ROZPRAWY
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217

MARCIN KRAJEWSKI

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217 DISSERTATIONS MONOGRAPHS

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WYDAWNICTWA AGH

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Published by AGH University of Science and Technology Press

Editor-in-Chief: *Jan Sas*



Reviewers: *Prof. dr hab. Barbara Olszewska*
*Prof. dr hab. Tadeusz Peryt*

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Recommended example citation

Krajewski M. 2010. *Facies, microfacies and development of the Upper Jurassic-Lower Cretaceous of the Crimean carbonate platform from the Yalta and Ay-Petri massifs (Crimea Mountains, Southern Ukraine)*. Dissertation Monographs 217, Wydawnictwa AGH, Kraków 2010.

Technical Editor: *Magdalena Grzech*


ISSN 0867-6631
ISBN 978-83-7464-337-5

Desktop Publishing: „Andre”, tel. 12 422 83 23

Publishers Office

Redakcja Wydawnictw AGH
al. Mickiewicza 30, 30-059 Kraków
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http://www.wydawnictwa.agh.edu.pl

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**Facies, microfacies and development of the Upper Jurassic-Lower Cretaceous of the Crimean carbonate platform from the Yalta and Ay-Petri massifs (Crimea Mountains, Southern Ukraine)**

## Summary


The following paper presents the results of study on Upper Jurassic (Kimmeridgian-Tithonian)-Lower Cretaceous (Lower Berriasian) sediments in the southwestern part of the Crimean Mts. (Yalta and Ay-Petri massifs, southern Ukraine). This is the first study in this region based upon microfacies analysis. In both the Yalta and the Ay-Petri massifs 16 sequences in total were examined and sampled for the purposes of microfacies analysis, and identification of depositional environments.

The studied sediments represent the Kimmeridgian, Tithonian and the Lower Berriasian. The presence of Oxfordian sediments mentioned in the literature has not been confirmed. In the studied sequences several facies varieties were recorded, representing three main stages of the Crimean carbonate platform: (i) platform slope (Kimmeridgian-Tithonian), (ii) platform margin reefs, ooidal shoals and internal platform facies (Tithonian), and (iii) open/restricted internal platform (Tithonian-Lower Berriasian). The sequences are dominated by sediments deposited in shallow subtidal environments. Moreover, numerous depositional gaps are observed along with erosional episodes and beds of siliciclastic deposits composed of material supplied from the adjacent land. In the Ay-Petri Massif depositional environments evolved into a vast platform-margin reef complex built mostly by sponges, algae, corals, microbialites and microencrusters. Ooidal-bioclastic shoals were common. The Yalta Massif is dominated by the internal platform sediments developed mostly as pelitic oncoidal facies.

In the following chapters the author discusses development, stratigraphy and interpretation of studied sediments, in reference to the older, traditional concepts and in relation to the recent developments. The influence of tectonics on currently observed facies distribution is analysed together with the relation of the Yalta and the Ay-Petri carbonate massifs to their basement. Furthermore, some selected aspects of the existence of coral reefs in the study area and of the role of microencrusters as important reef-builders are discussed. Finally, the remarks are presented on the problems of reef complexes in both the Crimean and the Caucasus Mts.

MARCIN KRAJEWSKI

**Wykształcenie facjalne i mikrofacjalne oraz rozwój platformy węglanowej Gór Krymskich na przykładzie masywów Jałtańskiego i Aj-Petri (górna jura–dolna kreda, Góry Krymskie, południowa Ukraina)**

## Streszczenie

W pracy przedstawiono wyniki badań osadów górnej jury i najniższej kredy w oparciu o analizę mikrofacjalną w południowo-zachodniej części Gór Krymskich (Masywy Jałtański i Aj-Petri, S-Ukraina). W tym rejonie są to pierwsze badania na podstawie analizy mikrofacjalnej. W masywach Jałtańskim i Aj-Petri wykonano 16 profili, które posłużyły do charakterystyki mikrofacjalnej osadów i określenia ich środowiska depozycyjnego. Na podstawie otwornic wiek osadów określono na kimeryd, tyton oraz dolny berias. Nie zostało potwierdzone istnienie osadów oksfordzkich wzmiankowanych w literaturze. W badanych profilach wyróżniono szereg odmian facjalnych osadów, które zaliczono do trzech głównych etapów rozwoju krymskiej platformy węglanowej: (i) stoku platformy (kimeryd-tyton), (ii) raf i płycizn ooidowych (tyton) oraz (iii) otwartej i ograniczonej wewnętrznej platformy (tyton-wczesny berias). W profilach dominują osady związane głównie z płytkim środowiskiem sedymentacji. Ponadto licznie obserwowano przerwy sedymentacyjne, etapy erozyjne, ślady wynurzeń oraz osady silikoklastyczne dostarczane z pobliskiego lądu. W rejonie Masywu Aj-Petri sedymentacja rozwinęła się w rozległy kompleks rafowy tworzony głównie przez gąbki, algi, koralowce, mikrobiality oraz mikroinkrustery. Powszechnie obserwuje się facje ooidowo-bioklastyczne. W rejonie Masywu Jałtańskiego dominują utwory związane z wewnętrzną platformą, gdzie występują głównie facje pelityczne i onkoidowe.

Ponadto przedyskutowano zagadnienia dotyczące wykształcenia oraz stratygrafii osadów na tle starszych, tradycyjnych poglądów w nawiązaniu do współcześnie prowadzonych badań. Poruszany jest wpływ tektoniki na współczesny obraz facjalny oraz miąższość osadów, a także omówiono problematykę pozycji węglanowych masywów Jałtańskiego i Aj-Petri w nawiązaniu do podłoża. Ponadto przedyskutowano problematykę istnienia raf koralowych na badanym obszarze, roli wybranych mikroinkrusterów, jako jednych z ważniejszych organizmów rafotwórczych. Dokonano również ogólnej próby porównania kompleksów rafowych Gór Krymskich i Kaukazu.

# 1. Introduction

The main, coastal range of the Crimean Mts. was a marginal portion of a broad, epicontinental basin, which rimmed the northern peripheries of the Tethyan Ocean at the turn of Jurassic. The basin hosted several types of sediments belonging to the microbial-sponge or coral-algal facies (e.g. Bendukidze 1982, Ziegler 1990, Matyszkiewicz 1997).

The Upper Jurassic sediments of the Crimean Mts., genetically related to those of the Caucasus Mts., belong to stratigraphically, faciesly and microfaciesly less-recognized among all the Northern Tethyan Upper Jurassic/Lower Cretaceous (mostly Tithonian-Berriasian) successions in Europe. Geological studies of the Crimean Mts. have commenced in the 19th century and have resulted in numerous papers published mainly before the end of the 20th century, mostly in Russian and Ukrainian languages. However, despite this enormous amount of work, both the geological structure and the stages of development of the Crimean Mts. still remain controversial and give rise to contradictory concepts and interpretations, and scientific debates (e.g., Popadyuk, Smirnov 1996, Leshukh *et al.*, 1999 Mileev & Baraboskhin 1999, Yudin 1999a, b, 2001, Mileev *et al.,* 2006, Afanasenkov *et al.,* 2007). Moreover, difficult problems faced when reading the literature from the study area are: the lack of precise localization of data sources and the highly insufficient illustrations of presented materials and conclusions, which would be useful in comparison and verification of published information. Therefore, for the purposes of the following paper the author verified and selected publication which, according to authors' best knowledge and experience, provide most comprehensive geological data and enable the comparison of the results with the other parts of the northern Tethys margins of similar geological structure.

Geological structure of the study area was displayed in several maps. Their analysis (particularly that of tectonic maps) brought numerous difficulties as many recorded fault systems reveal various strikes and positions, depending on the authors (e.g., Arkhipov *et al.*, 1967, Derenyuk *et al.* 1984, Yudin 2008 cf. Saintot *et al.*, 1998, 1999). This makes the existing tectonic pattern of the Crimea Mts. highly controversial, diversified, chaotic and commonly inconsistent (e.g., Popadyuk, Smirnov 1996, Yudin 1999b, Millev, Baraboskhin 1999). Therefore, only the main tectonic discontinuities were taken into considerations, basing on papers after Nikishin *et al.,* (1998, 2001), Milleev *et al.*, (2006) Yudin (2001, 2006, 2008, Fig. 3.1), and Afanasenkov *et al.*, (2007) supplied by author's own observations.

In the literature the microfacies of Tithonian and Berriasian sediments in the first range of the Crimean Mts. was rarely presented. Instead, geologists focused their attention on tectonics and stratigraphy of some selected areas. Only recently the author has started pilot research in this field of interest and his publications contain the first microfacies data from the main ridge of the Crimean Mts.

The aim of the following paper is to present general information on stratigraphy and microfacies development of studied sediments, referred to the earlier concepts and hypotheses. The obtained data and conclusions are not definitive as these provide only general characterization of most commonly observed facies and microfacies varieties, and their principal components. However, these data may constitute the basis for future, more detailed sedimentological research of selected parts of the Crimean Mts.

The author is very much indebted to many specialists who kindly helped him at various stages of the research. Sincere thanks are due to: J. Matyszkiewicz (Cracow) for discussions and advice, B. Olszewska (Cracow) for help in identification of foraminifers and discussion, E. Roniewicz (Warsaw) for assistance in identification of corals and discussion, F. Schalgintweit (Munich) for help in identification of some microorganisms, M. Rogov (Moscow) for assist and directories concerning the stratigraphic problems of the Crimean Mts., V. V. Yudin (Simferopol) for discussion, access to the literature, remarks on tectonics and geological map of the southern Crimean Mts., A. Nikishin (Moscow), V. V. Arkad'ev (St. Petersburg) and O.V. Anikeyeva (Lwów) for access to the literature, B. M. Romanyuk (Lwów) for help in literature search and in organization of field works as well as P. Kamiński (Cracow) and I. Felisiak (Cracow) for assistance in field works. Helpful remarks have been provided by the reviewers B. Olszewska (Cracow) and T. Peryt (Warsaw). The research was financed from the AGH-University of Science and Technology grants No. 10.10.140.463 (2006–2009), 10.10.140.905 (2010–2011), and the State Committee for Scientific Research grant No. 18.18.140.835 (2009–2011).

# 2. Geological setting

Mountain ranges of the Crimean Peninsula belong to the southern edge of the Scythian Plate. From the south the main bordering structure is the Black Sea Basin whereas the depression of the Kerch Peninsula separates the mountains from the northwestern edge of the Caucasus Mountains.

From the morphological point of view the Crimean Peninsula can be divided into two parts: northern and southern, each characterized by different relief and geological history. About 80% of the peninsula area is a lowland (the Crimea steppe) which occupies its central and northern parts. In the southern part the narrow and long (150 km) range of the Crimean Mountains is located (Fig. 2.1).

The Crimean Mts. include three parts: the Main Range, the Foreland Range and the Outer Range. The Main Range, which is the subject of the following paper, is located in the southernmost, coastal part of the peninsula. Elevations of particular massifs reach 1,200–1,500 m a.s.l. From the south the massifs are terminated by vertical limestone walls, commonly several hundred of meters high. Their upper surfaces are vast, karst plains, named „Yayla" in local language, which gently descend northward and grade into the Foreland Range (elevations 600–700 m a.s.l). The Outer Range is poorly marked in the morphology as its elevations do not exceed 250 m a.s.l. and it grades into the Crimean steppe.

Geological history of the area is still a matter of debates, controversies and numerous publications, which focus mostly on the succession of tectonic phases and the history of deformations (see e.g., Kazantsev 1982, Popadyuk, Smirnov 1996, Nikishin *et al.*, 1998, 2001, Saintot *et al.*, 1998, 1999, Yudin 1999a, b, 2001, 2006, Millev *et al.*, 1995, 2006, Afanasenkov *et al.*, 2007). The core of the Main Range is formed by sediments ranging in age from the Triassic to the Berriasian and deformed during the Cimmerian orogenic phases, i.e. at the Triassic/Jurassic break, in the Callovian and in the Early Cretaceous (Late Berriasian, cf. Yudin 2001, 2006, Millev *et al.*, 2006, Afanasenkov *et al.*, 2007, Figs 2.1, 2.2). During the Cimmerian phase the allochthonous series has developed, which represents Upper Jurassic and Lower Berriasian carbonate sediments forming the main part of the Crimean Mts (e.g., Nikishin *et al.*, 1998, 2001, Saintot *et al.*, 1998, 1999, Yudin 1999a, 2001, 2006, Millev *et al.*, 2006). Tectonic characterization of the Crimean Mts., particularly their central and western parts, brings serious problems as available maps reveal substantial differences in presentation of geological structures.

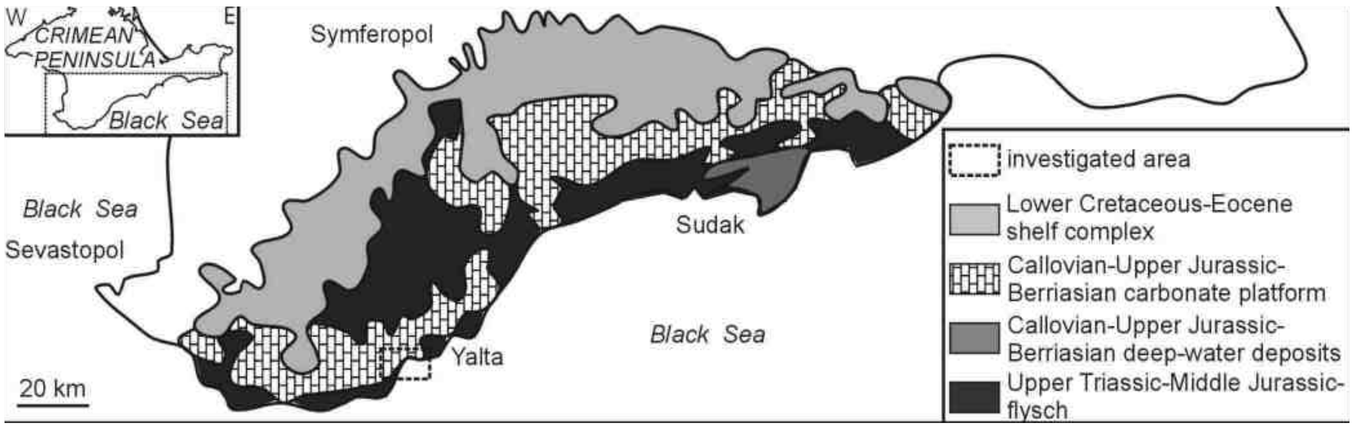



**Fig. 2.1.** Location of the study area against to the background of the main tectonic units of the Crimean Mountains, after Afanasenkov *et al*., 2007, simplified

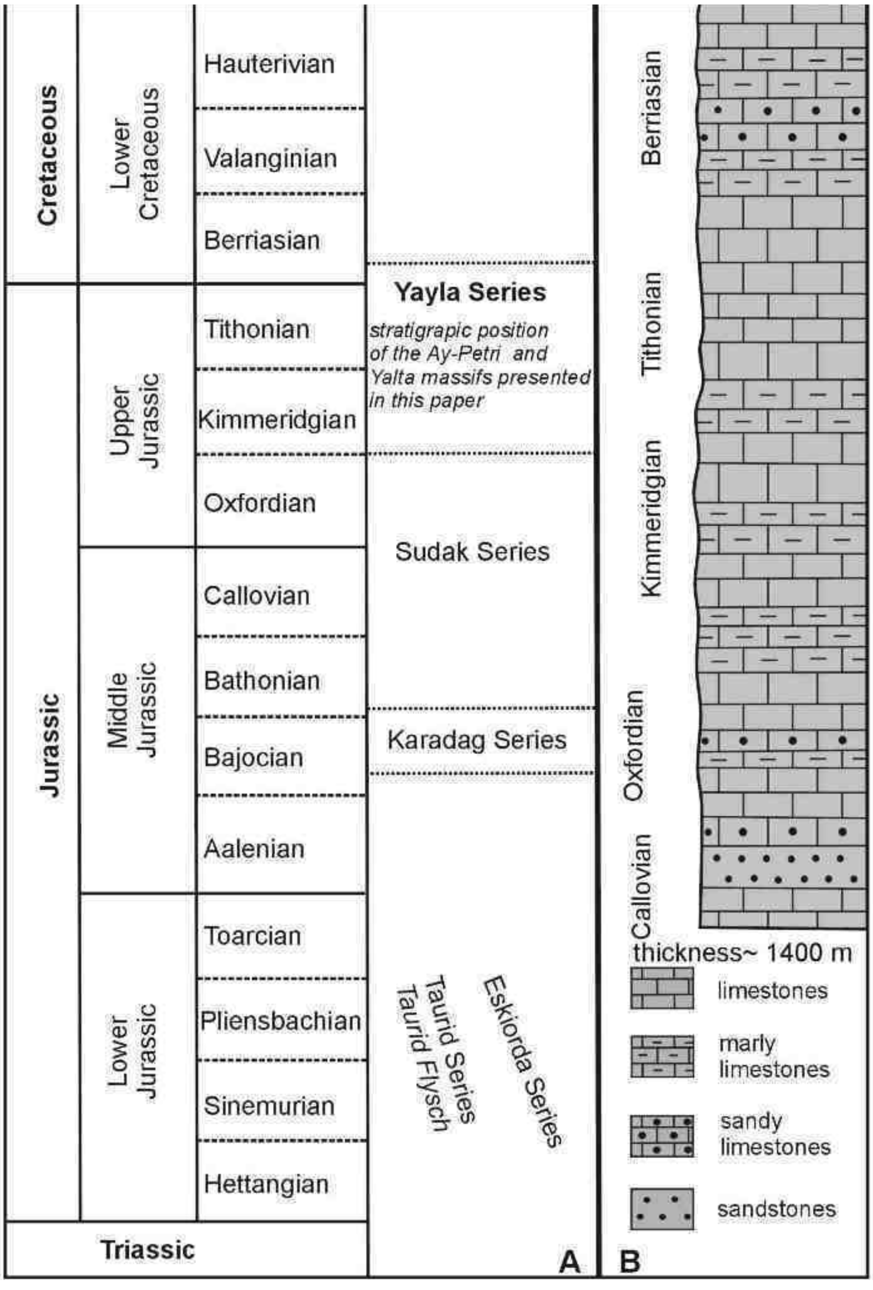



**Fig. 2.2.** A – General stratigraphy of the Crimean Mountains after Mileev *et al*., (2006), modified. B – Example of the lithological section (lograf Ridge) from Ay-Petri and Yalta Massifs, after Leshukh *et al*., (1999), simplified

According to recent views, geological structure of the Crimean Mts. includes five series: Eskiorda (Triassic-Upper Bajocian), Taurida (Norian-Lower Bajocian), Karadag (Upper Bajocian), Sudak (Bathonian-Kimmeridgian) and Yayla (Tithonian-Lower Berriasian; Millev *et al*., 2006, cf. Leshukh *et al*., 1999, Dorotyak 2006, 2007, Fig. 2.2).

These series build three main complexes of the Crimean Mts. The allochthonous complex includes Lower Cretaceous overthrusts, which affect Upper Jurassic-Lowermost Cretaceous strata and show tectonic transport along the distance of several tens of kilometers (Yudin 2001, 2006). The para-autochthonous complex comprises mainly folded Upper Triassic-Lower Jurassic flysch sediments. The autochthonous complex, located outside the study area, includes sediments ranging in age from the Cretaceous to the Neogene (e.g., Marcinowski, Naidin 1976, Millev *et al*., 2006, Yudin 2006, 2008, Afanasenkov *et al*., 2007, Nikishin *et al*., 2008, Fig. 3.1).

The Main Range occupies the southernmost, coastal part of the peninsula where it extends parallel along over 150 km. The basement of Jurassic sediments shows complicated structure, which includes several intrusions, chaotic overthrust systems, faults and tectonic breccia zones (e.g., Kazantsev 1982, Kazantsev *et al*., 1989, Yudin 1999a, 2001, 2008, Afanasenkov *et al.*, 2007).

The Main Range is divided into several smaller massifs named “Yayla”, of elevations reaching 1,500 m a.s.l. Specific massifs, although adjacent, represent separate, isolated structures characterized by different morphologies, lithologies and stratigraphic columns. Principal role in their geological structure is played by sediments ranging in age from the Callovian through the Oxfordian, Kimmeridgian, and Tithonian until the Lower Berriasian (e.g., Leshukh *et al.,* 1999, Millev *et al*., 2006, Dorotyak 2006, Krajewski, Olszewska 2007, Arkad’ev 2007, Arkad’ev *et al*., 2005, Arkad’ev, Rogov 2006, Anikeyeva, Zhabina 2009, Fig. 2.2). Deposition took place in a rift-like trough filled with various sediments: shallow- to relatively deep-marine limestones, conglomerates and flysch-like deposits (e.g., Zonenshain, Pichon 1986, Nikishin *et al*., 1998, 2001, Golonka 2004, Afanasenkov *et al*., 2007).

# 3. Outline of the research history of the study area

The Jurassic sediments of the Crimean Peninsula have long and extensive research history, beginning of which can be dated back to the early XIX century when Mesozoic age of strata has been proposed for the first time (e.g., Ptchlintsev 1962, Muratov 1960, 1969, 1973, Permjakov 1969, Leshukh *et al*., 1999, Dorotyak 2006, 2007, Zhabina, Anikeyeva 2007, Anikeyeva, Zhabina 2009).

Most of the early studies referred to stratigraphy of Upper Jurassic sediments and were run by Russian and Ukrainian geologists (e.g., Ptchelintsev 1962, Permyakov 1969, 1984, Permyakov *et al*., 1986, 1991, 1993, Muratov 1973, Leshukh *et al*., 1999). Their results have dominated the concepts of the Crimean Peninsula structure for next decades.

The Upper Jurassic sediments have been characterized in a monograph of Jurassic strata from the Southern Ukraine (Leshukh *et al*., 1999). The authors presented comprehensive lithostratigraphy of Oxfordian, Kimmeridgian and Tithonian deposits based upon earlier studies (particularly Permyakov 1984, Permyakov *et al.*, 1991, 1993, and others). In particular several local stratigraphic horizons were distinguished and their thicknesses and extended descriptions of ammonite and coral faunas were given (e.g., Leshukh *et al*., 1999, Dorotyak 2006). These faunas were the basis for stratigraphic subdivision of the Crimean Peninsula sediments. Unfortunately, the authors did not provide neither sampling locations nor illustrations of these fossil, which preclude verification of presented data. Recent, intensive and precise stratigraphic and sedimentological studied carried on mostly in the eastern (Dvuyakornaya Bay, Tonas River) and northern (Belbek River) parts of the Crimean Mts. provided new data, particularly on Callovian, Tithonian and Berriasian sediments (e.g., Arkad'ev, Bugrova 1999, Rogov *et al*., 2005, Arkad'ev, Rogov 2006, Arkad'ev *et al*., 2005, 2008, Arkad'ev 2007, and others).

The study area of the following paper belongs to the best-recognized and typical parts of the Crimean Mts. Main Range (Tab. 3.1). Published literature concerning this area is rather limited. Most publications deal with the Iograf Ridge where ammonite fauna was discovered (Oviekchin 1956, Muratov 1973, Leshukh *et al*., 1999, Rogov *et al*., 2005) which plays a crucial role in stratigraphy of the western part of the Main Range.

Moreover, along the Iograf Ridge a stratotype section was established, which is representative of the Yalta Massif (Leshukh *et al*., 1999). Some data important for the impact of tectonics on the arrangement of Upper Jurassic and Lower Cretaceous strata can be found in paper after Mileev and Baraboskhin (1999). These authors called into question common opinion on significant thickness of these sediments estimated previously as several kilometers (e.g., Muratov 1960, 1973, Leshukh *et al*., 1999, Dorotyak 2006).

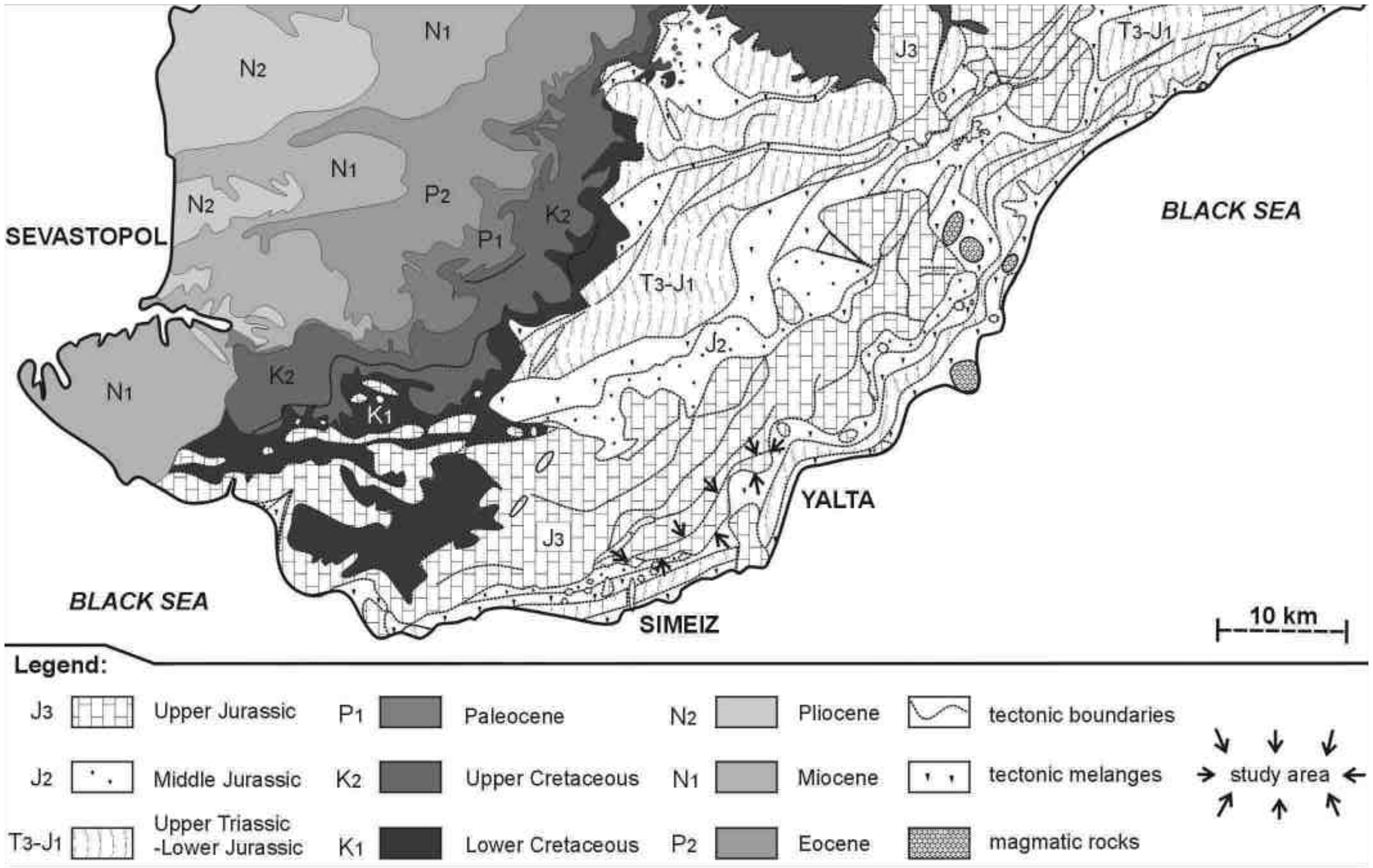



**Fig. 3.1.** Geological map of the Crimean Mountains, after Yudin 2008, simplified and modified. Study area represents southern part of the Crimean Mountains between Yalta and Simeiz

Instead, they suggested the effect of tectonics which led to the stacking of many sequences, the true thicknesses of which were less than 1 kilometer. It is evidenced by numerous tectonic discontinuities observed in the field as well as by relationship between thickness and deposition time, which should be several times longer than that known from other carbonate platforms if the concept of significant thickness is valid (Millev, Baraboskhin 1999). Other fragmentary data are available for the At-Bash Massif from which two carbonate complexes were described, separated by the Taurida Series (Triassic-Lower Jurassic). According to Millev and Baraboskhin (1999), it proofs unequivocally the allochthonous character of this part of the Crimean Mts (see also Popadyuk, Smirnov 1996, Millev *et al*., 1995, 1996, Yudin 1999b, 2008, Figs 3.1, 3.2, cf., Gintov, Borisenko 1999).

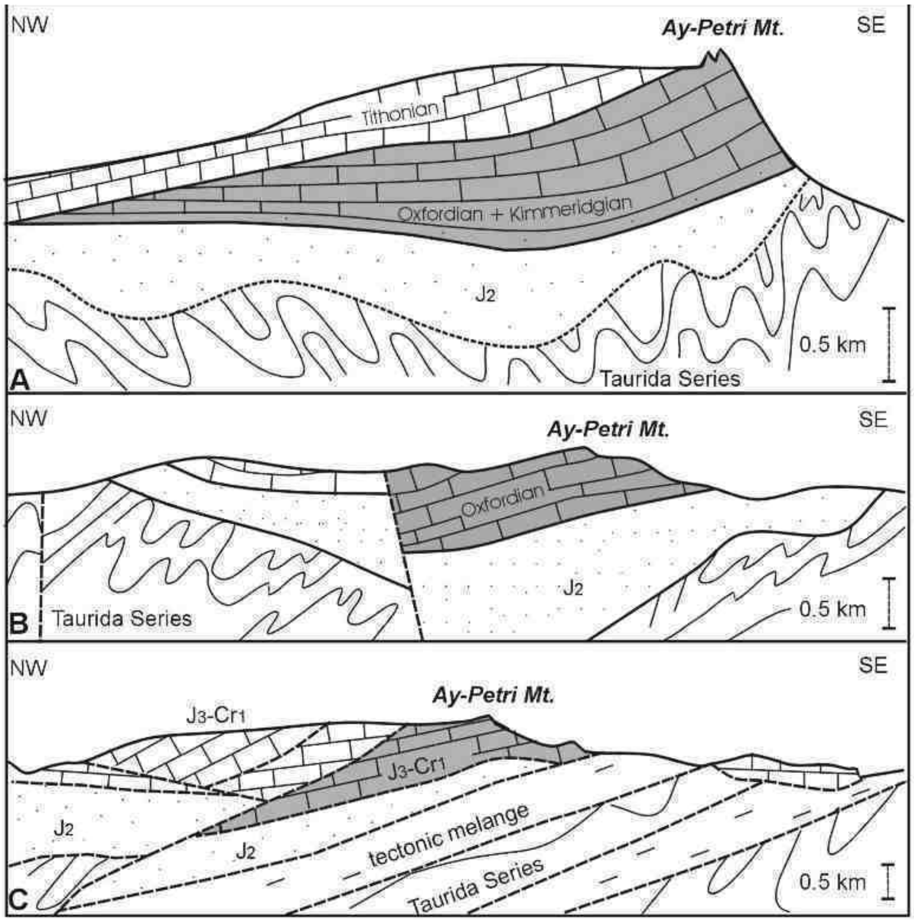



**Fig. 3.2.** Geological cross-sections through the Ay-Petri Mountain presented in the literature. A – interpretation of the geology of the Ay-Petri Mountain after Muratov 1960, 1973, B – interpretation after Arkhipov (in Mileev *et al*., (1995), C – interpretation after Yudin 2001, simplified. The studied interval is shaded in gray

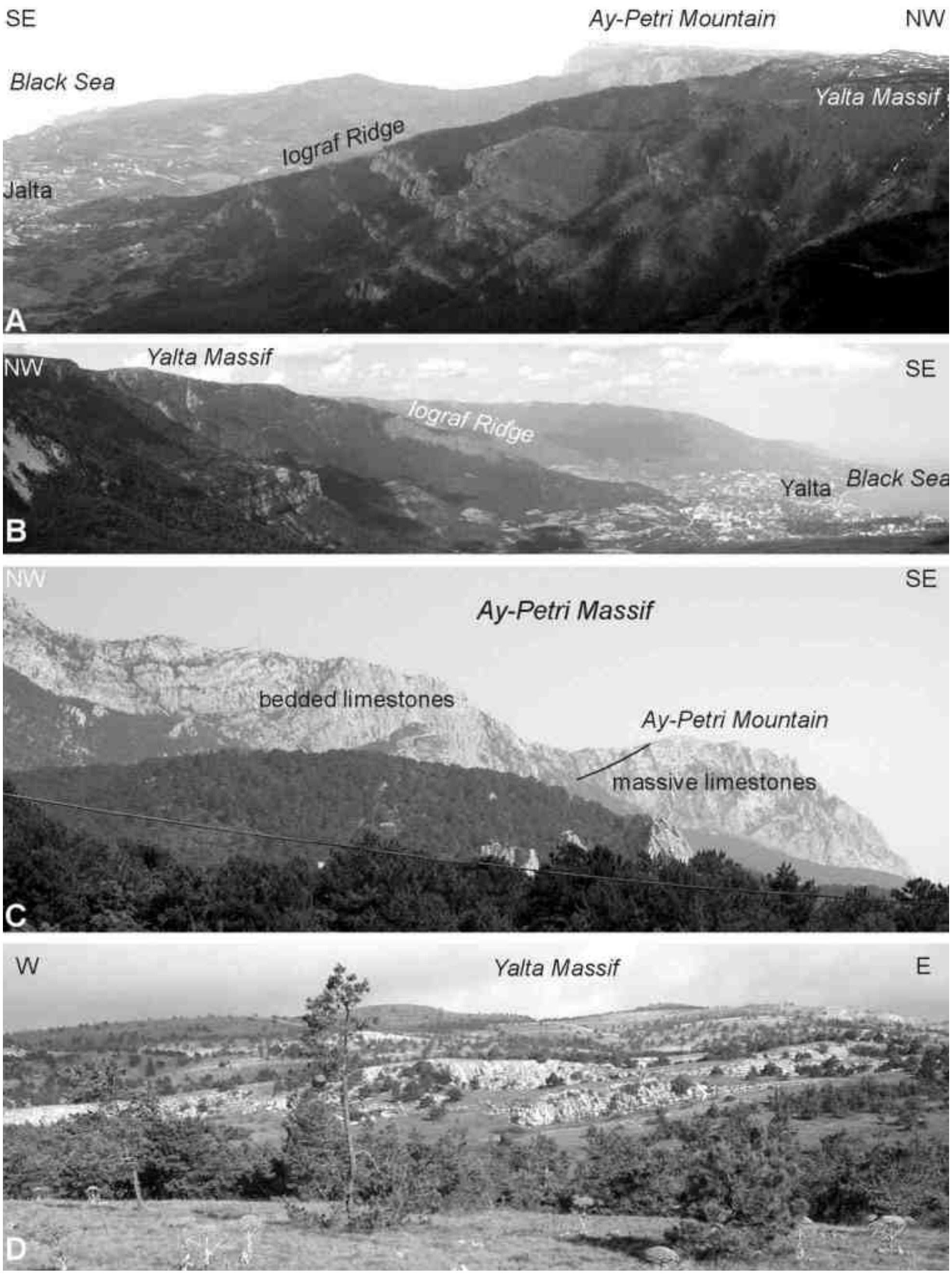

SE
Ay-Petri Mountain
NW
Black Sea
Yalta Massif
Iograf Ridge
Jalta
A
NW
Yalta Massif
SE
Iograf Ridge
Yalta
Black Sea
B
NW
SE
Ay-Petri Massif
bedded limestones
Ay-Petri Mountain
massive limestones
C
W
Yalta Massif
E
D

**Table 3.1.** Localization and views of the study area

A, B – southern escarpment of the Yalta Massif with numerous outcrops of the bedded limestones inclined to the north

C – southern escarpment of the Ay-Petri Massif. The central part of the Ay-Petri Mountain is build by massive limestones which gradually pass into bedded limestones

D – Upper part of the Yalta Massif. Karstic plateau with numerous outcrops of the thin and thick bedded limestones. The same situation is also observed on the Ay-Petri Massif

Considering the above mentioned data, it is concluded that the study area, although prominent in the morphology of the Crimean Mts., has not been investigated in detail up to date and that the available literature is rather poor. It seems that the main reasons are the scarcity of fossils and poorly recognizable sedimentary structures. Since 2005 the author has been studying the areas of, first, the Ay-Petri Massif, ("Ay-Petri Yayla") then also the Yalta Massif ("Yalta Yayla") applying the microfacies analysis. As a result, new data were obtained on microfacies development, depositional environment and foraminifer-based stratigraphy (Krajewski, Olszewska 2005, 2006, 2007, Krajewski 2008, cf. Kuznetsova, Gorbachik 1985, Dorotyak 2007, Anikeyeva, Zhabina 2009). These results and conclusions were included into the present paper.

# 4. Upper Jurassic-Lower Cretaceous deposits of the southern part of the Yalta and Ay-Petri massifs

## 4.1. Regional lithostratigraphic horizons

### 4.1.1. General remarks

Studies on stratigraphy of the Crimean Mts., although having long and extensive history, still bring numerous doubts concerning the stratigraphic position of strata exposed in many outcrops (e.g. Rogov *et al.*, 2005, Krajewski, Olszewska 2006, Arkad'ev *et al.*, 2008). In many cases the existing data do not allow us to date precisely the sediments, mostly due to scarcity of ammonites, as observed particularly in the south-western part of Upper Jurassic part of the Crimean Mts. Moreover, stratigraphic position of particular units is based mostly on studies completed many decades ago. These reports have rather poor illustrations and inaccurate location of described sites, which precludes data verification. This, in turn, affects correlation and comparison of results obtained in various areas. An additional factor hampering the stratigraphic studies is the presence of several faults of various directions and displacements (e.g., Saintot *et al.* 1998, 1999, Yudin 1999a, b, 2006, 2008, Figs 3.1, 3.2). Taking into account that some lithological varieties can be observed over long distances and that sediments from various regions are macroscopically similar, the method was applied in which some lithological varieties or strata sequences were ascribed to particular stratigraphic horizons (e.g., Ptchelintsev 1962, Permyakov *et al.*, 1991, 1993, Leshukh *et al.*, 1999, Dorotyak 2006). This method, well-known since decades, provides many advantages as it simplifies the making of stratigraphic subdivisions, especially in the areas where outcrops are well-preserved but ammonites are rare and micropaleontological data are poor. Unfortunately, this method may also cause mistakes due to possible macroscopic similarity of rock varieties and strata sequences from different stratigraphic horizons, as seen particularly in strongly tectonized areas. Moreover, similar sediments representing different stratigraphic horizons may occur at similar height over the base of Jurassic succession, which gives an impression of macroscopic continuity of beds.

Additionally, the method is controlled by facies transitions between different rocks, e.g. from hard, massive limestones to soft, fine-rhythmic marls. Recent studies confirm the doubts that stratigraphy based upon the stratotypes commonly does not fit to the real development of Upper Jurassic and Lower Cretaceous sediments of the Crimea Mts. Field studies allowed the author to recognize facies transitions over short distances. Furthermore, tectonic investigations run in last years proved that specific fragments of mountain massifs ascribed to the same stratigraphic horizons are allochthonous series (e.g., Popadyuk, Smirnov 1996, Yudin 1999a, b, 2006, 2008, Nikishin *et al.*, 1998, 2001, Millev *et al.*, 1995, 1996, 2006, Afanasenkov *et al.*, 2007, Figs 3.1, 3.2) and that their sediments might have been deposited at different time in different paleoenvironments.

All the factors mentioned above suggest that high caution is necessary in stratigraphic interpretation and correlation between various parts of the Crimea Mts. from which ammonites or foraminifer faunas have not been described and for which stratigraphy reported in the literature is only of general significance (e.g., Leshukh *et al.*, 1999).

### 4.1.2. Outline of the classic lithostratigraphy of the Yalta and the Ay-Petri massifs

The names of specific lithostratigraphic horizons originate from the names of areas where their stratigraphic positions were described in the literature and where the stratotypes occur, i.e. the lithologic varieties best-representing given sediments in a given area. Particular lithostratigraphic horizons were subdivided into several members. Below, the horizons closely related to the study area were briefly characterized, based upon subdivision after Permyakov (Permaykov 1969, 1984, Permyakov *et al.*, 1991, 1993, Leshukh *et al.*, 1999, Dorotyak 2006) and others (cf. for example Kuznietsova, Gorbachik 1985, Rogov *et al.*, 2005, Arkad'ev, Rogov 2006, Arkad'ev *et al.*, 2005, 2008, Krajewski, Olszewska 2005, 2006, 2007, Anikeyeva, Zhabina 2009).

**THE SUDAK HORIZON**

The Sudak Horizon (Permyakov 1969, 1984, Fig. 2.2B), named after the Sudak town located close to the stratotype site, was divided into four zones corresponding to the Upper Callovian (*Peltoceras athleta-Quenstedtoceras lamberti*) and Lower Oxfordian (*Quenstedtoceras mariae-Cardioceras cordatum*). Four members were distinguished: Gurzuf, Tapshansky, Bash-parmkhsky and Sudak. The study area belongs to the Sudak member (Leshukh *et al.*, 1999), which comprises two parts: the Lower Sudak

Member, 185 meter thick, composed of mudstones, sandstones, calcareous sandstones and conglomerates, and the Upper Sudak Member, from 190 to 600 meter thick, composed of limestones representing the carbonate buildups.

### THE YAILA HORIZON

The Sudak Horizon conformably rests upon the Yaila Horizon (Permyakov 1969, 1984). The Yayla stratotype is the succession observed in the Ay-Petri Massif. Four members were distinguished: Suha, Yaila, Demezhy and Mandzhy-Kaya. The study area belongs to the Yaila Member, its stratotype is located in the Iograf Ridge. The member consists of two parts: the Lower Yaila Member, about 1225 meter thick, which belongs to the Middle and Upper Oxfordian (*Perisphinctes plicatilis-Idoceras planula*) and includes bedded limestones and marly limestones intercalated by sandstones, mudstones and carbonate buildups whereas the Upper Yaila Member (Lower Kimmeridgian), about 185 meter thick, comprises thin-bedded limestones and marly limestones (Fig. 2.2B).

### THE YALTA HORIZON

The Yalta Horizon uncomfortably covers the Yaila Horizon (Permyakov 1969, 1984). The stratotype includes sediments typical of the Ay-Petri and the Yalta massifs. Two members were distinguished. The Lower Yalta Member comprises mostly thin- and medium-bedded limestones, and marly limestones, from 265 to 500 meters thick. Basing on ammonite fauna this member was ascribed to the Lower Tithonian. The Upper Yalta Member includes also thin- and medium-bedded limestones intercalated by marly limestones, of thickness from 125 to 840 meters. Ammonite fauna indicates the Middle Tithonian age (Oviekchin 1956, Leshukh *et al.*, 1999, cf. Rogov *et al.*, 2005, Fig. 2.2B).

### THE BEDENEKYR HORIZON

The Yaila Horizon is conformably covered by the Bedenekyr Horizon (Pchelincev 1962, Permyakov 1984). The stratotype consists of sediments occurring in the center of the Ay-Petri Massif, in the vicinity of the Bedenekyr Mt. Two members were distinguished. The Lower Bedenekyr Horizon comprises mostly marly, pelitic and detrital limestones with marls and mudstones, of total thickness of 640 meters. Ammonite fauna points to the Upper Tithonian age. The Upper Bedenekyr Horizon includes organogenic limestones and grainstones, up to 180 meter thick. Ammonite fauna indicates the Upper Tithonian-Berriasian age (e.g. Leshukh *et al.*, 1999, Fig. 2.2B).

## 4.2. Methods

The principal study method for various carbonate rocks is the microfacies analysis. In the Crimea Mts. such studies based on observations in thin sections are rather rare (e.g. Arkad'ev, Bugrova 1999, Krajewski, Olszewska 2005, 2006, Krajewski 2008, Baraboskhin, Piskunov 2010).

The study area is a mountain terrain with numerous, south-facing cliffs generally arranged parallelly to northward dip of the strata (Fig. 3.1). To the north the study area comprises vast, elevated plains or karst depressions. The sequences presented below were drawn mostly along the southern cliffs of the Ay-Petri and the Yalta massifs (Figs 3.1, 3.2, 4.1, Tab. 3.1). Their elevations vary from 1,000 to 1,300 meters a.s.l. Carbonate rocks, which can be regarded as remaining *in situ*, are sometimes located about 400 meters above the sea surface. On mountain slopes carbonate rocks appear at various elevations as isolated outcrops or larger, rocky hills. Some of such forms can be examined starting practically from the sea level, as e.g., the Koshka Mt (Yudin 2006). However, such hills are built of sediments which were tectonically and gravitationally stripped from the basement and displaced. These sites were eliminated during selection and description of the sequences.

The described sequences show diversified thicknesses, which are commonly lower than those observed in the field. This is an effect of applied assumption, that exposures selected for sedimentological studies along the same profile belong to the same tectonic block. Only for the Iograf Ridge sedimentological analysis was made for the full accessible length of the profile due to the historical importance of this site for the Crimea Mts. stratigraphy (see Oviechkin 1956, Leshukh *et al.*, 1999, Anikeyeva, Zhabina 2009, Fig. 2.2, Tab. 3.1).

Such methodology enabled the author to eliminate the randomness in the succession of studied sediments. Undoubtedly, it does not ensure the absolutely precise determination of sediments development; particularly in the bottom parts of sequences where it was difficult to prove whether the sediments remain *in situ* or, rather, were displaced. Commonly, the lowermost sediments in the sequences are not outcropped. The top parts of most studied sequences were located along the southern margin of the mountains, which rims the karstic plateau (sections: KJ, KM, KN, KP, KS, KR, KA, KB, KC, KE, KF, and KG). Only a single profile, some tens of test samples and some macroscopic observations were carried on northward, towards the center of the massif, in order to provide comparative materials (sections: KK, KL, KD). This is a result of an observation that sediments forming the upper surface of the massif perhaps belong to another tectonic block as revealed by clearly visible, angular unconformity between the strata commonly observed in the southern walls of the massif and those forming its caprock.

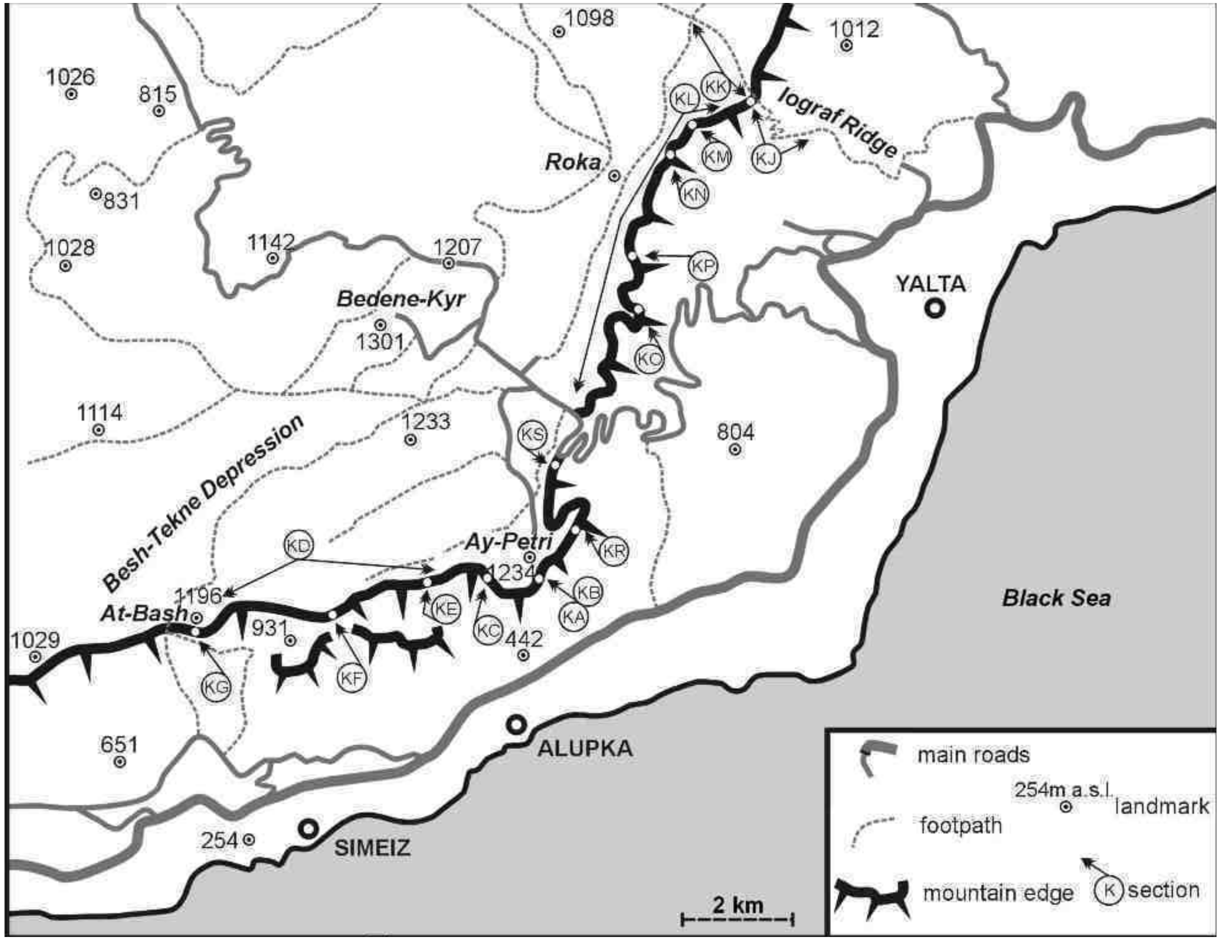



**Fig. 4.1.** Location of the presented sections between Iograf Ridge and At-Bash Mt

Moreover, there are sediments of the Middle Jurassic and Taurida Series (Triassic-Lower Jurassic) examined in some small tectonic windows, between two carbonate successions distinguished there (Millev, Baraboskhin 1999, Yudin 2008, Figs 3.1, 3.2).

Due to the specific character of the terrain, detailed field observations as well as rock sampling required the usage of mountaineering techniques in order to reach hardly accessible sites. It enabled the author to study in details the successions and to eliminate the randomness of collected rock samples. The preliminary observations and sampling led to the selection of 16 sequences along which the basic sampling was made (Fig. 4.1). In the remaining areas only the macroscopic observations were carried on. Because of considerable size of rock walls and the study area as a whole, the facies mapping and the profile correlations were supported by accurate positioning of sequences and sampling sites with the GPS and the altimeter. Sampling density for the purpose of microfacies examinations was controlled by the results of direct macroscopic observations – if studied sediments did not reveal variability their sampling density was lower. Proportionally to the variability of sediments development, the sampling spacing was modified, varying from some ten of meters to several centimeters. Simultaneously, during vertical profiling samples were collected also laterally in order to disclose, with maximum precision the lateral variability of sediments over short distances and in order to minimize the randomness of sampling collection from various sediments. Macroscopic observations were made also in sequences between sampling sites. Moreover, in some horizons samples for microscopic studies were taken also from the areas between the sequences in order to improve the quality of observations of lateral facies variability. Such methodology enabled the author to investigate large sedimentary sequences and their main components. During the profiling particular attention was paid to location and identification of tectonic disturbances, which allowed for the improvement of correlation accuracy between the sequences.

Field studies enabled the author to collect a huge population of 1,010 representative samples from a large majority of which oriented thin and polished sections were prepared for microfacies and microfossils examinations.

Stratigraphic identification of sediments from the study area is difficult due to scarce ammonite fauna and complicated fault tectonics. Relatively rare ammonites found in a single profile located in the Iograf Ridge (only in specific horizons, Oviechkin 1956, Rogov *et al*., 2005), hence for the purposes of the present research the results of foraminifer assemblages analysis were considered as well (Fig. 4.2, Tabs 4.1, 4.2, Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985, Dorotyak 2007, Anikeyeva, Zhabina 2009). Although microfossil-based stratigraphy is not as precise as the orthostratigraphic ammonite subdivision, foraminifers are common in the studied sediments, as opposed to ammonites (see Krajewski, Olszewska 2007). Moreover, the lack of ammonites in most of facies described from the study area causes that foraminifer-based stratigraphy is practically the only applicable and credible method.

