control of rounded, subfractured systems are dominant. However, besides the petrographic features of sandstones, different factors such as biogenic impacts, layer slope, salt disintegration, and wind condition and lichen disintegration play important role on the distribution of these structures and their dimensional properties. For this reason, from 4 different locations, selected from a line between sea level and 15 m height of Cape Büyükkemikli, 50 measurements from alveols were made considering the depth, width and length of alveols.

The first two measurement site is located in intratidal zone within a 0-1 m altitude range. At the first of these sites, the measurements from sandstone layers with N60E strike and 37° SE dip has given 15-65 mm length, 15-50 mm width, and 10-45 mm depth. Rounded and ellipsoidal alveols are dominant and at the regions where *Semibalanus balanoides* and *Littorina neritoides* species lived in vast amounts, alveol walls were enlarged and their morphology is deformed as a result of biogenic weathering (Plate II, Figure 3).

Another measurement from the same altitude range is among the sandstone layers with no difference at petrographical or structural features. The major difference here is the increase at the alveol sizes. This difference arise from the density increase at the colonies of Balanus over sandstones and their major nutrients, blue-green algae. At this site, alveol walls and heels vastly consists *Enteromorpha* sp., *Rhizoclonium tortuosum* and *Cladophora sericea* from green algae, *Calotrix confervicola* from blue-green algae as globular forms, and *Amphora* sp. and *Navicula* sp. from diatoms. The measurements indicate that the long axes vary between 3.5-10 cm, whereas width and depth change between 2.5-8 cm and 1.5-6 cm, respectively. Especially, the increase in depth and intergrowth structure (funnel) are morphological features defining locally-formed alveols. However, the major role for such formations is the disintegration impact resulted from the crystallization of salt coming from sea water and deposited into alveol heel and walls during dry season. For this reason, alveol walls get thinner and get perforated or coalesced within time (Plate II, Figures 4 and 5). Marine species such as *Semibalanus balanoides* (Linnaeus, 1758), *Euraphia depressa*, *Euraphia depressa* (Poli, 1795), and *Littorina neritoides* as a member of gastropoda family (Linnaeus, 1758), existing in the varying sizes of alveols, promote alveolisation biogenically, but, deform the morphology of structures (Plate II, Figure 6).

The third measurement point is located on the N70E trending, 30-38 southeast dipping sandstone beds 1-5-m above the sea level. In this section dimensions of the disintegration cells varies as follows: length 2 mm - 8.5 mm, width 1.5 mm- 6 mm and depth 1 mm - 4 mm (Plate III, Figure 1). In the parts where fracture systems intersected and frontal walls directly effected by south west winds; streched disintegration cells are abundant (Plate III, Figure 2). Tafoni formations were observed along the layers having the less than 20 cm thiknesses (Plate III, Figure 3). In addition, near the systematic alveol cavities; atleast one side open, low and thinner walled alveols (tendrils) (Plate III, Figure 4) and so called turtleback alveolar disintegration specimens (Plate IV, Figure 5) were partly observed on the surfaces of sandstones which are being weathered.

The last measurement site selected to evaluate the relation with alveolar disintegration is located in the region at the topmost part of Cape Büyükkemikli (15-h height) where lichen community is available. The results of measurements from sandstone layers with N85E strike and 32° dip, vary as 3.5-1 mm length, 2.5-1 mm width and 3-11 m depth. These rounded and very small alveolar cells were vastly filled with Xantoria species (Plate III, Figure 6).

DISCUSSIONS AND CONCLUSIONS

The results of petrographical and physicochemical analyses may lead the following conclusions.

In the study area, alveolar disintegration is related to the mineralogical composition, texture and presence of carbonate cement and its compaction degree in the sandstones. Alveolar is developed in fine-grained, carbonate-cemented, plagioclase and biotite-rich sandstones.

Elemental composition of sandstone is an important parameter of alveolar disintegration. Alveolar disintegration cannot be developed or is weakly developed in sandstones, which have poor Ca^{++} content and relatively rich Mg^{++} and Fe^{+} content.

The micropore and microfracture content of sandstone are important parameters which are effecting the development of disintegration. On the other hand, polygonal fracture systems delimit the lateral development of the disintegration, because mostly they are hardened by iron oxide infillings.

In the study area, disturbed and wet samples were recovered from the alveolar cavities which are found in the intratidal zones. Within these samples, *Rhizoclonium tortuosum* and *Cladophora sericea* belonging to green algae group are vastly observed, fibrous *Calotrix confervicola* and globular form of *Chorooccus minor*, belonging to blue-green algae and *Amphora* sp. and *Navicula* sp. from diatom group are intensely observed. These algaes are nutrients of some groups of gastropoda. *Enteromorpha* sp. from green algae is vastly observed in wet rocks and their peripherals. The vast occurence of patella and balanus species on the rock surfaces, salt content of the some dried alveols, within which blue-green algaes changed into black and fill the fractures in this small zone, sea organisms leaves their excrements and organic acid, as a result, sandstone are disintegrated. In addition to that, *Semibalanus balanoides*, *Euraphia depressa*, gastropoda *Littorina neritoides* as rock borrowers which are fed on this algae are observed on sandstone surfaces. These organisms have the ability to disintegrate carbonaceous rocks and sandstones, because they have carbonate shells or radula. In the study area, disintegration occurs effectively within 1 m below the sea level.

200 measurements of the alveols show that their dimensions vary between cm to dm. They are generally rounded in form, fractural disintegration cells contain ellipsoidal forms.

Salt disintegration in the dry season between May and August in the study area. As a result of salt disintegration, increase in size of alveols, thinning of alveol walls and connical development of alveols, rapid evaporation of salt solution due to wind. Therefore, in the layers, which are taking wind directly at right angles, the salt disintegration is more effective and sea water composition and especially NaCl couples effect the disintegration. Furthermore, for better understanding of disintegration process, pH, salinity, and excremence of marine organisms and acids with more samples will be evaluated and presented in a future study.

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PLATES

PLATE - I

Figure 1- General view of sandstones on which alveolar disintegration develops, in Cape Büyükkemikli. Impure yellow colored, medium to thick bedded, N50E trending sandstone beds. Sandstone conformably overlies the siltstone succession.

Figure 2- Dipping values of southeast dipping (towards the sea) sandstones varies between 38-50. In the NE-SW and NW-SE trending orthogonal and polygonal fractures, resistant shells have been developed due to iron aggragation. These structures are delimit the alveol formation.

Figure 3- Thin section of sandstone with alveolisation. Rock is fine grained quartzarenite. Rock has quartz and plagioclase coming from source rocks of granite and metamorphic rocks, with minor amounts of biotite and muscovite.

Figure 4- Thin section of sandstone without alveolisation. Rock is subgreywacke, and composed of angular grains of quartz with undulose extinction, rock fragments, plagioclase, muscovite and opaque minerals. Rock is clastic, and carbonate cemented.