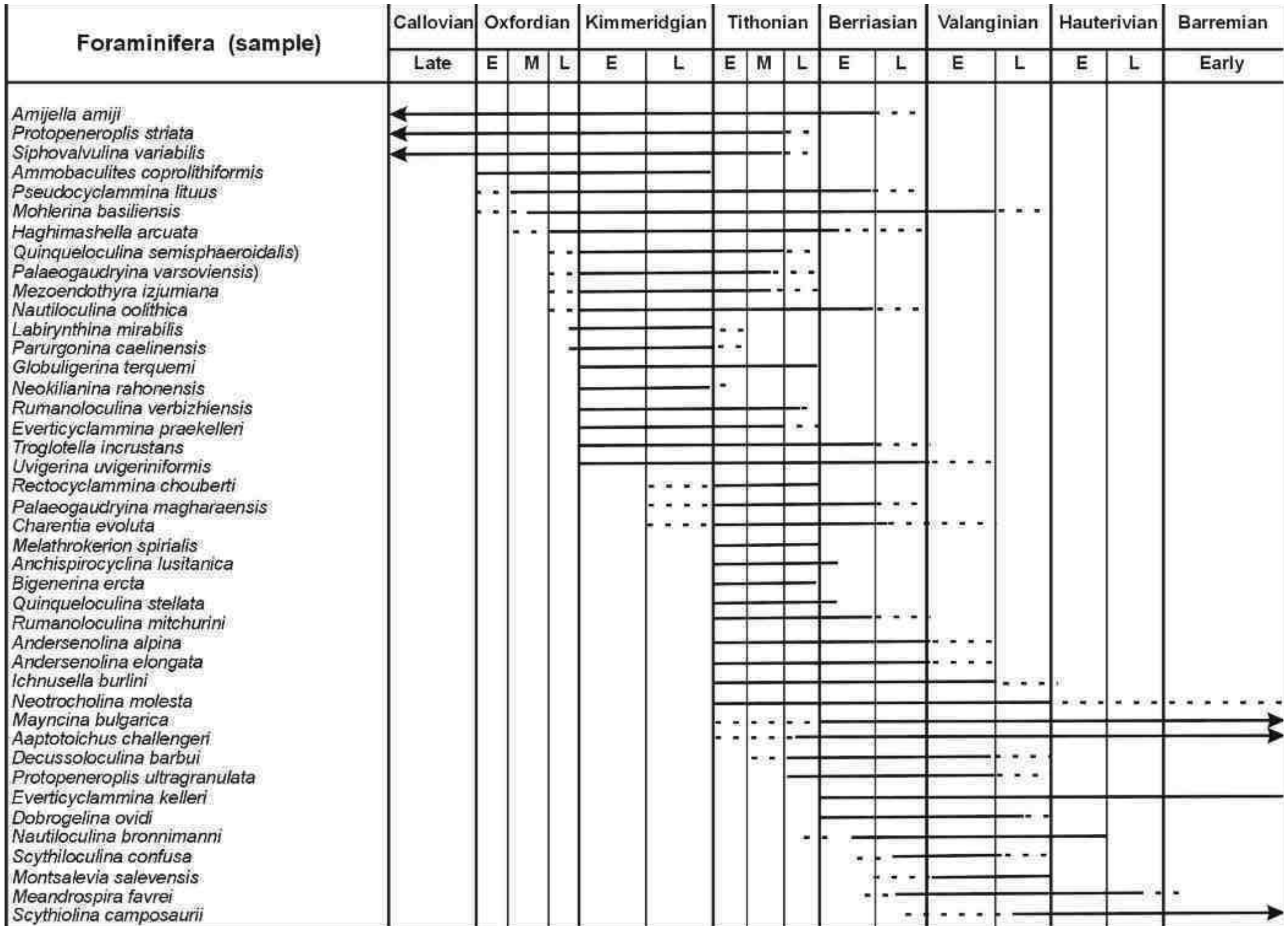
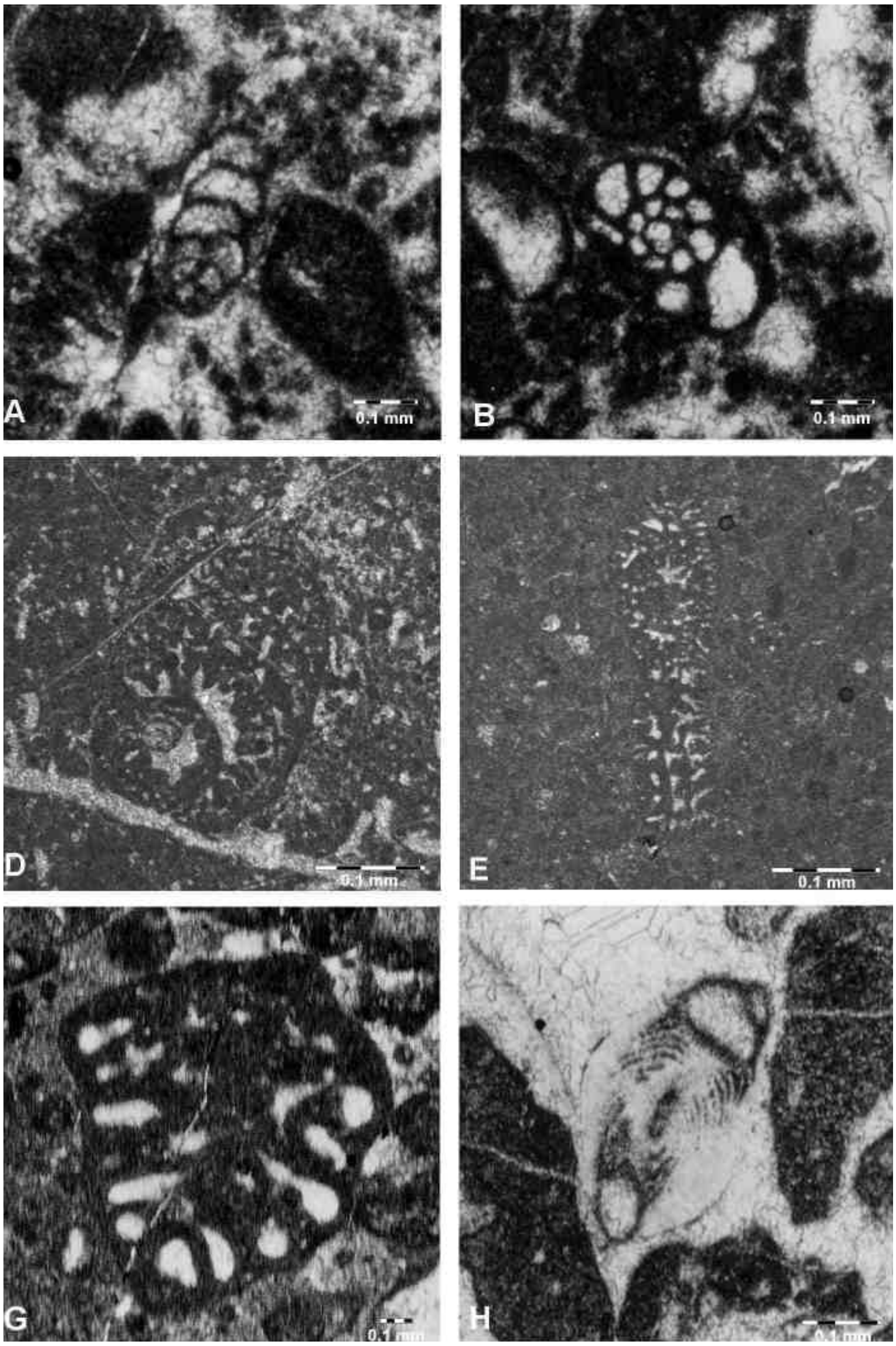



**Fig. 4.2.** Stratigraphic ranges of foraminifers from the study area, after Krajewski, Olszewska (2007)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B
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G
H

**Table 4.1.** Examples of the foraminifers used to establish of the stratigraphy of the Ay-Petri and Yalta massifs. For details see Krajewski, Olszewska 2007

A – *Haghimashella arcuata* (Haeusler), section KC, sample KC 4a

B – *Mayncina bulgarica* (Laugh, Peybernès, Rey), section KJ, sample KJ 12a

C – *Amijella amiji* (Henson), section KG, sample KG 5a

D – *Anchispirocyclina lusitanica* (Egger), section KL, sample KL 11

E – *Parurgonina caelinensis* (Cuvillier, Foury, Pignatti Morano), sectin KD sample KD 9

F – *Protopeneroplis striata* (Weynschenk), section KB, sample KB 2a

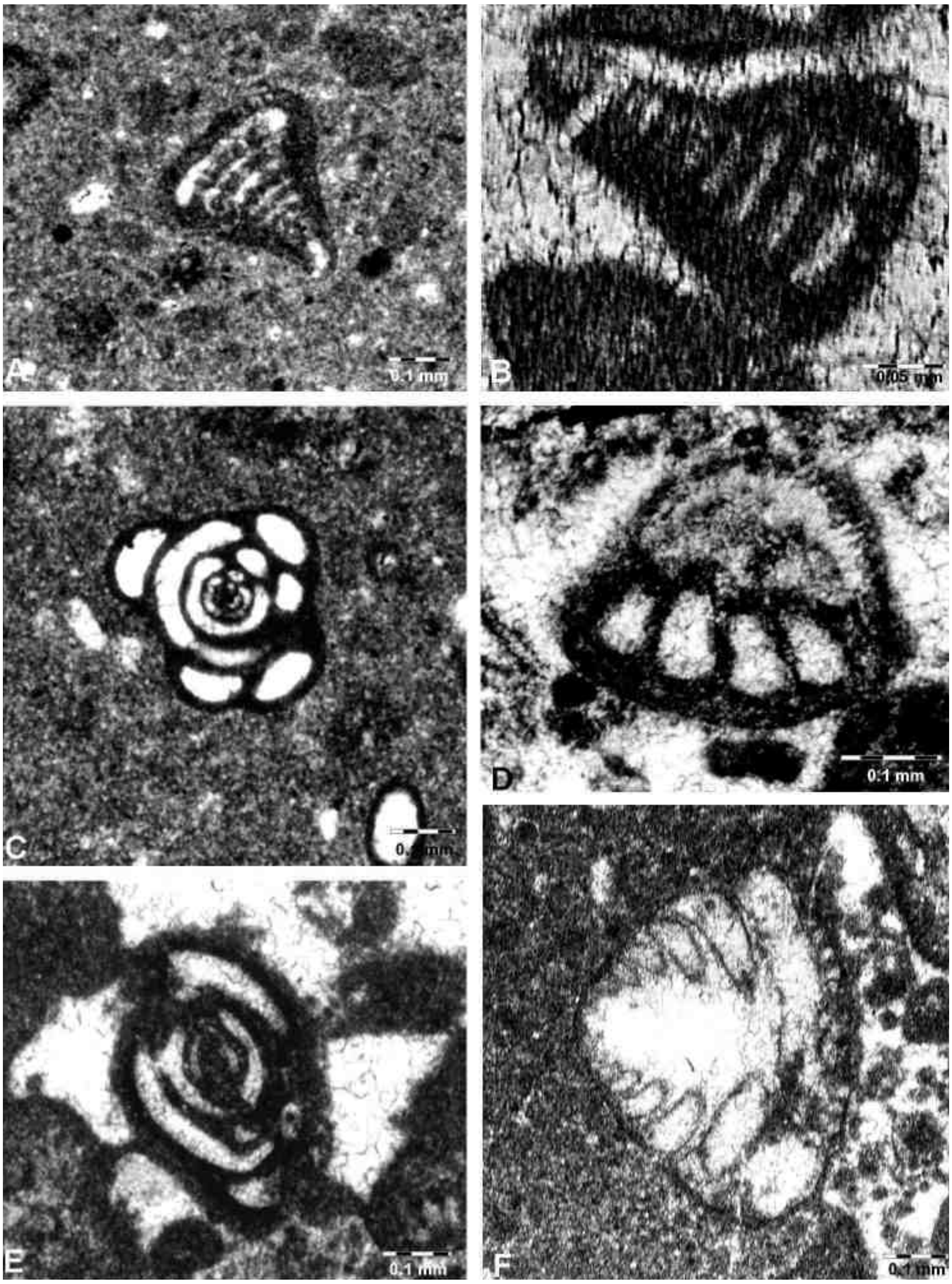
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**Table 4.2.** Examples of the foraminifers used to establish of the stratigraphy of the Ay-Petri and Yalta massifs. For details see Krajewski, Olszewska 2007

A – *Scythiolina camposaurii* (Sartoni, Crescenti), section KF, sample KF 3a

B – *Montsalevia salevensis* (Charollais, Brönnomann, Zaninetti), section KC, sample KC 36a

C – *Meandrospira favrei* (Charollais, Brönnimann, Zaninetti), section KO, sample KO 3a

D – *Protopeneroplis utragranulata* (Gorbatchik), section KC, sample KC4a

E – *Rumanoloculina verbizhiensis* (Dulub), section KB, sample KB 30a

F – *Andersenolina alpina* (Leupold), section KA, sample KA 1a

## 4.3. General lithostratigraphic characteristic of the southern part of the Yalta and the Ay-Petri massifs

Field studies were carried on in the southern rim of the Crimean Mts., in carbonate massifs exposed at the coast between Yalta and Simeyiz (Figs 3.1, 4.1, Tab. 3.1). This is a mountainous land characterized by steep, or even vertical, south-facing rock walls, up to several hundred meters high. To the south the walls grade into more gentle slopes descending towards the shoreline (Tab. 3.1). From the slopes numerous rock pinnacles rise. To the north the terrain evolves into a vast, karstic plateau with common depressions, sinkholes and limestone exposures.

The study area can be divided into two main parts. The first part includes the western fragment of the Yalta Massif contoured by its southern margin, which ranges from the Iograf Ridge to the Yalta-Bakhchysaray highway. In the center of the Massif the studies extend as far as to the vicinity of the Roka Peak. The second part covers the southern margin of the Ay-Petri Massif, from the Yalta-Bakhchysaray highway to the At-Bash Mountain. Northward, towards the center of the Massif, the study area extends to the Bedene-Kyr Mountain and to the Besh-Tekne Depression (Fig. 4.1).

Totally, 16 sections were completed (13 most important sequences from southern escarpment of the massifs are presented). Their location is shown in Fig. 4.1 and contained in detailed descriptions of particular sequences. Moreover, macroscopic observations and sampling were carried on between the sequences.

### 4.3.1. The KJ section (Yalta Massif, Iograf Ridge, Kimmeridgian-Tithonian-Lower Berriasian, bedded limestones)

#### LOCATION AND STRATIGRAPHY

The KJ section is located in the northeastern margin of study area (Fig. 4.1, Tab. 3.1A, B). The main part of the sequence builds the characteristic, prominent Iograf Ridge, well visible in the morphology (Fig. 4.3). The earlier studies provided general lithological and stratigraphic data (Oviechkin 1956, Leshukh *et al.*, 1999, Millev, Baraboskhin 1999, Rogov *et al.*, 2005, Krajewski, Olszewska 2007, Anikeyeva, Zhabina 2009). Among other results, sediments from the Iograf Ridge were accepted as a stratotype representative of lithology and stratigraphic position of the whole Yalta Series in the areas of the Yalta and the Ay-Petri massifs (Permayakov 1984, Leshukh *et al.*, 1999, Fig. 2.2B). Of particular importance are studies on sediments from the highest parts of the Iograf Ridge, close to the edge of karst plateau, in which ammonite fauna was found. According to Oviechkin (1956), ammonites: *Streblites oxy-pictus*

Quenst., *Perisphinctes breviceps* Quenst., *Pherisphinctes ernesti* Quenst., *Lithacoceras pseudobangei* Spath. and *Lithacoceras* cf. *spongiphilum* Moesch indicate Lower the Kimmeridgian age of the uppermost part of the sequence (cf. Rogov *et al*., 2005). These deposits grade into Tithonian sediments, which constitute the surficial part of the massif. In this part of the Yalta Massif as well as in the whole western Crimean Mts. the Jurassic ammonite fauna is still a rarity. In the study area this is the only site where ammonites were found and described. Unfortunately, data published by Oviechkin (1956) cannot be verified as his ammonite specimens are recently inaccessible (M. A. Rogov, pers. comm.). However, a part of ammonite assemblage was verified during last years. Considering foraminifer fauna disclosed in the lowermost part of the sequence, including *Aveosepta jaccardi* (Schrodt) indicative of the Upper Oxfordian-Kimmeridgian and *Everticyclammina virguliana* (Koechlin) indicative of the Kimmeridgian-Berriasian, it can be concluded that sediments from the lower part of the KJ section presumably belong to the Kimmeridgian whereas those from the uppermost parts represent mainly the Tithonian and, probably, also the Lower Berriasian, similarly to other sequences located in the upper parts of the massif (Krajewski, Olszewska 2007, cf. Anikeyeva, Zhabina 2009). Stratigraphic analysis combined with observations of tectonics prove the existence of disturbances in continuity of strata and the complicated tectonic pattern of the Iograf Ridge where the successions of sediments were tectonically repeated (see Millev, Baraboskhin 1999, V. Yudin pers. com.). Therefore, the earlier stratigraphic and lithologic data, which were the basis for establishing the stratotype of Upper Jurassic sediments in the southwestern part of the Crimean Mts. must be verified (Permyakov *et al*., 1991, 1993, Leshukh *et al*., 1999, Dorotyak 2006, 2007, cf. Millev, Baraboskhin 1999, Rogov *et al*., 2005, Krajewski, Olszewska 2006, 2007). The problem is the number of potential overthrusts and the amount of tectonic transport. In one of publications on the Yalta Massif (Millev, Baraboskhin 1999) the authors mentioned seven tectonically repeated successions but, unfortunately, they did not provide any facts, what seriously obstacles verification of their hypothesis. Taking into account field observations as well as facies and microfacies analyses, the author is in opinion that tectonically disturbed successions probably occur (also V. Yudin, pers. comm.) but their number is much lower and the cyclicity of sediments is typical of carbonate deposition. The successive appearance of similarly developed rock complexes is possible in transgressive-regressive cycles. Both the field observations and the laboratory data lead to the conclusion that the lower part of the KJ section is only insignificantly tectonically disturbed, hence, the sediments reveal a logical succession of Kimmeridgian and Tithonian ages (Fig. 4.4). The uppermost part of the KJ section, which forms broad plateau surface, belong to the Tithonian and, probably, also to the Lower Berriasian (Krajewski, Olszewska 2007, Tab. 3.1D). Taking into consideration the importance of sequence from the Iograf Ridge for traditional stratigraphy of the area (e.g., Leshukh *et al*., 1999, Anikeyeva, Zhabina 2009), the author shows the succession of sediments in a single, comprehensive column (Fig. 4.4, cf. Fig. 2.2A).


**Fig. 4.3.** The lograf Ridge, southern escarpment of the Yalta Massif. The sediments from lograf Ridge were purpose of former studies (Fig. 2.2B, e.g. Leshukh *et al*., 1999). Sediments from lower part of the lograf Ridge are also representative for the deposits below sections KM, KN, KO and KP

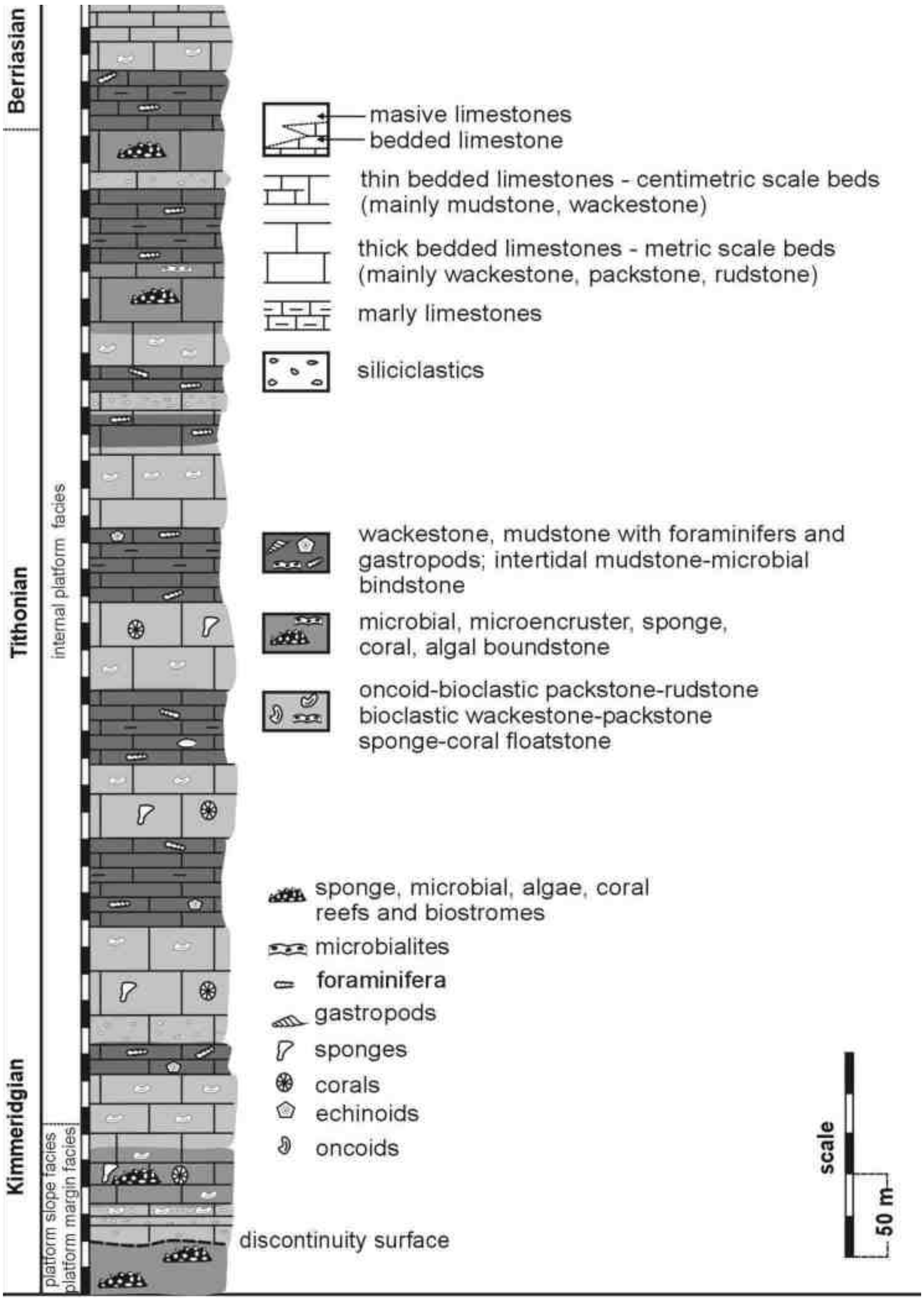


**Fig. 4.4.** Schematic lithological log of the KJ section
(Yalta Massif, lograf Ridge, bedded facies, Kimmeridgian-Tithonian-Lower Berriasian)

## MICROFACIES

The KJ section includes several rock complexes well visible in the morphology, which are composed mainly of thick-bedded and massive limestones separated by thin-bedded limestones and marly limestones (Figs 4.1, 4.3, 4.4). Several lithological varieties of limestones were identified: coral, sandy, oolitic, pelitic and marly, accompanied by sandstones (Fig. 4.4, cf. Fig. 2.2B, Leshukh *et al*., 1999, Anikeyeva, Zhabina 2009). These rock complexes continue laterally towards the northwest and northeast (Tab. 3.1A, B). Thus, the significant part of the KJ section can be representative also of adjacent fragments of the Yalta Massif. Only in the uppermost part of the sequence the sediments show higher, lateral facies variability and belong to tectonically disturbed rock complexes, as in the Iograf Ridge. Therefore, additional sections KM, KN, KP and KO were designed in the upper parts of the Yalta Massif, which belongs to the same tectonic block (Yudin 2008, Fig. 3.1).

The KJ section begins in an abandoned limestone quarry located in the lower part of the Iograf Ridge, where probably one of the mostbottom parts of Upper Jurassic succession in the whole KJ section is exposed (Fig. 4.3, Tab. 4.3A). Upper Jurassic strata rest unconformably upon Middle Jurassic ones and upon flysch sediments of the Taurid Series. Contact of both units is difficult to examine due to the cover of younger sediments gravitationally displaced from the upper portions of the massif.

Several varieties of sediments were identified in the quarry. In the lower part strongly fractured, grey and red, clotted limestones are present together with compact, massive limestones and thick-bedded limestones (Tab. 4.3A). In hand specimens abundant fauna is visible – mostly corals, accompanied by bivalves and gastropods, and cavities filled with cement (Tab. 4.3B).

Under the microscope limestones from the lower part of the sequence are bioclastic wackestones, which quickly grade into limestones with numerous corals – the main limestone variety exposed in the quarry (Tabs 4.3, 4.4). Up to date the following corals were identified: *Dimorphastraea*, *Microsolena*, *Thecosmilia*, *Montlivaltia, Bilaterocoenia* as well as Latomeandridae (E. Roniewicz, pers. comm.), which form coral-microbial biostromes.

Among the corals common is the platy *Microsolena* (Tabs 4.3C, D, 4.4A, B, 4.5 A, B). Coral skeletons are settled with abundant epifauna: serpulae, *Crescentiella morronensis* („*Tubiphytes*", Senowbari-Daryan *et al*., 2008), *Terebella lapilloides* and bivalves (Tabs 4.3D, 4.5B, 4.6D). Under the skeletons small sponges were locally observed. Sediments are bioclastic wackestones and thrombolitic bindstones (Tabs 4.4A, B, D). Bioclasts include fragments of coral skeletons as well as gastropods, brachiopods, bivalves and foraminifers occasionally with *Crescentiella morronensis* microframework (Tab. 4.5B). Microbial structures are mostly thrombolites (Tabs 4.4A, D, 4.5A, 4.6D). Moreover, fragments of coral floatstones were noticed, in which partly dissolved corals are embedded within micritic matrix.

Common constituents of studied sediments are cavities, which morphology often resembles stromatactis (Tabs 4.4B, 4.5C, 4.6A). These were found beneath the coral skeletons or in thrombolitic bindstones. Frequently, such cavities are geopetally filled with fine, occasionally graded vadose silt whereas the remaining upper parts are occupied by blocky cement. Some cavities exceed 2 cm across. Geopetal fillings show various roof directions, sometimes differing by tens of grades at the same level (Tab. 4.6A). Moreover, laminated fillings of cavities were observed with common graded lamination. Some laminated fillings reveal gradually changing dip angles of laminae (Tab. 4.6C).

Sediments dominated by *Microsolena* grade along a short distance to deposits rich in other assemblages of branched corals and sponges, including common chaetetids presumably belonging to *Chaetetopsis spengleri* (KOECHLIN), (Tabs 4.5D, 4.6B). Some of these skeletons were almost completely dissolved, which precludes their precise identification. Among corals both the *Montlivaltia* and *Thecosmilia* were identified. Their skeletons are settled by common *Crescentiella morronensis* („*Tubiphytes*", Senowbari-Daryan *et al*., 2008) accompanied by *Lithocodium aggregatum* and algae whereas thrombolites are rare. More often limestones are developed as sponge-coral floatstones-wackestones with *Lithocodium aggregatum* growing onto the skeletons rather than coral-microbial framestones with *Terebella-Crescentiella* association (Tab. 4.5D). The upper surface of the coral limestones have erosional character (Fig. 4.4).

Higher in the sequence grainstone horizons occur, developed as oncoidal packstones, rudstones and grainstones (Tabs 4.4C, 4.7C). These sediments contain various oncoids – from simple, small, oval forms to more complicated *Bacinella irregularis* ones. Cores of oncoids are usually bioclasts. At the contacts of oncoids microstylolites commonly appear (Tab. 4.7C). Apart from oncoidal grainstones, frequent are yellowish sediments with gradually increasing content of siliciclastics, initially represented by quartz grains filling the spaces between oncoids together with sparrite, then by polymictic orthoconglomerates composed of extraclasts of lithified and well-rounded grains of quartz sandstones accompanied by intraclasts and oncoids, all embedded within the quartz sand (Fig. 4.5, Tab. 4.7A, B). Moreover, pure quartz arenites were also encountered (Tab. 4.7D).

Up the sequence the sediments exposed in the quarry grade into a succession which builds the principal part of the Iograf Ridge. These are alternating complexes of light- to dark-grey or yellowish, thin-bedded limestones and marly limestones as well as thick-bedded, grey limestones.

In the entire KJ section thin-bedded limestones and marly limestones are similarly developed and are dominated by mudstones-wackestones with numerous foraminifers, small bivalves, fragments of echinoids and gastropods, occasionally also fragments of redeposited corals. Above the quarry, along the Iograf Ridge the yellowish or grey, thin-bedded limestones are exposed (Tab. 4.8A). These are bioclastic wackestones and coral-sponges floatstones (Tabs 4.8, 4.9, 4.10A). In their micritic matrix numerous fragments of redeposited corals occur, dominated by *Stylosmilia*, which skeletons are commonly dissolved (Tab. 4.8A, B). The abundance of corals resembles the biostromes but, in fact, the fossils are dispersed in carbonate mud (Tab. 4.9C). Apart from corals, also sponges were encountered (Tab. 4.9D). Typical feature of limestones from the middle parts of the KJ section is the presence of large, thick-shelled bivalves, which dark shells are perfectly visible within the grey limestone (Tabs 4.8D, 4.9A, B). These fossils are embedded in micritic matrix of a coral floatstone, together with common *Stylosmilia* (Tabs 4.8B, C, 4.9D).

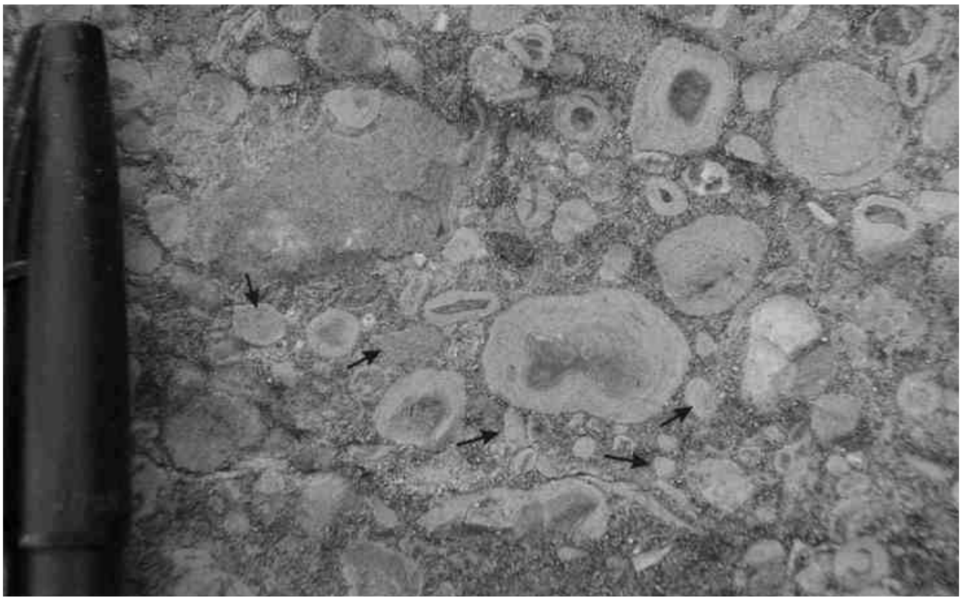

**Fig. 4.5.** Example of polymictic siliciclastic-carbonate facies from lower part of the KJ section, Iograf Ridge, quarry. Numerous oncoids and siliciclastic extraclasts (arrows) in siliciclastic matrix are visible, see also Tab. 4.7

Thick-bedded limestones observed in the higher part of the KJ section are mostly wackestones or bioclastic packstones with common, small, sponge-algal-coral patch-reefs and biostromes (Fig. 4.4, Tab. 4.12C). Skeletons are usually covered with *Lithocodium aggregatum*. Up the sequence the thick-bedded limestones grade into oncoidal packstones-bindstones, in which grains are commonly stabilized by microbial crust, and to oncoidal rudstones (Tabs 4.10B). Moreover, along the whole KJ section horizons of sandy limestones are observed with abundant fossil assemblage, mostly algae, gastropods, bivalves as well as intraclasts and skeletal fragments of sponges and corals (Tab. 4.11). In the middle and upper portions of the sequence numerous horizons of oncoidal packstones-rudstones occur (Tab. 4.12D). The oncoids are often small, oval forms with poorly marked internal structure or large *Bacinella irregularis* ones. These sediments usually grade into bioclastic wackestones or thin-bedded mudstones with numerous foraminifers (Tabs 4.12B, 4.13C). The sediments resemble those encountered in the uppermost part of the massif, at the plateau surface (Tab. 4.13A).

## INTERPRETATION

The KJ section includes several depositional sequences of diversified thicknesses and lithologies, interpretation of which brings some problems due to the tectonics (Tab. 4.13B, Millev, Baraboskhin 1999, Yudin, pers. comm.). The mostbottom part of the KJ is a single depositional cycle, which documents gradual shallowing and transition from deeper water (but still within the photic zone) through shallow-marine to siliciclastic facies.

The lower part of the KJ is represented mostly by *Microsolena*–thrombolitic limestones with common cavities resembling stromatactis (cf. Matyszkiewicz 1997), by sponge-coral limestones as well as by a complex of oncolitic and siliciclastic sediments. The sequence begins with a number of coral-microbial biostromes. Abundance of corals *Dimorphasraea* and *Microsolena* with thrombolites and *Crescentiella morronensis* indicates deposition in the lower parts of platform slope, at depth up to some ten of meters, under mesotrophic conditions and at low deposition rate (e.g., Nose 1995, Insalco 1996, Insalco *et al* 1997, Leinfelder *et al*., 1996, Dupaz, Strasser 1999, Morycowa, Roniewicz 2005, Lathuilière *et al*., 2005, Roniewicz 2008). Up the sequence both platy and branched corals appear, which may suggest their optimal deposition environment under oligotrophic, gradually shallowing conditions (Lathuilière *et al*., 2005, Roniewicz 2008). The latter is confirmed by numerous sponges and *Lithocodium aggregatum*. Larger percentage of grainstones and redeposited fragments indicate more higher-energy conditions. Such sediments can be attributed to the upper slope followed by low energy, barrier environment. Up this part of the sequence frequent become siliciclastic sediments and conglomerates composed of cemented sand fraction, oncoids and in-traclasts. Such material originated from terrestrial sources and erosion of bedrocks during regression and emergence.

Up the KJ section the sediments are dominated by deposits of back-reef, open and restricted lagoon. Limestones are usually oncoidal packstones, bioclastic wackestones and mudstones typical of the internal platform. Moreover, the horizons of *Stylosmilia*-sponge floatstones indicate low-energy conditions of open lagoon. These sediments represent several depositional sequences perhaps partly disturbed by later tectonics. Despite macroscopic similarity, microfacies analysis revealed that in some cases the same successions were tectonically repeated but the others consist of succeeding depositional cycles, tectonically displaced on small scale.

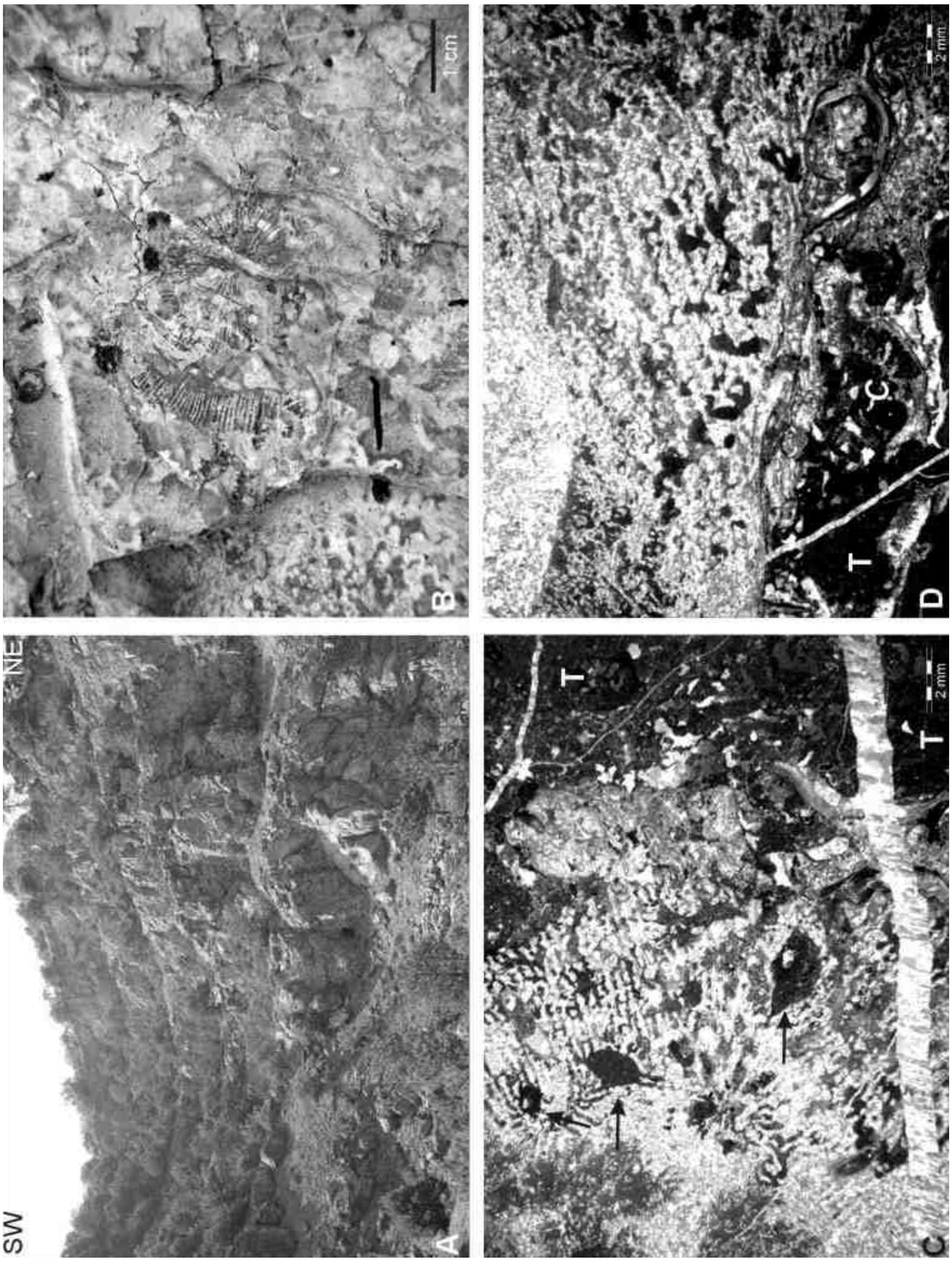
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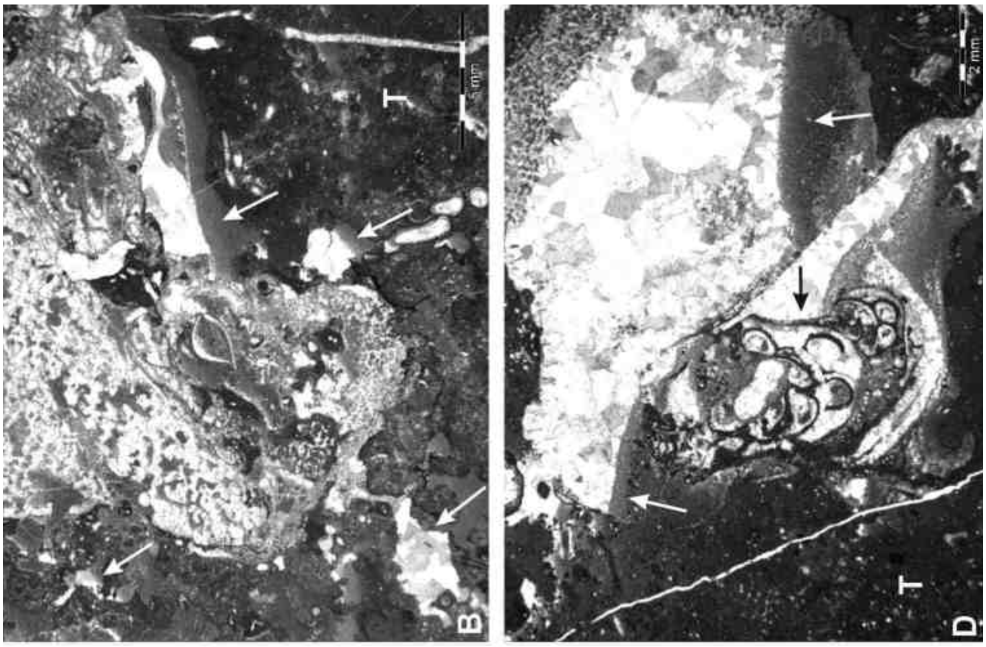
**Table 4.3.** Views and examples of microfacies from lower part of the KJ section, Yalta Massif, Iograf Ridge, quarry, bedded coral-thrombolite biostromal limestones, Kimmeridgian-Tithonian

A – The quarry in the lower part of the Iograf Ridge. In the lower part of the quarry coral-microbial biostromes can be observed; above appears erosional surface and oncoidal and siliciclastic facies

B – Coral-microbial biostromes from the lower part of the quarry; in the central part of the photo *Montlivaltia* sp.; on the left, fragment of Latomeandridae

C – *Microsolena*-thrombolite (T) framestone with numerous borings (arrows), sample KJ 1a

D – *Microsolena*-thrombolite framestone with *Crescentiella morronensis* (*C*), sample KJ 2a



A
B
C
D
T
5 mm
2 mm

**Table 4.4.** Examples of microfacies from lower part of the KJ section, Yalta Massif, Iograf Ridge, quarry, bedded coral-thrombolitic biostromal facies, Kimmeridgian-Tithonian

A – Coral-thrombolite (T) framestone with small growth cavities are visible (arrow), sample KJ 1b

B – *Microsolena*–microbial framestone. On the lower part of the coral numerous epifauna. In thrombolite, small growth and stromatactis-like cavities with geopetal infillings are visible (arrows), sample KJ 2e

C – Oncoidal packstone-rudstone with numerous bioclasts and deformed *Bacinella* oncoids with microstylolites among grains (white arrows), sample KJ 5a

D – Coral-microbial biostromes. In the central part dissolved coral with epifauna (black arrow). The corals are replaced by internal sediment (white arrows) and blocky cement, sample KJ 3e

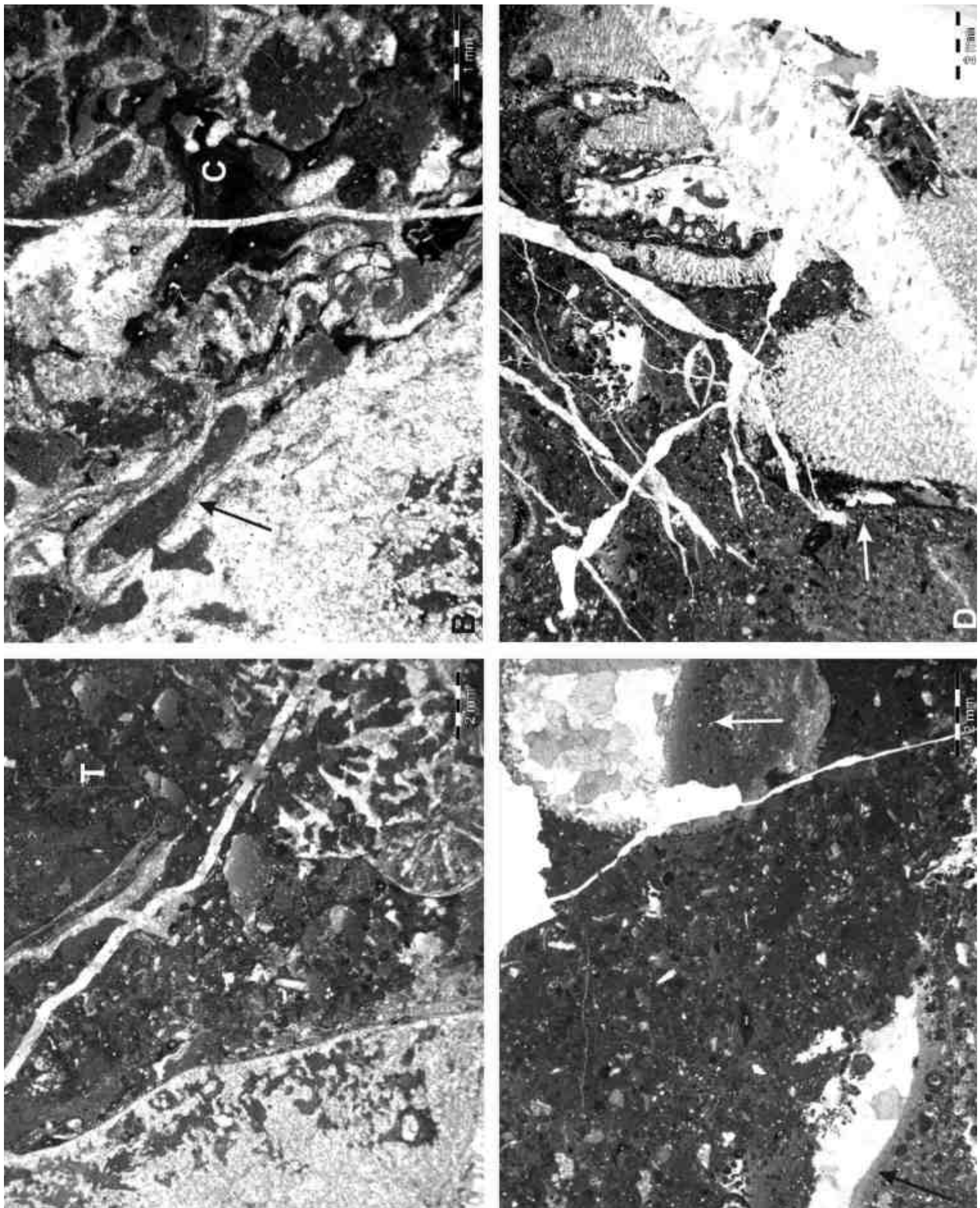

A
B
C
D

**Table 4.5.** Examples of microfacies from lower part of the KJ section, Yalta Massif, Iograf Ridge, quarry, coral-thrombolitic biostromal facies, Kimmeridgian- Tithonian

A – Coral-microbial framestone; different species of corals and thrombolites (T) forming biostromes, sample KJ 1b

B – Coral-microbial framestone; on the coral surfaces numerous epifauna are represented; on the right side, *Crescientella*-cement microframework (C), sample KJ 2c

C – Coral-microbialite floatstone with geopetal infilled stromatactis-like caverns (black arrow) and dissolved corals (white arrow), sample KJ 3b

D – Sponge baundstone; on the surfaces of the sponges *Lithocodium* are visible (arrow), sample KJ 3c

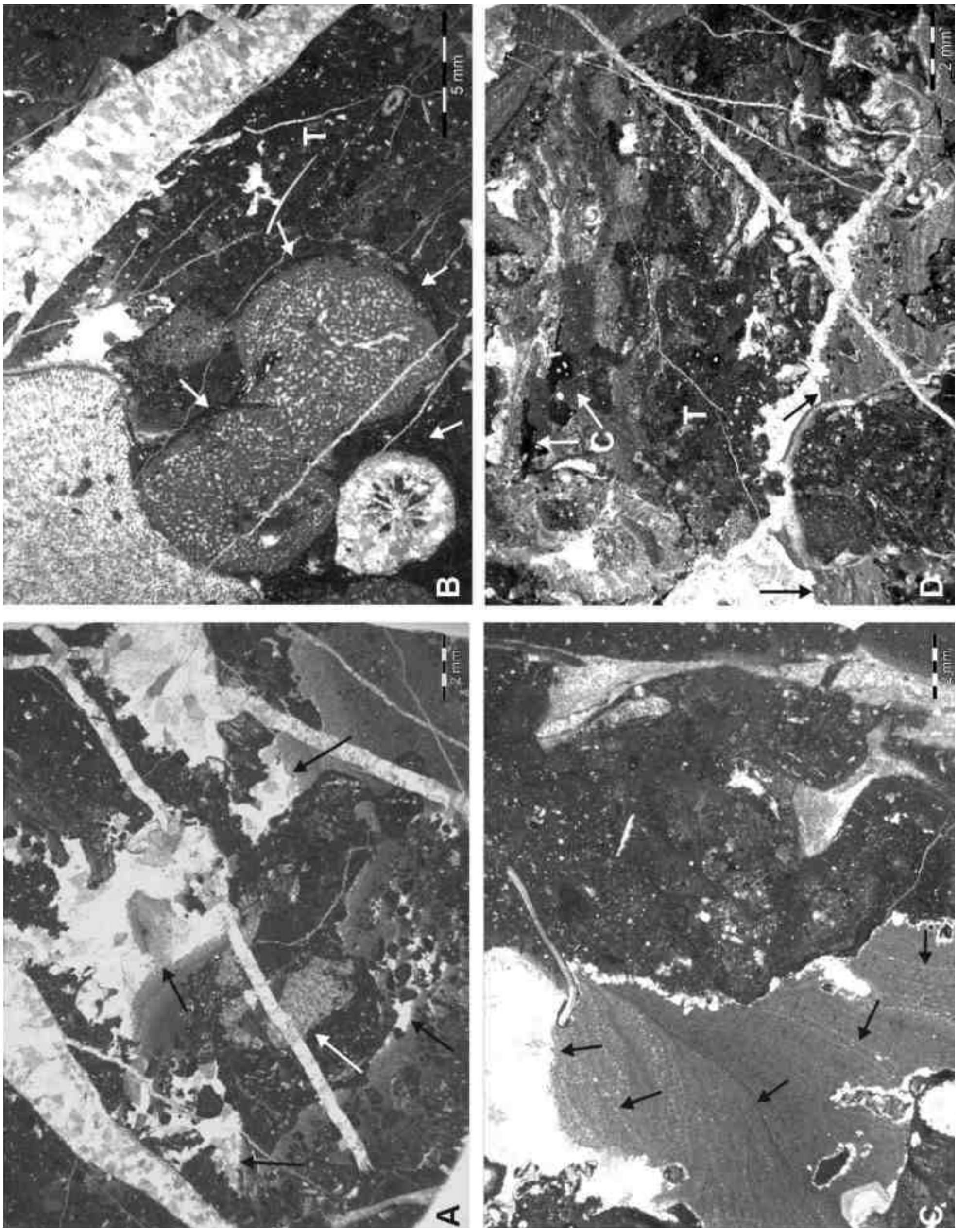

A
B
C
D
T
C
T
5 mm
2 mm
2 mm

**Table 4.6.** Examples of microfacies from lower part of the KJ section, Yalta Massif, Iograf Ridge, quarry, coral biostromal facies, Kimmeridgian-Tithonian

A – Coral-microbial biostrome; numerous cavities with geopetal infillings are visible; the directions of the infillings are different (arrows), sample KJ 3f

B – Coral-sponge-microbial framestone; fragments of sponges (?*Cyliocopsis*) and coral can be observed; on the surfaces of the fauna microencrusters are visible (arrows); on the right side second bed of the thrombolite (T), sample KJ 3i

C – Coral-microbial biostrome; caverns with laminated infillings with different, gradually changed, directions (arrows), sample KJ 4d

D – Thrombolit (T)-*Crescientella* (C-white arrows) bindstone with gepetal infilled caverns (black arrows), sample KJ 9c