PLATE - I

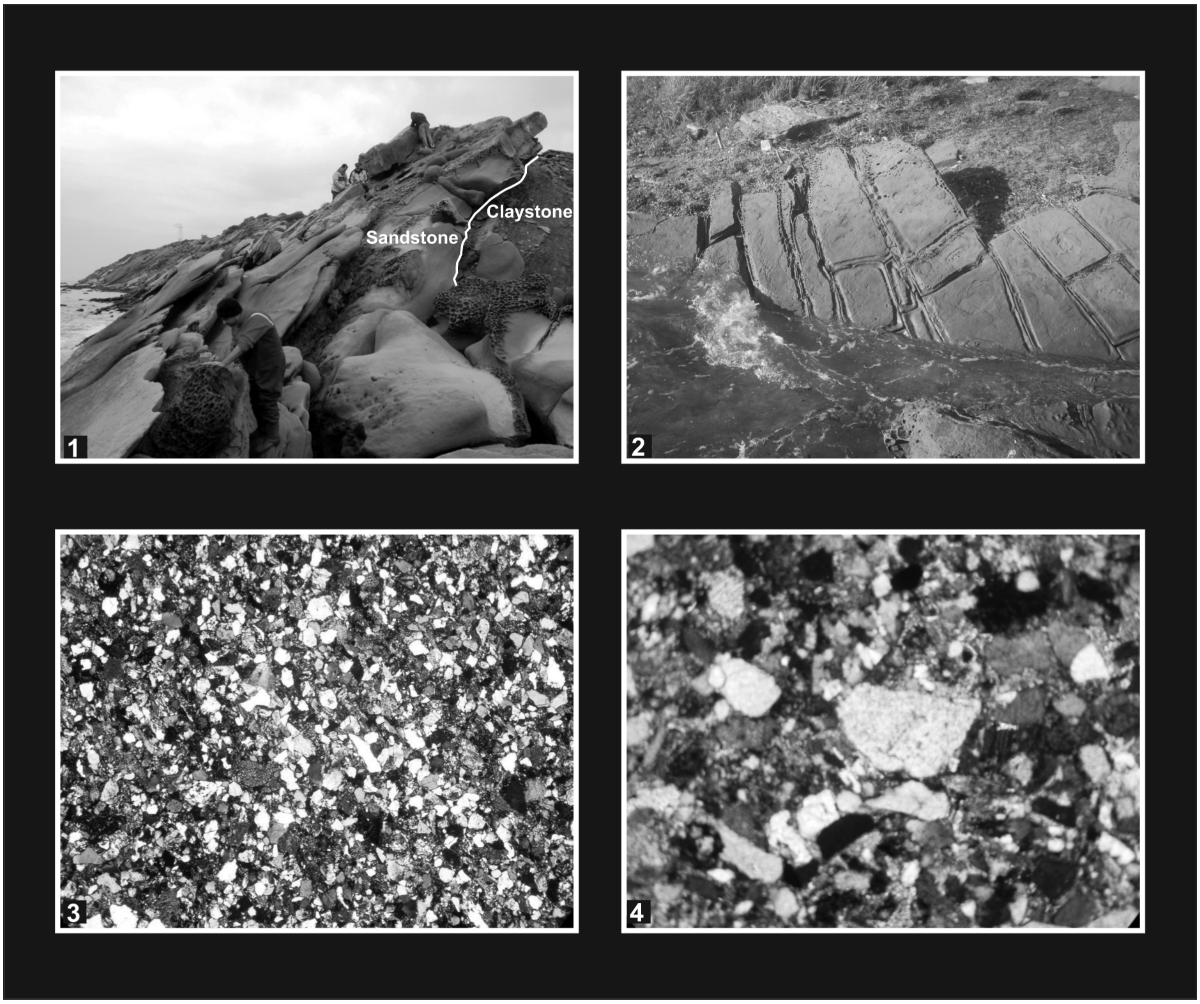

PLATE - II

Figure 1- SEM image of sandstone over which alveolar disintegration developed. Microporosity den sity over rock can be observed. Besides, microporosities with 400 μm-length among ellip soidal microporosities are observed. Fractures were enlarged upto 50 μm as a result of disintegration. Scale: 100 μm.

Figure 2- SEM image of carbonate cemented and muscovite-rich sandstone. Microporosity and microfracture formation on rock was not observed. Scale: 100 μm.

Figure 3- An example for bioerosional impact disturbing morphology of alveolar zones in intratidal zone

Figure 4- The increase of alveol sizes at the second measurement site from intratidal zone. Algae communities cover the heel and walls of alveols. At this part, the crystallization of salt coming from sea water during dry season is effective on disintegration. Arrow in the figure shows the thinning and perforation on the alveol walls.

Figure 5- An example for coalescent alveols located in the intratidal zones.

Figure 6- The impact of organisms at the heel and walls of alveols into the alveolar disintegration. Figure shows that patella and balanus species existing over alveols.

PLATE - II

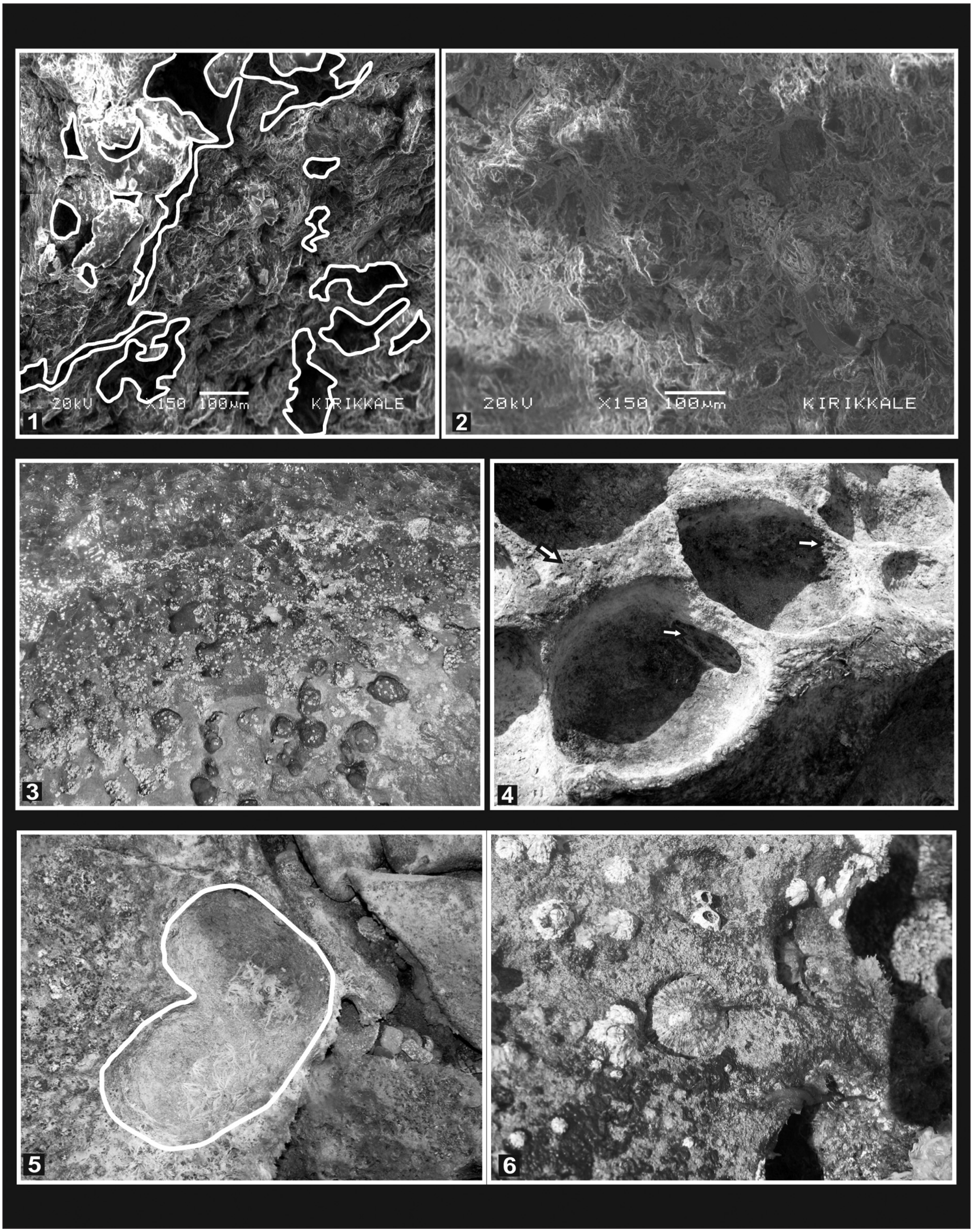
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PLATE - III

Figure 1- Alveolar disintegration cells at 1-5 m altitude from sea level. It is observed that alveols join and partially transform into tendrils.

Figure 2- Alveols within the orthogonal pores with iron and calcite infillings. It is observed that alveols are enlarged by joining, and the formation continued over the underlying sand-stones. Arrows indicate ellipsoidal Figureli alveols along the fractures.