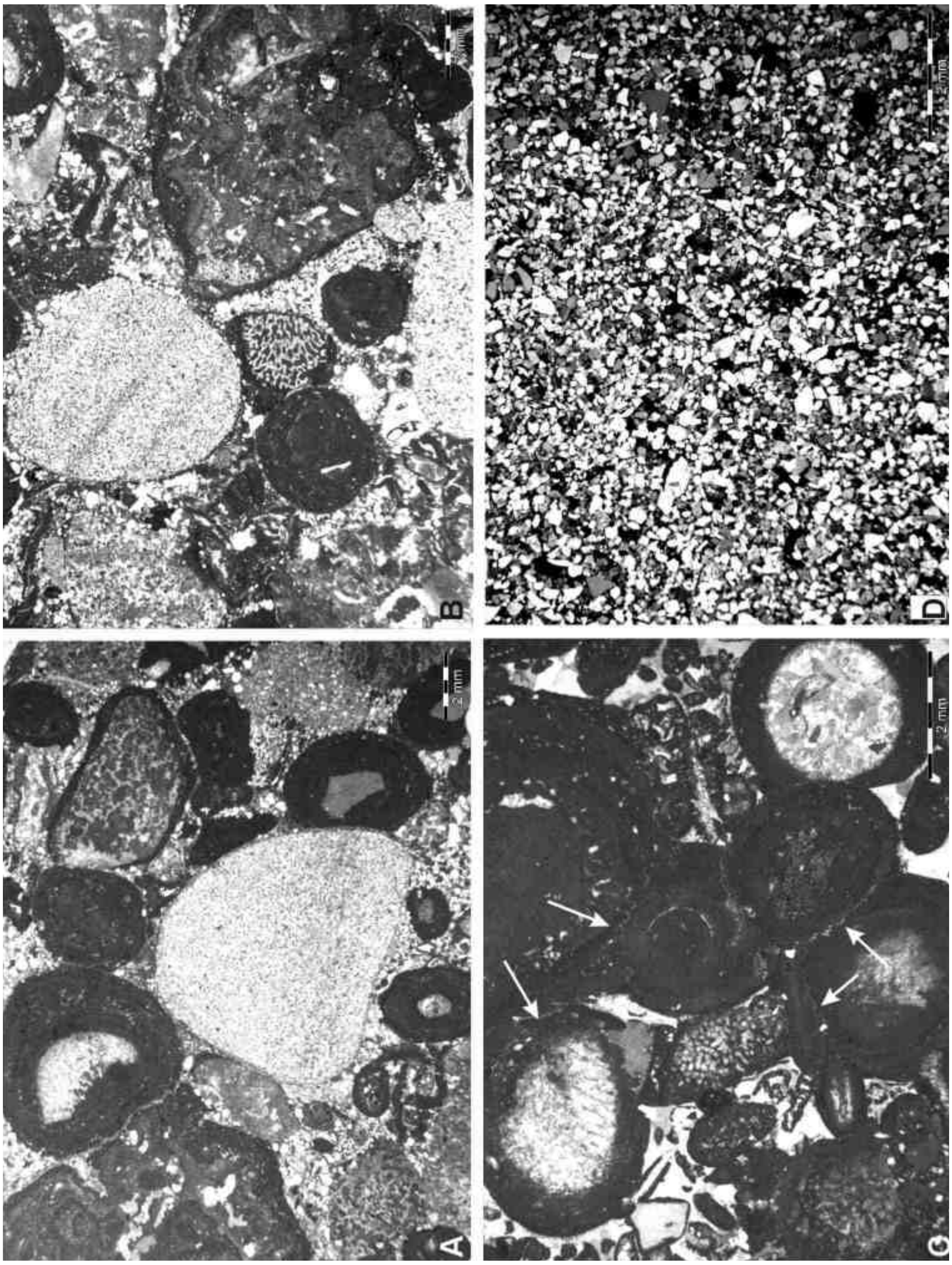
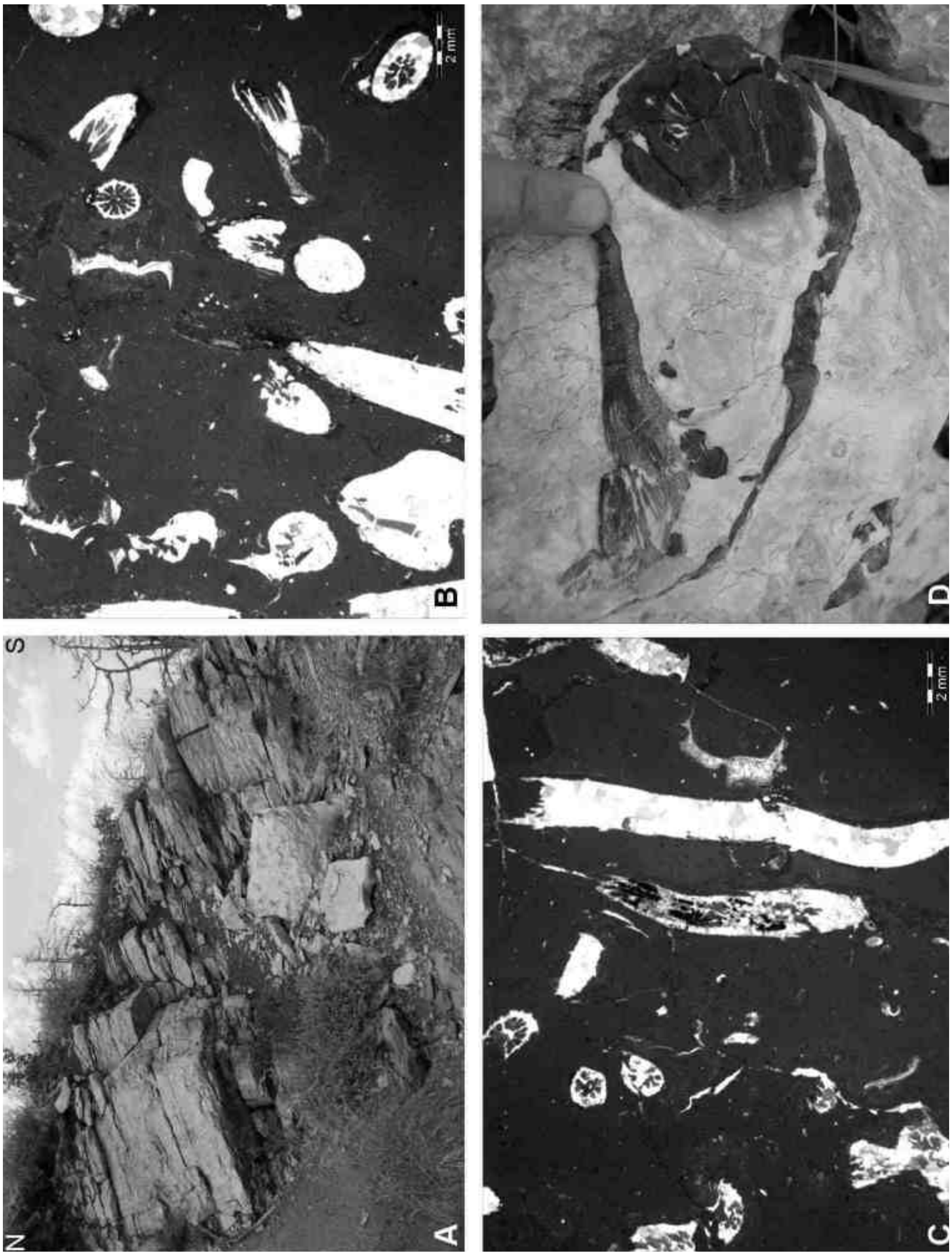

A
2 mm
B
C
2 mm
D

**Table 4.7.** Examples of microfacies from lower part of the KJ section, Yalta Massif, Iograf Ridge, quarry, bedded facies, Kimmeridgian-Tithonian

A, B – Mixed carbonate-siliciclastic sediments with numerous oncoids, intraclasts and siliciclastic extraclasts, sample KJ 8a, KJ 8b

C – Mixed oncoidal-siliciclastic grainstone-rudstone. Numerous deformed oncoids with microstylolites among grains (arrows) are visible,  sample KJ 5a

D – Sandstone. The material orginated from erosion older sandstones (probably Triassic-Middle Jurassic sediments), sample KJ 7



N
S
A
B
2 mm
C
2 mm
D

**Table 4.8.** Vievs and examples of microfacies from middle part of the KJ section, Yalta Massif, Iograf Ridge, bedded facies, Tithonian

A – Outcrop of the bedded limestones from the middle part of the Iograf Ridge presented in the photos B, C, D and Tab. 4.9

B, C – Coral floatstone with numerous fragments of partly dissolved *Stylosmilia*, samples KJ 11a, KJ 11d

D – Fragment of the bedded limestones with large bivalves

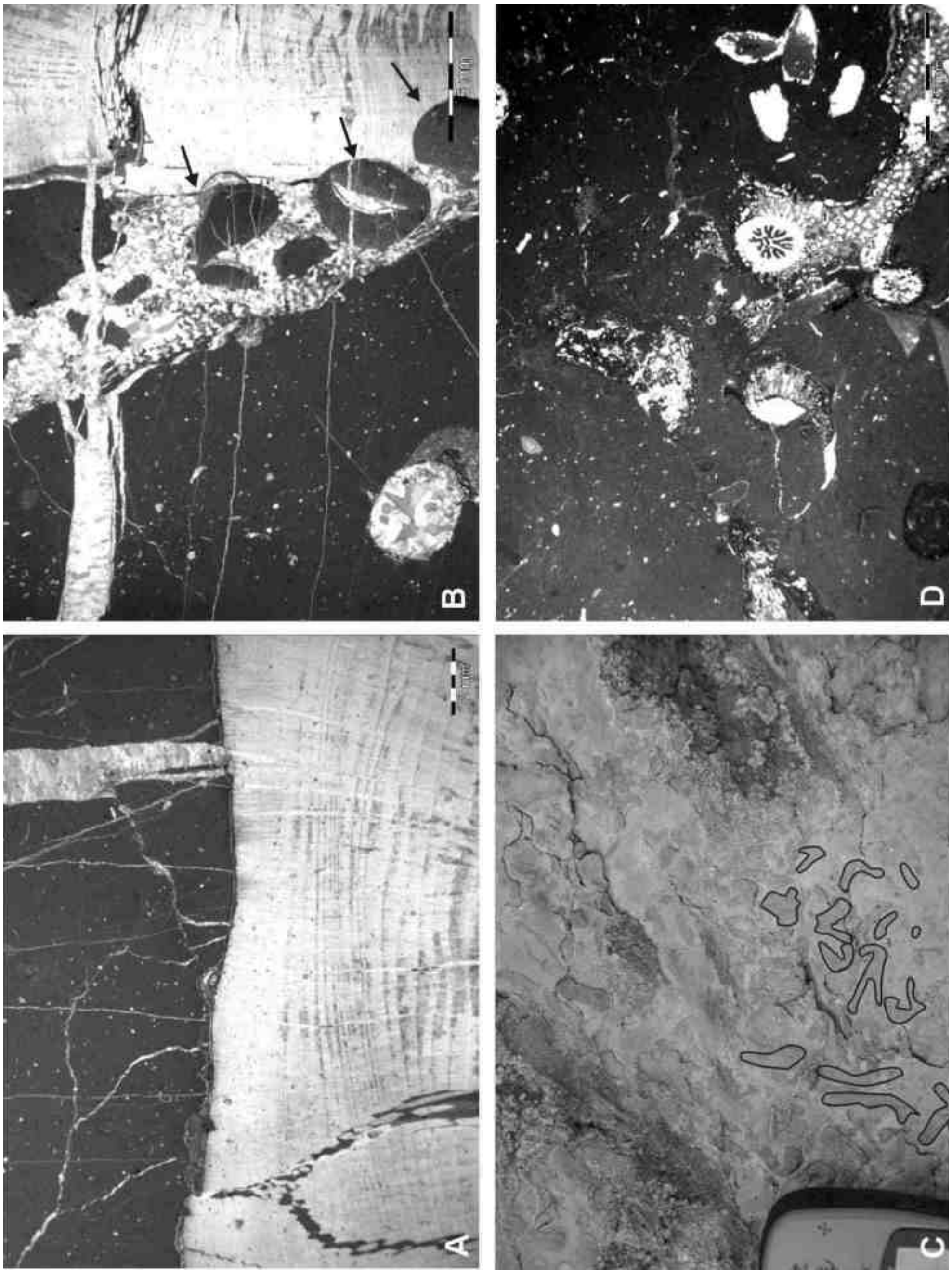

A
B
C
D

**Table 4.9.** Examples of microfacies from middle part of the KJ section, Yalta Massif, Iograf Ridge, bedded facies, Tithonian

A – Mudstone-coral floatstone with fragment of bivalve, sample KJ 17

B – Coral floatstone; on the surfaces of the bivalves numerous epifauna and borings can be observed, sample KJ 17b

C – Fragment of the outcrop of coral-sponge floatstone with numerous displaced fauna. Some of the fauna are underlined for better view

D – Coral-sponge floatstone presented in photo C. Most of the fauna are dissolved and displaced; besides corals numerous fragments of sponges (?*Actinostromaria*), sample KJ 16b

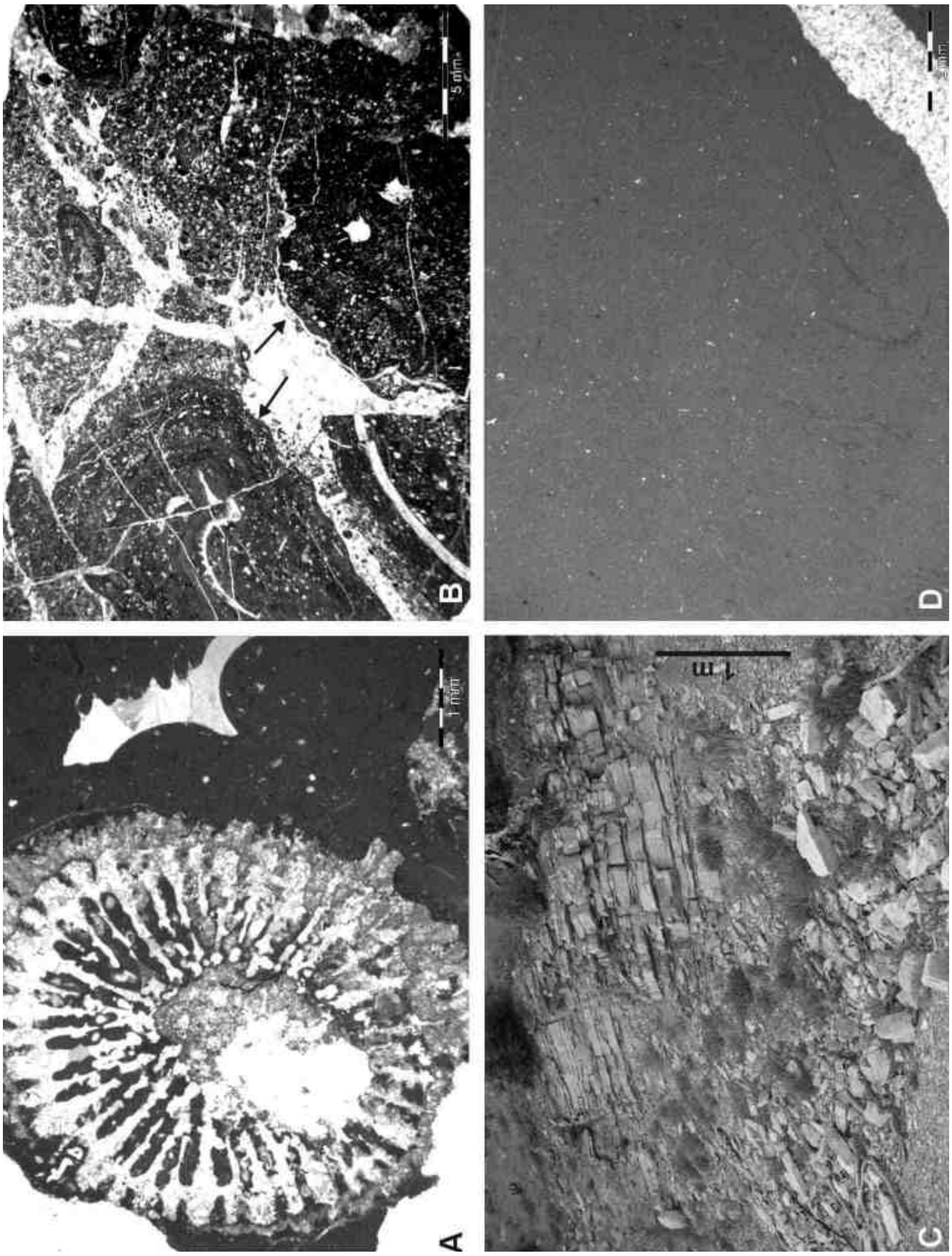

A
1 mm
B
5 mm
C
1 m
D

**Table 4.10.** Examples of microfacies from middle part of the KJ section, Yalta Massif, Iograf Ridge, bedded facies, Tithonian

A – Coral floatstone, sample KJ 16c

B – *Bacinella* oncoid (arrows) rudstone-packstone, sample KJ 20

C – Fragment of the outcrop with thin bedded limestone

D – Mudstone, sample KJ 22

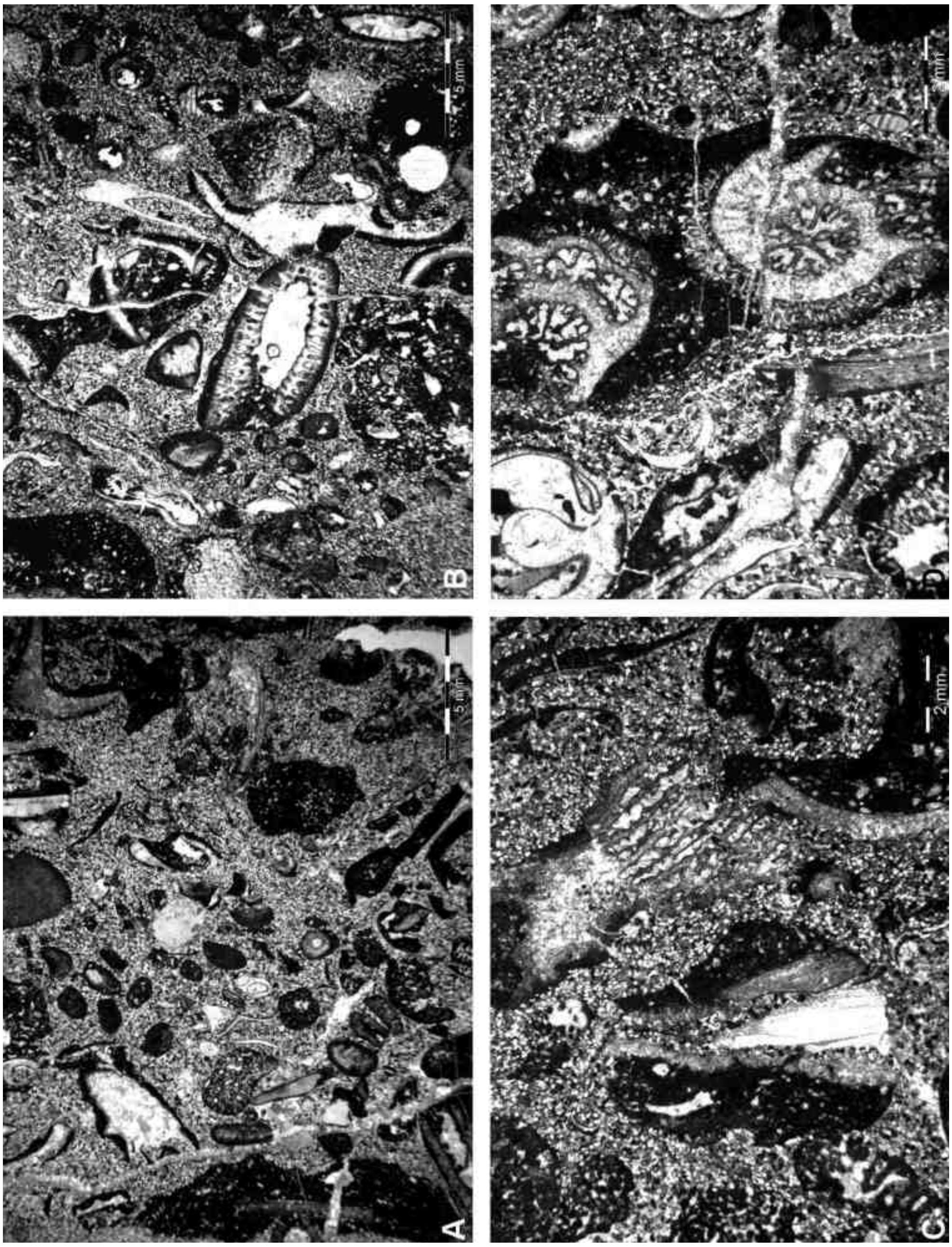

B
5 mm
D
A
5 mm
C
2 mm

**Table 4.11.** Examples of microfacies from upper part of the KJ section, Yalta Massif, bedded facies, Tithonian

A–D – Sandstones with numerous fragments of dasycladalean green algae, gastropods, corals, sponges and bivalves, sample KJ 23a, KJ 23b, KJ 23e, KJ 23e

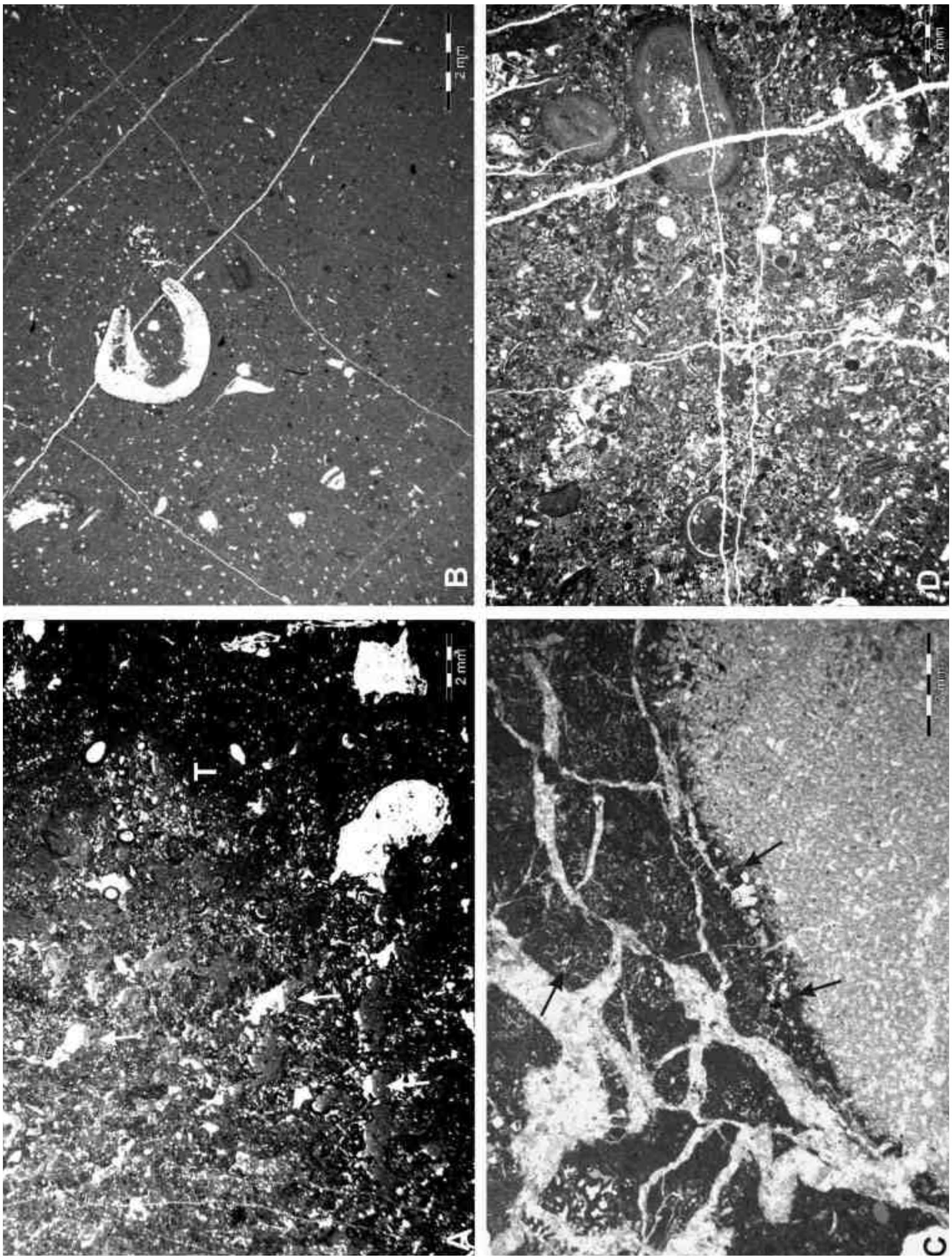

B
2 mm
D
2 mm
A
T
2 mm
C

**Table 4.12.** Examples of microfacies from upper part of the KJ section, Yalta Massif, bedded facies, Tithonian

A – Thrombolitic (T) bindstone with numerous small gepetal infilled growth caverns (arrows), sample KJ 25a

B – Bioclastic wackestone-mudstone with foraminifers, sample KJ 28

C – Sponge floatstone-packstone with *Lithocodium aggregatum* (arrows), sample KJ 30a

D – oncoidal-bioclastic packstone, sample KJ 40

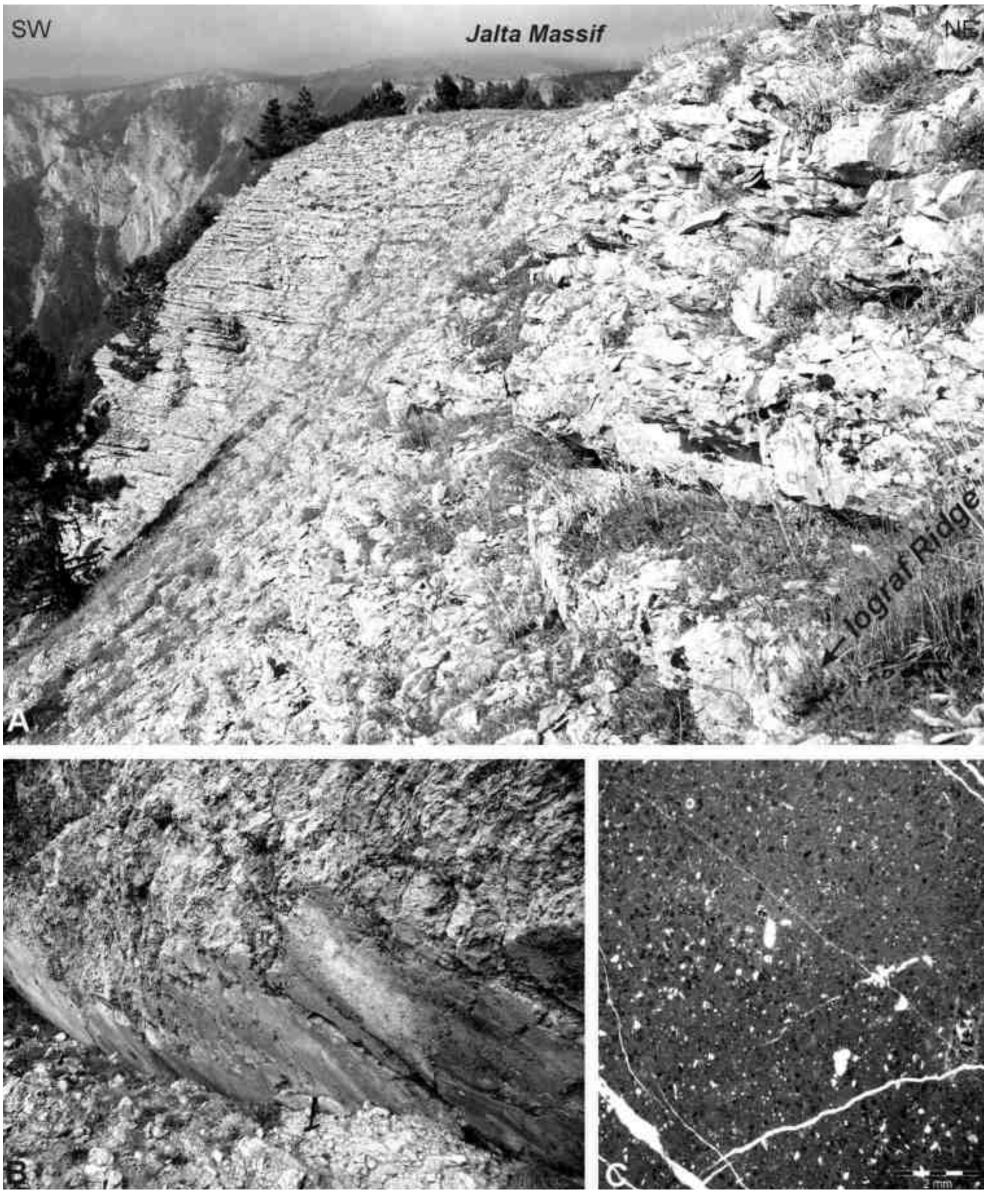

SW
Jalta Massif
NE
Iograf Ridge
A
B
C
2 mm

**Table 4.13.** Upper part of the Iograf Ridge; KJ section, Yalta Massif, Tithonian-Lower Berriasian

A – thin-bedded limestones on the border between Iograf Ridge and Yalta Massif plateau

B – Tectonic surfaces in the upper part of Iograf Ridge

C – Foraminiferal mudstone from the upper part of the KJ sequence, sample KJ 38

### 4.3.2. The KK section (Yalta Massif, Plateau, Tithonian-Lower Berriasian, bedded limestones)

#### LOCATION AND STRATIGRAPHY

The KK section is located on the plateau of the Yalta Massif and is a northern extension of the sequence located at the Iograf Ridge (Fig. 4.1, Tab. 3.1D). Sediments are mostly grey, thin-bedded limestones, which appear in morphology as characteristic rock steps, from several centimeters to several meters high. All sediments dip at low angle (10~15º) to the north (Tab. 3.1D).

The KK section begins with sediments already described from the crest of the Iograf Ridge. According to Oviechkin (1956), ammonites indicate that sediments from the uppermost part of the sequence represent the Lower Kimmeridgian and grade up the sequence into the Tithonian strata, which occupy the upper part of the plateau (see also Rogov *et al*., 2005). Studies on foraminifer assemblage provide additional information (Krajewski, Olszewska 2007). The following species were identified: *Troglotella incrustans* (Kimmeridgian-Berriasian), *Palaeogaudrina magharaensis* (Late Kimmeridgian-Middle Berriasian), *Nautiloculina oolithica* (Late Oxfordian-Berriasian), *Everticyclammina kelleri* (Berriasian-Valanginian) and *Anchispirocyclina lusitanica* (Tithonian-Earliest Berriasian, Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985, Anikeyeva, Zhabina 2009). Hence, it is concluded that studied strata represent the Tithonian/Berriasian break.

#### MICROFACIES

Macroscopically, the limestones are monotonous, mostly pelitic or detrital, locally clotted (Tab. 3.1D). Fossils include gastropods and small bivalves. Thin-bedded limestones are usually pelitic whereas thicker beds are mostly fine- to coarse-detrital limestones accompanied by the pelitic ones. Generally, limestones varieties differ only in thickness of the beds. Similar succession was observed along the total length of the KK section. As both the field observations and microfacies analysis point out to depositional cyclicity, the description was limited to a set of thick-bedded limestones, and enveloping, thin-bedded ones. The only difference between various sets of beds along the KK section is their thickness and proportions between specific microfacies varieties.

Under the microscope the thin-bedded limestones developed as mudstones do not show essential variability in any part of the KK section (Tabs 4.14A, 4.15C, D). In a micritic matrix small bioclasts can be locally encountered and fossil assemblage consists almost exclusively of foraminifers.

In the transitional zone from thin-bedded to thick-bedded limestones gradual increase of various bioclasts and grains is observed (Tabs 4.14C, 4.15B, C). Common are fine-detrital packstones composed of numerous bioclasts, peloids and small oncoids. Bioclasts are usually foraminifers, fragments of thin-shelled bivalves, echinoderms and rare fragments of sponges and corals. These sediments grade into floatstones-packstones-rudstones with numerous oncoids (Tabs 4.14B, D, 4.15A). Two types of oncoids were distinguished: (i) fine, oval forms up to 0.5 mm across, having nuclei composed usually of fine bioclasts or entirely micritized and (ii) large (usually 8–15 mm across) *Lithocodium-Bacinella* oncoids (porostromate oncoids, Peryt 1981, Flügel 2004) which sometimes form floatstones-rudstones (Tab. 4.14B, D). Surfaces of oncoids are irregular and wavy. Laminated cortex is composed of dark, micritic laminae and *Bacinella irregularis,* and *Lithocodium aggregatum* microencrusters (Tab. 4.15A).

**INTERPRETATION**

Results of microfacies analysis enabled to relate the KK sediments to the lagoon, internal platform environment. Limestones developed as mudstones with foraminifer fauna constitute limits of the sequence. Packstones composed of fine, concentric oncoids indicate somewhat higher energy of the environment. Rudstones-floatstones with *Lithocodium-Bacinella* oncoids are products of low-rate deposition in a shallow subtidal environment during the maximum submergence and high sea level (cf. Peryt 1981, Flügel 2004, Védrine *et al*., 2007, Rameil *et al*., 2010). The final members are peloidal wackestones with small oncoids and foraminifers. Locally, within a single bed variability can be observed in development of oncoids, from small, oval to *Bacinella irregularis* forms, which may suggest minute changes in hydrodynamics of sedimentary environment.

Particular depositional sequences document frequent but minor changes in sea level, which played important role in the opening or the closure of intra-platform areas and strongly modified depositional environment (e.g. Dupraz, Strasser 1999, Strasser *et al*., 1999). In the monotonous sequences, as e.g., the KK, oncoids are particularly important for determining the succession of changes in sedimentary environment. Both the growth and the distribution of oncoids are related to the changes of sea level and climate (Peryt 1981, Flügel 2004, Védrine *et al*., 2007). Most important environmental parameters are: deposition rate, water energy, depth and trophic conditions (Flügel 2004). Of particular importantance are changes of sea level, which affect the growth of specific types of oncoids. Sea level changes, in turn, cause the opening or the closure of lagoon zones and, consequently, modify the sedimentary environment by changing water energy, temperature, salinity and deposition rates.

The *Bacinella* oncoids grew in the periods of maximum submergence and high sea level, under the low-energy conditions of deeper environment but still within the range of the photic zone. Diversified morphology of the platform was responsible for patchy distribution of oncoids. *Bacinella* oncoids point out to clear water and oligotrophic conditions. Other controlling factors of oncoids growth are water transparency and trophic level, both dependent on, among others, the terrigenous influx.

The sediments described from the KK section form several, succeeding depositional sequences characterized by similar development, which indicates cyclicity of deposition. Observations made in the KL, KM, KN and KD sections located on the plateau and in the higher parts of the southern edge of the massif as well as the results of studies on controlling samples collected between the sequences reveal similar development of sediments, on the contrary to strata encountered in the south-facing walls of the Yalta and the Ay-Perti massifs, where frequent facies changes and diversified microfacies development were found.

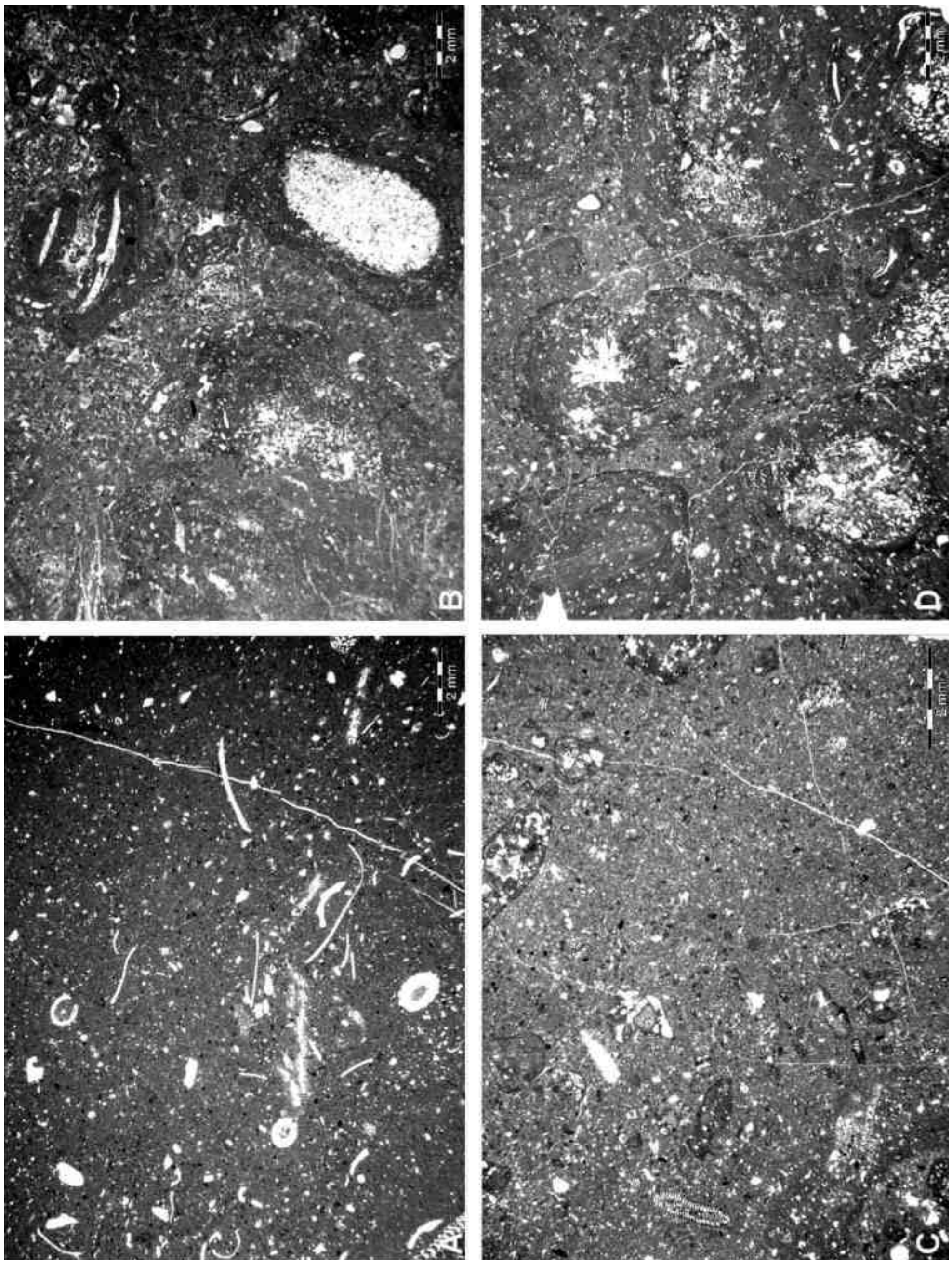

B
2 mm
D
2 mm
A
2 mm
C
2 mm

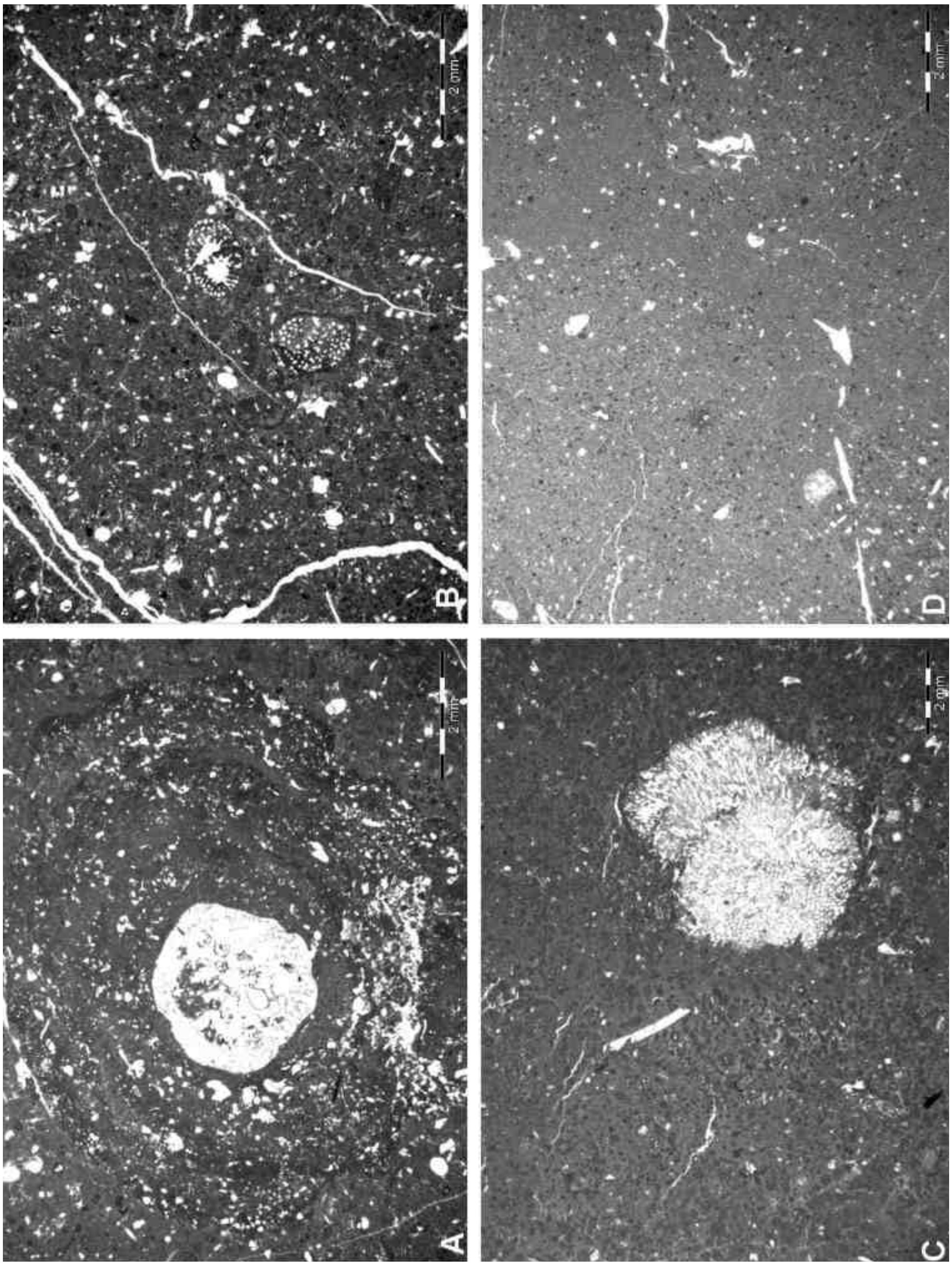
**Table 4.14.** Examples of microfacies from KK section, Yalta plateau, bedded facies, Tithonian-Lower Berriasian

A – Bioclastic wackestone-mudstone with *Anchispirocyclina lusitanica*, sample KK 1

B – Oncoidal rudstone, sample KK 3a

C – Mudstone-foraminiferal wackestone, sample KK 7a

D – Oncoid packstone-rudstone. Among numerous oncoids occur large *Bacinella* oncoids, sample KK 5b



A
B
C
D
2 mm

**Table 4.15.** Examples of microfacies from KK section, Yalta plateau, bedded facies, Tithonian-Lower Berriasian

A – *Bacienella* oncoid, sample KK 7b

B – Foraminiferal wackestone-packstone, sample KK 9

C – Bioclastic wackestone with numerous peloids, sample KK 2a

D – Mudstone, sample KK 12

### 4.3.3. The KM section (Yalta Massif, Tithonian-Lower Berriasian, bedded limestones)

**LOCATION AND STRATIGRAPHY**

The KM section embraces sediments which form middle and highest parts of the Yalta Massif, between the Iograf Ridge and the Taraktysh Rocks (Fig. 4.1, Tab. 4.16A). The underlying sediments are lateral extensions of lithological varieties observed in the lower parts of the Iograf Ridge described in the KJ section.

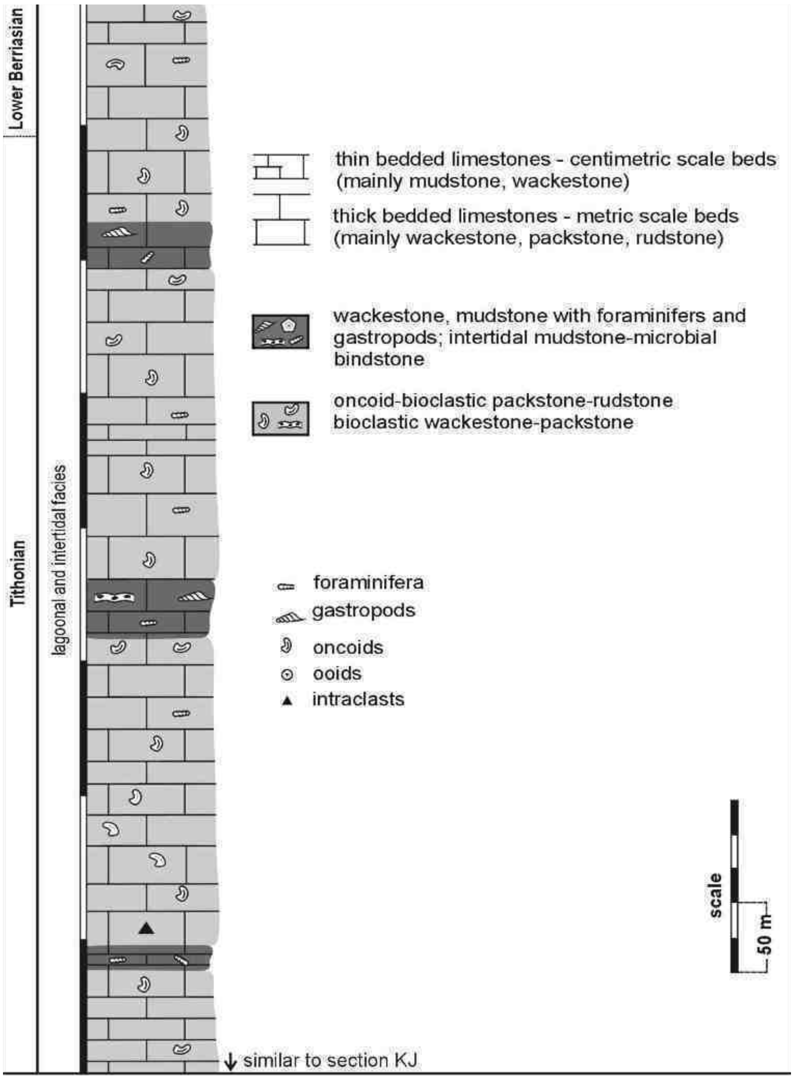



**Fig. 4.6.** Schematic lithological log of the KM selection
(Yalta Massif Tithonian/Berriasian boundary, bedded limestones)

The sediments are light- or dark-grey, mostly thin-bedded, rarely thick-bedded limestones (Fig. 4.6, Tab. 4.16A). These rocks build south-facing, vertical walls of the Yalta Massif. Horizontally, the limestones grade into thin-bedded limestones observed in the crest parts of the Iograf Ridge (Tab. 4.16B).

Foraminifers observed in studied sediments are identical with those found in both the KN and KJ sections, and represents the Tithonian/Berriasian break. Typical are *Amijella amiji* (Tithonian-Berriasian) and *Anchispirocyclina lusitanica* (Tithonian-Earliest Berriasian, Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985).

**MICROFACIES**

Macroscopic observations showed the dominance of pelitic or fine-detrital sediments varying in thickness of beds. Under the microscope several complexes can be distinguished, composed of bioclastic wackestones and oncoidal packstones, rarely rudstones.

Similar to other sequences, the microfacies reflect the macroscopic features of sediments. Thin beds (from a dozen to some tens of centimeters) are wackestones (Tab. 4.17A). Among bioclasts the fragments of bivalve shells prevail. On the contrary, thick-bedded limestones are more diversified. Several types of packstones can be distinguished, mostly fine-detrital, peloidal packstones and poorly sorted oncoidal packstones (Tabs 4.17, 4.18). Oncoids are dominated by small forms of hardly visible internal structure. Their nuclei are usually fine bioclasts. Common are large *Bacinella* oncoids, sometimes forming the rudstones (Tabs 4.17D, 4.18A). These forms reveal complicated but well-visible internal structures produced by *Bacinella irregularis*. Their morphology is diversified and irregular. On the upper surfaces of *Bacinella* oncoids *Lithocodium aggregatum* was often observed. Fossils are represented by bivalves and very abundant foraminifers, particularly *Anchispirocyclina lusitanica* (Krajewski, Olszewska 2007).

**INTERPRETATION**

Basing on both the fossil assemblage and the microfacies, sediments from the KM section can be interpreted as products of internal platform deposition laid down in a low-energy lagoon with sporadic episodes of somewhat higher-energy conditions. Cyclicity of sediments from thin-bedded wackestones to oncoidal packstones probably indicates cyclic bathymetric changes as a main controlling factor of deposition. Sediments were deposited in a shallow-water environment, within the photic zone. The presence of *Lithocodium-Bacinella* oncoids documents low deposition rates in the open lagoon, low-energy environment subjected to oligotrophic conditions during the rising sea level (e.g. Leinfelder *et al.*, 1996, Dupraz, Strasser 1999, Flügel 2004, Rameil *et al.*, 2010).

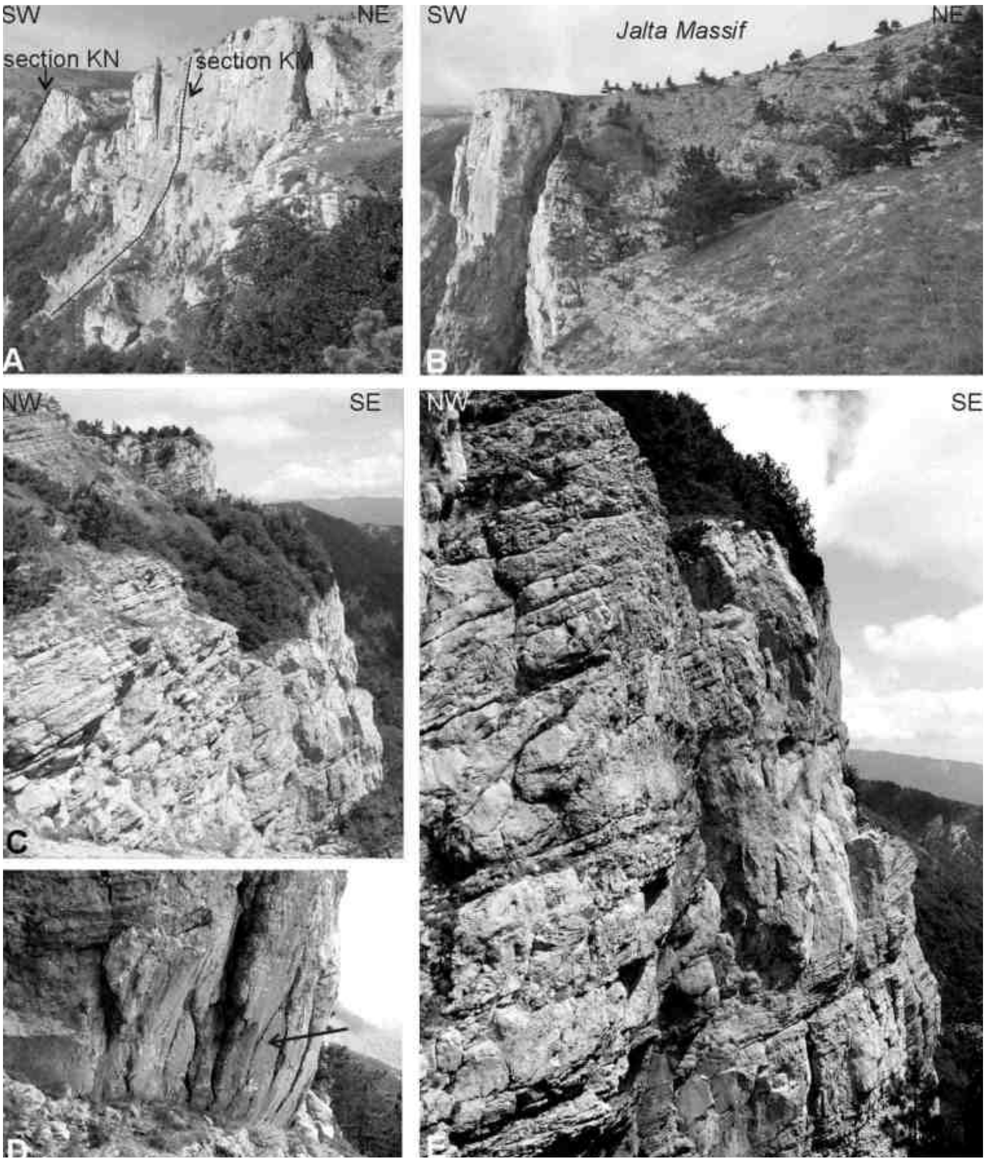

SW
NE
section KN
section KM
A
SW
Jalta Massif
NE
B
NW
SE
C
D
NW
SE
E

**Table 4.16.** Vievs of the study area from the upper part of Yalta Massif, Tithonian/Berriasian boundary

A – Location of the sections KM and KN; upper part of the southern escarpment of the Yalta Massif

B – Thin bedded limestone represents wackestone-mudstone to the south-west, gradually pass into thick bedded oncoidal-bioclastic limestone; upper part of the southern escarpment of the Yalta Massif

C, E – Thin and thick bedded limestones observed in KN section

D – Outcrops (KN section) with vertical fault observed along section KN (arrow)

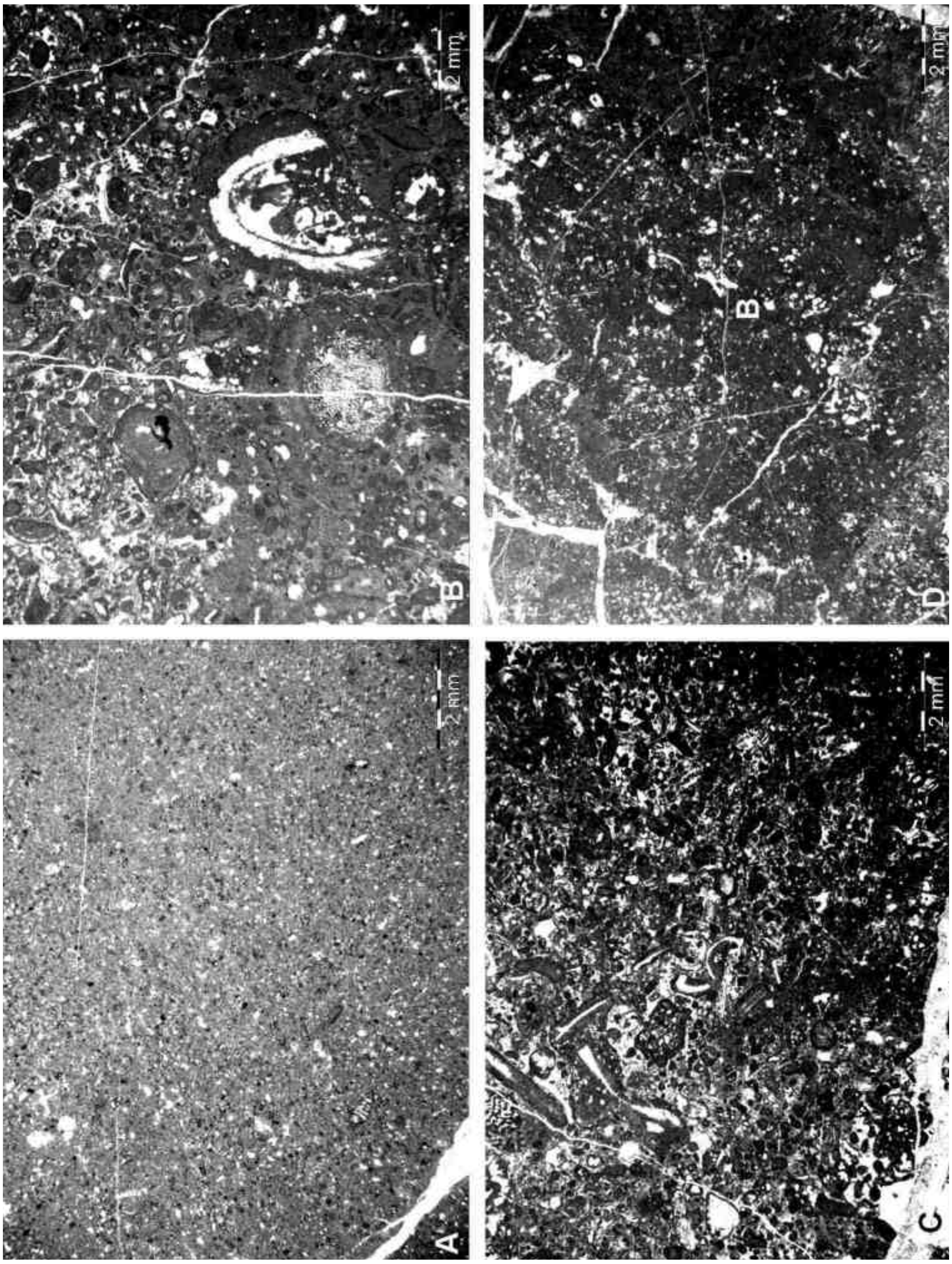

A
2 mm
B
2 mm
B
C
2 mm
D
2 mm

**Table 4.17.** Examples of microfacies from KM section, Yalta Massif, bedded facies, Tithonian-Lower Berriasian

A – Mudstone-foraminiferal wackestone, sample KM 12

B, C – Bioclastic packstone with oncoids and foraminifers, samples KM 1, KM 14

D – Oncoidal rudstone with large *Bacinella* oncoids, sample KM 16

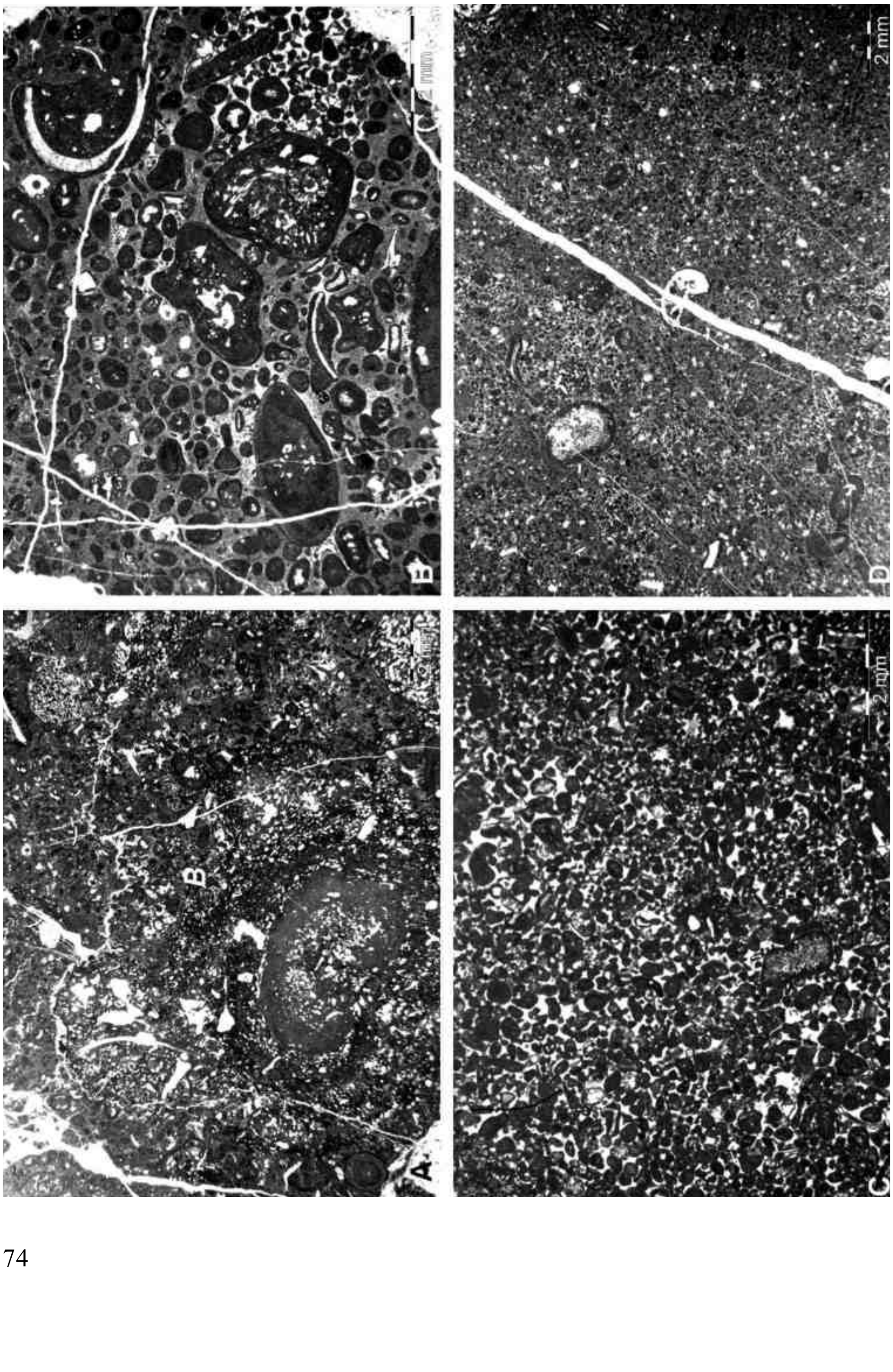

A
B
C
D
2 mm
2 mm

**Table 4.18.** Examples of microfacies from KM section, Yalta Massif, bedded facies, Tithonian-Lower Berriasian

A – *Bacinella* (*B*) rudstone, sample KM 17

B – oncoidal-bioclastic packstone, sample KM 18

C – peloidal-bioclastic packstone, sample KM 2

D – peloidal-bioclastic packstone-wackestone with foraminifers, sample KM 6

### 4.3.4. The KN section (Yalta Massif, Tithonian-Lower Berriasian bedded limestones)

**LOCATION AND STRATIGRAPHY**

The KN section was located at the southern edge of the Yalta Massif, in one of typical, south-trending gullies (Fig. 4.1, Tab. 4.16C, D, E). Detailed observations were made in the upper parts of the Yalta Massif whereas in its lower parts only the controlling samples for microfacies studies were collected. The thickness of sequence reaches about 120 meters (Fig. 4.7).

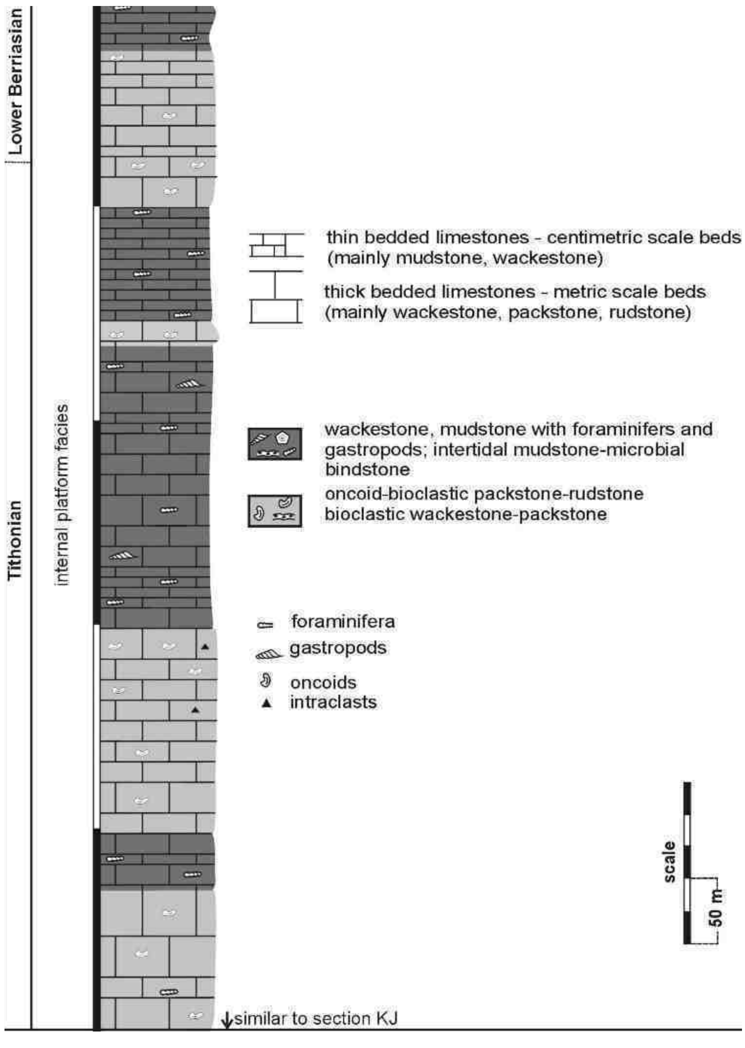



**Fig. 4.7.** Schematic lithological log of the KN selection
(Yalta Massif, Tithonian/Lower Berriasian, bedded limestones)

The underlying strata were identified as limestones from the lower parts of the Iograf Ridge (see the KJ section), as revealed by macrosco-pic observations and controlling samples.

In the KN sediments several foraminifers were identified: *Paleogaudryina magharaensis* (Late Kimmeridgian-Middle Berriasian), *Everiticyclammina kelleri* (Kimmeridgian-Tithonian), *Dobrogelina ovidi* (Berriasian-Valanginian), *Amijella amiji* (Liassic-Berriasian), *Anchispirocyclina lusitanica* (Tithonian-Earliest Berriasian, Krajewski*,* Olszewska 2007, cf. Kuznetsova, Gorbachik 1985). Therefore, it is concluded that the lower part of the sequence represents the Tithonian whereas the upper part grades into the Berriasian. Moreover, a vertical, NW-SE-trending fault cuts the sequence (Tab. 4.16D). Observations were made in the northeastern block of the fault.

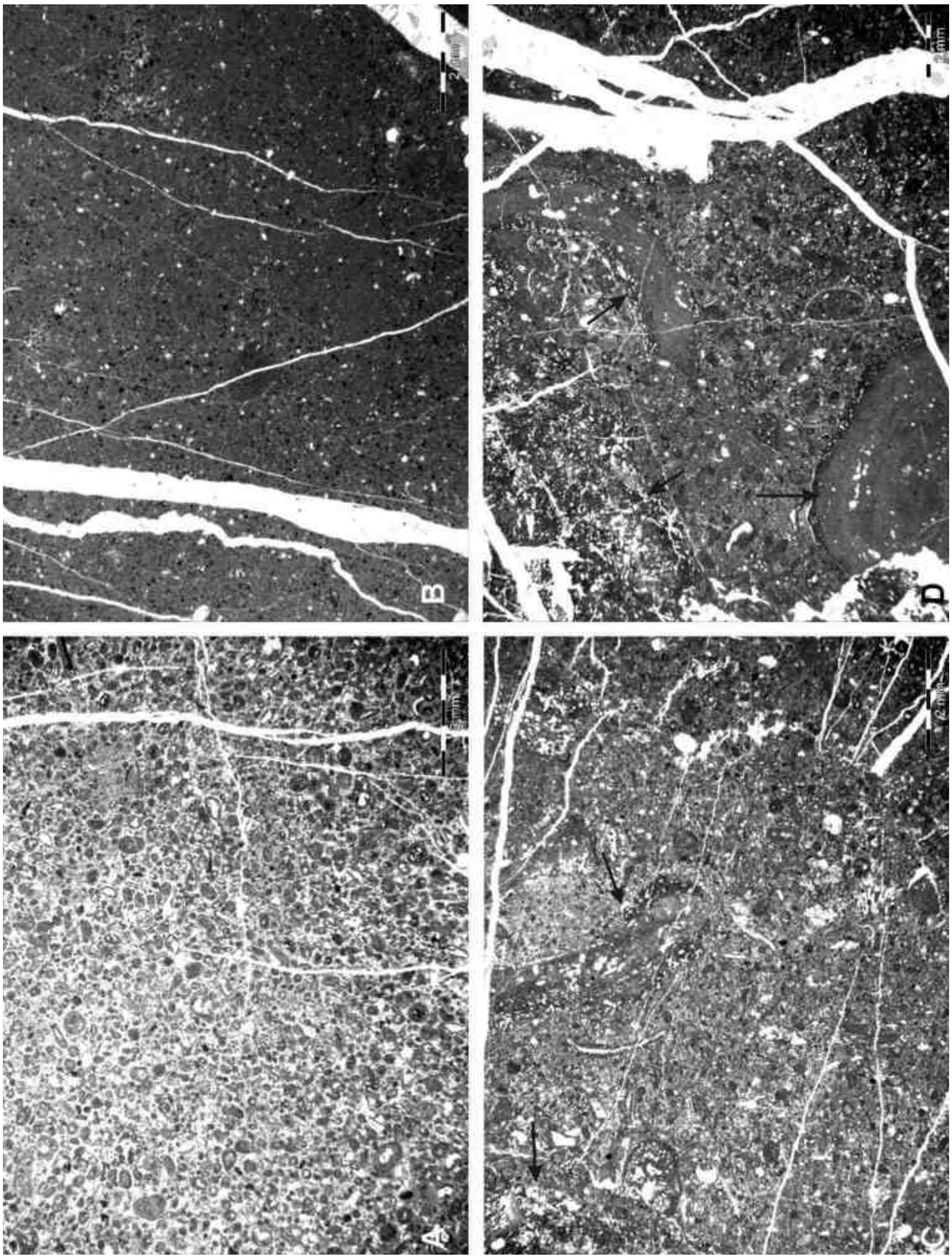
**MICROFACIES**

The sediments are bedded limestones varying from loose, thin-bedded to hard, thick-bedded ones (Fig. 4.7). Macroscopically scarce fossils were observed, mostly bivalve shells. Microfacies development is rather monotonous and is dominated by bioclastic wackestones, rarely mudstones and oncoidal packstones. In wackestones and mudstones common are systems of cracks filled with blocky cement (Tabs 4.19B, 4.20B, C, D). Apart from bivalves, common fossils are foraminifers.

More diversified are packstones, which commonly form thick-bedded limestones. These are fine-detrital, peloidal packstones and oncoidal packstones (Tabs 4.19 A, C, 4.20A). Oncoids are usually small, oval forms. Their nuclei are bioclasts but in many forms the internal structure is poorly visible. Moreover, *Bacinella* oncoids were found in the KN strata. Two varieties were indentified: irregular oncoids composed of alternating, micritic and *Bacinella* laminae, and oncoids almost entirely composed of micrite with only outer laminae deposited by microencrusters (Tab. 4.19D).

**INTERPRETATION**

Similarly to the adjacent sequences, the facies development of the KN section reflects links between macroscopic development and thickness of beds. Thin beds are usually wackestones whereas thicker beds are mostly packstones. However, the basic difference in comparison to other sequences is the proportion of various microfacies. In the KN section wackestones prevail over packstones. Moreover, packstones are usually fine-detrital. These features point out to deposition in the shallow but low-energy environment of the outer platform. Changes in proportions of various microfacies varieties in comparison to adjacent sequences reflect diversified morphology of the platform whereas variability within the sequences indicates cyclicity of deposition probably caused by the changes of sea level. The presence of *Bacinella* oncoids points to the lower deposition rates under oligotrophic-low mesotrophic conditions during the rising sea level whilst the presence of wackes or muds with rare fossils reflects the shallow-marine environment of more restricted lagoon (Peryt 1981, Flügel 2004, Védrine *et al.*, 2007).



A
B
C
D

**Table 4.19.** Examples of microfacies from KN section, Yalta Massif, bedded facies, Tithonian-Lower Berriasian

A – Peloidal packstone-grainstone, sample KN 10

B – Mudstone, sample KN 11c

C, D – Wackestone-packstone with large *Bacinella-Lithocodium* oncoids (arrows), samples KN 14, KN 15

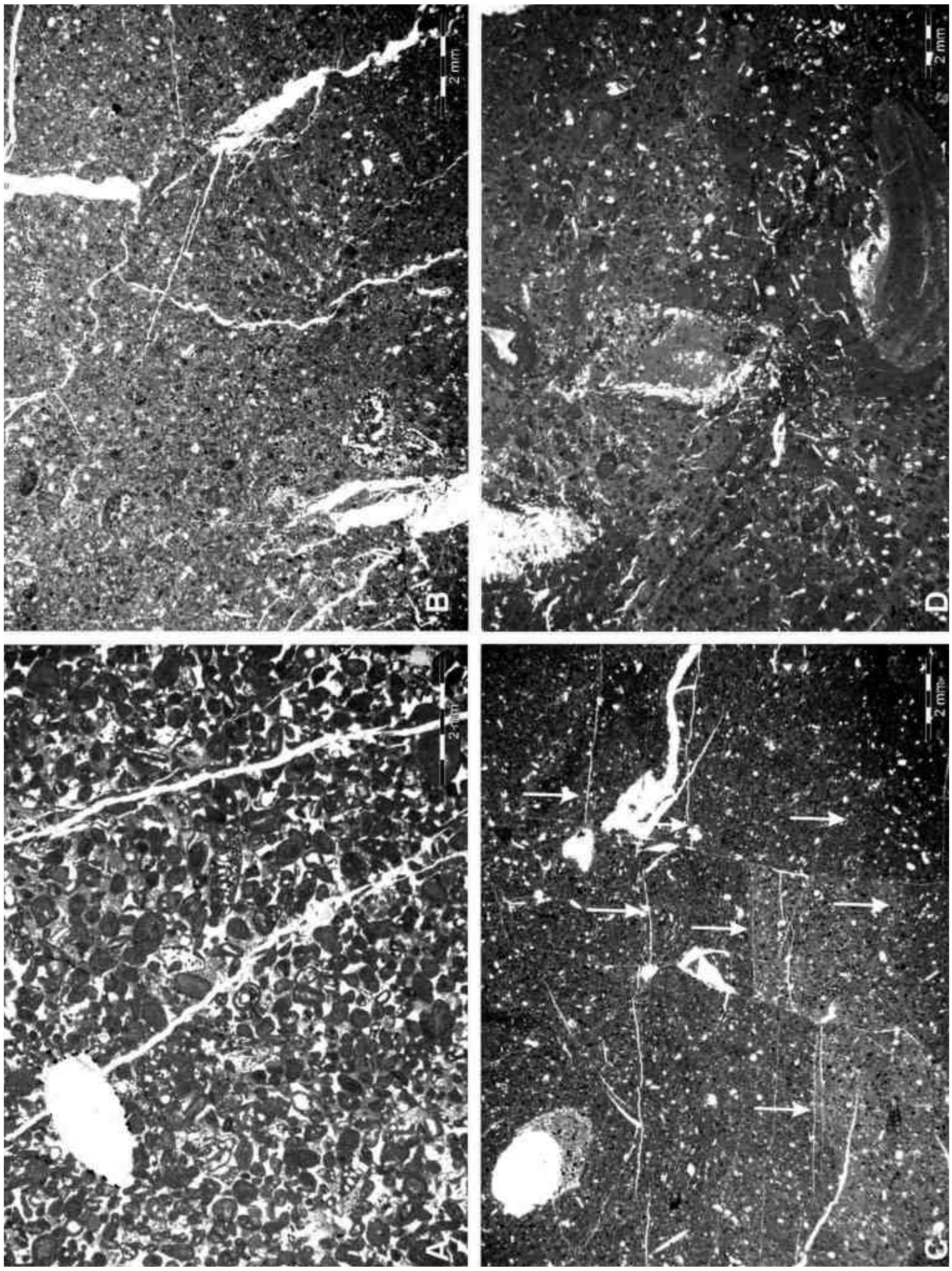

A
B
C
D
2 mm

**Table 4.20.** Examples of microfacies from KN section, Yalta Massif, bedded facies, Tithonian-Lower Berriasian

A – Peloidal packstone with numerous foraminifers, sample KN 4

B – Foraminiferal wackestone, sample KN 7

C – Wackestone-mudstone with small microfaults (arrows and broken line), sample KN 16

D – Oncoidal-peloidal packstone-wackestone, sample KN 3

### 4.3.5. The KL section (Yalta Massif, Plateau, Tithonian-Lower Berriasian, bedded limestones)

#### LOCATION AND STRATIGRAPHY

The KL section is located along the southern edge of the Yalta Massif, between the Iograf Ridge and the Bakhchysaray-Yalta road (Fig. 4.1). Samples were collected from sets composed of several or a dozen of beds, at sites positioned between the southern edge of the massif and the karstic plateau. Such sampling pattern aimed to recognize the possible, lateral facies variability, hence, the comprehensive column of sediments have not been drawn. To the northwest the sediments are identical with those encountered in the KK section.

Basing upon foraminifer assemblage: *Palaeogaudrina varsoviensis* (Late Oxfordian--Tithonian), *Andersenolina alpina* (Tithonian-Early Valanginian), *Anchispirocyclina lusitanica* (Tithonian-Earliest Berriasian) and *Everticyclammina kelleri* (Berriasian--Valanginian) (Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985), the age of the KL sediments was determined as the Latest Tithonian-Early Berriasian. Moreover, Late Oxfordian-Early Albian calcareous dinocysts *Crustocadosina semiradiata* were also found.

#### MICROFACIES

Sediments of the KL section are thin-bedded, grey limestones (Tab 3.1D). The thin-bedded strata include mostly mudstones and wackestones with numerous foraminifers, particularly *Anchispirocyclina lusitanica* (Tab. 4.21). In wackestones abundant echinoderm plates, gastropods and thin-shelled bivalves were observed. Thicker beds are usually fine-detrital, peloid-oncoid packstones with common foraminifers and bivalve shells (Tab. 4.22A). Moreover, in some beds the oncoidal packstones-rudstones horizons were observed (Tabs 4.21D, 4.22A, C, D). These are dominated by oval oncoids, which shapes are closely controlled by morphology of the nuclei. The nuclei are in most cases foraminifers, algae or shells of gastropods and bivalves. Observations of oncoids revealed the presence of forms with poorly marked lamination or those of complicated internal structure which includes several micritic laminae separated by *Bacinella irregularis* (Tab. 4.22B).

#### INTERPRETATION

Both the sediment development and the fossil assemblage indicate deposition within the internal platform. Large benthic foraminifers, algae and also *Bacinella* oncoids point to the shallow but quiet depositional environments (e.g. Flügel 2004, Védrine *et al*., 2007). The succession of mudstones-oncoidal packstones-rudstones probably advocates cyclic insignificant changes in bathymetry and energy of the basin, which resulted in opening or closure of some areas. In the case of mudstones-wackestones the sporadic appearance of typically shallow-water fauna: corals or microencrusters (encountered in large number also in other sequences) typical of shallow, oligotrophic environments and the dominance of wackestones with foraminifers and gastropods may suggest sedimentation in a closed lagoon (Flügel 2004). Only during the periods of rising sea level the *Bacinella* oncoidal packstones-rudstones were deposited in more open lagoonal environment (e.g. Flügel 2004, Védrine *et al*., 2007).

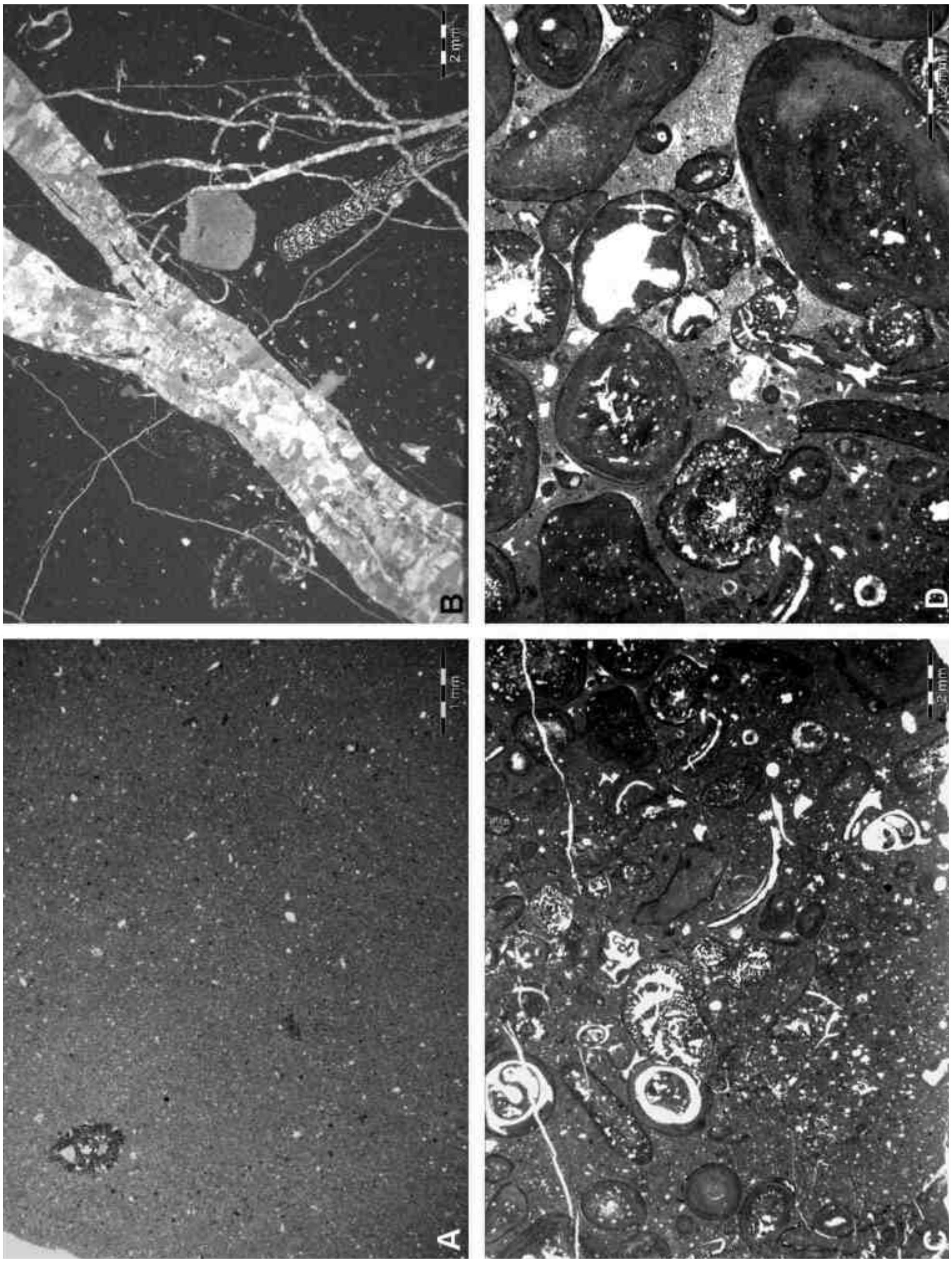

A
1 mm
B
2 mm
C
D

**Table 4.21.** Examples of microfacies from KL section, Yalta Massif, plateau, Tithonian-Lower Berriasian

A – mudstone, thin bedded limestones, sample KL1

B – mudstone-wackestone with *Anchispirocyclina lustianica*, KL 2a

C – packstone with numerous foraminifers and micrited oncoids, sample KL 3a

D – oncoidal rudstone with numerous foraminifers, sample KL 3c

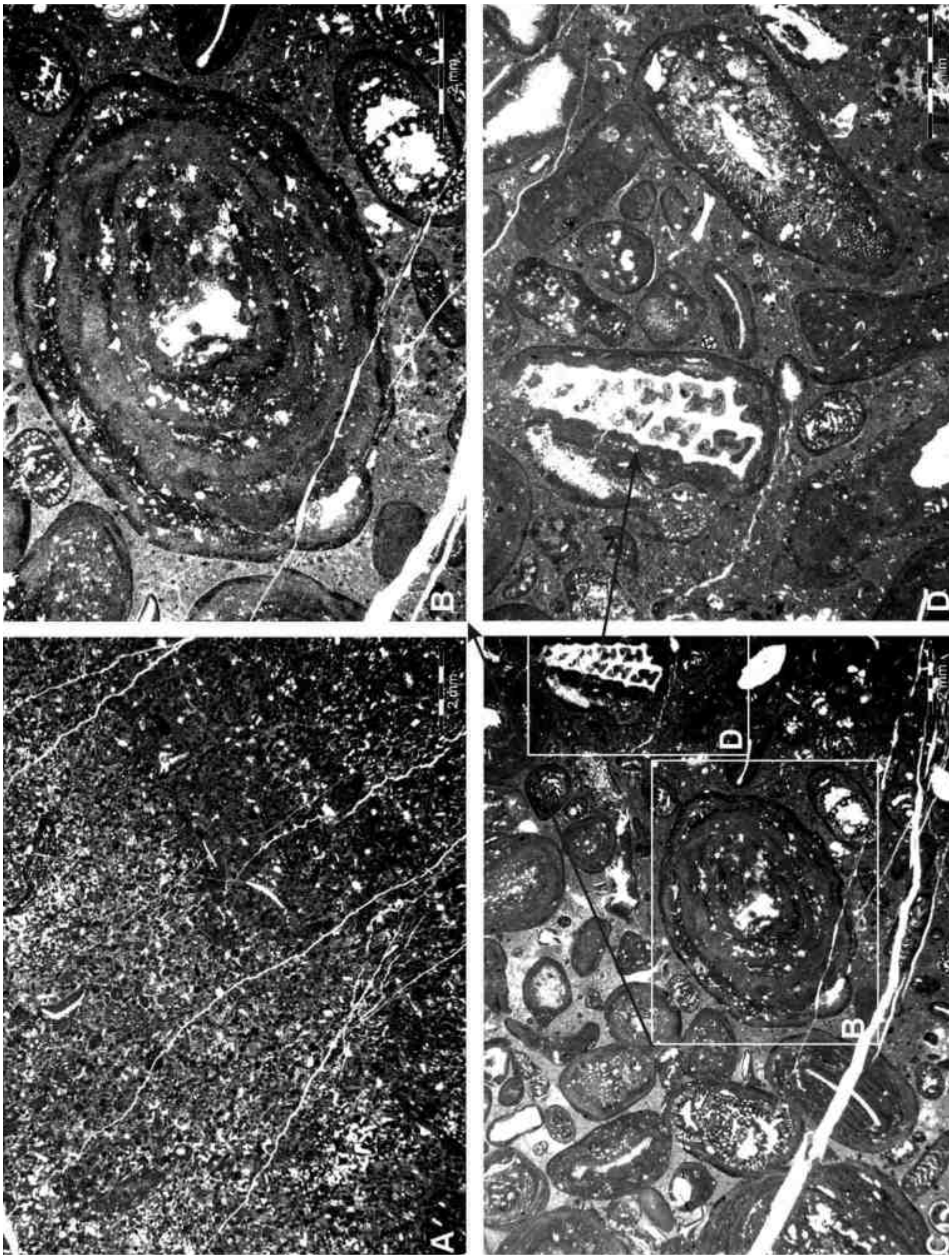

A
B
C
D
B
D
2 mm
2 mm

**Table 4.22.** Examples of microfacies from KL section, Yalta Massif, plateau, Tithonian-Lower Berriasian

A – peloidal-bioclastic packstone, sample KL 10

B – oncoid rudstone; enlargement of the photo C, *Bacinella* oncoid with well visible internal laminated structure, sample KL 3d

C – oncoid rudstone, sample KL 3d

D – oncoid rudstone; enlargement of the photo C. Nucleus of the oncoids are often built by foraminifers, algae, bivalves and gastropods, sample KL 3d

### 4.3.6. The KP section (Yalta Massif, Taraktysh Rocks, Tithonian, thin-bedded limestones)

**LOCATION AND STRATIGRAPHY**

The KP section is located in the western part of the Yalta Massif, in the vicinity of the Taraktysh Rocks (Fig. 4.1). Here, studies included the complex of characteristic, thin-bedded, poorly lithified limestones, which build the upper part of the Massif (Fig. 4.8, Tab.4.23A, C). These are underlain by the suite observed in the vicinity of the Uchan Su waterfall. Basing upon macroscopic observations, it was found that studied sediments are similar to those encountered in the KJ section. Up the sequence, the Taraktysh Rocks limestones grade into more compact, light limestones, which form a vast, karstic plateau. Foraminifers are represented by: *Amijella amji* (Liassic-Berriasian), *Everticyclammina praekelleri* and *Globuligerina terquemi* (Kimmeridgian-Tithonian, Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985). Moreover, calcareous dinocyst *Comittosphaera sublapidosa* was identified, which indicates Tithonian-Hauterivian age. Hence, the Tithonian age of the KP section was determined.

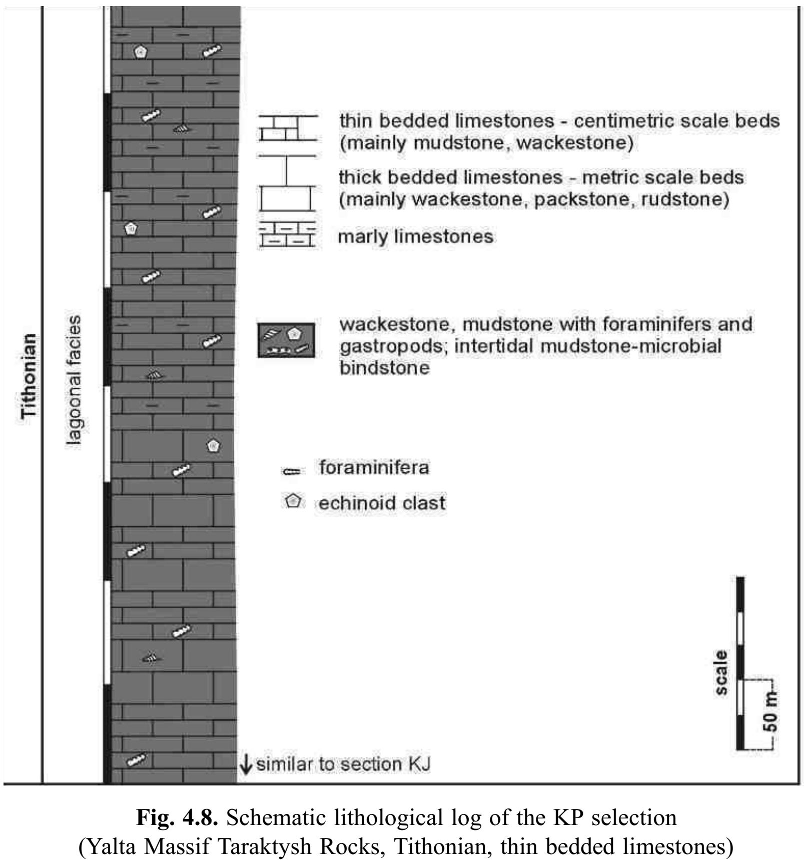



**Fig. 4.8.** Schematic lithological log of the KP selection
(Yalta Massif Taraktysh Rocks, Tithonian, thin bedded limestones)

## MICROFACIES

Macroscopically, this rather monotonous sequence includes light- and dark-grey, usually thin-bedded limestones (Tab. 4.23A, C). No significant, macroscopic diversity of sediments was observed except for changes in thickness and in hardness of beds. Both hard and soft beds form cyclic sets ranging in thickness from a few ten of centimeters to several meters, well-visible in the morphology due to variable erosion rates (Tab. 4.23C). The specific set usually includes a dozen or so of thin beds. The sets differ in thickness and in proportions between harder and softer beds. Due to diversity of sediments in selected sets of beds, the insoluble residuum was collected bed-by-bed and analyzed. The results indicate variable contents of residuum, depending on the hardness of particular bed: in harder beds residuum content reaches 4.2% whereas in softer beds it raises up to 7.48% (T. Bajda pers. com.).

Microfacies development of sequences is as monotonous as the macroscopic one and includes mudstones and wackestones in various proportions within particular beds (Tab. 4.23B, D). The harder beds occasionally show clotted structure, higher thickness (up to a dozen or so, rarely up to some tens of centimeters) and are dominated by wackestones. The softer beds are usually thinner (from several to a dozen or so centimeters) and are dominated by mudstones. The mudstones rarely contain bioclasts, mostly foraminifers. Fossils are more common in wackestones and comprise mostly foraminifers and fine bioclasts, the latter dominated by echinoderm plate fragments and thin-shell bivalves.

## INTERPRETATION

The KP section is a pile of monotonous sediments grading in the bottom part into bedded limestones, similarly to those observed in other sequences from the Yalta Massif. Microfacies and scarce fossils together with the presence of foraminifers *Amijella* and *Everticyclammina* point out to deposition in the internal platform of a lagoon. The sediments show distinct cyclicity, which presumably reflects cyclic changes of sea level. It is supported by the results of studies on insoluble residuum contents in particular beds, which is related to changes in the influx of non-carbonate material and in deposition rates. Variable contents of insoluble residuum may reflect depositional sequences which, in turn, may define the transgressive-regressive cycles (e.g. Flügel 2004). Precisely, single, thin beds presumably correspond to single transgressive-regressive cycles whereas beds sets composed of a dozen of thin beds represent the higher-order cycles. At the present state of studies it is difficult to determine more accurately the character and the duration of these cycles.

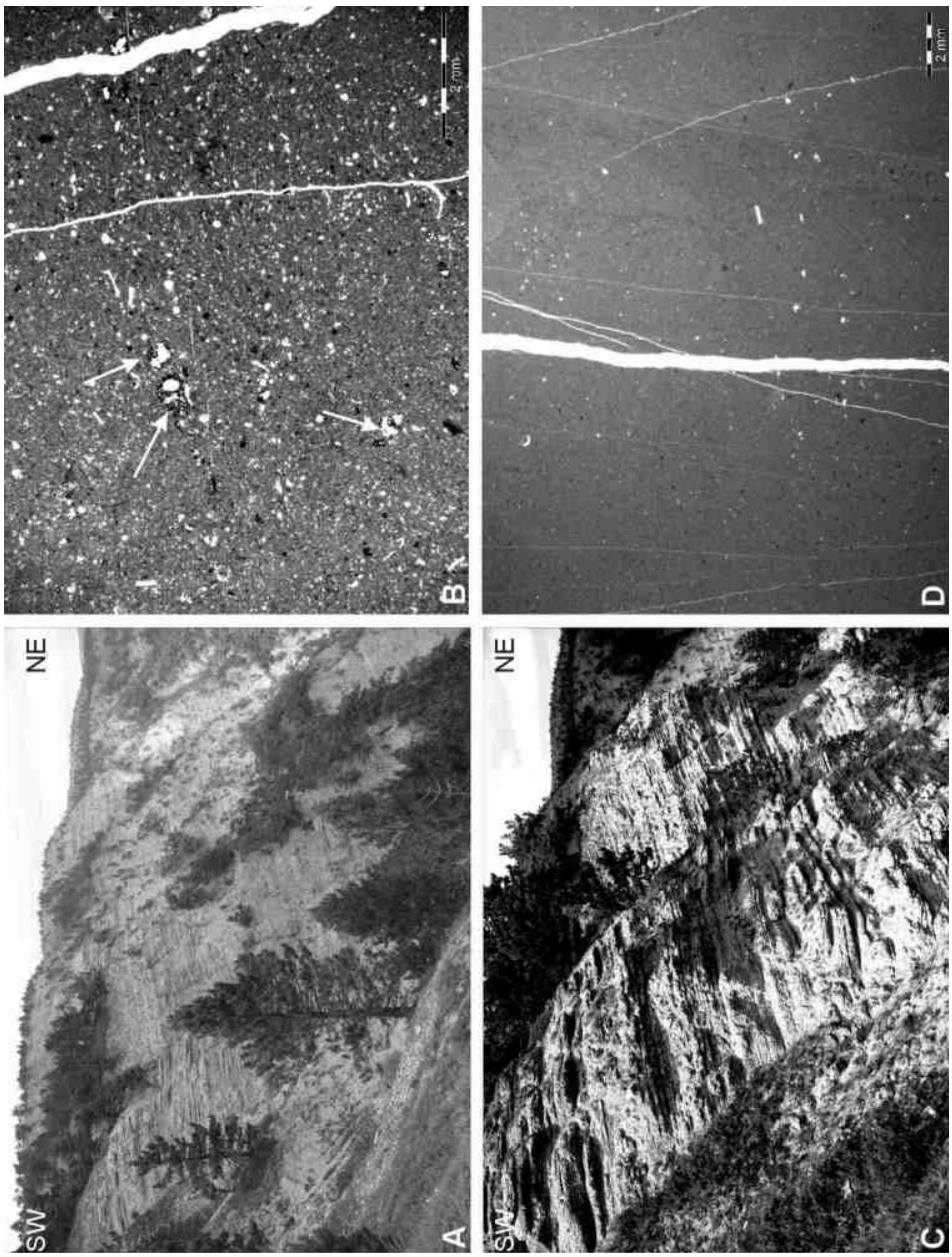

SW
NE
A
B
2 mm
SW
NE
C
D
2 mm

**Table 4.23.** Views of the outcrops and examples of microfacies from sequence KP, Yalta Massif, Taraktysh Rocks, thin bedded limestones Tithonian

A, C – Taraktysh Rocks, thin bedded limestones

B – mudstone-wackestone with numerous foraminifers (arrows), sample KP 5

C – mudstone, sample KP 3

### 4.3.7. The KO section (Yalta Massif, Taraktysh Rocks, Upper Tithonian-Berriasian, thin bedded and nodular limestones)

#### LOCATION AND STRATIGRAPHY

The KO section is located in the vicinity of the Taraktysh Rocks (Fig. 4.1). Observations were carried on at the edge of the plateau towards the southeast, as far as to the group of rocks near the Uchan Su waterfall. Macroscopic examinations revealed that limestone complexes located beneath the KO section are similar to those described from the KJ section, thus, microfacies studies of these sediments were neglected. The following foraminifers were identified: *Amijella amji* (Tithonian-Berriasian), *Aaptotoichus challengeri* (Tithonian-Barremian), *Palaeogaudryina varsoviensis* (Late Oxfordian-Tithonian), *Nautiloculina oolithica* (Late Oxfordian-Berriasian), *Mayncina bulgarica* (Tithonian-Barremian), *Everticyclammina praekelleri* (Kimmeridgian-Tithonian), *Anchispirocyclamina lusitanica* (Tithonian-Earliest Berriasian), indicative of the Late Tithonian-Early Berriasian ages (Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985).

#### MICROFACIES

The mostbottom parts of the sequence comprises thin- and medium-bedded, grey, macroscopically rather monotonous limestones (Fig. 4.9). Occasionally, bioclasts are seen. Under the microscope these sediments resemble thin-bedded sediments described from the KP section as well as strata known from the other parts of the Taraktysh Rocks (see Tab. 4.23). These are mostly mudstones and wackestones with small bioclasts, peloids and foraminifers (see description of the KP section).

In the uppermost part of the sequence the nodular limestones occur, exposed in a dozen-of-meter-high rock wall, and located close to the edge of the plateau (Fig. 4.9, Tab. 4.24A). The nodular limestones reveal high microfacies diversity (Tabs 4.24, 4.25, 4.26, 4.27). The bedding planes are poorly marked. In the lowermost part of the exposure, in the transitional zone from thin-bedded to nodular limestones, the number of fossils increases (Tab. 4.25A, B). The rocks are mostly bioclastic wackestones-packstones with abundant foraminifers, echinoderms, gastropods, bivalves and fragments of sponges and algae, accompanied by peloidal packstones. Up the sequence, the amount of bioclasts gradually increases. The central part of the exposure is dominated by sediments with nodules from several to a dozen or so of centimeters across (Tab. 4.24). Individual nodules reveal high hardness and massive structures, and are embedded within less-compact sediment. Such inhomogeneity is responsible for the clotted structure. Microscopic observations revealed that some of the nodules are composed of massive, dome-shaped sponges with radial-fibrous (actinostromid) wall structure (Tab. 4.24, e.g. Turnsek 1968, Leinfelder *et al.*, 2005). Their skeletons are partly recrystallized. Taking into account obvious macroscopic similarity of nodules in the remaining parts of the exposure, it is suggested that these are also composed of massive, domal sponges.

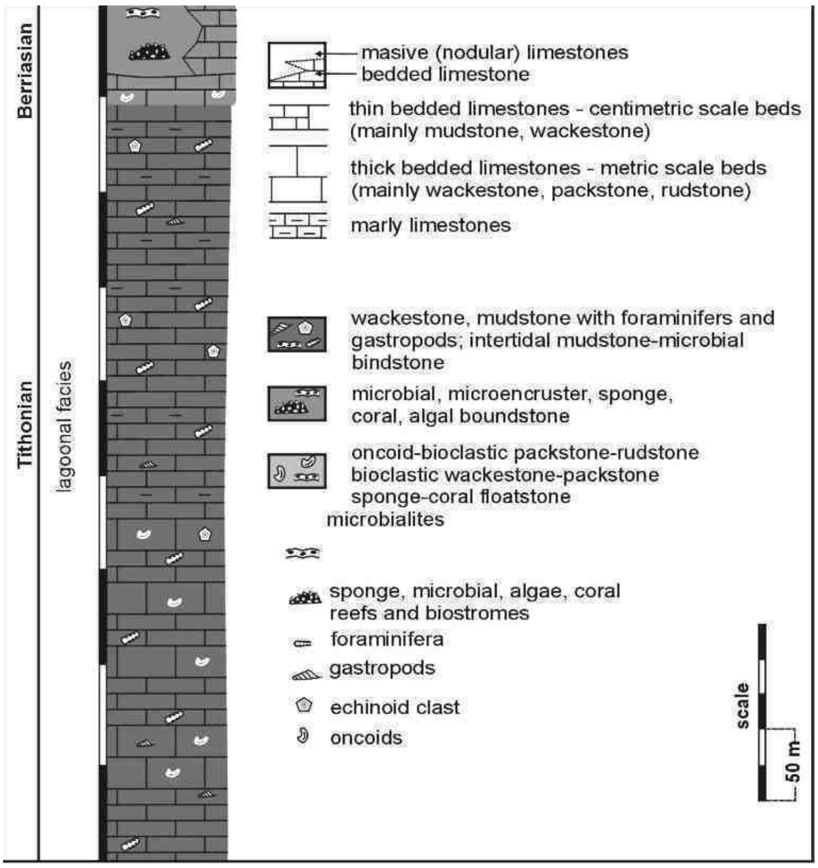



**Fig. 4.9.** Schematic lithological log of the KO selection
(Yalta Massif Taraktysh Rocks, Upper Tithonian-Berriasian,
thin-bedded and nodular limestones)

In the upper part of the exposure changes in microfacies development are observed. Sponges, which form numerous, densly packed and strongly recrystallized, branched forms become common (Tabs 2.25D, 4.26, 4.27A). Sediments which fill the interskeletal spaces are highly diversified and include wackestones-mudstones with poorly marked microbial structures, *Crescentiella morronensis* and locally encountered *Koskinobullina socialis*, and bioclastic packstones-grainstones (Tabs 4.26, 4.27). Some parts of sediments are rich in fine-grained quartz mixed with bioclasts, which fills interskeletal spaces (Tabs 4.26). Commonly, pure quartz sandstone fills niches between the branches (Tab. 4.26C). Locally, in spaces between skeletal fragments numerous ?*Crescentiella morronensis* occur (Tab. 4.25D). In the uppermost part of the sequence thrombolitic bindstones and, bioclastic wackestones-packstones with frequent fragments of algae and sponges (Tab. 4.27). Skeletons are partly dissolved and replaced with mudstones-wackestones.