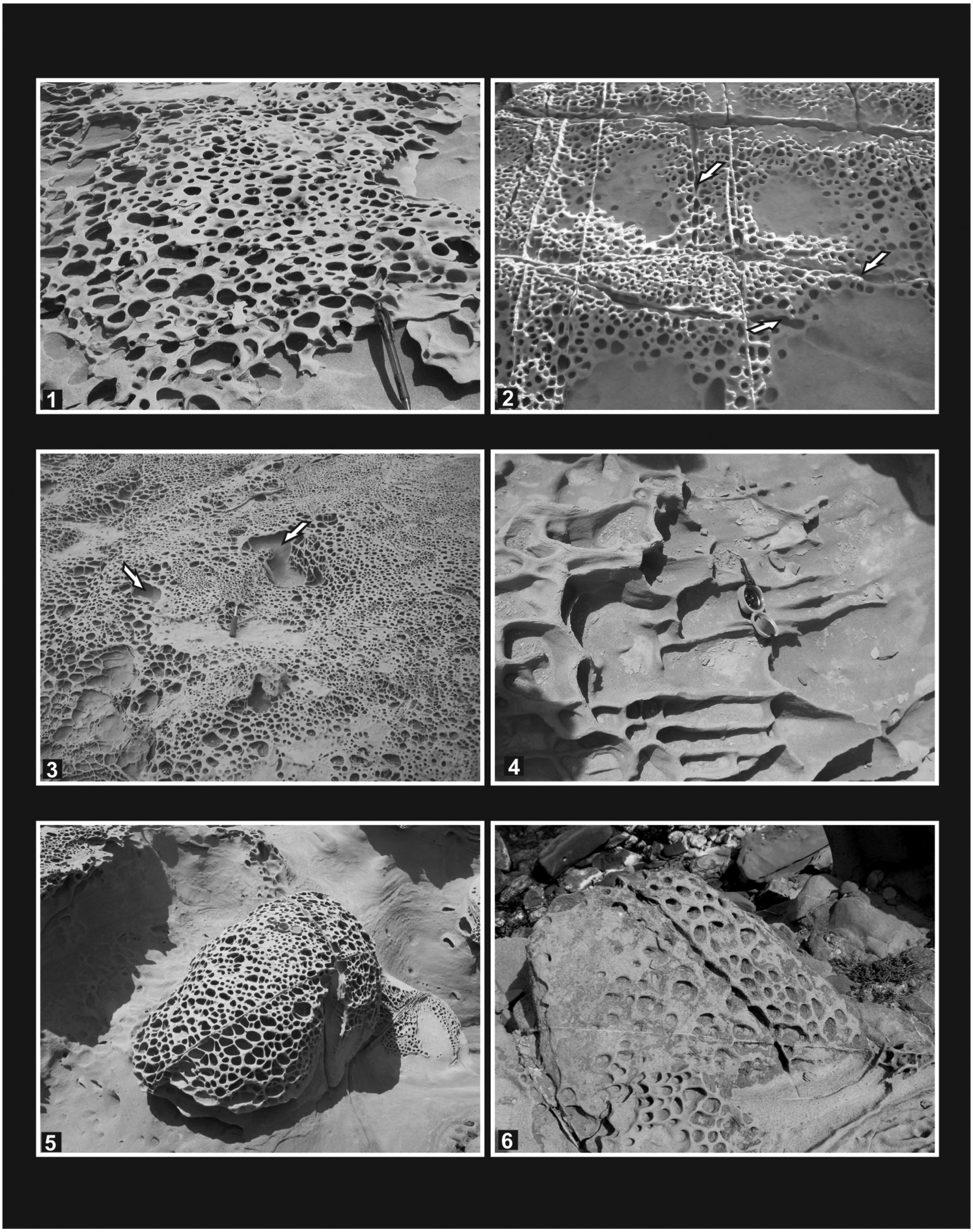
Figure 3- Initial stage for tafoni formation close to section where Figure 2 was taken. Especially, the evaporation promoting effect of wind over layer surfaces and frontal layers accelerates the crystalization of brine salt and results in tafoni formation.

Figure 4- Rectangular and very brittle alveols (tendril). In such formations, alveol walls are very thin so as different than closed disintegration cells, a few alveol walls have been abandoned.

Figure 5- An example for turtleback examined in study area. Development of such structures is generally related with parts, which are more resistant to disintegration compared to disintegration cells, generally highly weathered and tafoni or cavity-sized.

Figure 6- Alveols with very small sizes compared to lichen communities (*Xantoria* sp.) at the high flat of Cape Büyükkemikli.

PLATE - III



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