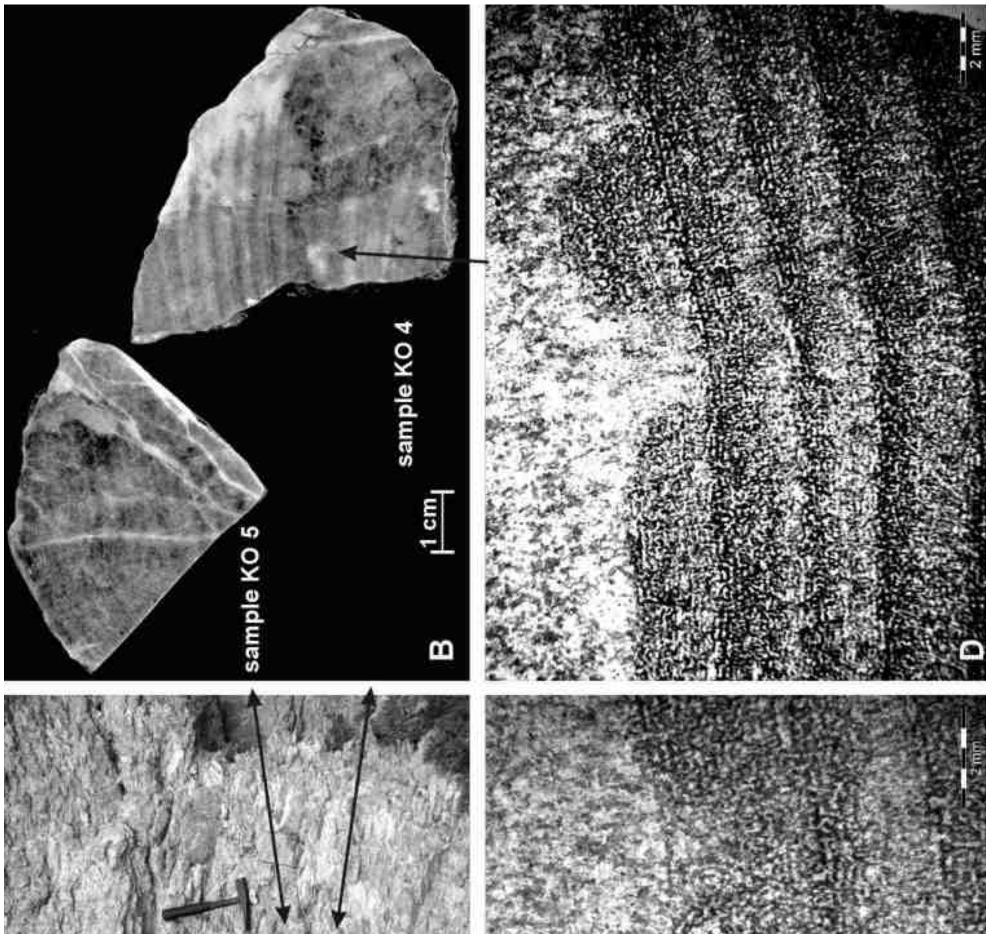

A
B
sample KO 5
sample KO 4
1 cm
C
D
2 mm
2 mm

**Table 4.24.** The nodular limestones from uppermost KO section, Yalta Massif, plateau and Taraktysh Rocks

A – fragment of the outcrop with nodular limestones. Marked locations of the samples presented in photos B, C, D

B – polished sections from fragments of nodules

C, D – sponge with radial-fibrous (actinostromid) wall structure which forms some of the nodules, samples KO 4b, KO 4a

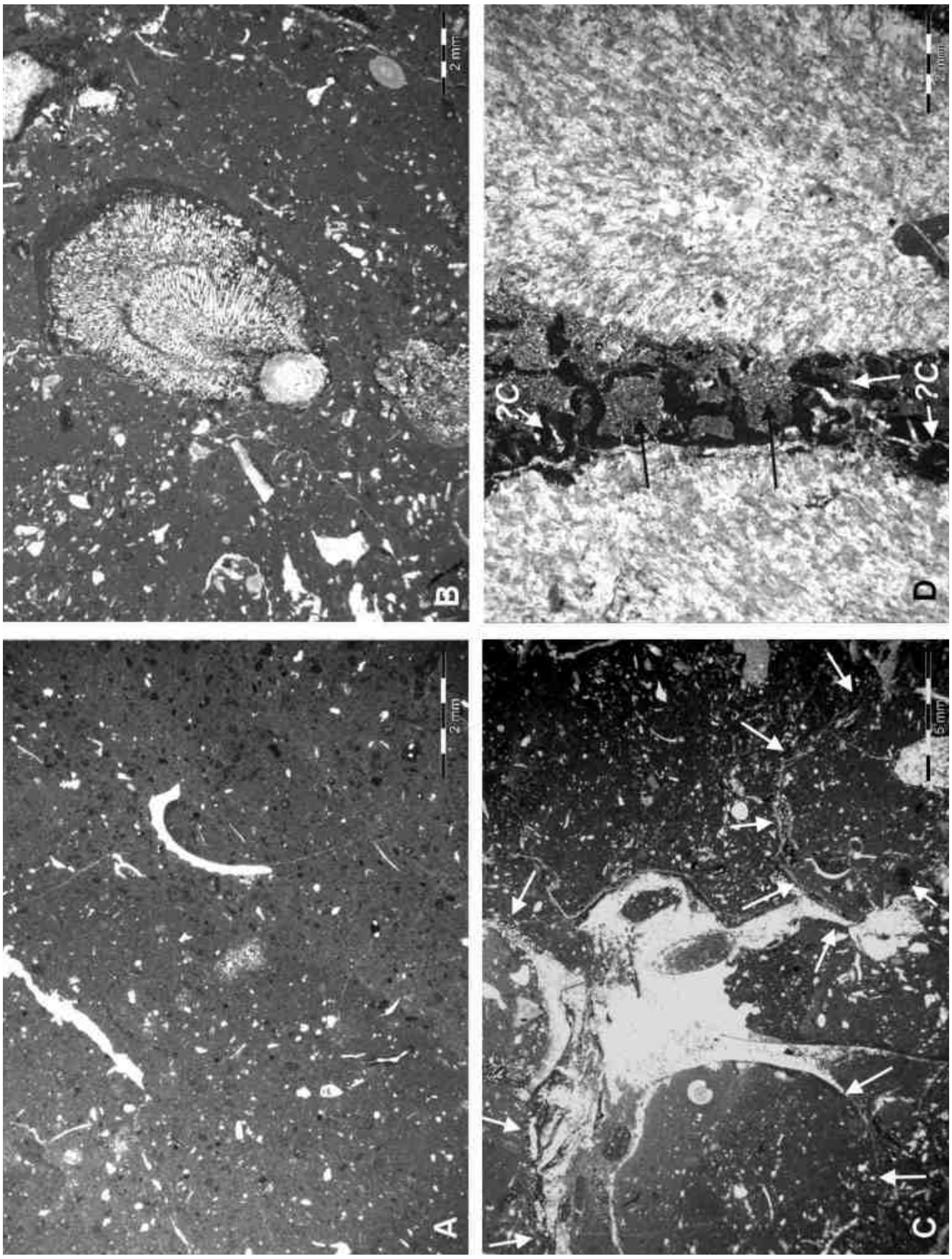

A
B
C
D
2 mm
2 mm
5 mm
2 mm
?C
?C

**Table 4.25.** Examples of microfacies from upper part of the KO section, Yalta Massif, Taraktysh Rocks, nodular limestones, Tithonian-Lower Berriasian

A – wackestone-mudstone with fragments of bivalves and foraminifers, sample KO 1a

B – bioclastic wackestone, in the centre *Rivulariacean* alga (*Rivularia lissaviensis* sensu Dragastan), sample KO 3a

C – bioclastic wackestone-bindstone, on the left side contours (arrows) of relic after macroorganisms, at present, they are filled in micrite, on the outer part microencruster *Lithocodium aggregatum*, on the right, thrombolitic bindstone, sample KO 6

D – framestone-bafflestone, skeletons of sponges, between skeletons numerous bioclasts and siliciclastics, the skeletons are bounded by ?*Crecientella*, sample KO 7d

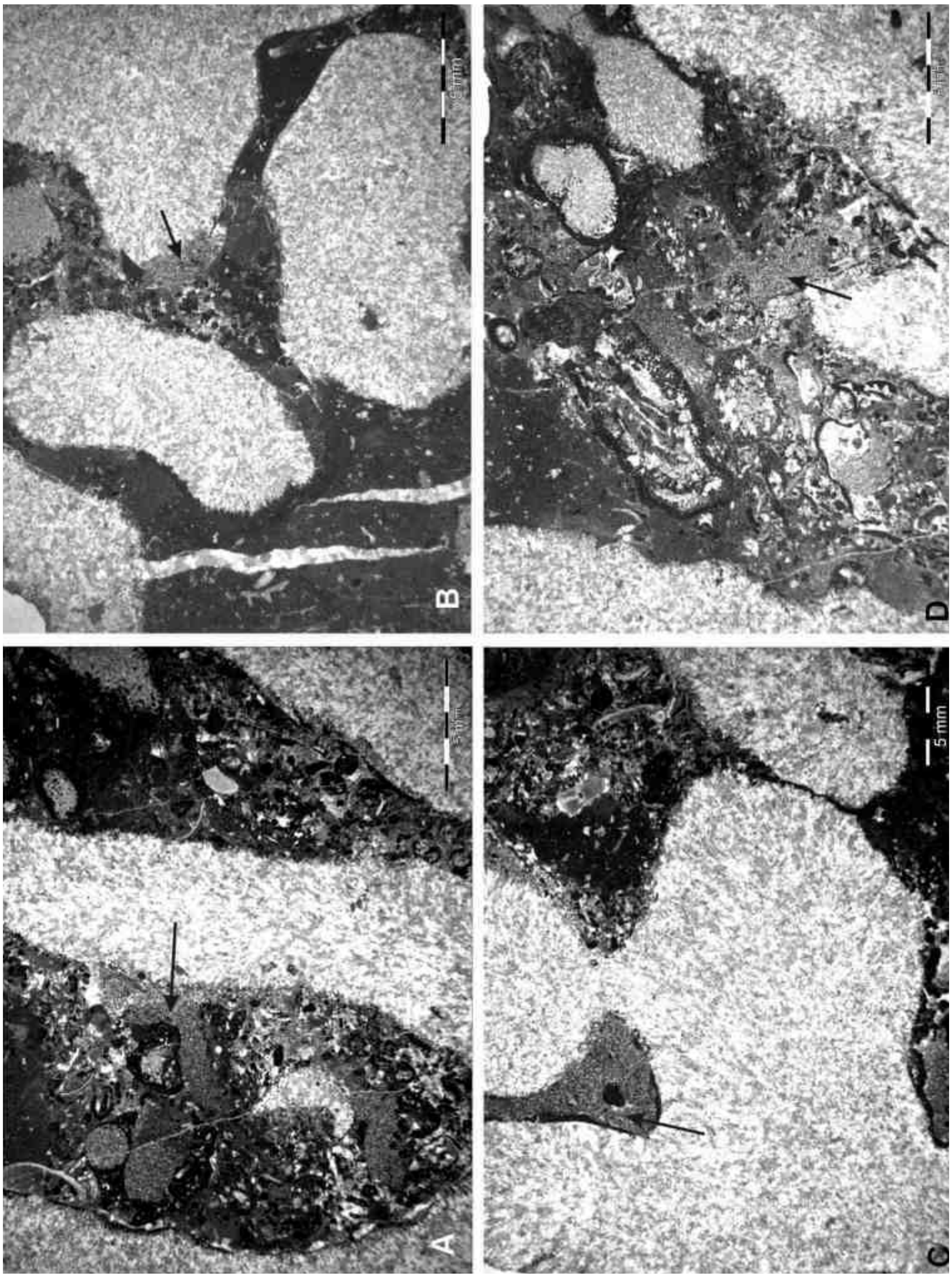

A
B
C
D
5 mm

**Table 4.26.** Examples of microfacies from upper part of the KO section, Yalta Massif, Taraktysh Rocks, nodular limestones, Tithonian-Lower Berriasian

A–D – framestone-bafflestone, strongly recrystalized skeletons of sponges, between skeletons numerous bioclasts and siliciclastics (arrows), samples KO 7a, KO 7b, KO 7e, KO 7h

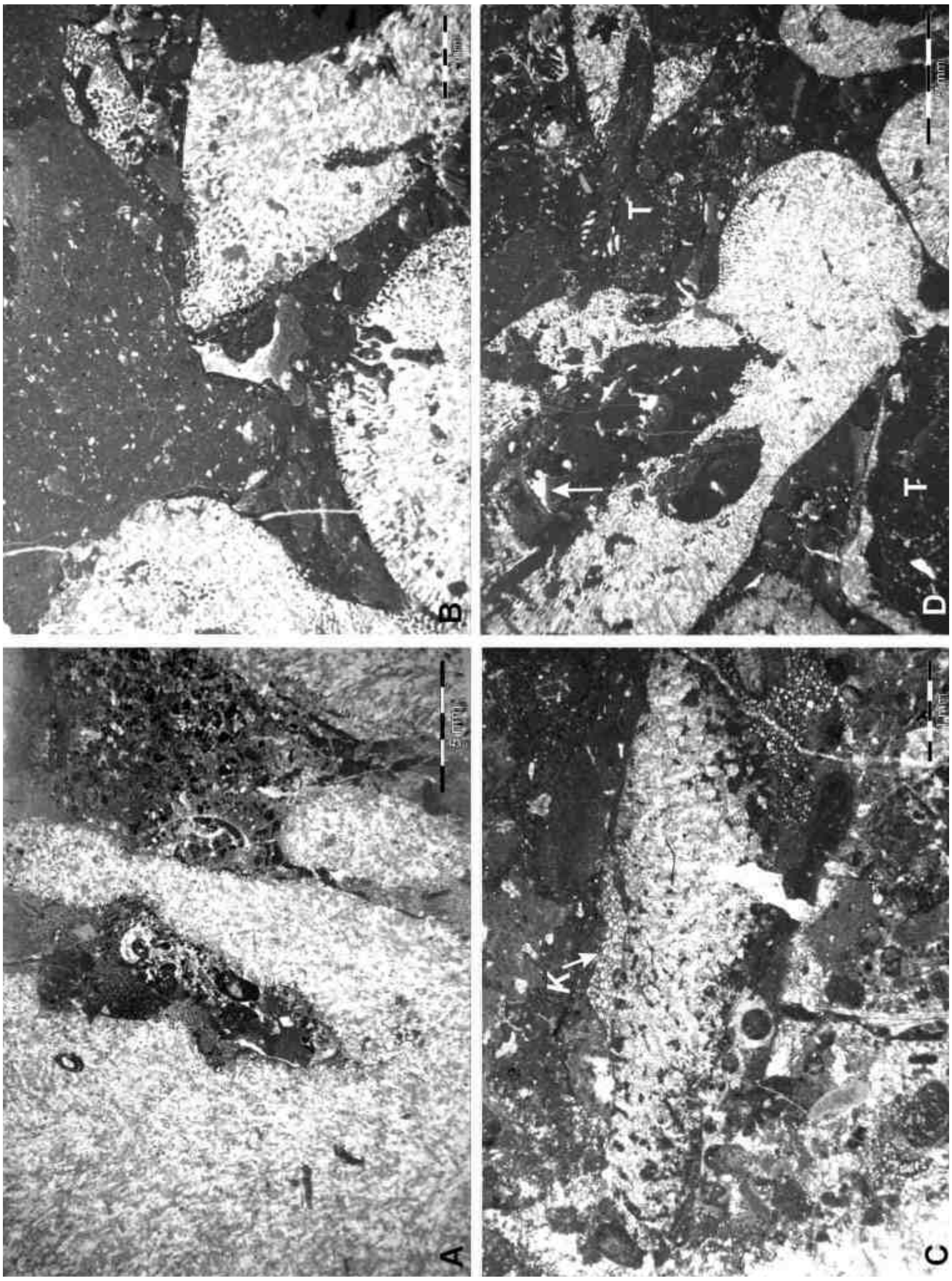

A
B
C
D
K
T
T

**Table 4.27.** Examples of microfacies from upper part of the KO section, Yalta Massif, Taraktysh Rocks, nodular limestones, Tithonian-Lower Berriasian

A – bafflestone, strongly recrystalized skeletons of sponges, between skeletons numerous bioclasts, sample KO 7g

B – sponge floatstone, sample KO 8a

C – bioclastic wackestone-packstone with *Koskinobullina socialis* (*K*) on the fragment of sponge (?*Caldocyropsis*), sample KO 7d

D – thrombolite (T)-sponge framestone with small geopetal infilled caverns (arrow), sample KO 8b

**INTERPRETATION**

Similar to the adjacent KP section, the fine-bedded limestones from the lowermost part of the KO section represent the lagoonal environment of the internal platform. Distinct cyclicity observed in sediments presumably corresponds to periodical changes of sea level (see the KP section).

Much more diversified is the facies development of nodular limestones exposed along the southern edge of the plateau. In comparison to thin-bedded sediments from the lower part of the sequence, the gradually increasing number of fossils in the upper part indicates more optimal environmental conditions for fauna development. Numerous, massive sponges found in these strata, which form small patch-reefs, belong probably to *Actionostromaria* sp.

Higher in the sequence, sponges appear as small, branched clusters representing the shallow, subtidal environments. Some skeletons are binded with microencrusters, mostly *Crescentiella morronensis.* High amount of bioclasts detritus indicate abrasional conditions. Moreover, abundant, fine-grained quartz points to high, periodical siliciclastic influx strongly modifying the environment. It is presumably the reason of low number or absence of other organisms, typical of shallow-marine environments. These sediments probably represent very shallow deposition, close to the eroded land. Above, bioclastic wackestones-floatstones-packstones are developed. Common growth of *Lithocodium aggregatum* on skeletal fragments indicates shallow, subtidal zone of back-reef and open-lagoon environments. Sponge floatstones and bioclastic wackestones-packstones were encountered also in other sequences at the edge of plateau, which suggests wide distribution of similarly developed sediments forming the highest parts of the Yalta and the Ay-Petri massifs.

## 4.3.8. The KS section (Ay-Petri Massif, Yalta-Bakhchysaray road, Tithonian, bedded limestones)

**LOCATION AND STRATIGRAPHY**

The KS section is located along the Yalta-Bakhchysaray road (Figs 4.1, 4.10, 4.11) and includes about 50-meter-thick strata resting over a monotonous complex of predominantly bioclastic wackestones-packstones.

The strata are thin-bedded, locally somewhat clotty limestones of inferred Tithonian age (Krajewski, Olszewska 2007). To the east these carbonates grade into thin-bedded limestones, similar to those described from the Taraktysh Rocks area whereas to the west these pass into the succession of thin-bedded limestones which envelope the Ay-Petri reef complex from the northeast. Macroscopically, the KS sediments are rather monotonous (Fig. 4.11). Single beds show variable thickness, from a dozen or so to some tens of centimeters.

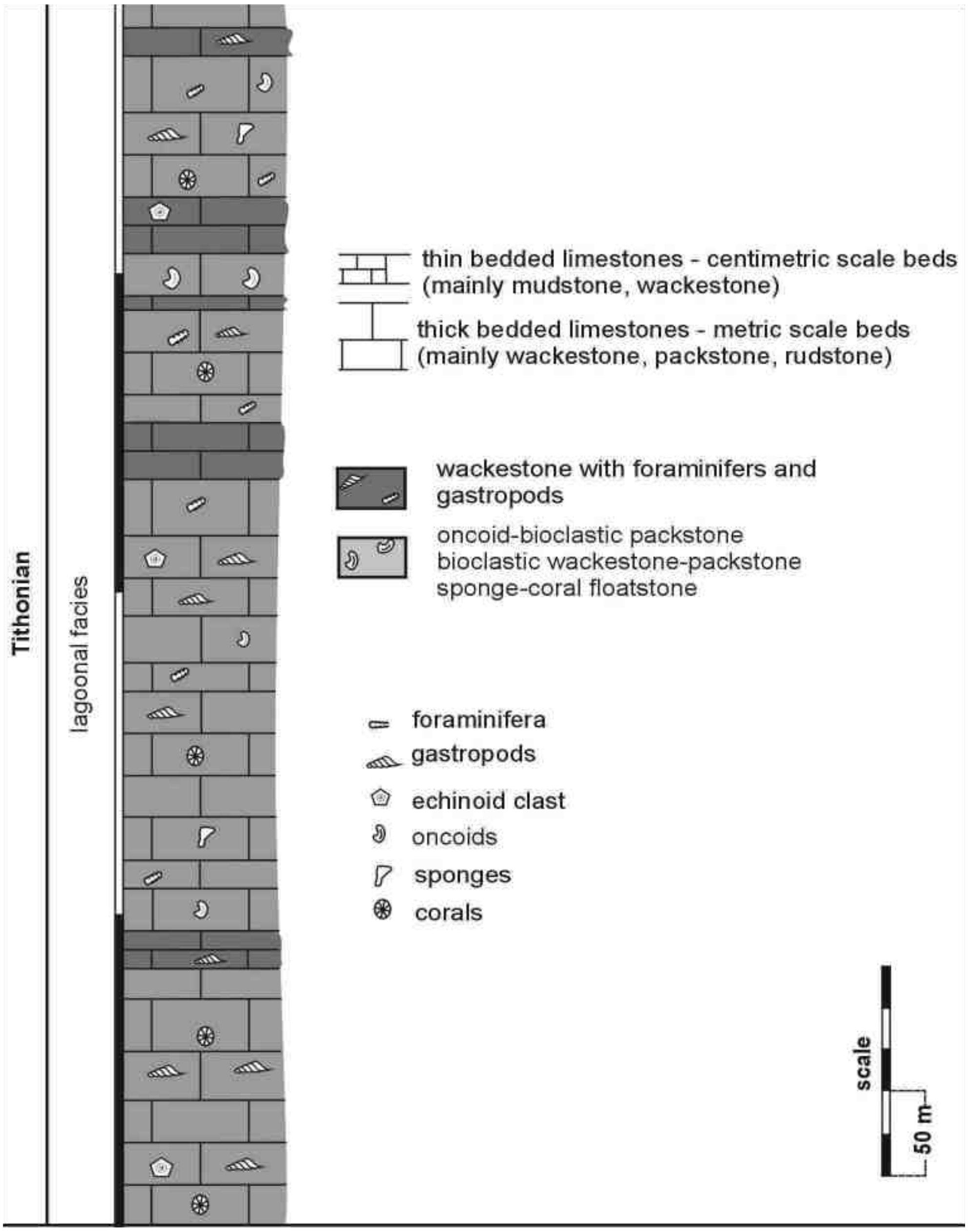



**Fig. 4.10.** Schematic lithological log of the KS selection
(Ay-Petri Massif, Tithonian, bedded limestones)

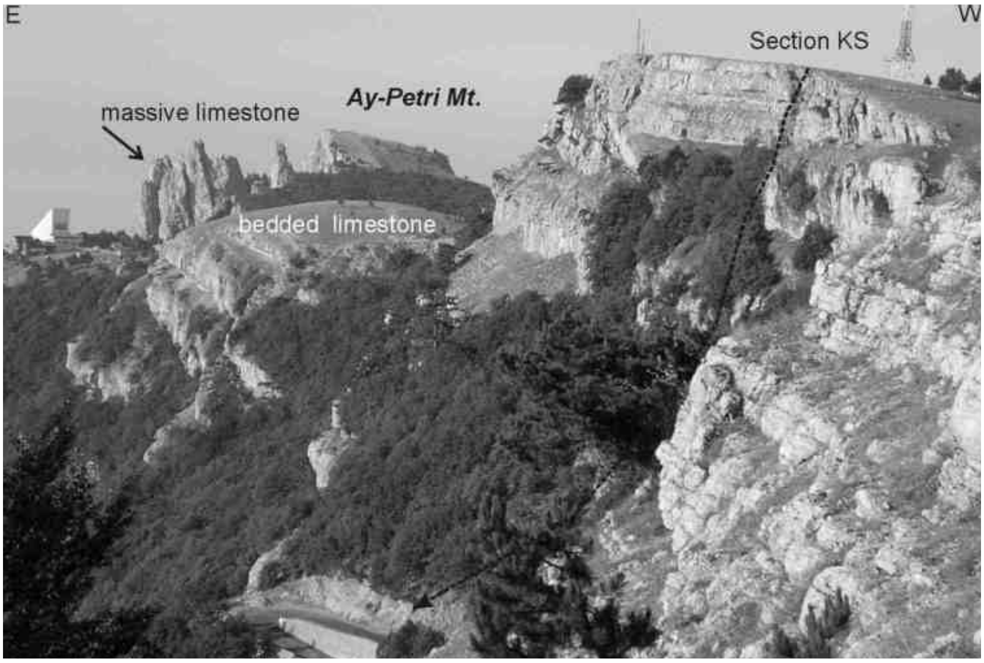



**Fig. 4.11.** Location of the section, bedded limestones pass to the south-west into massive limestones of the Ay-Petri reef complex

## MICROFACIES

Three main microfacies varieties were identified: mudstones-wackestones, oncoidal packstones and coral-sponge floatstones (Tab. 4.28). Similar to other sequences, microfacies development corresponds to thickness of beds: thin-bedded limestones are mostly mudstones-wackestones whereas thicker beds are mostly oncoidal packstones.

The mudstones-wackestones occur usually in the upper parts of the sequence. Fossil assemblage is dominated by gastropods and foraminifers accompanied by thin-shelled bivalves as well as fragments of corals and sponges. Skeletons of the latter two fossils are mostly dissolved and filled by blocky cement. Locally, more abundant macrofossils are observed, forming sponge-coral floatstones (Tab. 4.28D). Among corals only strongly dissolved fragments of *Stylosmilia* were identified. The mudstones-wackestones are intensively fractured. Several systems of microcracks are filled with calcite. Moreover, fragments of microbreccias occur composed of mudstone and wackestone clasts (Tab. 4.28A).

Fine, micrite-dominated forms of poorly visible internal structure prevail in the oncoidal packstones. Fossils are rare and include mostly gastropods, foraminifers, thin-shelled bivalves, echinoid spines and fragments of corals, presumably *Stylosmilia*, and sponges. Most of skeleton fragments are already dissolved and their place is taken by cement, thus their detailed characterization is difficult.

## INTERPRETATION

Basing upon microfacies development, the KS sediments are interpreted as monotonous limestone complex dominated by packstones in the lower part and by mudstones-wackestones in the upper part. Considering their position in relation to the Ay-Petri reef complex, their microfacies development and, particularly, low diversity of their fossil assemblage, the KS sediments represent mostly the restricted lagoon environment, rarely more open lagoon. Generally, the KS section consists of several, minor depositional sequences related probably to the changes of sea level. Initially, the sediments were laid down in the open lagoon, as documented by oncoidal limestones. Higher up the sequence, the environment evolved into more restricted lagoon represented by mudstones-wackestones with abundant fossils, mostly gastropods, foraminifers, corals and sponges. Most of macrofossil fragments were transported with mud from areas covered by vigorously growing coral-sponges meadows. Moreover, the presence of numerous cracks, which may be the mud cracks filled with cement as well as the occurrence of microbreccias suggest periodical intertidal episodes during the drop of sea level, although fenestral structures typical of the tidal flat deposits and common in the area of Ay-Petri Massif have not been observed up to date in the KS sediments.

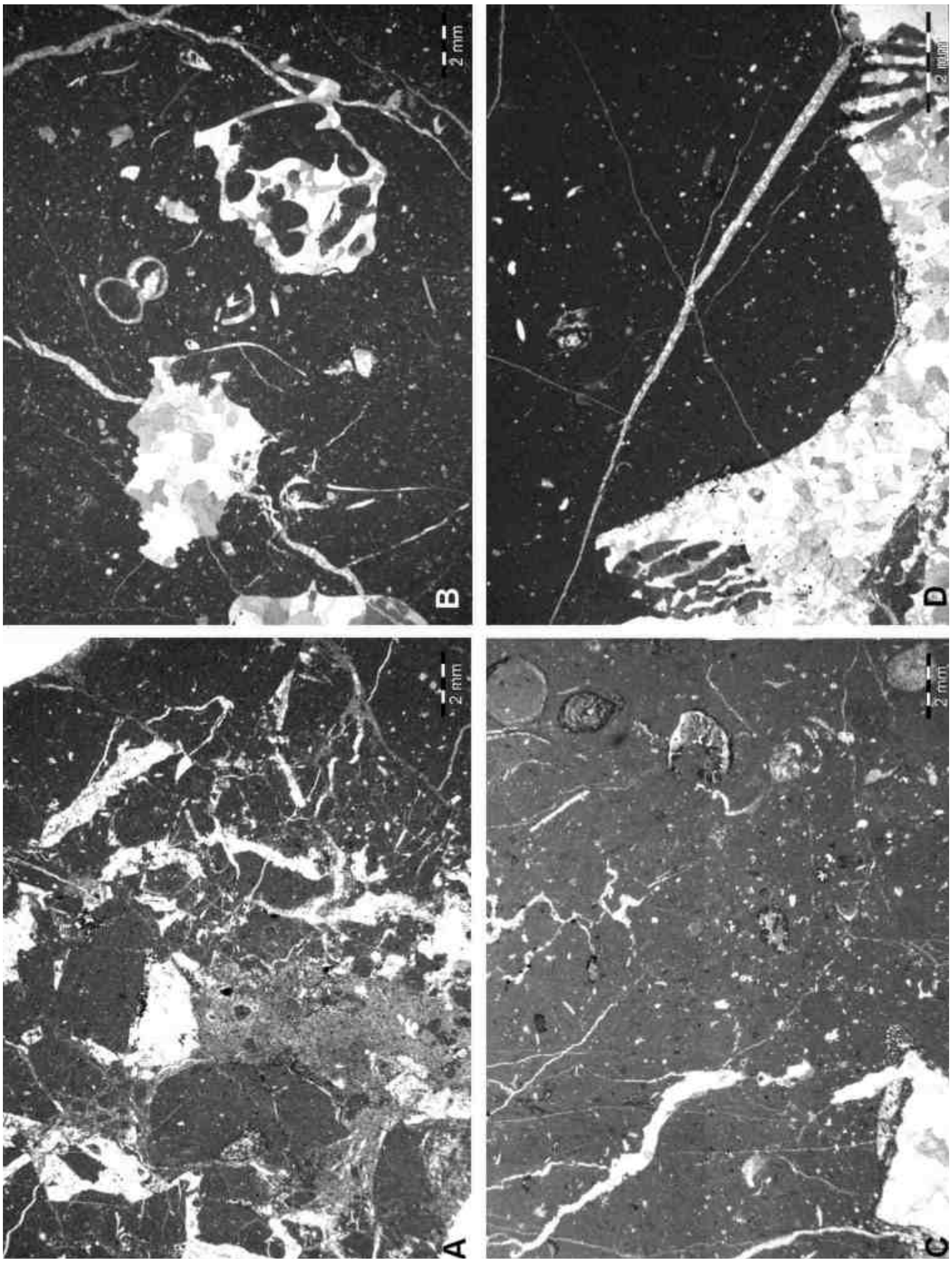

A
B
C
D
2 mm
2 mm
2 mm
2 mm

**Table 4.28.** Examples of microfacies from KS section, Ay-Petri Massif, bedded limestones, Tithonian

A – microbreccia, sample KS 1d

B – wackestone with numerous gastropods, sample KS 2

C – wackestone with numerous bioclasts, sample KS 5

D – coral floatstone, most of the ?*Stylosmilia* skeletons are dissolved, sample KS 7

### 4.3.9. The KB section (Ay-Petri Massif, Ay-Petri Mountain, Kimmeridgian-Tithonian-Lower Berriasian, massive limestones)

**LOCATION AND STRATIGRAPHY**

The KB section is located in the main, southern wall of the Ay-Petri Massif (Figs 4.1, 4.12). It extends from the western, summit part of the mountain to the walls of characteristic, steep gully, which grades in its lower part into vertical walls towering over the foothills. Thickness of the sequence is about 600 meters (Fig. 4.13).

The KB section hosts abundant foraminifers assemblage with *Troglotella incrustans* (Kimmeridgian-Berriasian), *Haghimashella acurata* (Middle Oxfordian--Berriasian), *Palaeogaudryina varsoviensis* (Late Oxfordian-Tithonian), *Nautiloculina bronnimanni* (Berriasian-Hauterivian), *Everticyclammina praekelleri* (Kimmeridgian--Tithonian), *Anchspirocyclina lusitanica* and *Quinqueloculina stellata* (Tithonian--Earliest Berriasian). Moreover, calcareous dinocysts *Cadosina parvula* (Late Oxfordian-Tithonian) were identified. Basing on foraminifer assemblage (see Krajewski, Olszewska 2006, 2007), the age of sediments was determined as possible Kimmeridgian, mostly Tithonian and, in the upper parts, Lower Berriasian (cf. Muratov 1973, Kuznetsova, Gorbachik 1985, Leshukh *et al.*, 1999, Anikeyeva, Zhabina 2009).

**MICROFACIES**

In macroscopic observations the massive limestones appear as monotonous succession of pelitic or detrital carbonates. In the lower part horizons of sandstones and sandy limestones were found, of thicknesses usually about some tens of centimeters (Fig. 4.13). In some portions of the sequence poorly visible, thin-bedded limestones were encountered (not marked in the column), which usually grade into massive facies. Only in the topmost part of the KB section, at the edge of the plateau, massive limestones grade into bedded limestones (Tab. 4.29A). The strata dip to the north at several ten degrees and are unconformably covered by bedded limestones, dipping at a dozen or so degrees. These bedded limestones form the karst plateau.

Both the fossils and sedimentary structures are poorly visible in most of the KB rocks. Fauna assemblage includes gastropods, bivalves, corals, sponges, rudists, brachiopods and unidentified fossils affected by strong recrystallization (Tab. 4.29). Irregular grainstone horizons with nume-rous, crushed bioclasts and ooids are common. Frequent fractures and cavities are filled with sparrite. Fine lamination noticed in some parts of the sequence is related to microbial structures. In the topmost part of the KB section, at the edge of the plateau, the reddish breccias and neptunian dykes are visible (Tab. 4.29F). All varieties observed in the sequence are affected by strong cementation, which obliterates any macroscopic features of sediments. Hence, the Ay-Petri deposits appears as a monotonous monolith composed of massive limestones (Fig. 4.12).

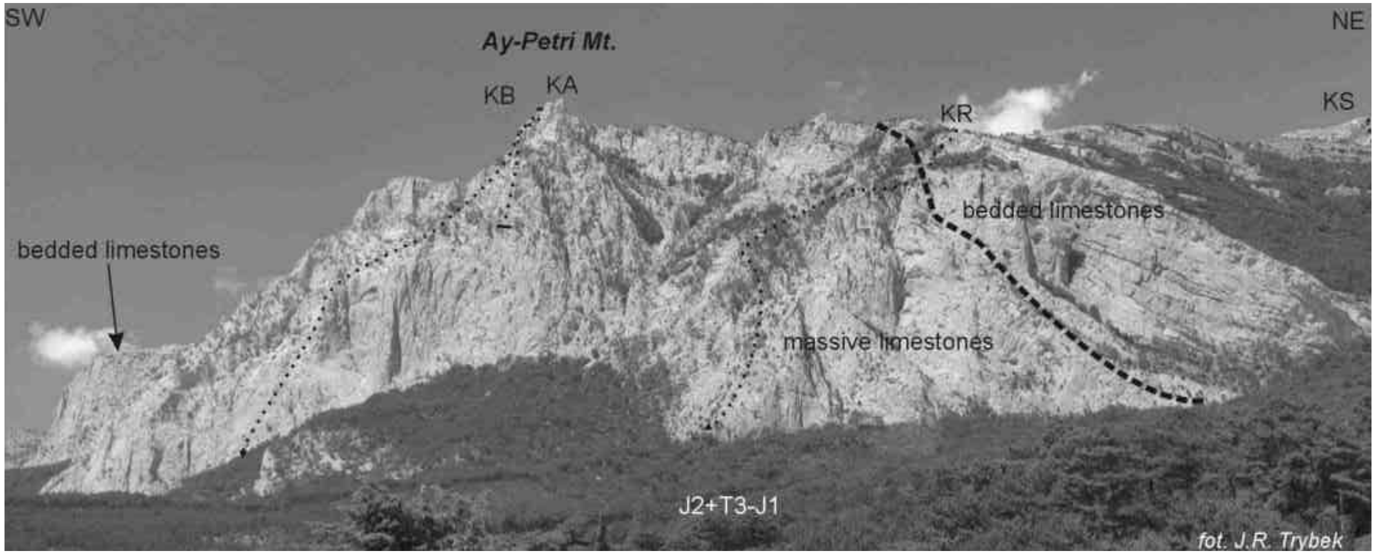



**Fig. 4.12.** Ay-Petri Mountain with locations of the KS, KR, KB and KA sections. Central part of the mountain is build by strongly cemented massive limestones which represents Ay-Petri reef complex, the outer part of the mountain is build by bedded limestones and represents back-reef facies

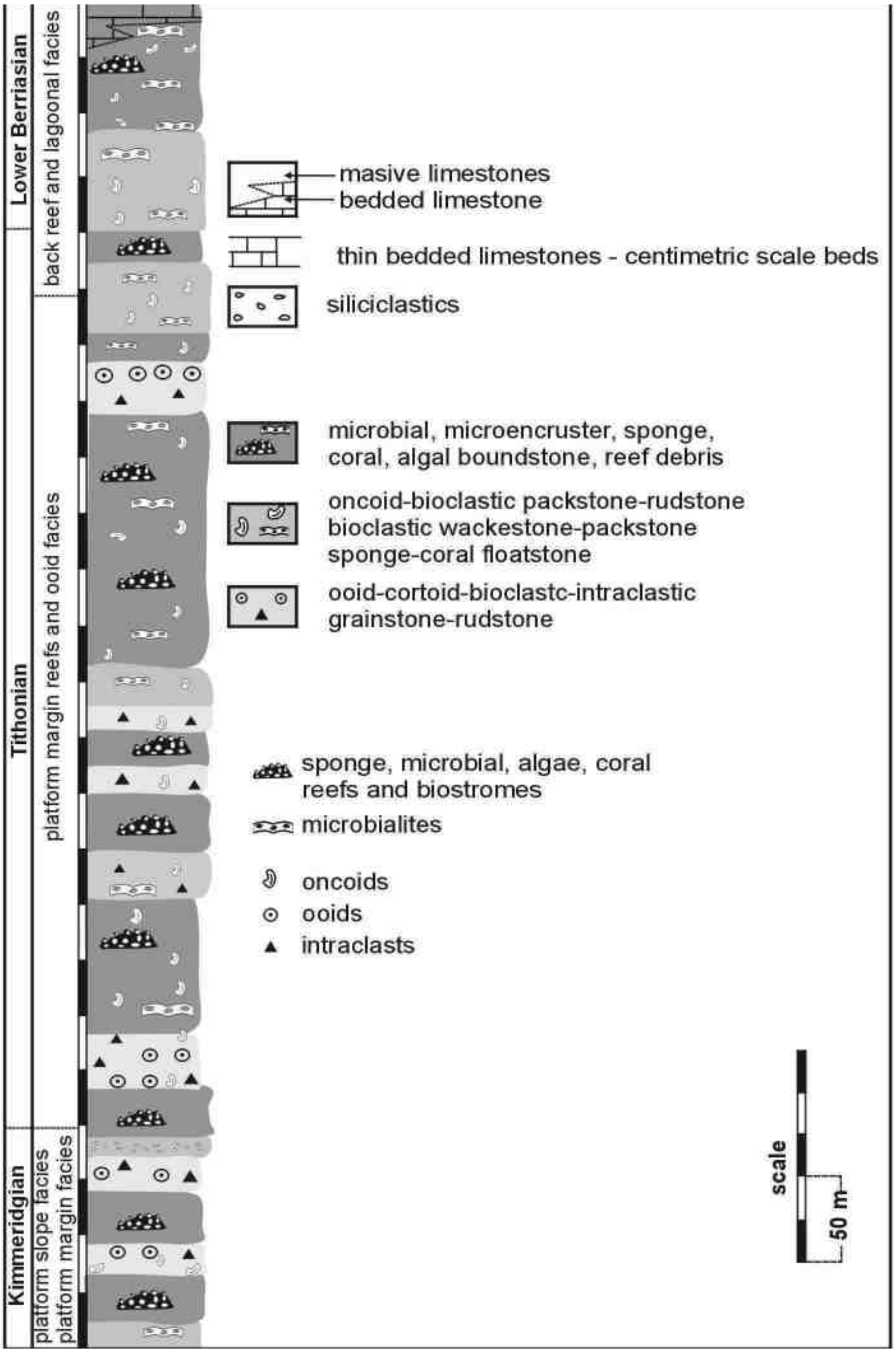



**Fig. 4.13.** Schematic lithological log of the KB and KA section (Ay-Petri Massif, Ay-Petri reef, massive limestones, Kimmeridgian-Tithonian-Lower Berriasian)

The results of microscopic examinations led to the distinguishing of several microfacies varieties, which, on the contrary to macroscopic observations, reveal a complicated structure of the Ay-Petri reef complex (Figs 4.13, Krajewski, Olszewska 2005, 2006, Krajewski 2008). The Ay-Petri limestones form several cyclic successions of various thickness. Each cycle is dominated by various microfacies representing various depositional environments.

The collected materials and microfacies varieties identified in specific horizons enabled the author to distinguish four main groups of microfacies (Tabs 4.30–4.48):

– framestones-bindstones. The principal components are sponges, microbialites, algae, microencrusters and corals. Moreover, biolithites were found, developed as thrombolitic-*Crescentiella* bindstones,
– bioclastic floatstones-grainstone. The main components are various bioclasts, mostly fragments of sponges, corals, algae, bivalves, gastropods, echinoderms and brachiopods,
– oncoidal-bioclastic packstones. The most common are various oncoids (micrite-dominated and *Bacinella* ones), redeposited fragments of metazoans, foraminifers, algae and peloids. In some sequences fenestral structures are observed. Sometimes the sediments are binded with microbial crusts,
– ooid-cortoid-bioclastic grainstones-rudstones.

Moreover, in the lower and the middle parts of the sequence horizons were observed of mixed, carbonate-siliciclastic and siliciclastic sediments.

Massive limestones examined along the KB section are composed mostly of various biolithites and detrital sediments. The lowermost portions are occupied by bioclastic wackestones-floatstones, sometimes stabilized by microbial crusts forming microbial bindstones (Fig. 4.13). Moreover, thrombolitic bindstones were noticed. Up the sequence, most important become bioconstructions dominated by various organisms: sponges, algae and corals, which, together with microbialites and microencrusters form small patch-reefs and biostromes (Tab. 4.30, 4.31). Their erosion supplied material for detrital sediments, which were then subjected to early cementation together with bioconstructions (Tab. 4.31C). In most of the sequence skeletons of corals and sponges were partly or entirely dissolved and replaced with cements, which in many cases precludes their identification (Tabs 4.30D, 4.31A, B). Basing on the frequency of reef-building fossils, in which details of internal structure were preserved, it can be concluded that biolithites are composed mostly of sponges, microbialites and microencrusters.

Similarly to the adjacent sequences, in the KB corals are rare in comparison to other reef builders. Some observed coral fragments are redeposited, what suggest that in other parts of massive limestones their precentage can be higher. Despite insufficient data on corals, a distinct trend was found in their occurrence. Platy Microsolenidae are in the lower parts of the sequence numerous (Tab. 4.30A, C). On outer parts of their skeletons *Crescentiella morronensis* and *Terebella lapilloides* microencrusters grow. Frequent are thrombolites, which form coral-microbial biostromes, usually together with *Microsolena* (Tab. 4.30A, C). Up the sequence the coral assemblage seems to become more diversified because, apart from *Microsolena*, also *Stylina, Heliocoenia* and *Latomeandra* were encountered in small, coral patch-reefs although their occurrence is limited to only a few levels (Tabs 4.32B, 4.33A, D, 4.42A, D). On the outer surfaces of corals *Lithocodium aggregatum* grows whereas interskeletal spaces are filled with microbialites or fine-detrital sediment. In many samples primary, external morphology of corals was preserved by microbial crusts and microencrusters whereas the skeletons were completely dissolved and replaced with the cement (Tab.4.42D).

Most common bioconstructions in the whole KB section are those built of sponges (Tabs 4.30–4.41). Such buildups were encountered at many levels of the sequence but are particularly abundant in its middle parts (Fig. 4.13). The buildups are composed of skeletons revealing diversified morphologies – from branches to wineglasses (Tabs 4.30–4.41). On the skeletons and between them microencrusters are growing: *Lithocodium aggregatum* crusts on the upper surfaces, *Crescentiella morronensis* on the lower parts and *Thaumatoporella parvovesiculifera*, *Bacinella irregularis* and *Pseudolithocodium carpathicum* between the skeletal fragments or, if the fragments are loosely packed, bioclastic packstones appear (Tabs 4.36, 4.37C, 4.38, 4.39). Skeletons are observed in both the life positions and as displaced but both are always binded by microencrusters. Internal structure of skeletons is often poorly visible due to dissolution and precise determination of such forms is very difficult (Krajewski 2008). Commonly, skeletons are completely replaced with the cement while their morphology is reflected by external crusts built by microencrusters (Tabs 4.30D, 4.31A, B). Typical features of such buildups is the mass occurrence of green alga *Thaumatoporella parvovesiculifera* or *Pseudolithocodium carpathicum* (Tabs 4.31B, 4.33B, 4.39, 4.40). Within the sponge bioconstructions corals are sometimes observed, e.g. *Heliocoenia* (Tab. 4.33A). Usually, sponges form patch-reefs, which grade upward into biostromes of larger lateral extent, although their dimensions are hard to measure due to unaccessibility of exposures. Within the biostromes several succeeding horizons were distinguished, composed mainly of large skeletal fragments preserved in life positions and numerous, fine, redeposited pieces.

One of the most common facies varieties is bioclastic wackestone-floatstone-rudstone composed of fragments of various organisms. It is found especially in parts of the sequence where various bioconstructions occur. Among bioclasts redeposited fragments of sponges, algae, corals, bivalves and gastropods occur, derived from adjacent bioconstrutions (Tabs 4.35B, 4.37A, B, D).

Another typical bioconstructions are patch-reefs built of sponges, particularly chaetetids, among which *Chaetetopsis spengleri* (KOECHLIN), probable *Pseudoseptifer* sp. as well as *Actinostromaria* and *Milleporidium* were identified (Tabs 4.36, 4.42C). Their skeletons, usually found in life positions, form well-developed, rigid framework together with microencrusters and microbialites (cf. Olivier *et al*., 2005). On their outer surfaces thin crusts of *Lithocodium aggregatum* grow wheres the interskeletal spaces are filled mostly with thrombolites in which numerous cavities are filled geopetally or with fine-detrital sediment (Tab. 4.36).

In some sediments, particularly in the lower part of the sequence, abundant biolithites were noticed, composed of thrombolitic bindstones and *Crescentiella morronensis* microframestones forming the microbial buildups. In the upper parts of the sequence such forms are less common and microbialites are represented mostly by microbial crusts which stabilize fine-detrital packstones.

At various levels of the KB section but particularly in its middle and upper portions, numerous are grainstones and rudstones. Despite the position, most of them show similar features – their main components are various, crushed bioclasts of dasycladaleans, gastropods, bivalves shells, echinoderms and fragments of metazoans. In grainstones frequent are isopachous cements developed around grains. Some bioclastic grainstone are cut by veins commonly filled with isopachous cement. Thin, microbial crusts, which stabilize detrital grains are rare. Frequently, intraclastic grainstones-rudstones are noticed in which intraclasts are fragments of micritic sediments, wackestones or packstones (Fig. 46E). In thin sections transitions from sponge-algal biostromes to unconformably overlying, intraclastic grainstones are observed, the latter originating from erosion of the bedrocks (Tab. 4.44A, B). The boundary between these two microfacies is of hardground nature. Less common are bioclastic packstones which have the same grain-size distribution as grainstones from which micrite originally filling the intergranular spaces was removed and its place was taken by marine phreatic cements. Common are cortoid grainstones in which cores are various bioclasts: algae, gastropods and bivalve shells (Tab. 4.35D). Frequent are ooids (Tab. 4.34C). As in to other grainstones, the intergranular spaces are filled with isopachous cements.

Common facies variety is oncoidal packstone (Fig. 4.13). It is especially abundant in the upper part of the KB and KA sections (Tab. 4.45B, C). The components are mostly small oncoids of poorly visible internal structure and peloids often binded into microbial mats. In some parts of the sequence fenestral structures are observed (Tabs 4.45, 4.47). Among oncoids several forms can be distinguished: from small, oval, of obliterated internal structures to large *Bacinella irregularis* ones, the latter often containing vadose silt.

In various parts of the KB section erosional horizons and hard grounds are observed (Tab. 4.44A, B). These are separated by biostromes which surfaces are covered with numerous borings and microbial crusts. Abover, the intraclastic grainstones-rudstones occur, composed usually of angular clasts.

### INTERPRETATION

The studies revealed high variability of the KB sediments and complicated internal structure of the Ay-Petri reef complex (Krajewski, Olszewska 2005, 2006, Krajewski 2008). In fact, massive limestones include several types of sediments, mostly bioconstructions and peri-reefal bioclastic floatstones-grainstones-rudstones. The bioconstructions are separated by beds of grainstones related to erosion, development of ooidal shoals and back-reef oncoidal facies. Moreover, the bioconstructions have rigid frameworks typical of carbonate buildups whereas detrital sediments, as bioclastic grainstones-rudstones or ooid-cortoid grainstones were subjected to early lithification. Commonly noticed marine phreatic cements document intensive flow of solutions, which, combined with the low deposition rate, led to early cementations. Hence, the recently observed detrital limestones form relatively homogeneous mass with biolithites embedded within the massive limestones. Such homogeneity obstacles the mapping of particular limestone varieties as poor weathering does not reveal the lithologic variability. Therefore, it can be concluded that in the Ay-Petri reef complex the important processes forming the massive limestones were the development of numerous, although small bioconstructions and the early marine freatic cementations.

The microfacies analysis revealed that the KB sediments were deposited in a shallow-marine environment, within the photic zone, at depths not exceeding some tens of meters but usually in a much shallower sea. The deepest facies related to slope deposition are thrombolitic-*Crescentiella* bindstones and microsolenid biostromes observed in the lower parts of the sequence. *Microsolena* lives in deeper environment of the outer slope and, presumably, documents the initial stage of platform development (e.g., Nose 1995, Morycowa, Roniewicz 1995, Insalco 1996, Lathuilière *et al*., 2005). The depth of this environment probably did not exceed several tens of meters (i.e., still within the photic zone), deposition rate were low and trophic conditions were high (Insalco 1996, Insalco *et al*., 1997, Roniewicz 2008). Such interpretation is supported by association of *Crescentiella morronensis-Terebella lapilloides* microencrusters and by common occurrence of thrombolitic biolithites typical of microbial-sponge facies (e.g., Leinfelder *et al*., 1996, Krajewski 2000, Matyszkiewicz *et al*., 2006). The *Microsolena*-thrombolitic facies provided stable ground for the growth of next carbonate buildups formed by various organisms. Similarly to the KJ and the KC sections, up the KB section these sediments rapidly grade into deposits of shallow subtidal environments. Intercalations of sandstones indicate the proximity of land and the supply of terrestrial clastic material, which strongly modified the depositional environment. Initial, more deeper deposition was relatively short and it evolved into shallow, subtidal sedimentation controlled probably by small oscillations of sea level, which resulted in common environmental changes and periodical erosion of sediments (e.g. Dupraz, Strasser 1999, Strasser *et al*., 1999, Flügel 2004).

Up the sequence the fossil assemblage becomes more diversified, i.e., numerous dasycladalean algae, demosponges, chaetetids, corals and *Lithocodium aggregatum, Pseudolithocodium carpathicum, Bacinella irregularis, Thaumatoporella parvovesiculifera* microencrusters appear together with ooid-cortoid horizons. Since the appearance of these organisms the sediments reveal frequent changes of dominating microfacies varieties and fossils. In the sequence several complexes can be distinguished of sediments deposited in shallow subtidal, intertidal and supratidal environments probably related to lower-rank, transgressive-regressive cycles. The shallow, subtidal environments are represented by patch-reefs and biostromes built by various organisms: algae, demosponges or corals. In the case of corals the collected materials document the building of rare, individual patch-reefs, usually together with other organisms, especially sponges. In the KB section most common are sponge patch-reefs and biostromes. It seem that chaetedis occupied oligotrophic environments, as revealed by thin crusts of *Lithocodium aggregatum* growing on outer surfaces. Growth of *Lithocodium* and other microencrusters took place on dead parts of skeletons. Thrombolites, which fill the interskeletal spaces and microbialites, growing on the outer surfaces of sponge patch-reefs represent succeeding stages of microbialite development, which can be interpreted as reef crisis (e.g. due to changes of trophic conditions and deposition rates), similarly to coral and microbial-sponge reefs (e.g. Olivier *et al.*, 2005).

The growth of the patch-reefs can be related to shallow and variable depositional environments. Common detrital components suggests variable, higher-energy conditions. On densly packed skeletons intensive growth of *Thaumatoporella parvovesiculifera* oraz *Lithocodium aggregatum* took place, which indicates oligotrophic conditions and low accumulation rates (e.g. Leinfelder *et al.*, 1996, Dupraz, Strasser 1999). Displaced and crushed sponges fragments frequently noticed in the KB section point out to their intensive destruction in an abrasional environment.

Commonly observed ooids-cortoid barriers represent the platform marginal facies. Oncoidal packstones and bioclastic wackestones-floatstones are indicative of back-reef and lagoonal environments. Moreover, in some parts of the sequence peloidal packstones, microbial bindstones and mudstones with fenestral structures were noticed, evidencing deposition in intertidal environment. Other components: breccias, meniscus and isopachous cements, dissolved skeletons of various organisms and cavities filled with vadose silt manifest periodical emergences.

In particular sequences, within successions of shallow, subtidal to inter- and supratidal environments numerous discontinuities are observed, related to deposition breaks and erosion. Hence, some sedimentary sequences are erosionally reduced and particular parts of the KB depositional sequences are only partly preserved (Gómez, Fernández-López 1994, Flügel 2004).

The upper parts of the KB section are dominated by sediments related to back reef, lagoonal and intertidal environments. Here, several depositional sequences can be distinguished, probably related to cyclic bathymetric changes. In generaly, each sequence starts with disconformity related to intensive erosion of sediments laid down during the previous cycle. Sometimes between particular sequences angular unconformities occur, which may document tectonic events or gravitational movements during the emergence of some portions of sediments. The sequence is dominated by sediments related to various bioconstructions and peri-reefal deposits. These deposits show highest thicknesses and were deposited in shallow, subtidal environments. The sediments often show traces of cavitational erosion and hardgrounds, indicating minor but frequent deposition breaks. Most macrofossil skeletons were dissolved and replaced with radial and blocky cements. The sediments grade into cycles related to intertidal environments with dominating mudstones, microbial bindstones and packstones with fenestral structures. Although low in thickness, these sediments multiply repeat in the sequence, which indicates common, cyclic changes of depositional environment.

### 4.3.10. The KA section (Ay-Petri Massif, Ay-Petri Mountain, Tithonian-Lower Berriasian, massive limestones)

**LOCATION AND STRATIGRAPHY**

The KA section is located in the top portion of the Ay-Petri massive limestones, close to the KB one (Figs 4.1, 4.12). It is up to 100 m thick and represents the final deposition stage of the Ay-Petri reef complex. Similar to other sequences, the massive limestones seem to be macroscopically monotonous, on the contrary to the results of microscopic studies, which disclosed several microfacies varieties (Fig. 4.13). These varieties form characteristic horizons, which development resembles those of the adjacent KB section. Among fossils the following foraminifers were indentified: *Palaeogaudryina magharaensis* (Late Kimmeridgian-Middle Berriasian), *Palaeogaudryina varsoviensis* (Late Oxfordian-Tithonian), *Nautiloculina bronnimanni* (Berriasian-Hauterivian), *Nautiloculina oolithica* (Late Oxfordian-Berriasian), *Labyrinthina mirabilis* (Latest Oxfordian-Early Tithonian) and *Everticyclammina praekelleri* (Kimmeridgian-Tithonian). Basing on these data, the Tithonian age of sediments was determined grading into the Berriasian in the topmost part of the sequence (Krajewski, Olszewska 2005, 2006, 2007).

**MICROFACIES**

Microscopic observations revealed facies diversity of limestones. The most common varieties are coral-sponge-algae framestones, microbial-*Bacinella* bindstones, bioclastic wackestones-floatstones, mudstones, oncoidal packstones and intraclastic grainstones-rudstones (Tabs 4.45–4.48). Microfacies development is similar to that of the adjacent KB section (see the KB description), hence, only the sediments from the uppermost portions of the KA were described, which represent the final stage of the Ay-Petri reef complex deposition.

The sediments are rich in macrofossils, which usually form small patch-reefs or are scattered in the rocks (Tabs 4.29B, E, 4.46, 4.48). Their precise description is difficult or impossible because most skeletons, particularly from the upper portions of the sequence, are completely replaced with sparite (Tab. 4.48). Among corals, *Latomeandra* sp was identified, which forms small patch-reefs with demosponges (Tab. 4.46). Skeletons are usually dense packed and their morphology is accentuated by microbial crusts or microencrusters growing onto surfaces (Tab. 4.48C, D). Interskeletal spaces are filled usually by fine-detrital packstone-grainstone. Sediments enclosing the patch-reefs are bioclastic wackestones and packstones, rarely grainstones. Bioclasts are represented by numerous bivalves, fragments of sponges, corals, rudists gastropods and foraminifers (Tabs 4.29, 4.48A).

Commonly observed are microbial and *Bacinella* bindstones developed as thin crusts covering the skeletons of other organisms, as crusts on sediment surface, as stromatolites or less frequent thrombolites (Tabs 4.45C, 4.47A). Moreover, bioclastic wackestones-packstones were found with faint but marcoscopically distinguishable bedding planes.

Numerous are oncoidal packstones-rudstones with large *Bacinella* oncoids and common *Lithocodium aggregatum* growing on their upper surfaces (similar to Tab. 4.45B). The intraclastic rudstones were frequently noticed in the upper portions of the sequence as horizons or fillings of large caverns or depressions. The intraclasts are usually embedded within the sparry matrix.

The sediments contain cavities and fractures geopetally filled with vadose silt and sparite, and fenestral structures (Tabs 4.43B, D4.47C, D). Common are hardgrounds with frequent borings (Tab. 4.44).

**INTERPRETATION**

The KA section documents deposition of the uppermost parts of the Ay-Petri reef complex. Development of strata is similar to that from the adjacent KB section, which enables the author to conclude that types of sediments encountered in both sequences are widely laterally distributed over the study area.

In the lower part of the KA abundant are bioclastic packstones-grainstones and bioconstructions formed by sponges, algae and corals (see description of the KB section) and deposited in shallow, subtidal environments. Similarly to other sequences, most of skeletons was dissolved, which makes more precise characterization difficult.

The top parts of the KA section are composed of sediments related to the back-reef environment and represented mostly by oncoidal-*Bacinella* packstones. There occur also microbial mats, which stabilize the grainstones, and common fenestral structures, vadose silt, breccias and sedimentary unconformities, the latter documenting frequent emergences of buildups and their intensive erosion. These data allow to identify the uppermost parts of the KA section as representative of intertidal environments with frequent deposition breaks and erosion. The upper surface of the KA is simultaneously the angular unconformity, which was observed also in the other parts of the massifs (Tab. 4.29A).

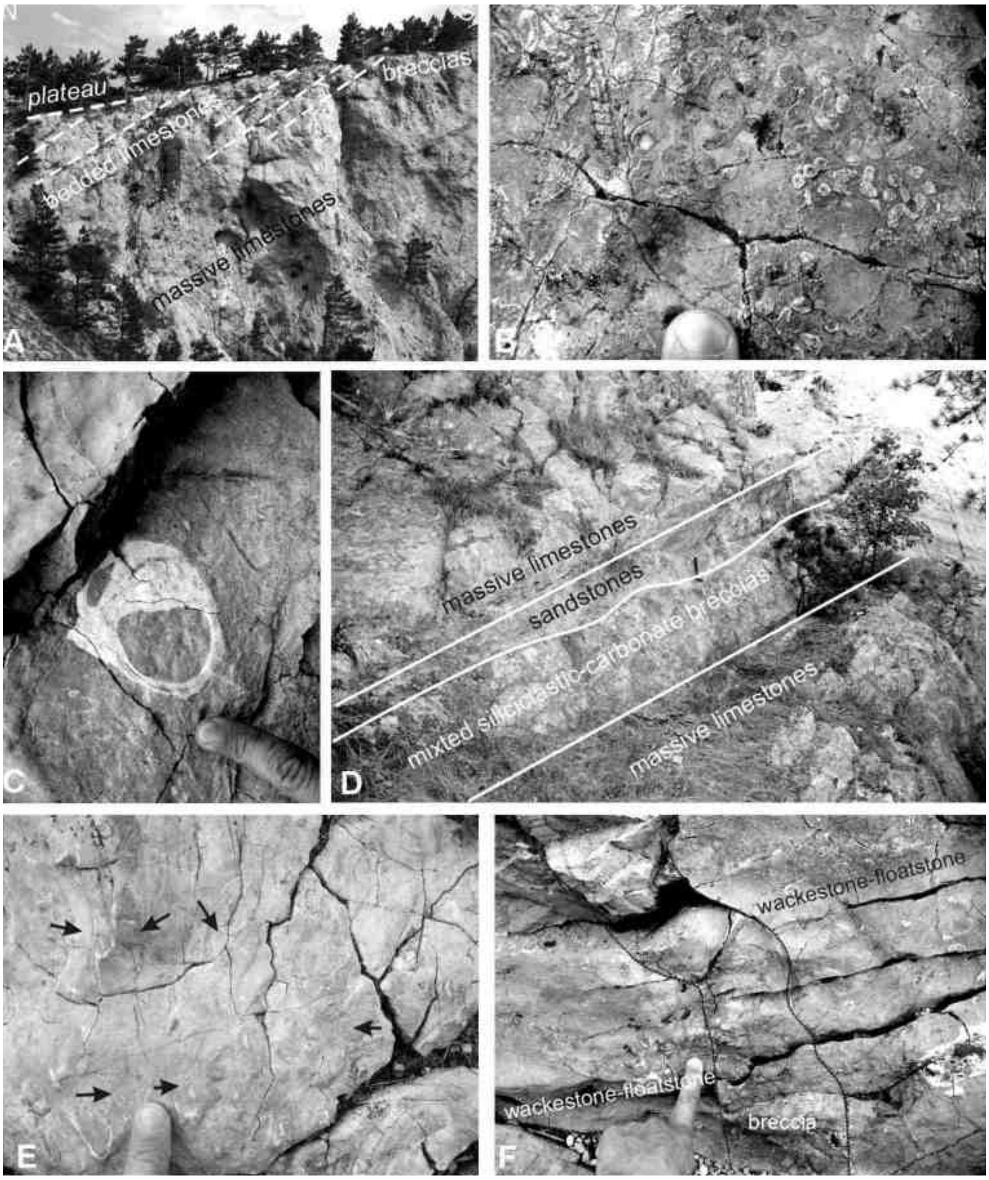

plateau
bedded limestones
breccias
massive limestones
A
B
C
massive limestones
sandstones
mixted siliciclastic-carbonate breccias
massive limestones
D
E
wackestone-floatstone
wackestone-floatstone
breccia
F

**Table 4.29.** Deposits from different parts of the Ay-Petri Mountain

A – summit of the Ay-Petri Mountain, visible angular unconformity between limestones which forms the southern escarpment and the plateau, upper part of the KB and KA sections

B – sponge path-reef from the massive limestones of the Ay-Petri reef complex, upper part of the KB and KA sections

C – bedded limestone of Ay-Petri reef complex with numerous gastropods and rudists, top of the KA section

D – lower part of the Ay-Petri reef complex with siliciclastic beds, lower part of the KC section

E – bedded limestones with corals (arrows), the border of the plateau and southern escarpment of the Ay-Petri Massif, KA section

F – summit of the Ay-Petri Mountain, bedded limestones with neptunian dyke filled by reddish breccias, KA section

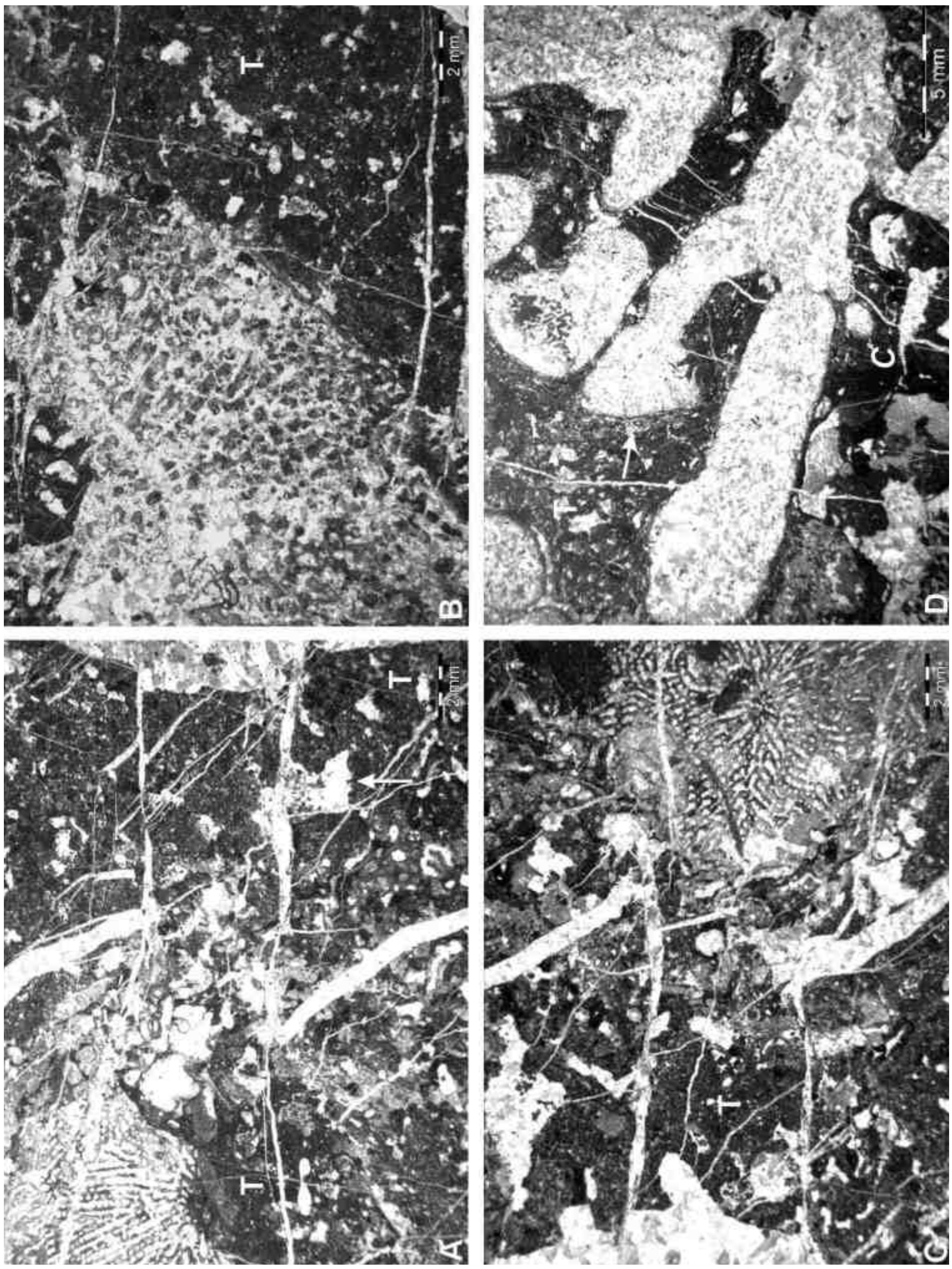

A
B
C
D
T
2 mm
5 mm

**Table 4.30.** Examples of microfacies from lower part of the KB section, Ay-Petri Yalta, Ay-Petri Mt., massive limestones, Kimmeridgian-Tithonian

A, C – *Microsolena*-thrombolitic (T) framestone with *Crescentiella morronensis*, and geopetal in-filled growth cavities (A-arrow) samples KB 36a, KB 36d

B – thrombolitic (T)-sponge framestone, sample KB 36g

D – sponge-algal-microbial (T) framestone with *Crescentiella morronensis* (*C*) samples KB 38j

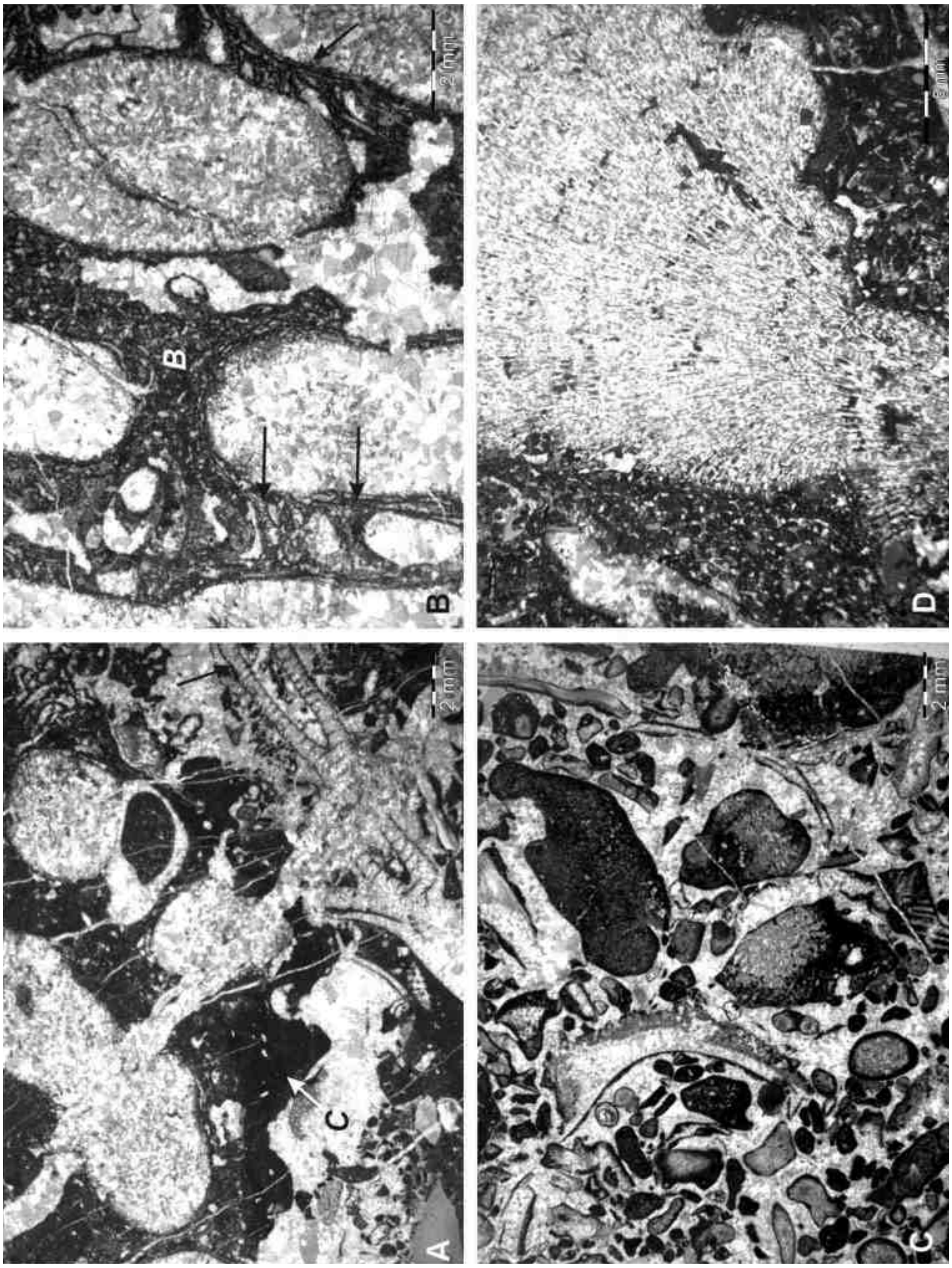

A
C
2 mm
B
B
2 mm
C
2 mm
D

**Table 4.31.** Examples of microfacies from lower part of the KB section, Ay-Petri Yalta, Ay-Petri Mt., massive limestones, Kimmeridgian-Tithonian

A – sponge-algae-microbial framestone with *Crescentiella morronensis* (*C*) and dasycladalean green algae (black arrow), samples KB 38b

B – sponge-algae framestone, numerous fragments of strongly recrystalized sponges, among algae filaments (arrows) and *Bacinella* (*B*), sample KB 37a

C – bioclastic grainstone with fragments of bivalves, sponges and corals, around the bioclast isopahous cement is visible, sample KB 39

D – peloidal-bioclastic packstone-bafflestone with fragment of the sponge (?*Milleporidium*), sample KB 40d

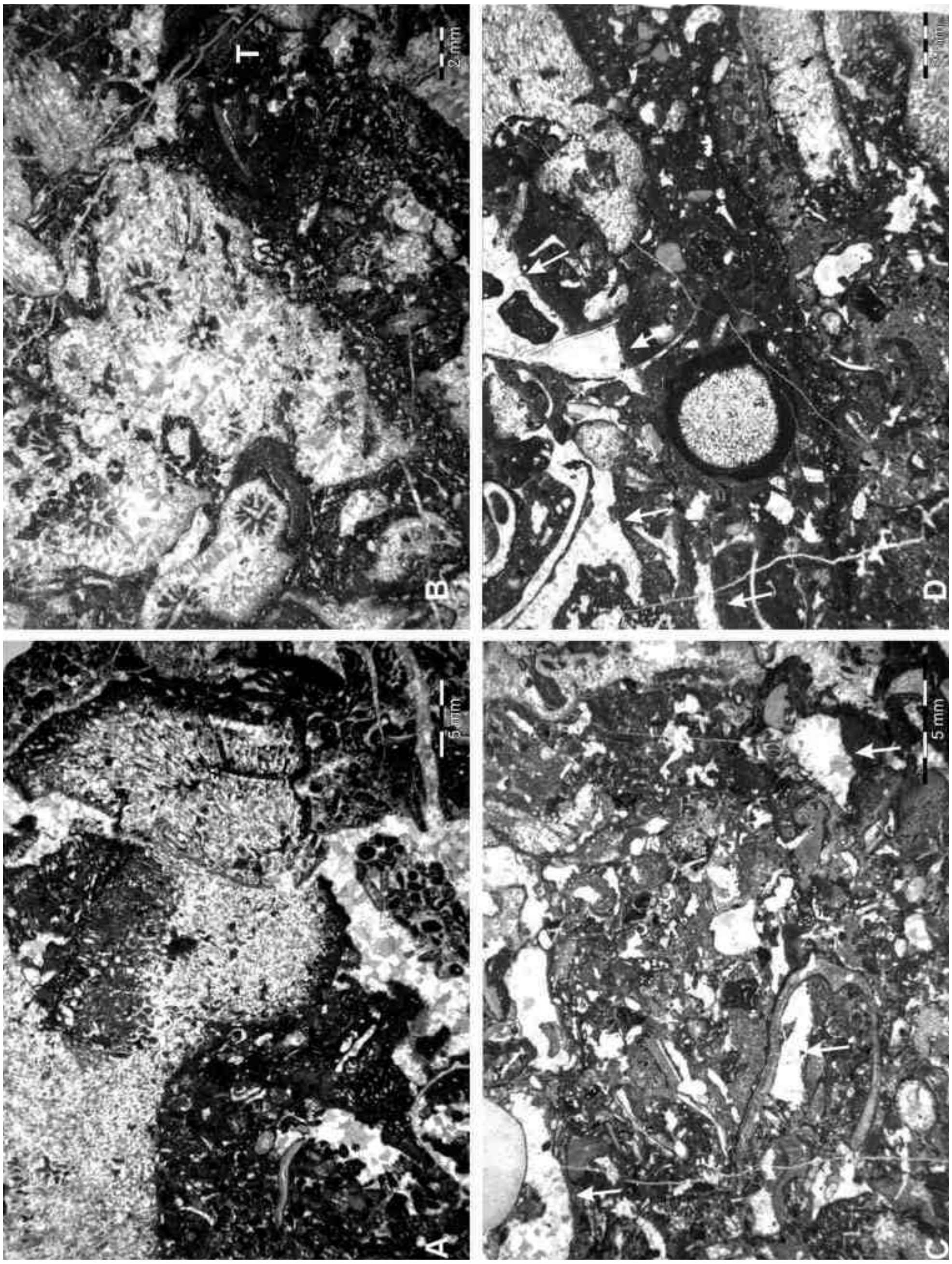

A
5 mm
B
T
2 mm
C
5 mm
D

**Table 4.32.** Examples of microfacies from middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – framestone, chaetetids, perhaps *Chaetetopsis spengleri* (KOECHLIN), sample KB 40e

B – coral-thrombolitic framestone, fragment of *Heliocoenia* cf. *variabilis* colony, sample KB 41c

C, D – bioclastic floatstone with numerous bioclasts and geopetal infilled cavities, samples KB 42c, KB 44a

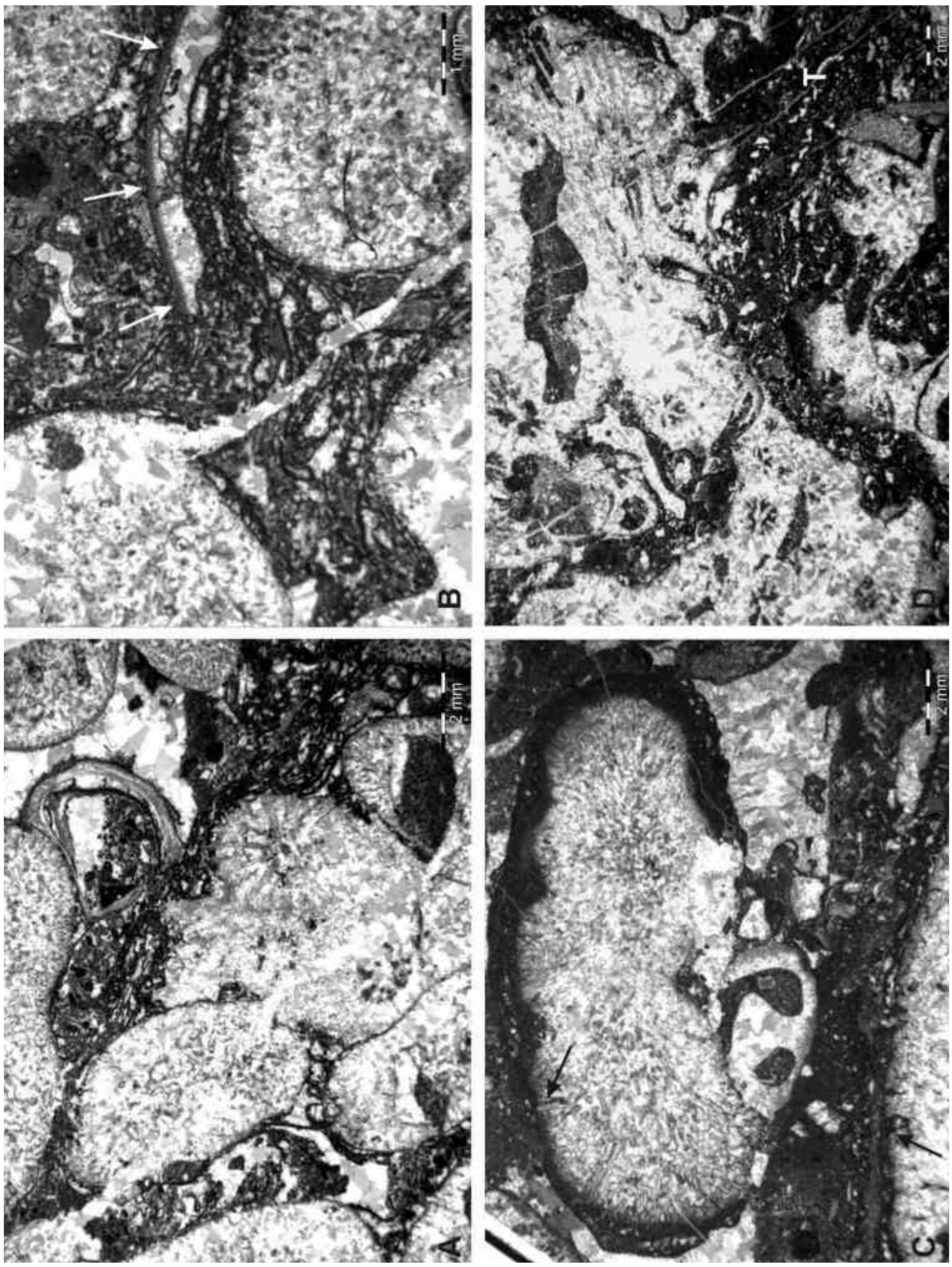

A
2 mm
B
1 mm
C
2 mm
D
2 mm
T

**Table 4.33.** Examples of microfacies from middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – sponge-algal framestone with corals (?*Heliocoenia*), sample KB 51e

B – framestone with sponges, spaces between skeletons are filled by *Thaumatoporella parvovesiculifera* green algae (arrows), sample KB 51h

C – rudstone with reworked sponges, on the surfaces consortium *Lithocodium aggregatum-Troglotella incrustans* (arrows), sample KB 44b

D – coral-thrombolit (T) framestone, sample KB 41b

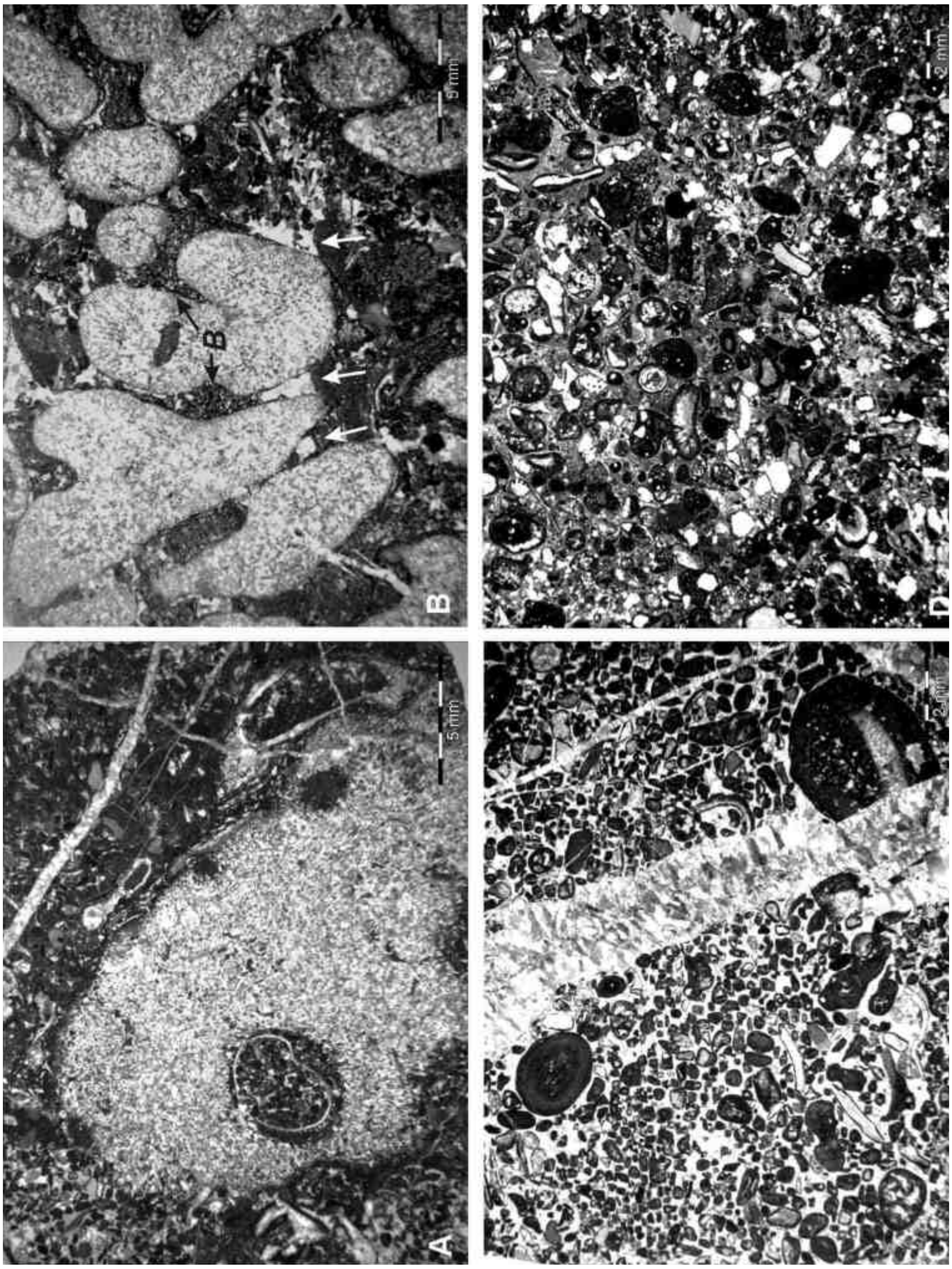

A
B
C
D
5 mm
5 mm
B

**Table 4.34.** Examples of microfacies from the middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – bioclastic packstone-grainstone with fragment of reworked sponge, sample KB 40f

B – sponge framestone-bafflestone, among skeletons grains, bioclast or *Bacinella* (*B*), numerous small geopetal infilled caverns are visible (white arrows), sample KB 51c

C – ooid-cortoid-bioclastic grainstone, sample KB 45

D – mixed siliciclastic-carbonate packstone with numerous bioclasts mainly dasycladalean green algae and siliciclastic grains, sample KB 47f

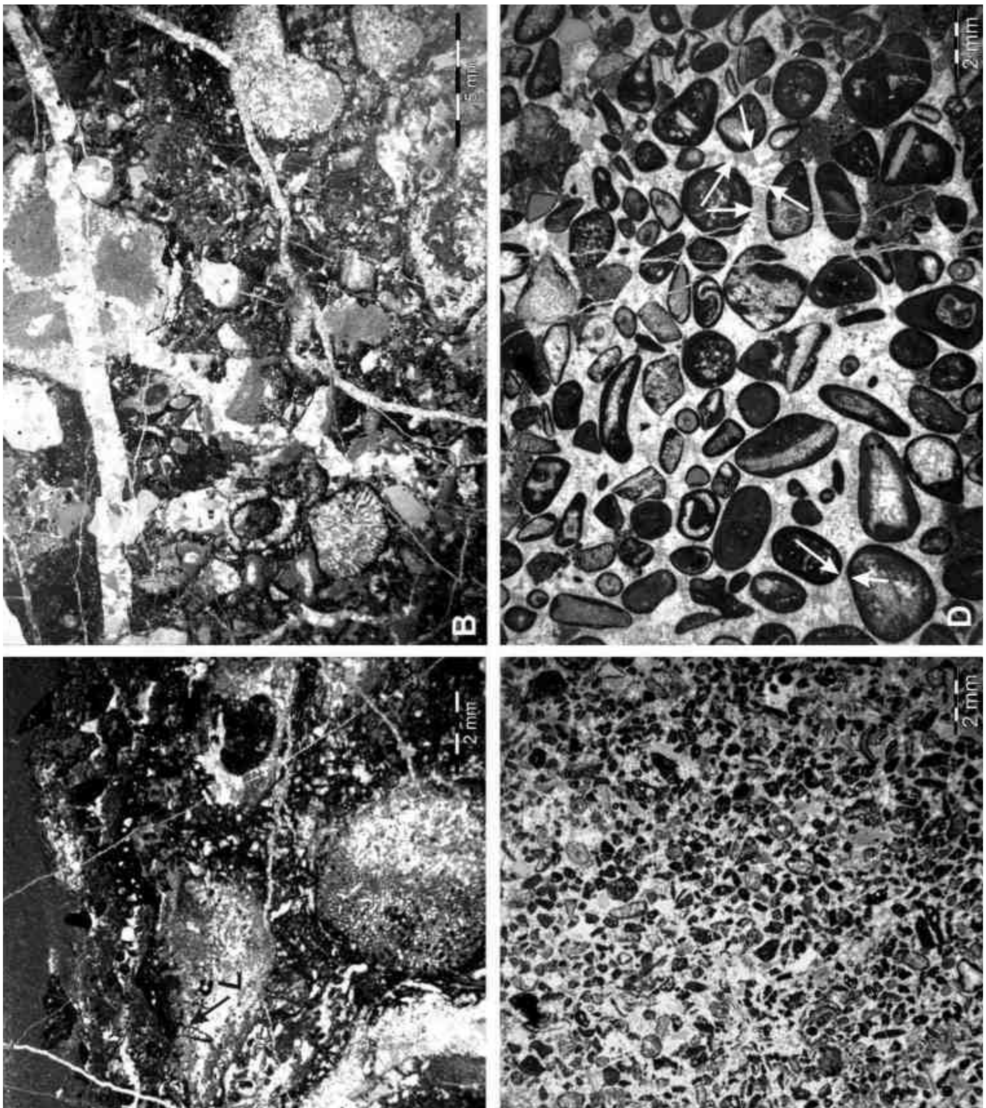

A
2 mm
B
5 mm
C
2 mm
D
2 mm

**Table 4.35.** Examples of microfacies from the middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – in the lower part framestone with fragment of sponge-algal biostromes with encrustation of *Lithocodium aggregatum-Troglotella incrustans* consortium (*L*-arrow), in the upper partinter tidal mudstone, sample KB 4c

B – sponge-microbial framestone, sample KB 49d

C – grainstone with numerous small intraclasts and dasycladalean green algae, sample KB 45

D – cortoidal grainstone with isopachous cement (arrows), sample KB 15

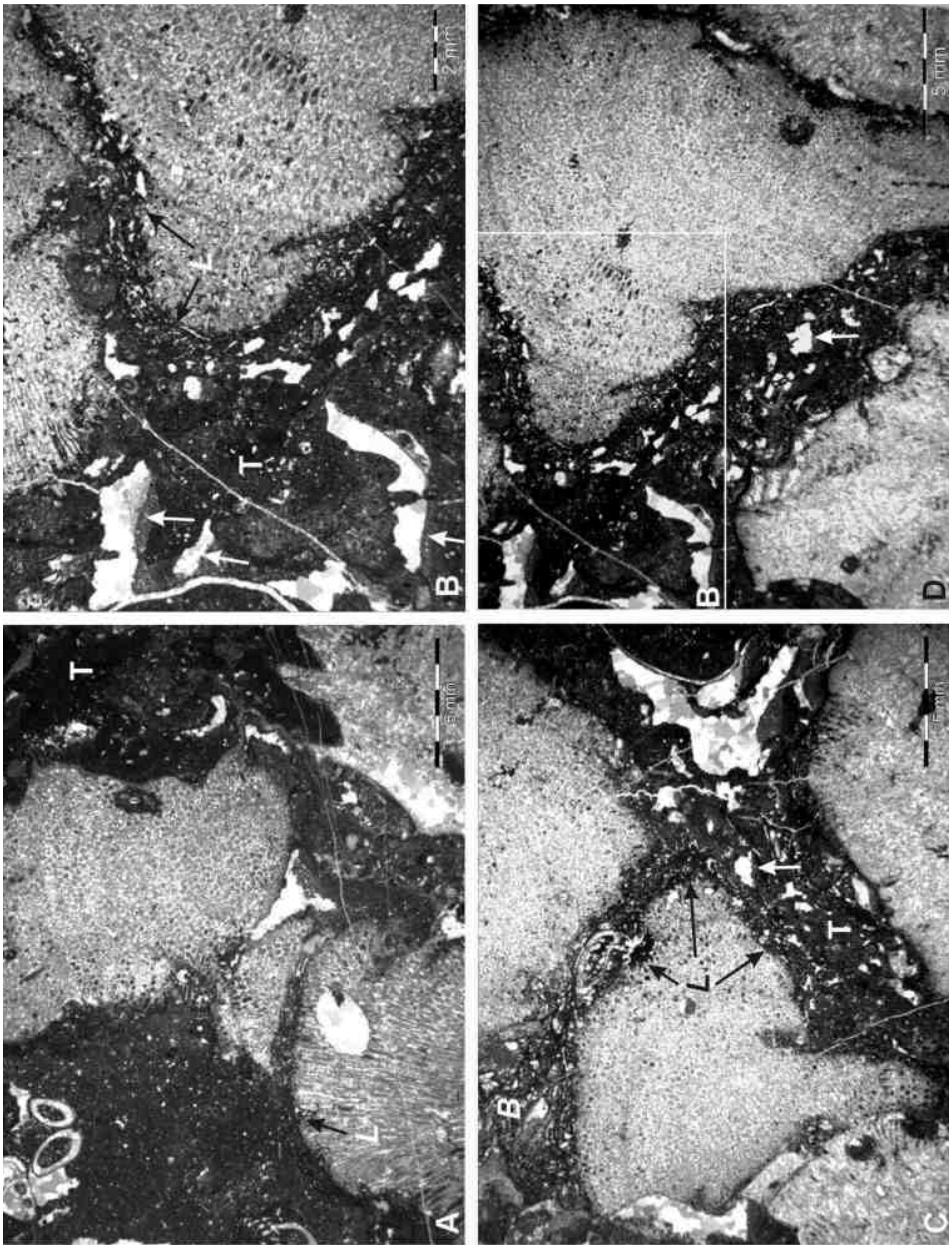

A
B
C
D
T
L
2 mm
5 mm

**Table 4.36.** Examples of microfacies from the middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A, B, C, D – sponge-microbial framestone, association composed of micritic and peloidal thrombolites with growth cavities (white arrows) and sponges (?*Chaetetopsis spengleri* (KOECHLIN)) with encrustation of *Lithocodium aggregatum* (black arrows), samples KB 12e, KB 12a, KB 21e, KB 12a. Thrombolitic overgrowth occurs as the second encrustation of sponge skeletons. The early litification is evidenced by growth cavities. The thrombolites developed together with phototrophic macroorganisms reflecting nutrient rich conditions in internal parts of the reefs

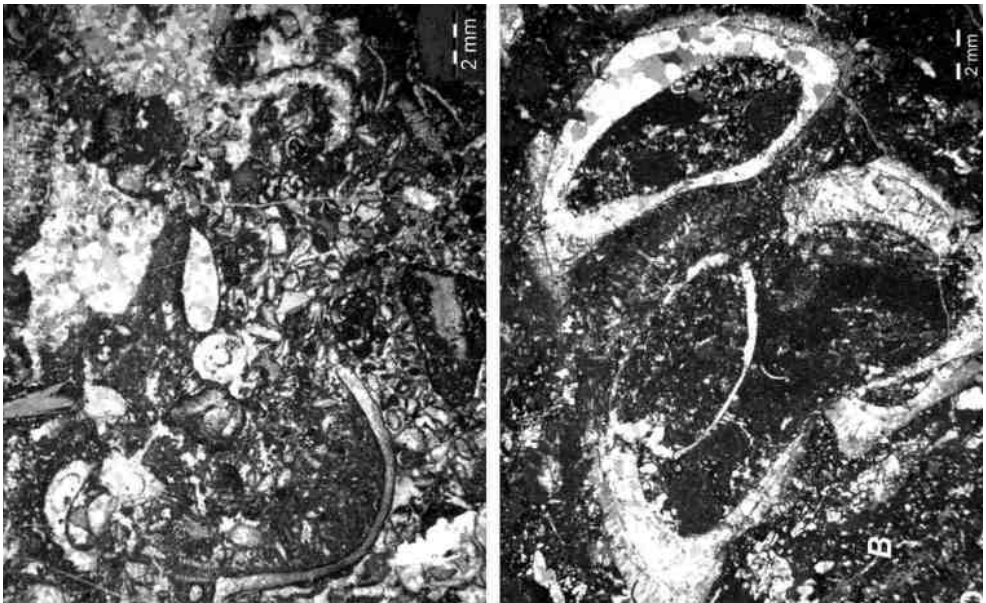

A
5 mm
B
2 mm
C
T
L
D
B
2 mm

**Table 4.37.** Examples of microfacies from the middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A, B – peri-reefal packstone-rudstone-floatstone with numerous fragments of sponges, algae and bivalves, samples KB 42a, KB 13

C – sponge-microbial (T) framestone with *Lithocodium aggregatum* (*L*) on the surface, sample KB 21c

D – *Bacinella* (B)-microbial bindstone with bivalves, sample KB 25a

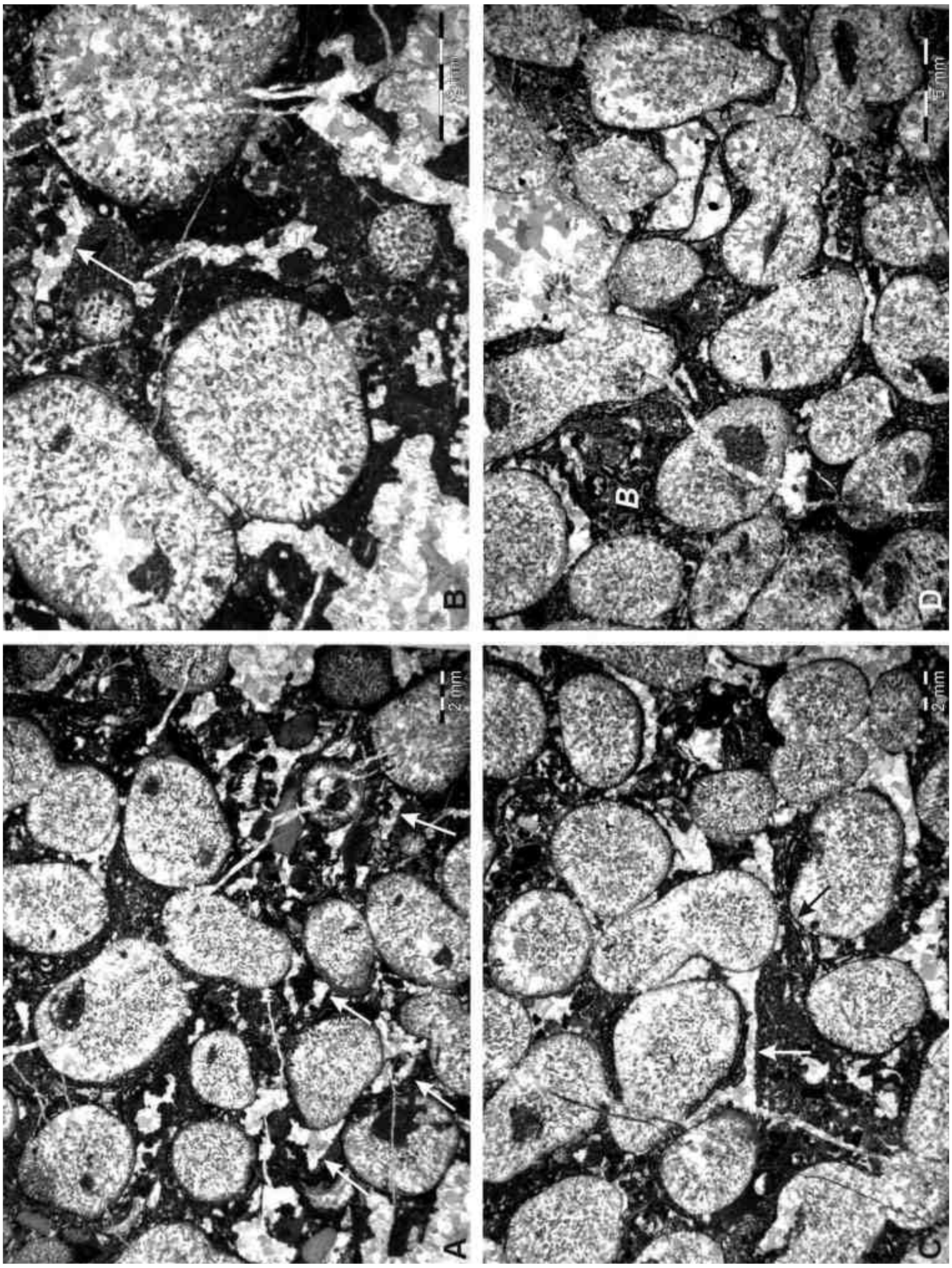

A
B
C
D
2 mm
2 mm
5 mm
B

**Table 4.38.** Examples of microfacies from middle part of KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, sponge-coral-algae patch-reefs and biostromes

A–D – framestone with numerous sections strongly recrystallized sponges, in the spaces between skeletons *Thaumatoporella parvovesiculifera* green algae, commonly small fenestre structures and small caverns with geopetal infillings are visible (A, B, C), samples KB 51k, KB 51k, KB 51o, KB 51g

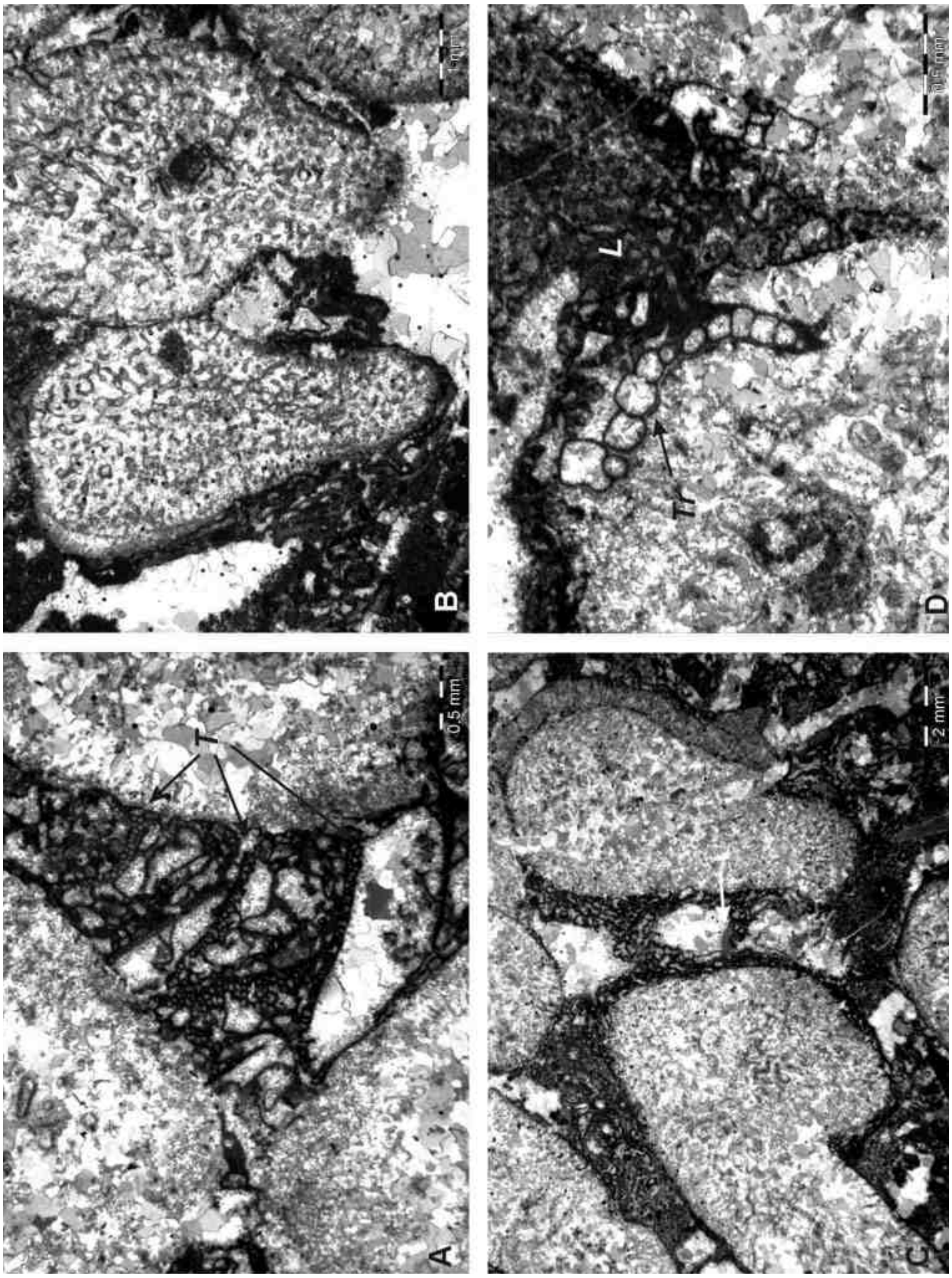

A
T
0.5 mm
B
1 mm
C
2 mm
D
L
T
0.5 mm

**Table 4.39.** Examples of microfacies from middle part of KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, sponge-coral-algae patch-reefs and biostromes

A – framestone, enlargement of sponge-algae path-reef, among strongly recrystallized organisms ?*Thaumatoporella* green algae (arrows), sample KB 51c

B – framestone, fragments of sponges with microencrusters on the surfaces, sample KB 51p

C – framestone, strongly recrystalized sponges are bounded by microencrusters, sample KB 51r

D – framestone, enlargement of strongly recrystalized sponges with consortium of *Lithocodium aggregatum* (*L*)-*Troglotella incrustans* (*Tr*), sample KB 51h

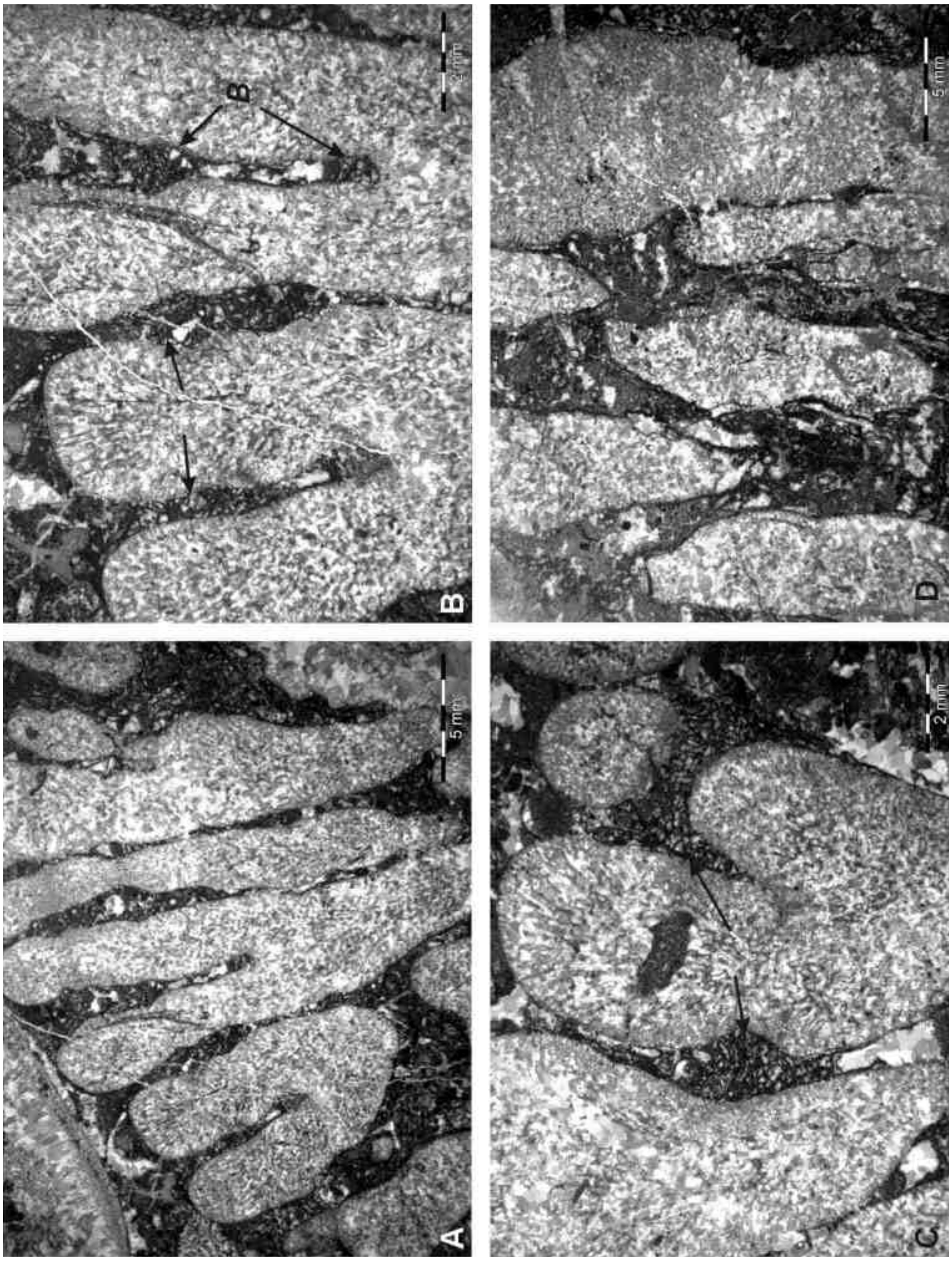

A
5 mm
B
2 mm
B
C
2 mm
D
5 mm

**Table 4.40.** Examples of microfacies from the middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, sponge-algae patch-reefs and biostromes

A–D – framestone, sponge-algal path-reef, B – enlargement of photo A, samples KB 51j, KB 51j, KB 51c, KB 47c

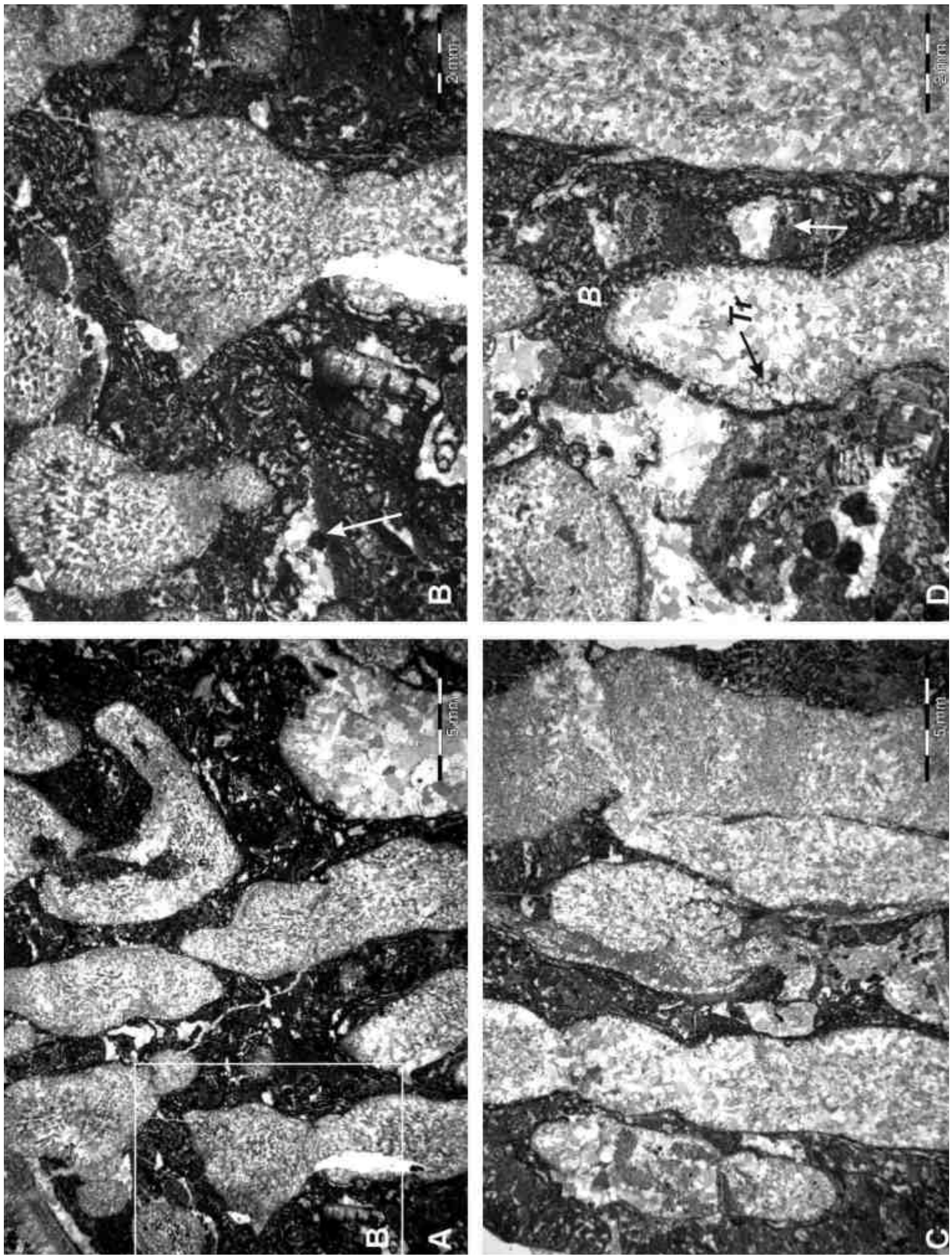

A
B
B
C
D
B
Tr

**Table 4.41.** Examples of microfacies from middle part of KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, sponge-algal patch-reefs and biostromes

A–D – framestone, numerous sponges which are bounded by microencrusters, small growth cavities are geopetal infilled (photos B, D-arrow), B- enlargement of photo A, samples KB 51a, KB 51a, KB 47k, KB 47h

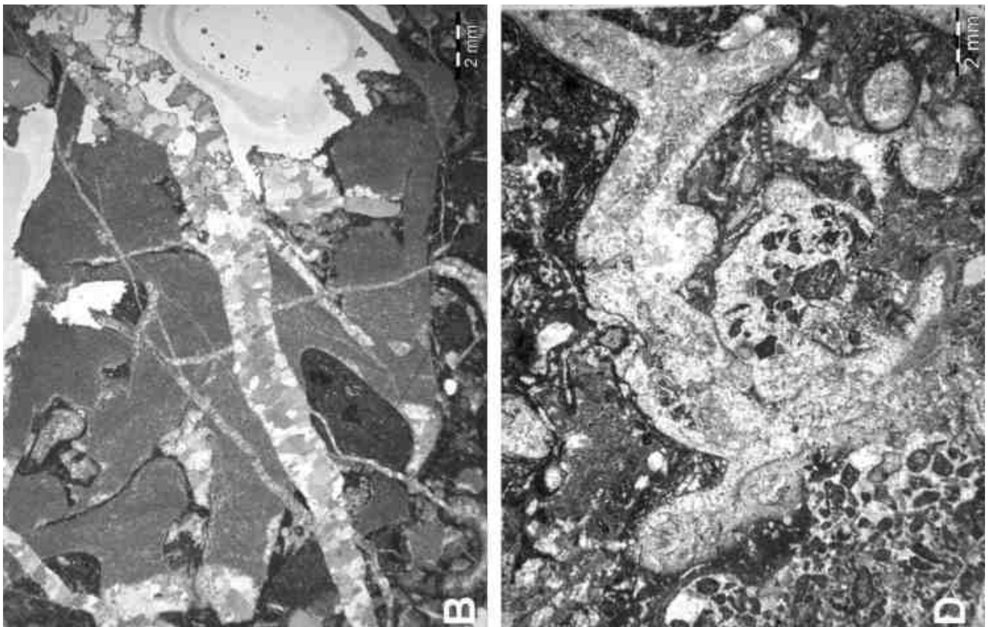

A
B
D
2 mm
2 mm
2 mm

**Table 4.42.** Examples of microfacies from the middle part of the KB sequence, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – coral framestone, sample KB 7

B – relics of dissolved skeletons filled in micrite, sample KB 49b

C – sponge framestone with fragment of *Actionostromaria* and dasycladaleans, sample KB 7c

D – coral framestone, sample KB 7b

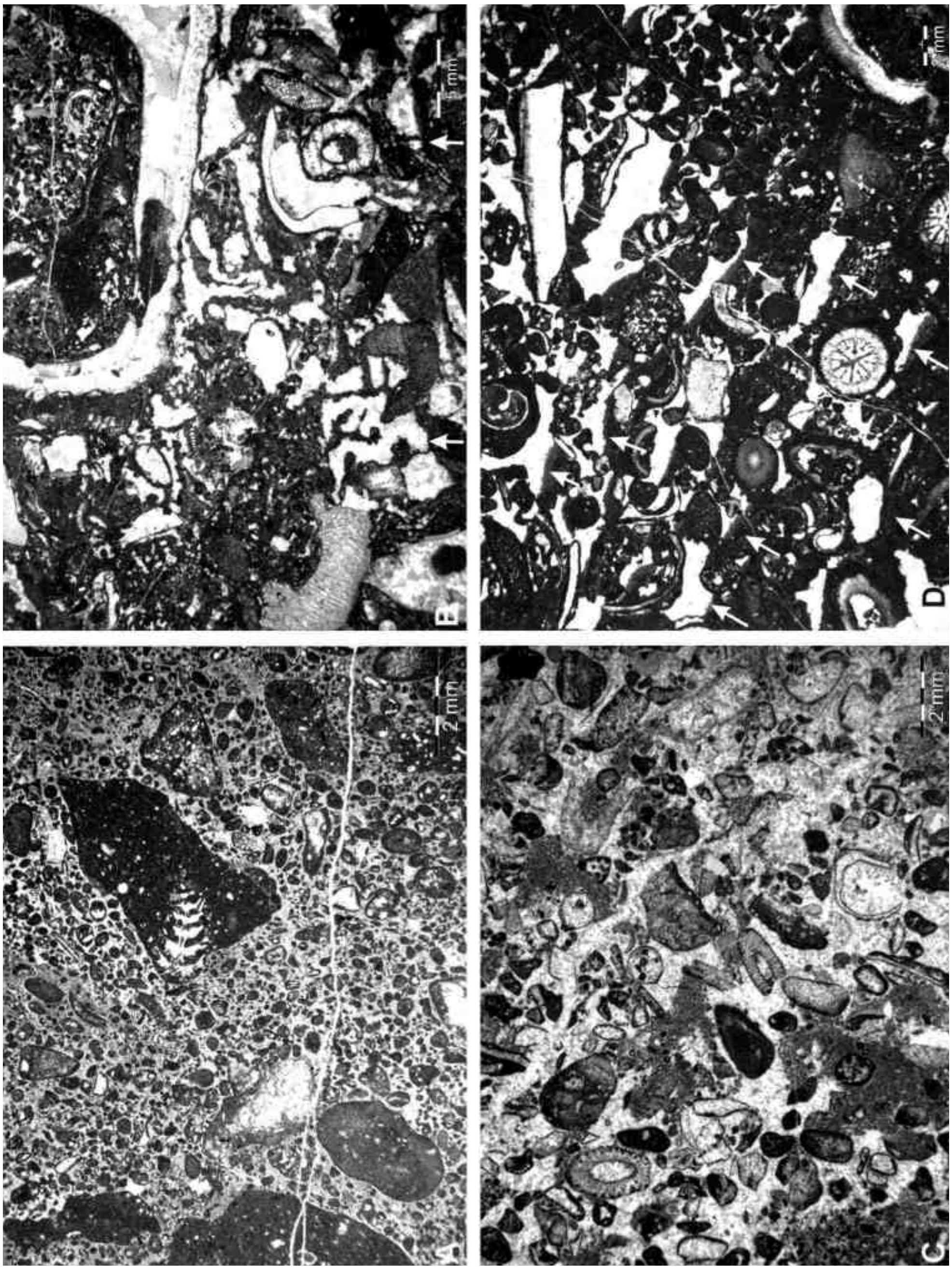

A
B
C
D
1 mm
2 mm

**Table 4.43.** Examples of microfacies from the middle part of the KB section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – bioclastic-intraclastic packstone-grainstone, sample KB 22

B – bioclastic-microbial bindstone with fragments of sponges, dasycladaleans, and bivalves, small caverns (?fenestral structures) are geopetal infilled (arrows), sample KB 54a

C – bioclastic grainstone with numerous fragments of algae, gastropods, foraminifers and bivalves, sample KB 6

D – fenestral packstone-grainstone with algae, corals and gastropods, sample KB Aj 4f

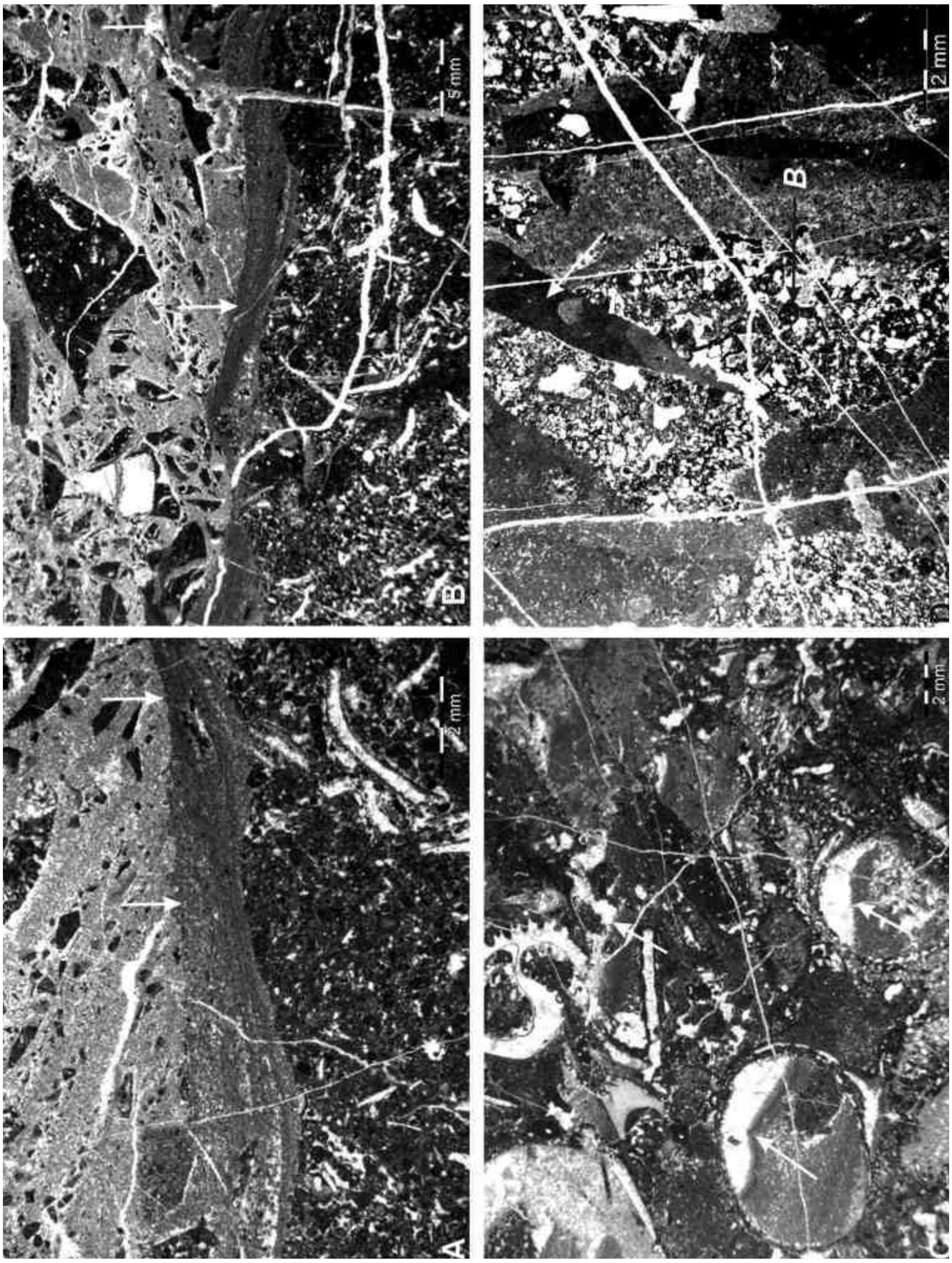

A
2 mm
B
5 mm
C
2 mm
2 mm
B

**Table 4.44.** Examples of microfacies from the upper part of the KB and KA sequence, Ay-Petri Massif, Ay-Petri Mt., massive limestrones, Tithonian-Lower Berriasian

A, B – unconformity surface, in the lower part bioclastic packstone-wackestone with microbial crust (arrows), in the upper part intraclastic grainstone, samples KB 24a, KB 24d

C – bioclastic-microbial floatstone with dissolved and geopetal infilled relics of macrofauna, on the surfaces of the fauna microencrusters can be observed, sample 4b

D – *Bacinella irregularis* (*B*) bindstone with numerous borings (arrow), sample KA 4

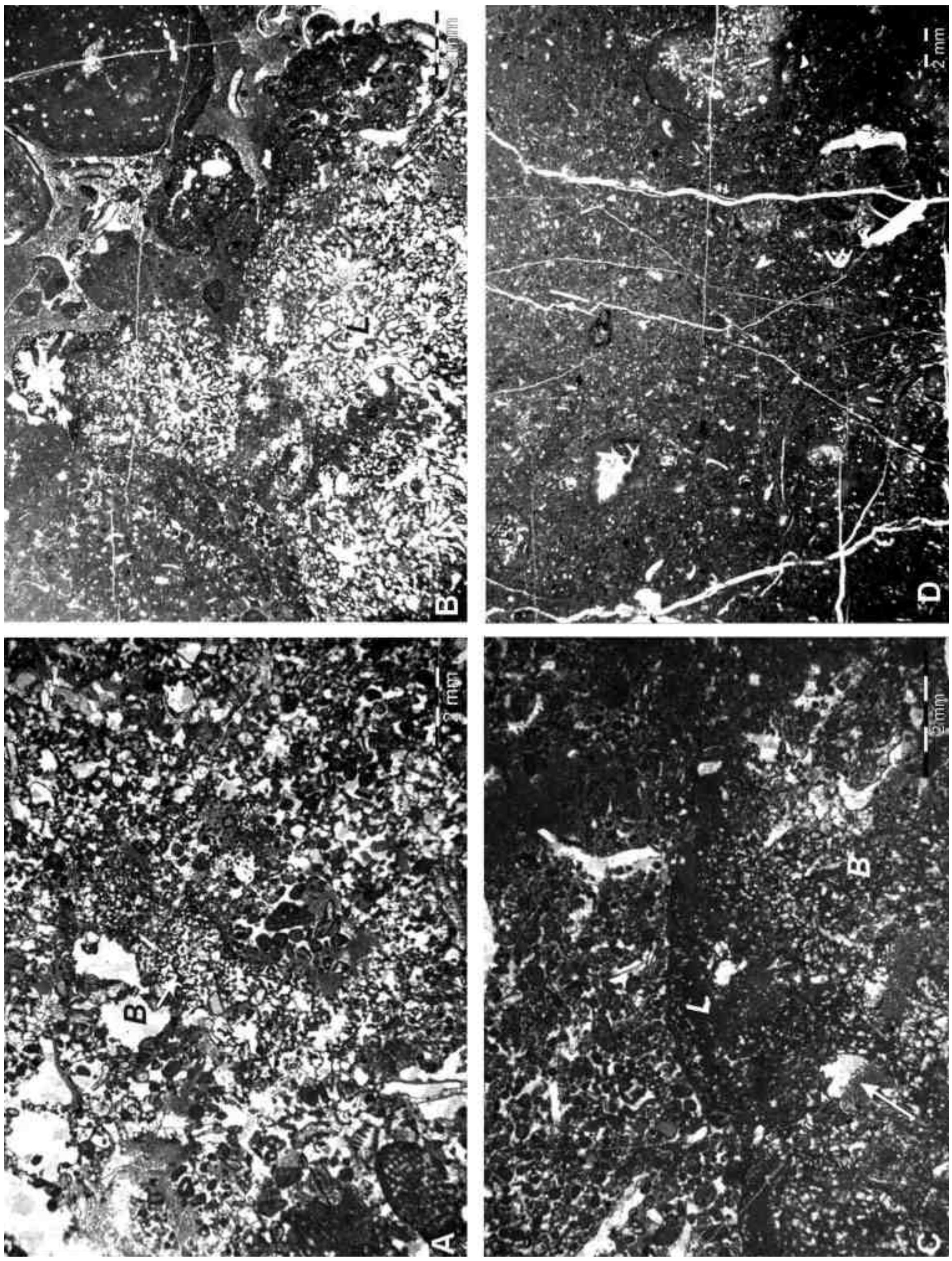

A
B
2 mm
B
L
2 mm
C
L
B
2 mm
D
2 mm

**Table 4.45.** Microfacies from the upper part of KB and KA sections, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian-Lower Berriasian

A – *Bacinella* bindstone-packstone, numerous grains are bounded by *Bacinella* (*B*), sample KB 30

B – *Bacinella* oncoid rudstone with *Lithocodium aggregatum*, sample Aj 1a

C – oncoid-peloid packstone with *Bacinella* (*B*) and *Lithocodium* (*L*) and small geopetal infilled caverns (arrow), sample KB 24d

D – thrombolite bindstone, in the upper part of the photo wackestone, sample KB 29

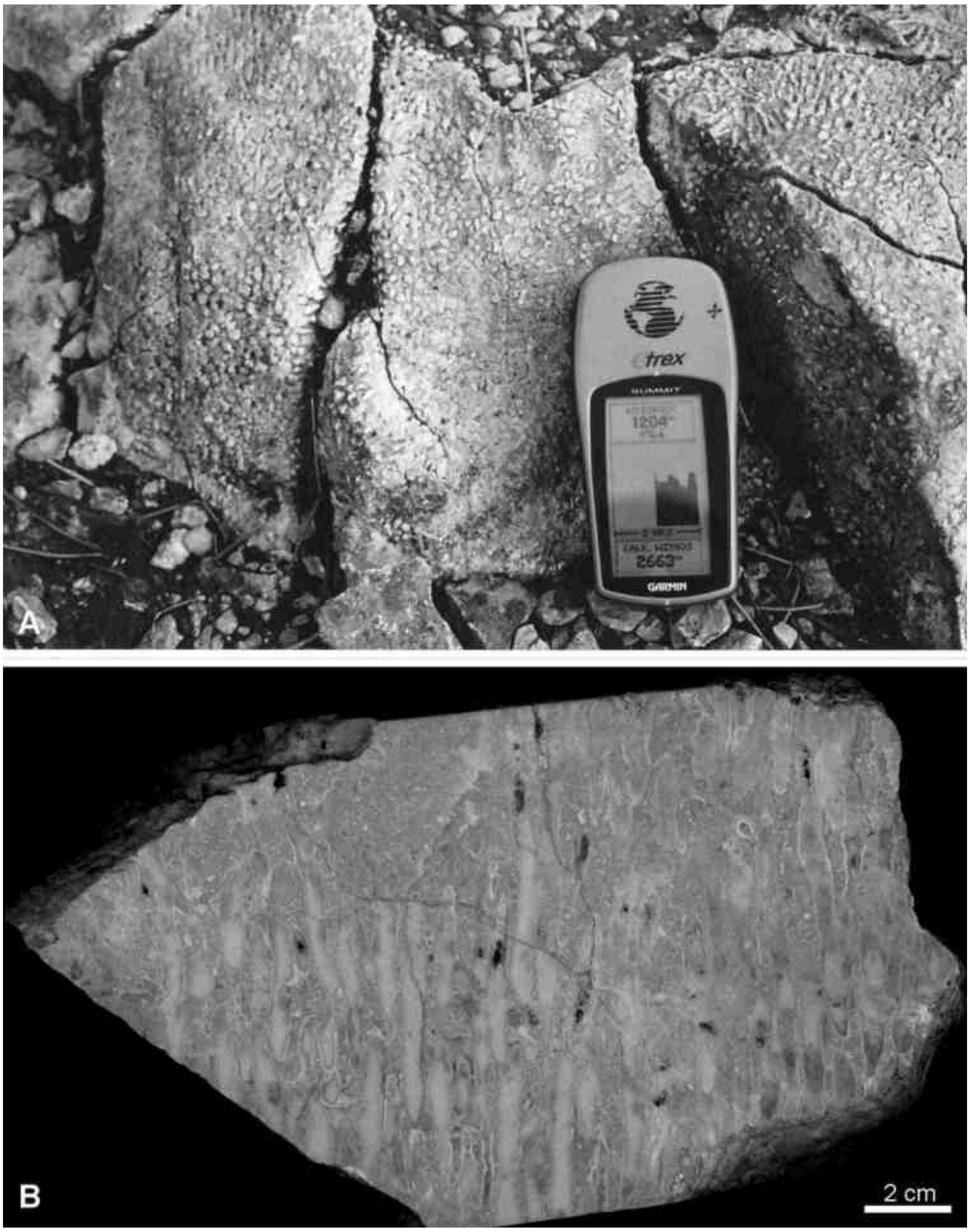

A
B
2 cm
trex
GARMIN

**Table 4.46.** Example of path-reef from the massive limestones of the Ay-Petri reef complex

A – fragment of the patch-reef, most often diameter of the patch-reefs is 1–2 m

B – polished section of the patch-reef with numerous longitudinal sections of the skeletons, for details see Tab. 4.48

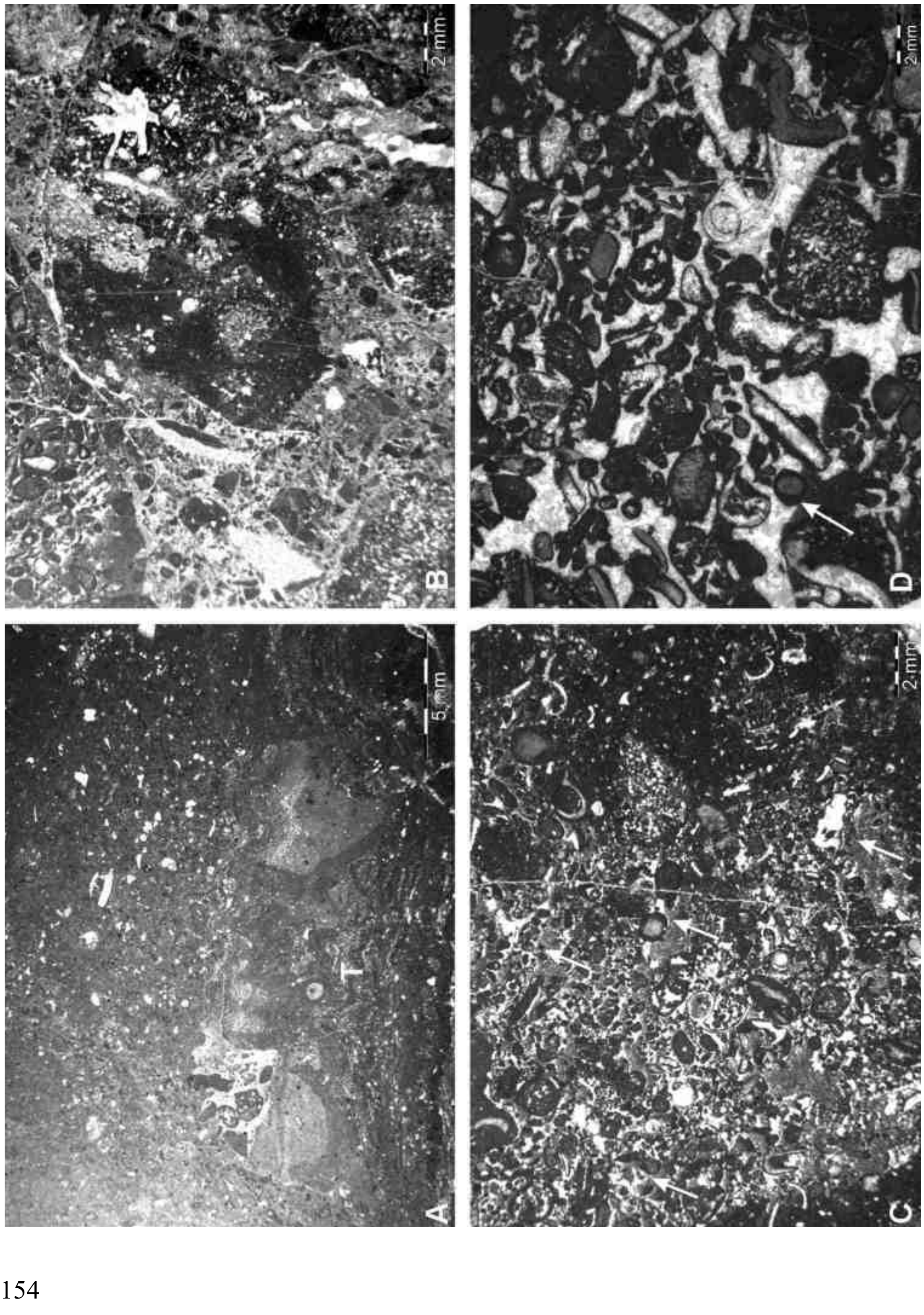

A
B
C
D
5 mm
2 mm
2 mm
2 mm

**Table 4.47.** Examples of microfacies from the upper part of the KB and KA sections, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian-Lower Berriasian

A – microbial bindstone (T-laminated thrombolite), in the upper part wackestone, sample KA 5

B – grainstone with breccias, sample KA 7

C – bioclastic packstone with numerous foraminifers, gastropods and cavities filled by internal sediment (arrows), sample KA 10

D – fenestral packstone, sample Aj 4b

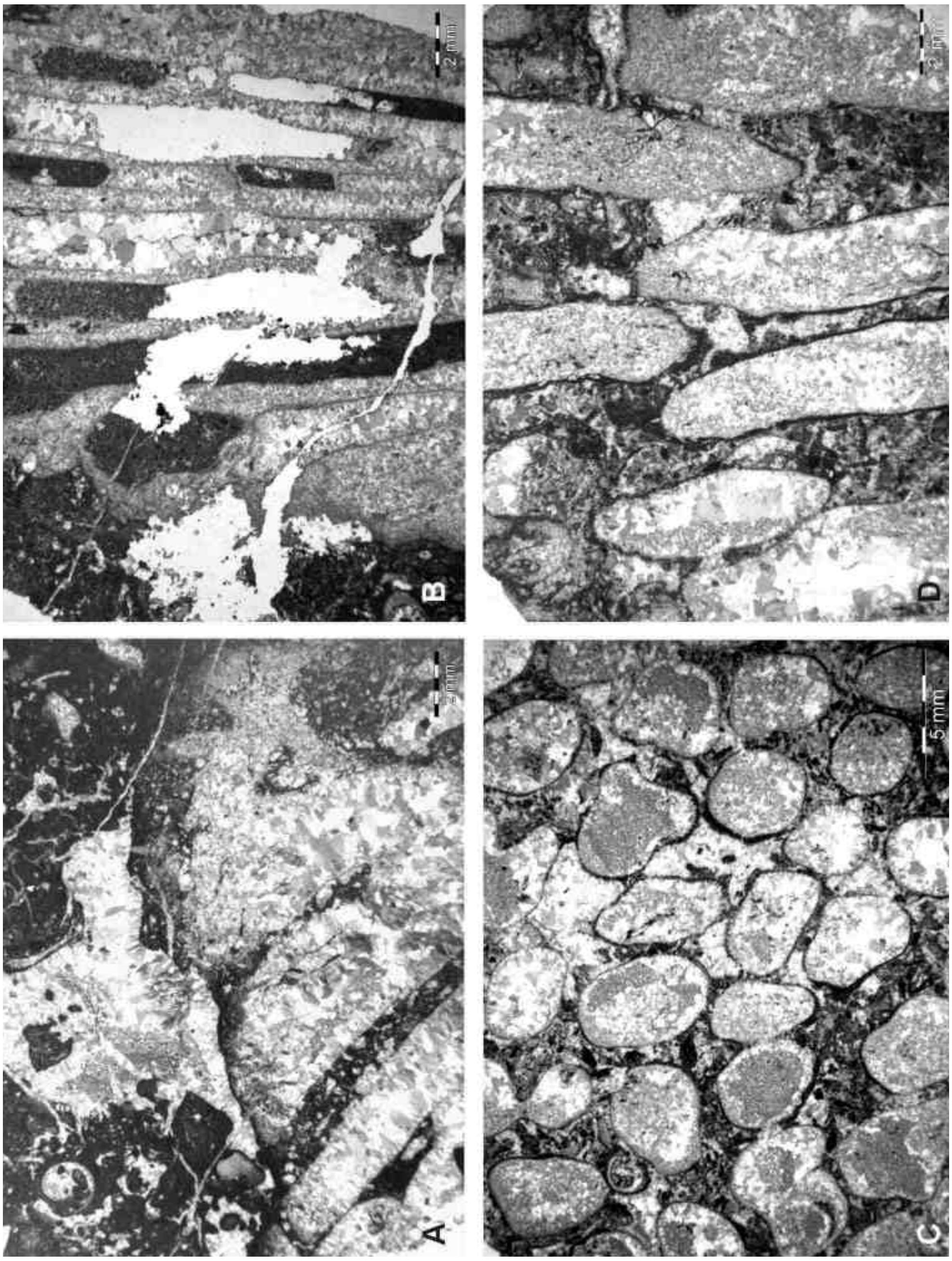

B
2 mm
D
2 mm
A
C
5 mm

**Table 4.48.** Examples of microfacies from the upper part of the KB and KA sections, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian-Lower Berriasian

A, B, C, D – fragment of the ?coral patch-reef (see Fig. 65), numerous perpendicular and parallel sections relics of the skeletons filled by micrite or cement, on the outer surfaces thin microbial crusts are visible, samples Aj 4c, Aj 4d, KA 12a, KA 12c

### 4.3.11. The KR section (Ay-Petri Massif, Ay-Petri Mountain, Tithonian, massive-bedded limestones)

#### LOCATION AND STRATIGRAPHY

The KR section is located at the eastern margin of the Ay-Petri Mt., some hundred meters from the top station of the gondola lift (Figs 4.1). The upper parts of the sequence include mainly thick-bedded limestones grading down the sequence to massive limestones (Fig. 4.12). The sequence is located in the transition zone from massive limestones, which built the central parts of the Ay-Petri Mt., to bedded limestones enclosing the massif from the northeast (Fig. 4.12). In hand specimens the limestones seem to be mostly pelitic, sometimes clotted, with poorly marked detrital horizons. Fossils are represented by gastropods, bivalves and macrofossils with obliterated internal structure, which makes them rather difficult to identification.

The foraminifers assemblage includes: *Troglotella incrustans* (Kimmeridgian--Berriasian), *Palaeogaudryina magharaensis* (Late Kimmeridgian-Middle Berriasian), *Everticyclammina praekelleri* (Kimmeridgian-Tithonian), *Melathrokerion spirialis* (Tithonian-Valanginian), *Dobrogelina ovidi* (Berriasian-Valanginian), *Amijella amiji* (Liassic-Berriasian) and *Quinqueloculina stellata* (Tithonian-Early Berriasian), all indicating the Tithonian-Early Berriasian age (Krajewski, Olszewska 2007).

#### MICROFACIES

Microscopic studies supplied more precize data. The lower and middle parts of the KR section show similarities to the KB one (cf. Figs 4.13 and 4.14). Several important microfacies varieties were distinguished: sponge, coral and algal framestones-bindstones, bioclastic wackestones-packstones, sponge-coral floatstones, oncoidal packstones-rudstones and bioclastic-intraclastic grainstones (Fig. 4.14). These varieties were found at various levels where the limestones form several depositional sequences varying in thicknesses. Only the sponge-coral floatstones were commonly observed in bedded limestones from the upper part of the sequence. In the lower part bioclastic wackestones-packstones initially prevailed, sometimes cemented with microbialites. Up the sequence, sponge, coral patch-reefs and biostromes were observed and the sediments resemble those from the KB section (Krajewski 2008). However, the data collected up to date evidence that the KR rocks contain less macrofossils building the bioconstructions whereas bioclastic and oncoidal wackestones-packstones are more frequent, when compared to the KB section.

In the upper part of the KR section massive limestones grade into thick-bedded limestones (Fig. 4.12, Tab. 4.29B). Three main microfacies varieties were observed. The most common are bioclastic-intraclastic packstones composed mainly of fine, crushed bioclasts. Common are also oncoidal packstones with abundant foraminifers, fragments of bivalve and gastropod shells as well as with large, irregular oncoids often hosting several cores. Cores of larger oncoids are usually fragments of sponges and gastropods. The outer surfaces of fossil fragments are frequently covered by thin *Bacinella* crusts (Tab. 4.49C). In some horizons sponge-coral floatstones-rudstones occur, composed of numerous fragments of sponges, gastropods and corals (particularly *Heliocoenia*) redeposited from other parts of the reef (Tab. 4.50). Moreover, relicts of dissolved macrofossils filled with cement are abundant. Skeletal fragments are usually covered with thin microbial crusts, rarely by microencrusters.

In the uppermost parts of the KR section the sediments are bioclastic wackestones-mudstones and oncoidal packstones (Tab. 4.49D). Bioclasts are dominated by foraminifers, fine bivalves and gastropods. Such development resembles rocks from other sequences located in the upper part of the massif.

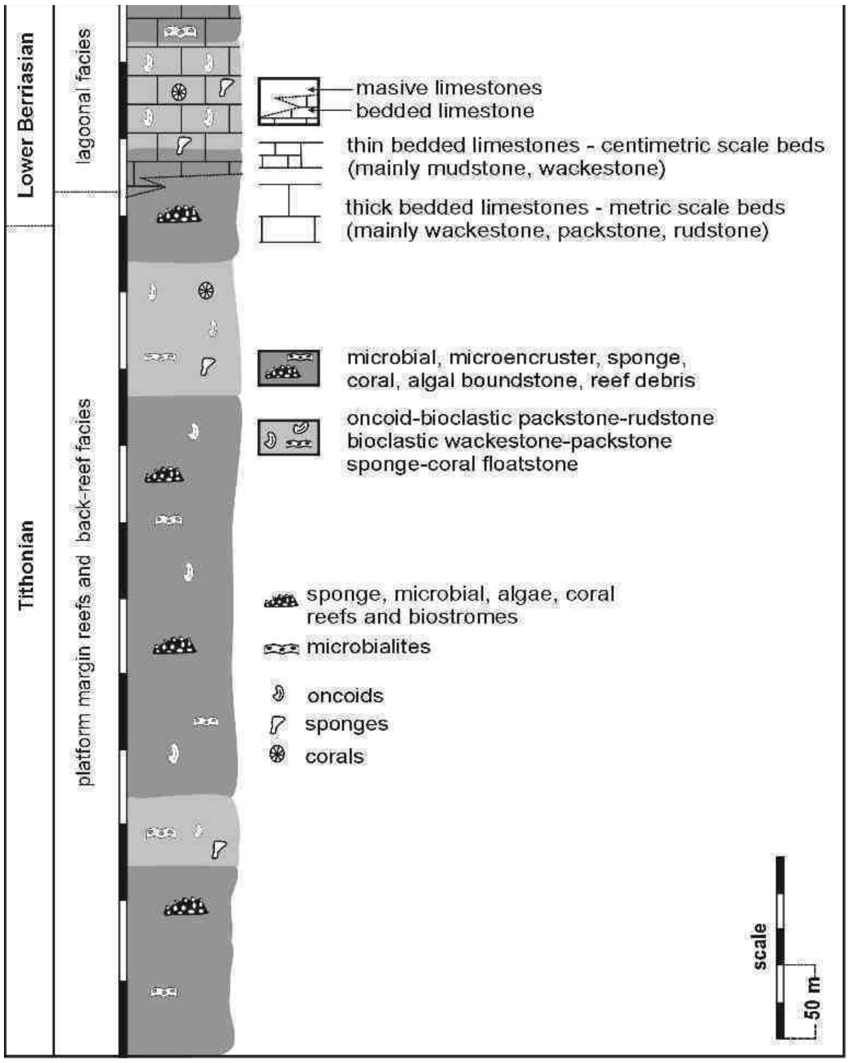



**Fig. 4.14.** Schematic lithological log of the KR section (Ay-Petri Massif, Ay-Petri reef massive and bedded limestones, Tithonian-Lower Berriasian)

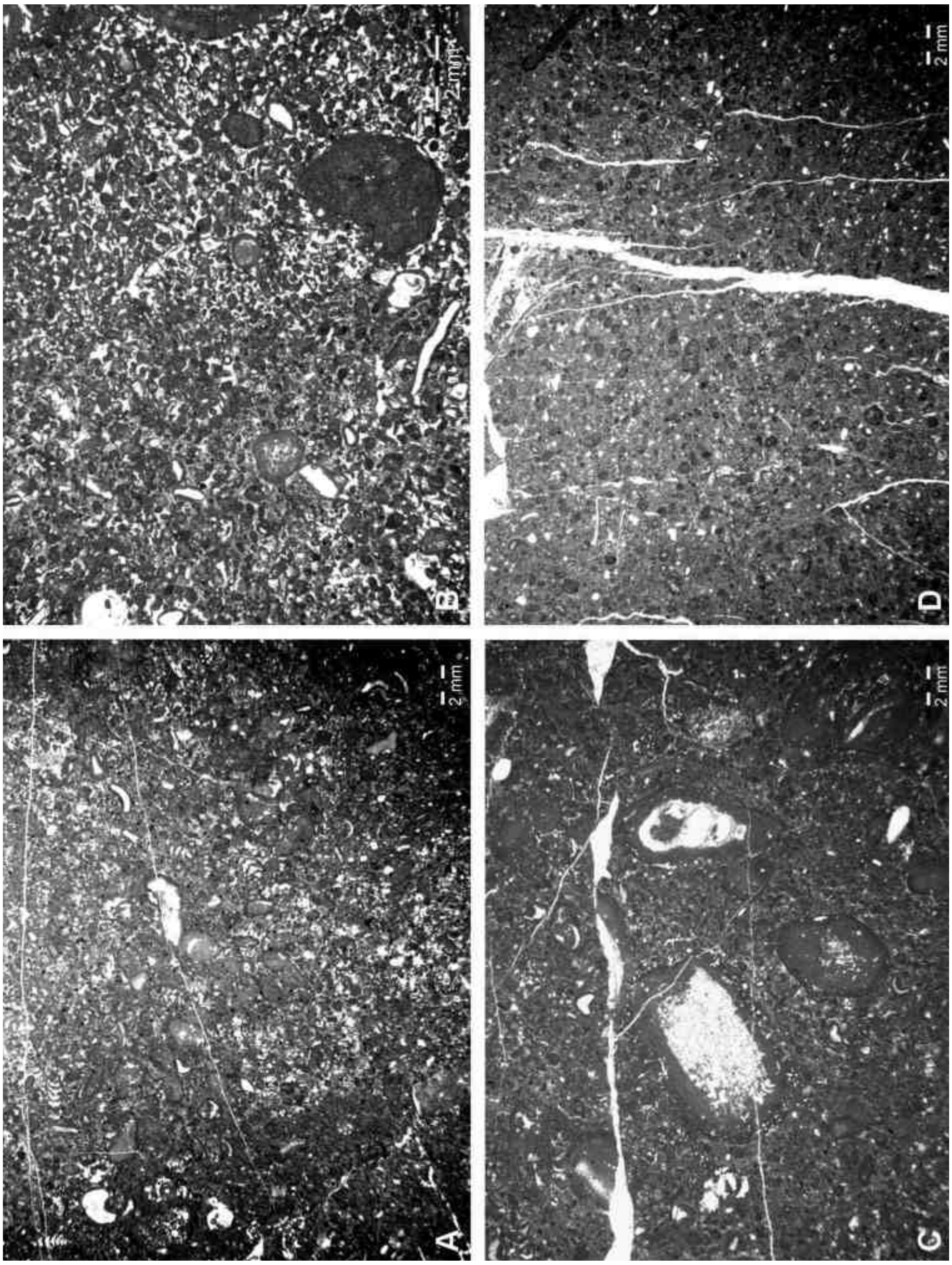

A
B
C
D
2 mm

**Table 4.49.** Examples of microfacies from the upper part of the sequence KR, Ay-Petri Massif, Ay-Petri Mt., bedded and massive limestones, Tithonian-Lower Berriasian

A – packstone with numerous foraminifers, sample KR 18a

B – packstone-grainstone with peloids, bioclasts and oncoids, sample KR 17

C – wackestone-packstone with fragments of the *Cladocoropsis*, gastropods and foraminifers which form the nuclei of oncoids, sample KR 15

D – wackestone with foraminifers, sample KR 13b

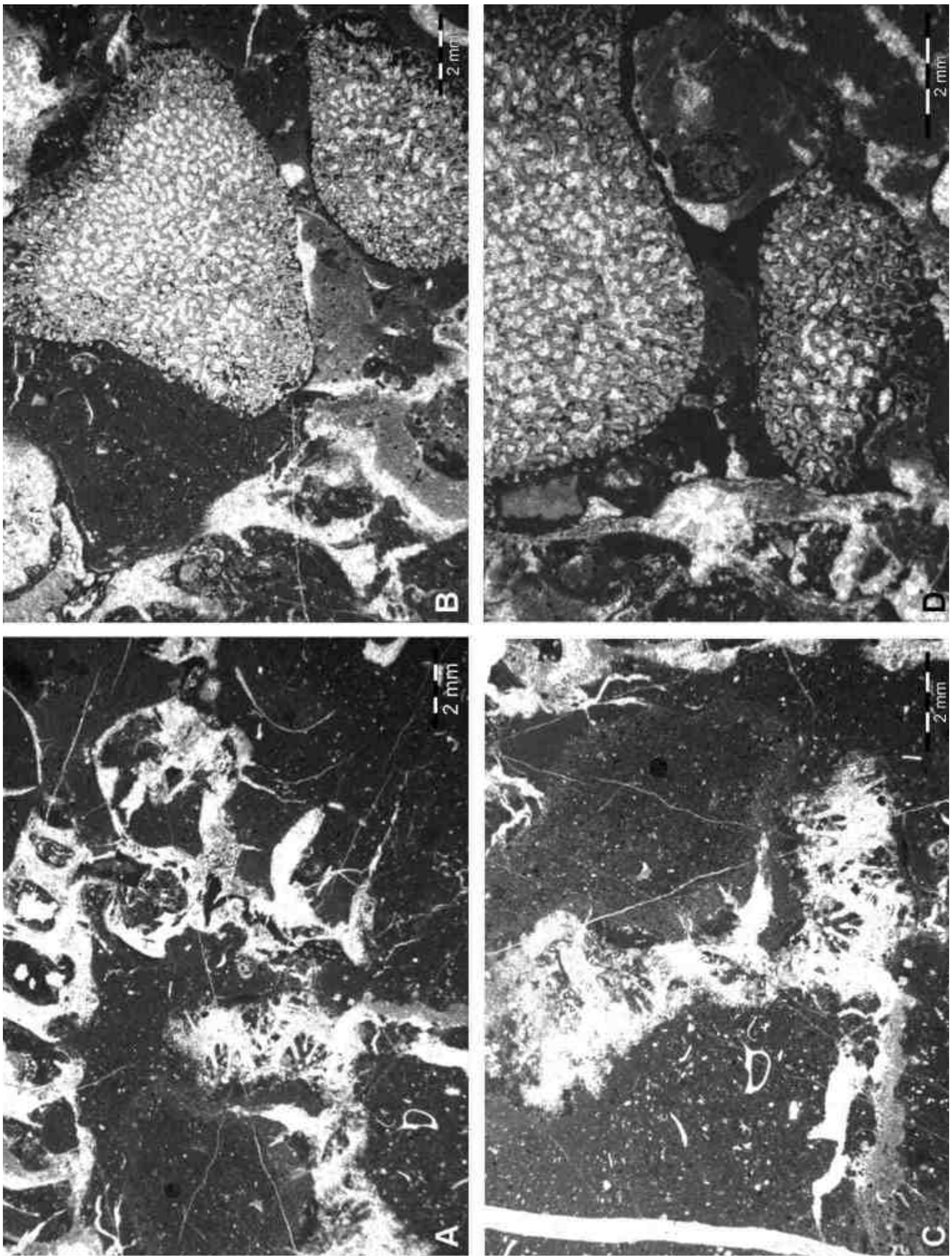

A
2 mm
B
2 mm
C
2 mm
D
2 mm

**Table 4.50.** Examples of microfacies from the KR section, Ay-Petri Massif, Ay-Petri Mt., bedded and massive limestones, Tithonian-Lower Berriasian

A – coral floatstone with fragments of gastropods, sample KR 18a

B – sponge floatstone, sample KR 17

C – coral floatstone, fragment of *Heliocoenia* colony, sample KR 15

D – sponge floatstone, samples KR 13b

**INTERPRETATION**

Microfacies from the lower and the middle parts of the KR section resemble those from the KB section, being the intergral part of the Ay-Petri reef complex. Similar to adjacent KB and KC sections, the lower part of the KR one were deposited in a moderate-energy environment, only periodically interrupted by higher-energy episodes. The rocks are mostly bioclastic wackestones-packstones, in which microbialites can be observed, grading up the sequence into various bioconstructions and bioclastic grainstones. This deposition can be related to the initial stage of somewhat deeper carbonate platform. Up the sequence the rocks are mostly packstones or wackestones-floatstones, which indicates rather moderate-energy, back-reef environment where only periodically higher-energy conditions appeared. Both the development and the position in the transitional zone from massive to thick- and medium-bedded limestones show that the sediments from the middle and upper parts of massive limestone succession represent mostly the lagoonal environment. Numerous detrital horizons composed mostly of crushed, fine bioclasts, intraclasts and fragments of sponges and corals are indicative of material derived from erosion of both the central and marginal parts of the reef.

The common presence of wackestones-mudstones with foraminifers and gastropods as well as horizons of oncoidal packstones in bedded limestones from the uppermost part of the sequence reflect deposition in the internal platform lagoon environment, similar to that known from the KS, KL or KK sections. These rocks represent probably several shallow-marine depositional sequences, probably related to the changes of sea level.

## 4.3.12. The KC section (Ay-Petri Massif, Ay-Petri Mountain, Kimmeridgian-Tithonian-Lower, Berriasian, massive-bedded limestones)

**LOCATION AND STRATIGRAPHY**

The KC section is located in the western part of the Ay-Petri Massif where it extends from the footslopes, along the southwestern wall of the Ay-Petri and towards the upper edge of the massif (Fig. 4.1). Thickness of the sequence is about 600 meters (Fig. 4.15). The lowermost parts of the massif together with the basement rocks are covered with large limestone blocks and rubble, and are inaccessible. In the lower parts slickensides and tectonic breccias occur, which indicates the tectonic character of the lower edge of southwestern Ay-Petri margin (Tab. 4.29F). Apart from summit part, the KC section includes almost exclusively hard, light- or dark-grey or reddish, massive limestones. Sediments with obscured bedding are rarely observed, mostly in the lower part of the massif (not marked in Fig. 4.15). Usually, bedded limestones grade horizontally and vertically along short distances into massive limestones. In the lower part of the sequence beds of sandstones, sandy limestones and conglomerates occur, the latter up to some tens of centimeters thick (rarely over 1 meter) and composed of sandstones and limestones fragments (Tab. 4.29D). Moreover, within the massive limestones poorly bedded, lenticular channels are visible, filled with mixture of siliciclastic material and fragments of carbonate rocks. Macroscopically, massive limestones seem to be rather monotonous due to strong cementation. Fossils are gastropods and poorly visible, mostly dissolved metazoans embedded within peloidal matrix.

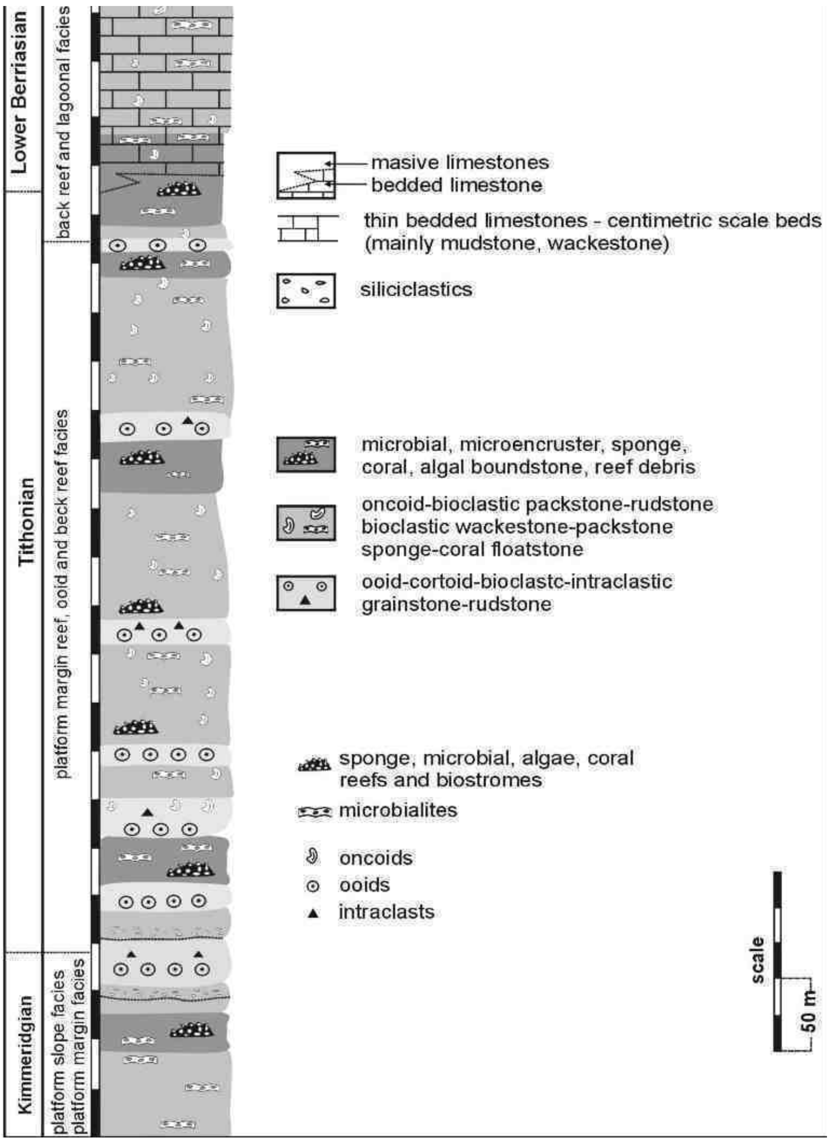



**Fig. 4.15.** Schematic lithological log of the KC section (Ay-Petri Massif, Ay-Petri reef, massive-bedded limestones, Kimmeridgian-Tithonian-Lower Berriasian)

Detailed observations revealed the following foraminifer assemblage: *Ammobaculites coprolithiformis* (Oxfordian-Kimmeridgian), *Troglotella incrustans* (Kimmeridgian-Berriasian), *Nautiloculina bronnimanni* (Berriasian-Hauterivian), *Mayncina bulgarica* (Tithonian-Barremian), *Everticyclammina praekelleri* (Kimmeridgian-Tithonian), *Dobrogelina ovidi* (Berriasian-Valanginian) and *Protopeneroplis ultragranulata* (Late Tithonian-Valanginian), which enables the author to ascribe the KC sediments to the Kimmeridgian-Early Berriasian time span but most of sediments belong to the Tithonian (Krajewski, Olszewska 2007, cf. Kuznetsova, Gorbachik 1985).

## MICROFACIES

Deposits of the KC section show high microfacies variability (Fig. 4.15). Dominating are various grainstones composed of many bioclasts, ooids, oncoids, intraclasts and peloids sometimes binded by microbialites. Usually, the sediments are poorly sorted. Three main grainstone varieties were distinguished: oncoidal packstones-rudstones, ooidal-cortoidal grainstones and bioclastic-intraclastic grainstones (Tabs 4.51–4.55).

The first variety is composed of peloids and various oncoids. The latter comprises small, micritized forms of very poorly marked internal structure. Frequent are oncoids of well-visible details of microbial crusts growing onto fragments of bivalve shells and other, small bioclasts. Sometimes, particularly in the upper parts of the sequence, large *Bacinella* oncoids occur; their upper surfaces are commonly settled by *Lithocodium aggregatum* (Tabs 4.52C, 4.53B). In such oncoids several micritic films can be observed, deposited by *Bacinella irregularis*. Cores of oncoids are fragments of algae, corals and sponges. In some horizons large, complex oncoids (oncoidal aggregates) are observed, composed of numerous, smaller oncoids and peloids binded with outer microbial crusts. Various types of oncoids usually occur together forming a poorly sorted sediments encountered mostly in the upper part of the KC section.

The second variety includes strongly cemented grainstone horizons composed of cortoids and ooids (Tabs 4.52, 4.54B, D). Cortoids consist usually of fragments of gastropods, bivalves, algae, foraminifers and/or echinoderms with thin, micritic films growing on the outer surfaces of bioclasts. In ooidal-cortoidal grainstones blocky cements are accompanied by isopachous cements developed on grains (Tab. 4.54B, D). Ooids are mostly small forms of diameters up to 2 millimeters. Their internal structure is sometimes poorly visible or the forms are practically entirely micritized.

The ooidal-cortoidal grainstones and oncoidal packstones form a number of alternating horizons of variable thicknesses intercalated by beds dominated by bioclastic wackestones-floatstones and patch-reefs (Fig. 4.15). In some parts of the KC section peri-reefal bioclastic-intraclastic grainstones are developed, usually in the vicinity of patch-reefs. This grainstone comprises mostly molusc shells, algae and intraclasts, the latter being usually the fragments of poorly rounded bioclasts with microencrusters growing onto their surfaces. Common are also breccias composed of strongly fractured bioclastic wackestones, oncoidal packstones and ooidal grainstones. Fractures are often filled with vadose silt or cements.

Apart from described above grainstones and breccias, the KC section includes locally developed horizons of conglomerates, some tens of centimeters thick (Tab. 4.55A). Their lateral extend is difficult to estimate due to hardly accessible terrain. These conglomerates contain both well- and poorly rounded clasts of algae, *Bacinella*, macrofossils and other organisms as well as fragments of lithified sediments derived from erosion of the reef. Grain size reaches 1.5 cm. Grain surfaces are covered with thin (0.5 mm), red coatings on which radial or fibrous cements develop (Tab. 4.55B, C).

At several levels, particularly in the uppermost parts of the sequence, common are fenestral bindstones-packstones-mudstones (Tab. 4.56B). Usually, these sediments consist of oncoids, peloids and bioclasts stabilized by microbial mats.

Locally, fenestral packstones grade into mudstones. Most of cavities observed in the sediments are geopetally filled with vadose silt.

In comparison with the other sequences from the Ay-Petri Massif (KA, KB and KR), in the KC section less common are biolithites. Relatively rare are also macrofossils, mostly sponges and corals. Most of skeletons are dissolved, which usually precludes their precise identification (Tabs 4.51C, D). Most commonly the fossils form small patch-reefs, scattered within the grainstones or biostromes. Such forms were observed chiefly in the lower part of the KC section.

Several types of biolithites can be distinguished, depending on main components. In the lowermost parts of the sequence sponge-*Microsolena*-thrombolitic framestones-bindstones occur with abundant *Crescentiella morronensis* and rare *Bacinella irregularis* (Tab. 4.51A). Widespread are growth cavites and geopetally filled open spaces left after dissolved fossils. Higher in the sequence, among biolithites the sponge-microbial framestones are observed, which form patch-reefs, and peri-reefal bioclastic packstones (Tabs 4.51C, D, 4.53C).

In the lower portions of the KC section massive limestones were encountered, developed as *Crescentiella* microframestones and thrombolitic bindstones (Tabs 4.51B, 4.68A–D). The former are composed of numerous, mostly vertically elongated forms with well-visible internal structures. Sediments between *Crescentiella morronensis* include microbial micrite, fine peloids and, less commonly, various bioclasts. Part of the matrix is built of sparite. Moreover, abundant are small, geopetally filled cavities and fissures. Most of open spaces is developed between *Crescentiella morronensis,* beneath the distinct microbial crusts or arcuated *Crescentiella*.

In the upper part of the KC section biolithites are less common and sediments are dominated by grainstones. Among biolithites *Bacinella* bindstones and coral-sponges bafflestones-floatstones are observed together with widespread oncoidal-microbial bindstones with numerous fenestral structures (Tab. 4.57).

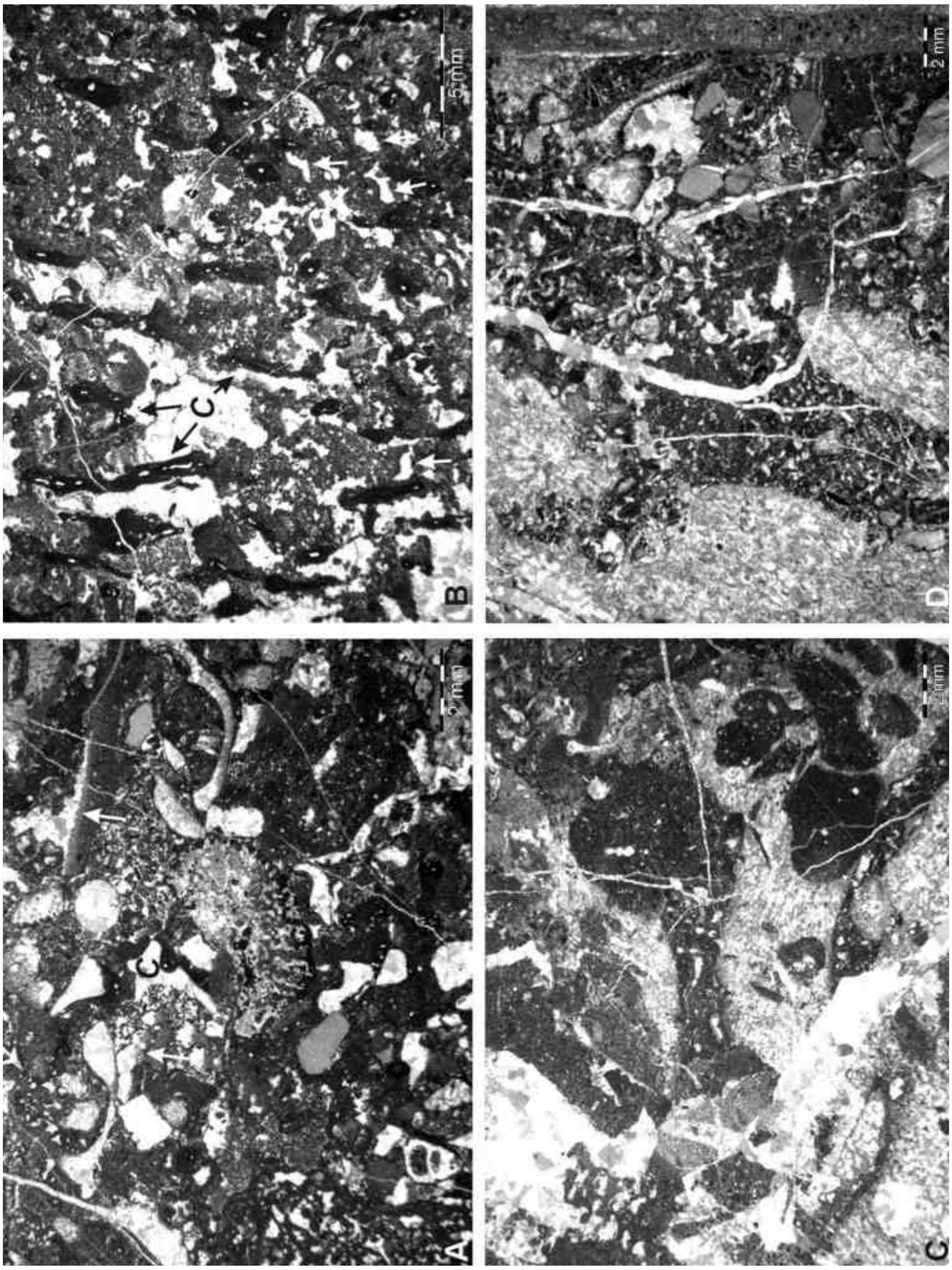

A
B
C
D
C
5 mm
2 mm

**Table 4.51.** Examples of microfacies from the lower part of the KC section, Ay-Petri Massif, Ay-Petri Mt., massive limestone, Kimmeridgian-Tithonian

A – bioclastic wackestone-floatstone with sponges and stromatactis-like cavities (arrows), sample KC 2

B – microframestone with numerous *Crescientella* (C) which forms microframework, numerous small cavities with geopetal infillings are visible (arrows), sample KC 7b

C – sponge-microbial framestone with *Crescentiella morronensis*, sample KC 6

D – bafflestone with strongly recrystalized ?sponges, sample KC 4

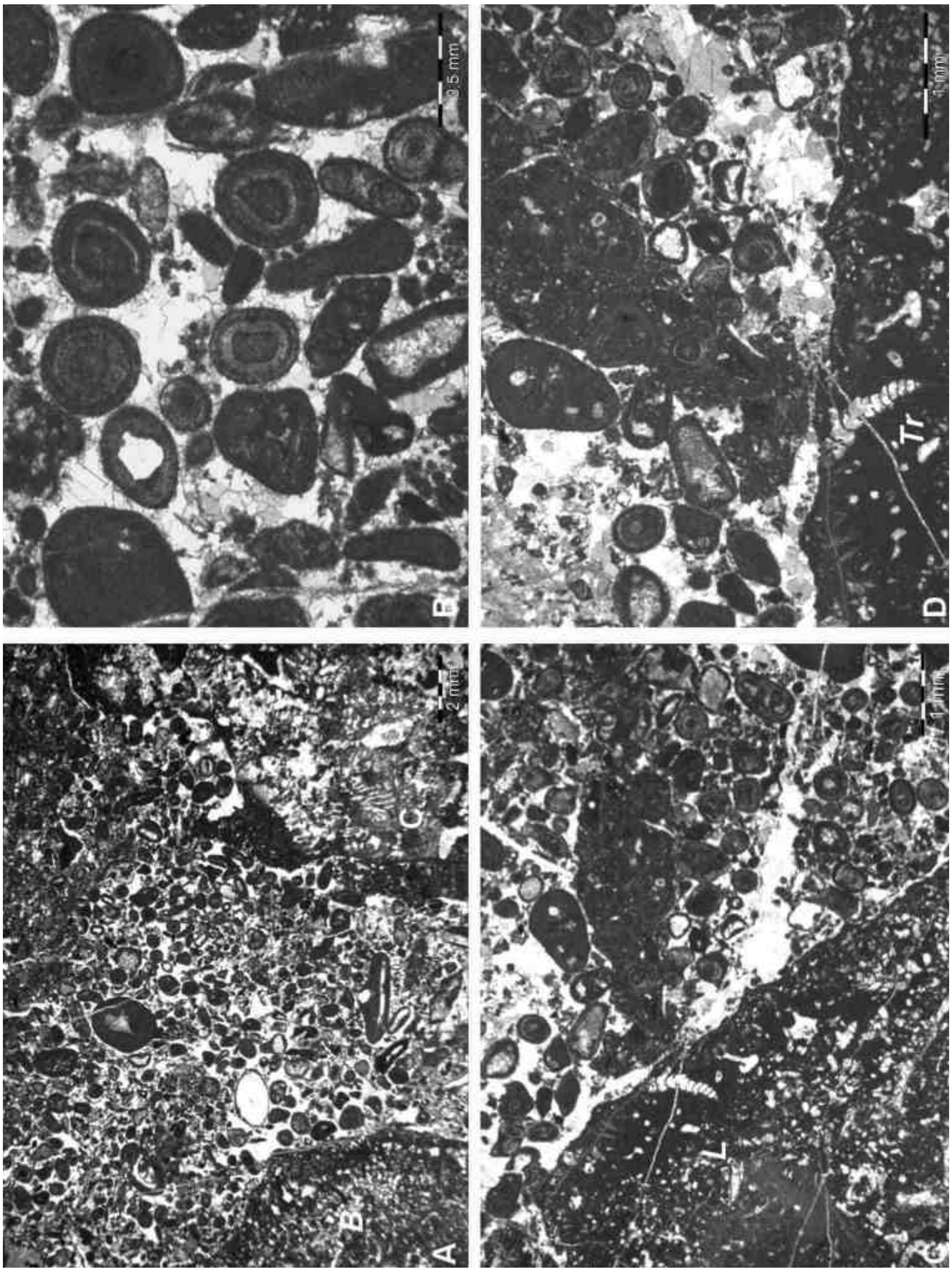

A
B
C
D
Tr
L
0.5 mm
2 mm
1 mm

**Table 4.52.** Examples of microfacies from the middle part of the KC section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Kimmeridgian-Tithonian

A – grainstone with ooids and fragments of coral (C) and *Bacinella* (*B*), sample KC 10d

B – ooid grainstone, sample KC 10d

C – ooid-bioclastic grainstone, on the right numerous ooids, on the left consortium of *Bacinella irregularis*-*Lithocodium aggregatum* (*L*) with *Troglotella incrustans*, sample KC 9a

D – enlargement of the photo C, on the lower part *Lithocodium aggregatum* with *Troglotella incrustans* (*Tr*), on the upper part ooid grainstone, sample KC 9a

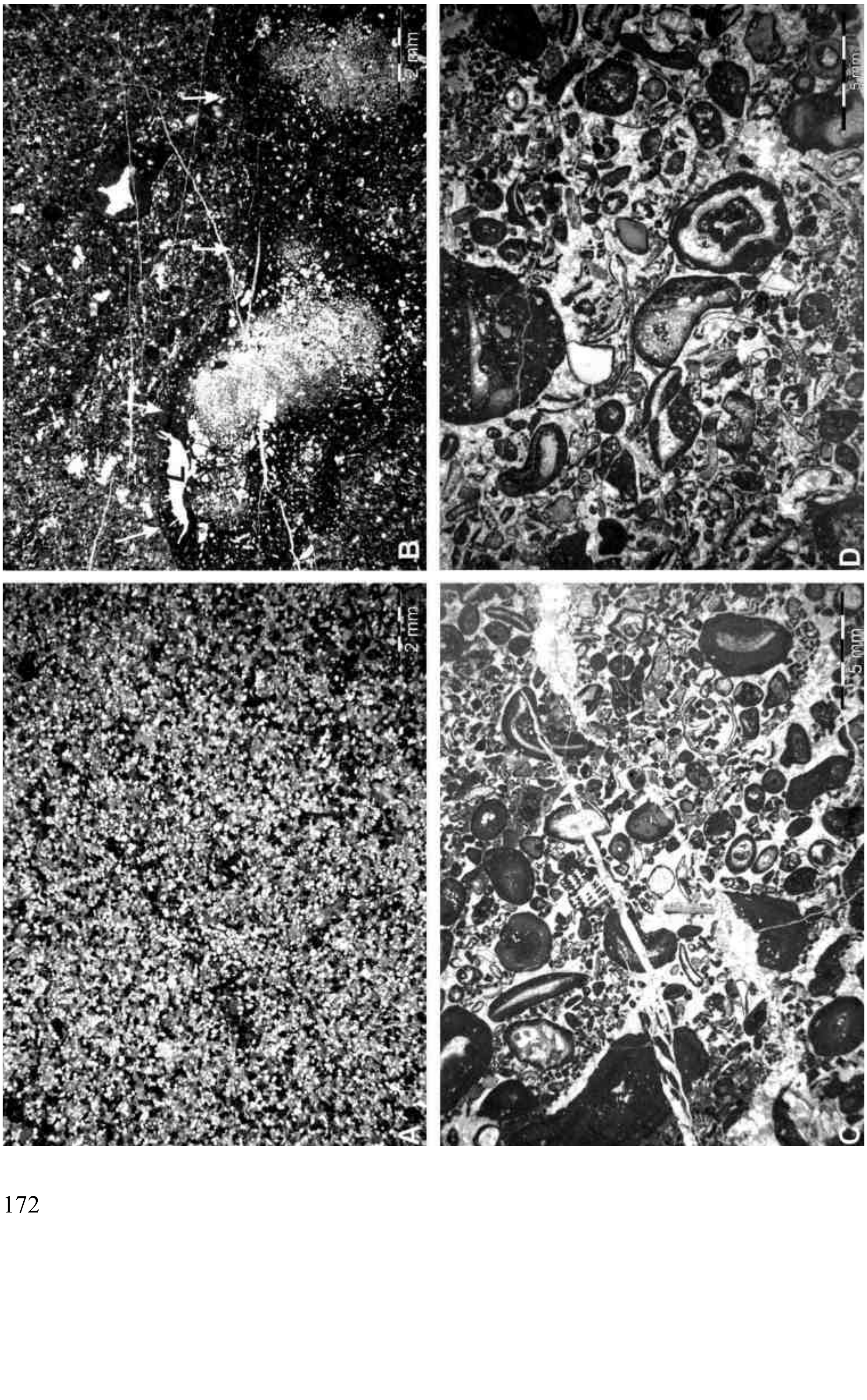

A
2 mm
B
2 mm
C
5 mm
D
5 mm

**Table 4.53.** Microfacies from the middle part of KC sections, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – siliciclastic sandstone, sample KC 12

B – peloidal-microbial bindstone with *Lithocodium aggregatum* (arrows), sample KC 14

C – cortoid-ooid-intraclastic grainstone-rudstone, sample KC 16

D – bioclastic-lithoclastic grainstone-rudstone, sample KC 11

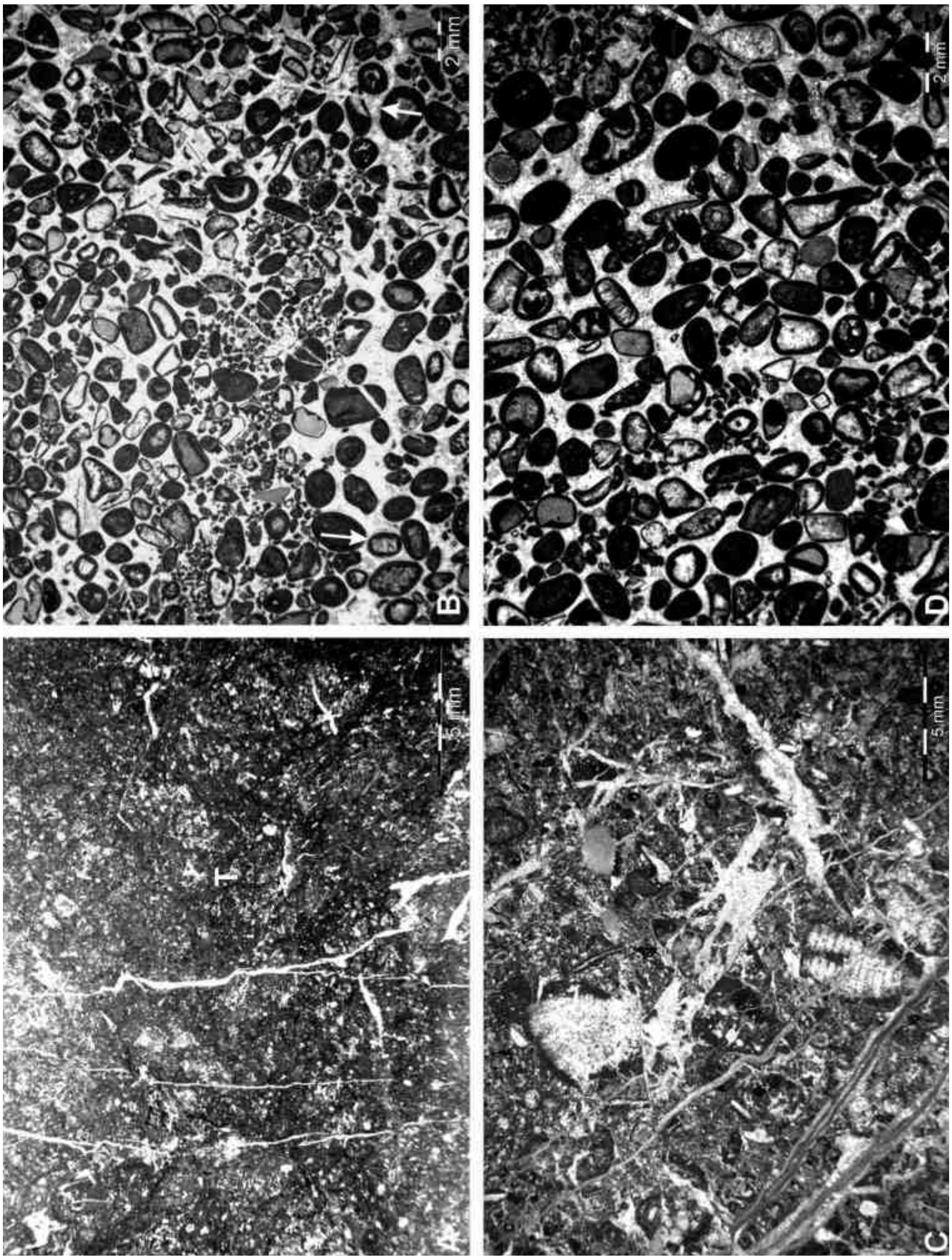

B
2 mm
D
2 mm
A
5 mm
T
C
5 mm

**Table 4.54.** Microfacies from the middle part of KC sections, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A – thrombolitic bindstone (T), sample KC 13

B, D – ooid-cortoid grainstone with isopachous cement among grains, samples KC 19, KC 19b

C – bioclastic floatstone with fragments of algae, sample KC 18a

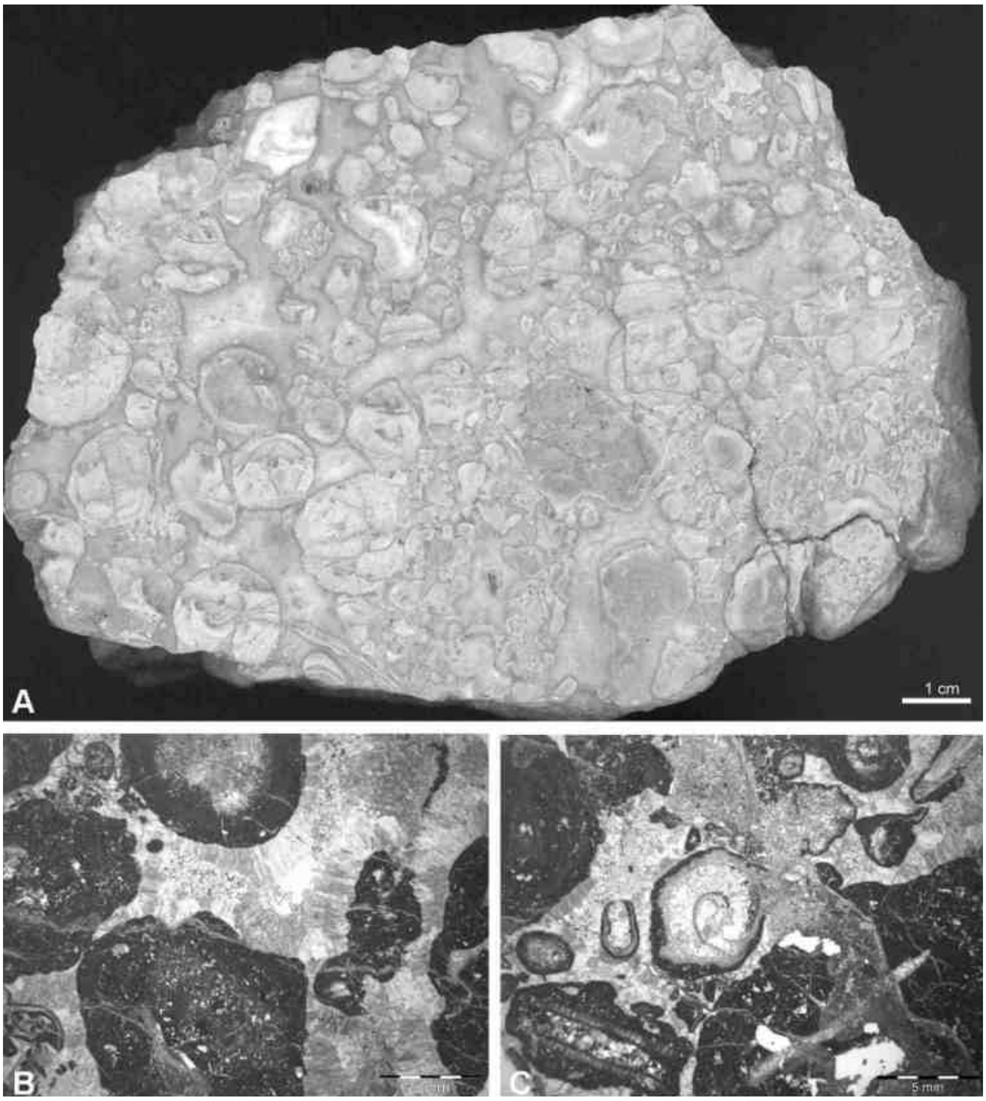

A
1 cm
B
C
5 mm

**Table 4.55.** Conglomerate observed in the lower part of the KC section

A – polished-slab with numerous of bioclastic grains and sparite matrix

B, C – rudstone with numerous clasts of *Bacinella irregularis*, gastropods, dasycladaleans, among clasts fibrous cement, samples KC 17a, KC 17b

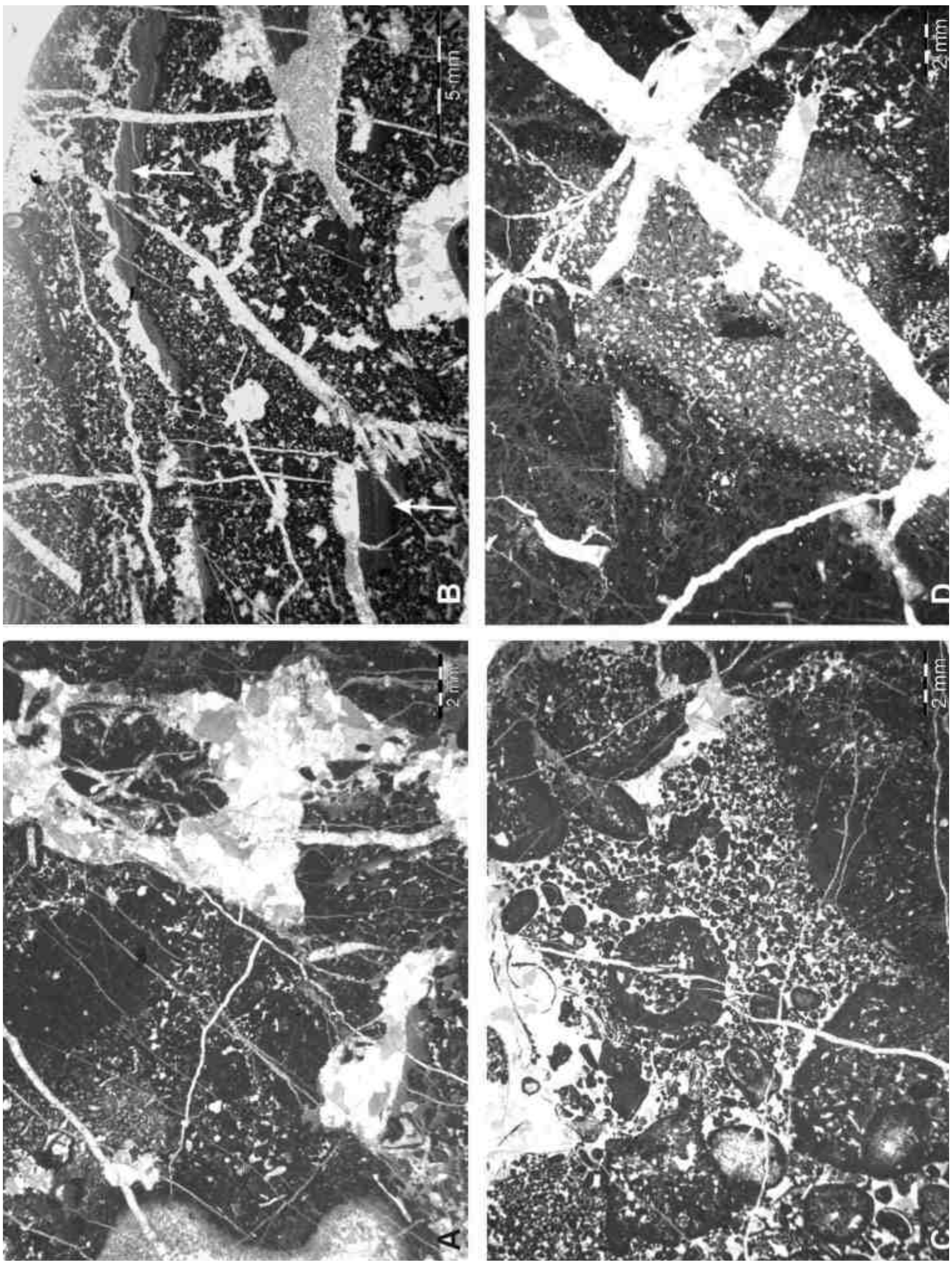

A
2 mm
B
5 mm
C
2 mm
D
2 mm

**Table 4.56**. Microfacies from the upper part of KC section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A, C – *Bacinella irregularis*-peloid packstone, samples KC 44, KC 41

B – fenestral peloidal bindstone, sample KC 40

D – sponge floatstone with *Actionostromaria*, sample KC 42

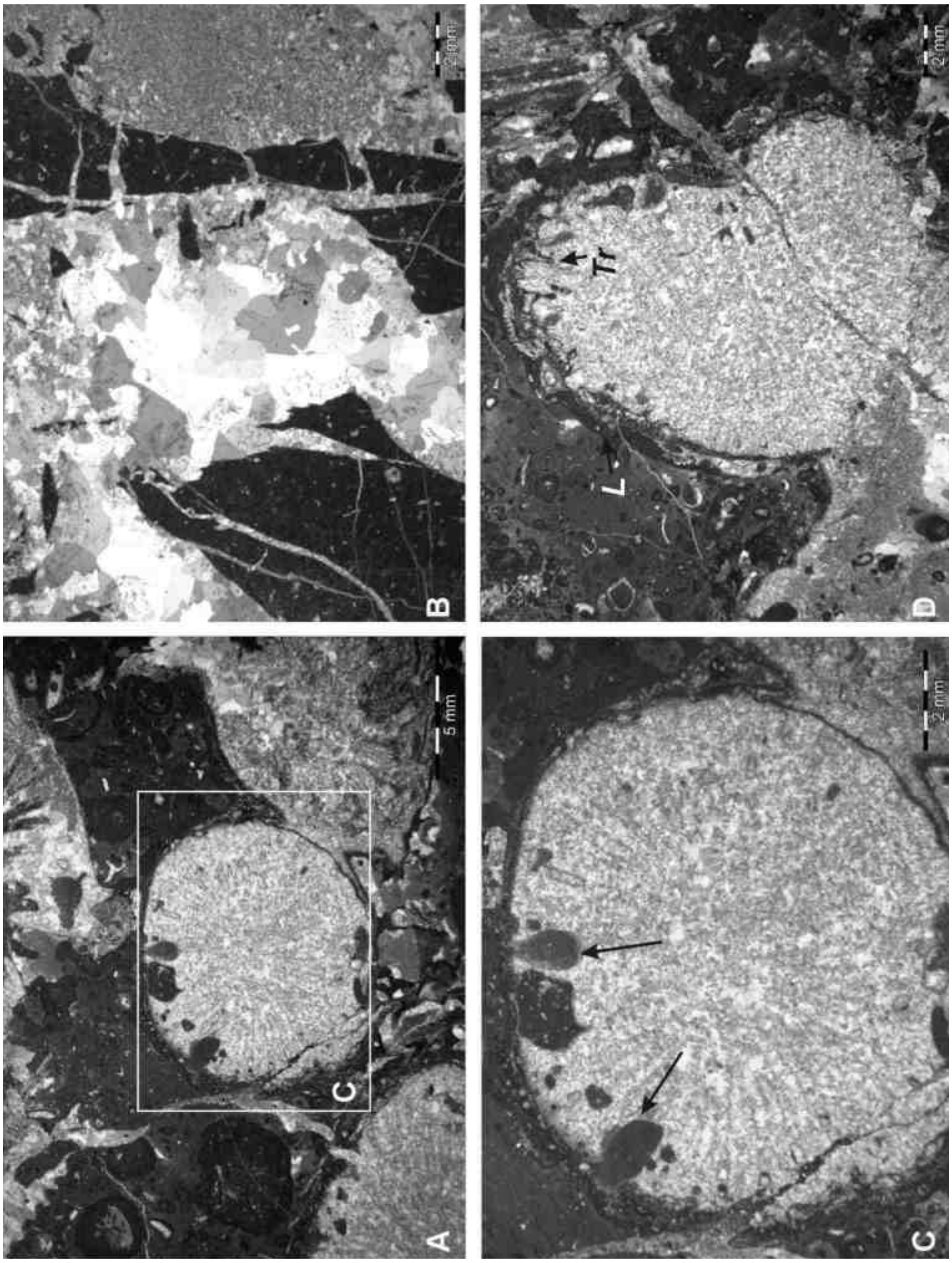

A
5 mm
C
B
2 mm
C
2 mm
D
Tr
L
2 mm

**Table 4.57.** Microfacies from the upper part of KC section, Ay-Petri Massif, Ay-Petri Mt., massive limestones, Tithonian

A–D – coral floatstone with numerous borings on the corals (arrows), most of the fauna are strongly recrystalized, on the surfaces of the fauna thin *Lithocodium aggregatum* (*L*) with *Troglotella incrustans* (*Tr*) are visible, C – enlargement of photo A, samples KC 43e, KC 38, KC 43c

## INTERPRETATION

The KC section is an inherent part of the Ay-Petri reef complex and shows complicated internal structure. The exposed, lowermost part of the sequence is developed as bioclastic wackestones-packstones. Common are biolithites composed mainly of *Microsolena*-sponge-microbial biostromes or *Crescentiella* microframework as well as sponge-microbial framestones. These sediments can be related genetically to the initial stage of platform development, i.e., to the ramp and platform slope environments. The principal reef-building organisms, as e.g. *Microsolena*, microbialites and *Crescentiella morronensis* indicate mesotrophic conditions, depth of some tens of meters or shallower and stirred water of increased trophic character, related to close proximity of land. Up the sequence grainstones appear, represented by bioclastic and ooidal varieties laid down on platform marginal barriers. Above, mixed, siliciclastis-carbonate deposits occur. Locally, purely siliciclastic deposition took place, supplied from the adjacent, eroded land and accompanied by breaks in growths of the buildups.

Practically, the most part of the KC section is occupied by platform sediments deposited in marginal, ooidal-bioclastic barriers separated by back-reef oncoidal packstones. In the ooidal barrier sediments the early diagenetic cements developed as a result of permanent washing of sediments. Grainstones built of bioclasts and cortoids represent areas of continuous circulation of waters above the wave base, in the environment of current-washed sand shoals.

The upper parts of the KC section are dominated by various grainstones and breccias deposited mostly in the back-reef, lagoonal and/or intertidal environments. Several, succeeding depositional cycles of grainstones are evident, in which the sediments are formed mostly by oncoids and peloids, rarely by ooids and cortoids. Moreover, shallow or peritidal marine breccias are observed. In horizons dominated by oncoids common are *Bacinella irregularis* and *Lithocodium aggregatum*, which documents shallow, oligotrophic, back-reef environment and low deposition rates. In some horizons scattered, coral-sponge-algal patch-reefs are widespread. Variability of sediments development is related to the changes of sea level reflected in transitions from ooidal barrier to oncoidal reef-flat and back-reef facies. Moreover, in the transition zone from massive to bedded limestones common are fenestral bindstones-packstones deposited in tidal flat environment.

### 4.3.13. The KE section (Ay-Petri Massif, Tithonian-Lower Berriasian, bedded limestones)

## LOCATION AND STRATIGRAPHY

The KE section is located southwest from the Ay-Petri Mt. (Fig. 4.1). Microfauna studies revealed the presence of foraminifers: *Palaeogaudryina varsoviensis* (Late Oxfordian-Tithonian), *Everticyclammina kelleri* (Berriasian-Valanginian), *Everticyclammina parakelleri* (Kimmeridgian-Tithonian), *Siphovalvulina variabilis* (Middle Jurassic-Tithonian) and *Quinqueloculina stellata* (Tithonian-Early Berriasian, Krajewski, Olszewska 2007), which indicates the Tithonian-Lower Berriasian age of sediments. Rocks occurring north from the KE section were described in the KD section.

**MICROFACIES**

The sediments are rather monotonous, bedded limestones dominated by macroscopically identified, hard, pelitic, rarely granular limestones (Fig. 4.16). Fossils are rare and represented mostly by bivalves and gastropods. Only in the uppermost part of the sequence, at the edge of plateau the clotted structures appear together with abundant macrofauna.

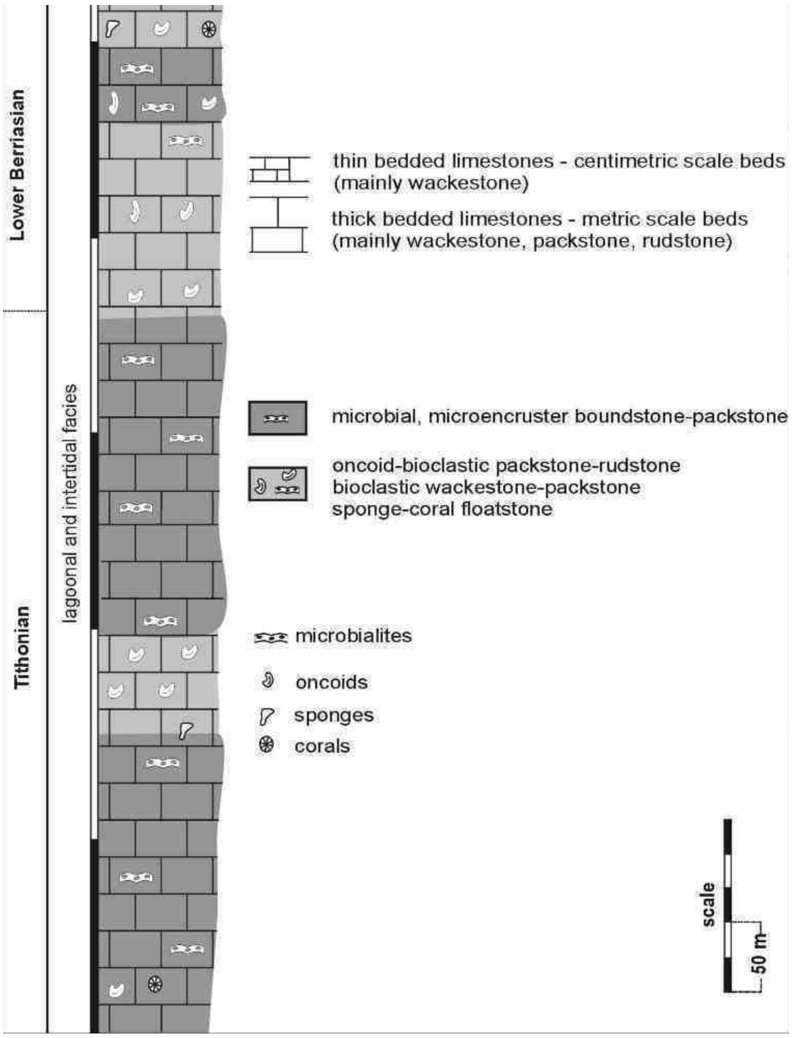



**Fig. 4.16.** Schematic lithological log of the KE section
(Ay-Petri Massif, Tithonian-Lower Berriasian, bedded limestones)

Microscopic observations supplied more valuable data. The lower part the sequence is dominated by microbial bindstone, bioclastic wackestones and oncoidal packstones (Fig. 4.16). Fauna is less common than in other sequences and includes foraminifers, bivalves, gastropods and more rare corals. Microencrusters are *Bacinella irregularis,* which forms large oncoids or *Bacinella* bindstones in grainstones (Tab. 4.58A, D). Typical are fenestral packstones-mudstones-bindstone as well as in-terconnected cavities filled usually with blocky cement (Tabs 4.58B, C, 4.59A). In biolithites formed by *Bacinella irregularis* the cavities are commonly geopetally filled with vadose silt (Tabs 4.58D, 4.59D). In the top part of the sequence the sediments are thin-bedded limestones representing several, repeating depositional cycles. Each cycle includes *Bacinella* oncoidal packstone and fenestral packstone-mudstone. Moreover, at the edge of south-facing rock walls and on the plateau numerous burrowings filled with micrite are observed, which document deposition breaks and intensive bioerosion.

In the uppermost part of the sequence, at the egde of the massif, the oncoid-bioclastic packstones contain abundant sponges, which form *Cladocoropsis* floatstones-packstones (Tab. 4.59D). These are observed on the plateau surface as extended horizons of commonly clotted limestones (Tab. 29E). On the skeletal fragments numerous, thin coatings of *Lithocodium aggregatum* occur, only on their upper surfaces (Tab. 4.59D).

**INTERPRETATION**

Sediments from the KE section and particularly from its upper part represent several shallow-water deposition cycles related to back-reef and lagoonal facies (*Bacinella*-bindstones as well as oncoidal packstones and bioclastic wackestones). Relatively rare macrofossils point out to lagoonal environments (mostly restricted, rarely open). Sediments deposited in an intertidal environment are common in the upper part of the sequence. Studied rocks contain numerous fenestral structures and cavities filled with vadose silt. Traces of intensive boring indicate sedimentation breaks and vigorous bioerosion whereas the presence of vadose silt may document temporary emergence. In the topmost part of the sequence numerous sponges occur, representing the internal platform *Cladocoropsis* meadows. The presence of *Lithocodium aggregatum* on their upper surfaces evidences the shallow, subtidal, oligotrophic conditions. *Cladocoropsis* was observed as plentiful, loosely scattered skeletal fragments deposited during e.g., storm episodes. The sponge floatstones-packstones prove transitions from intertidal environment observed in the upper parts of the sequence to open lagoon ones encouneterd at the edge of the plateau. An angular unconformity found in the top part of the sequence is presumably the boundary between the intertidal/supratidal and the open lagoon facies. Similarly to the neighbouring sequences, it may suggest emergence, deposition break and, may be, also small-scale tectonic movements, which were active between the deposition of both facies varieties of limestones and which caused tilting of strata. The new, transgressive cycle produced new sequence of sediments laid down onto the older strata with a minor angular unconformity.

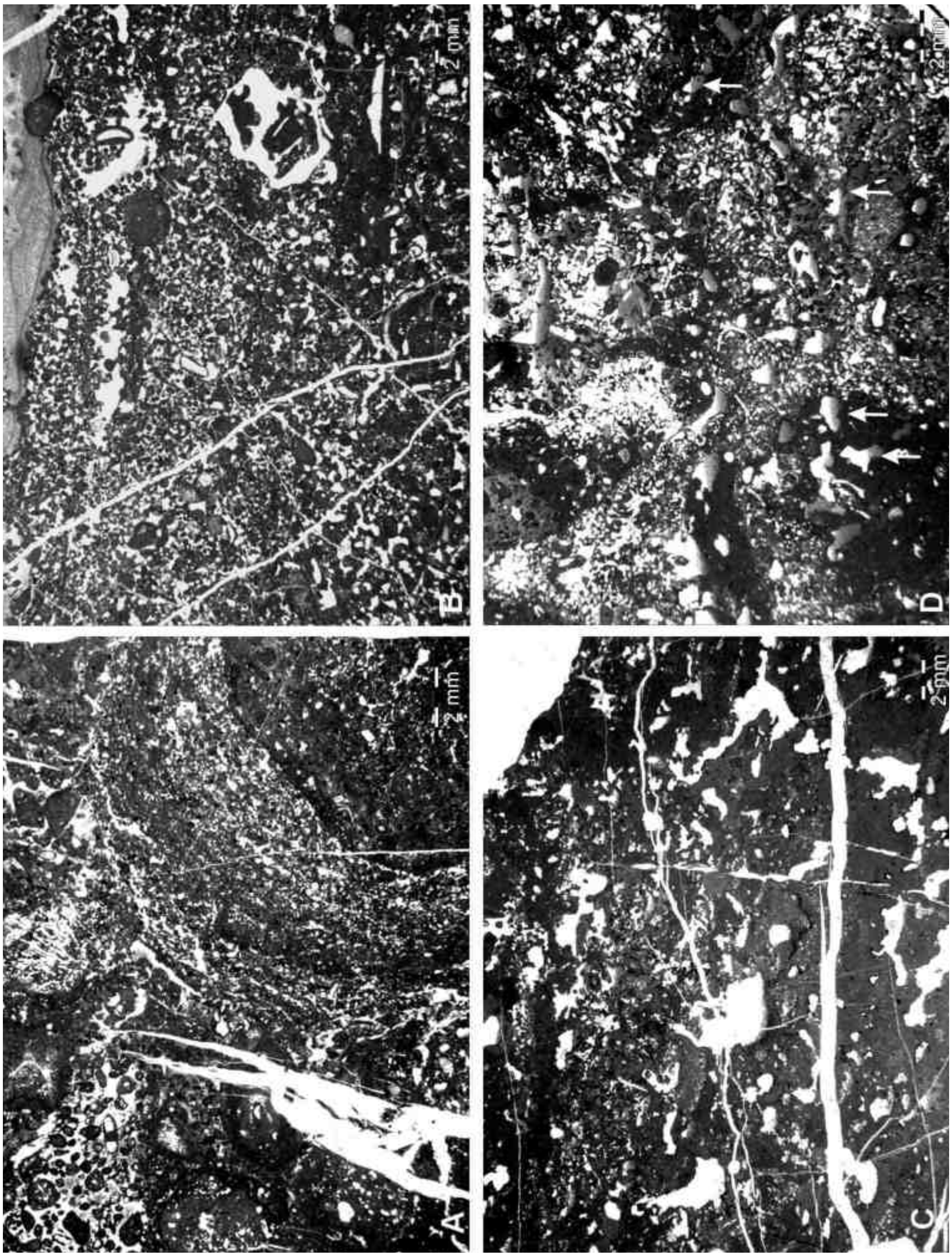

A
B
C
D
2 mm
2 mm
2 mm
2 mm

**Table 4.58.** Examples of microfacies from KE section, Ay-Petri Massif, bedded limestones, Tithonian

A – oncoid packstone, sample KD 3

B – fenestral packstone-bindstone, sample KE 1

C – mudstone-bindstone (in the upper part) with fenestral structures, sample KE 11

D – *Bacinella irregularis* bindstone with vadose silt in the internal structure (arrows), sample KE 4

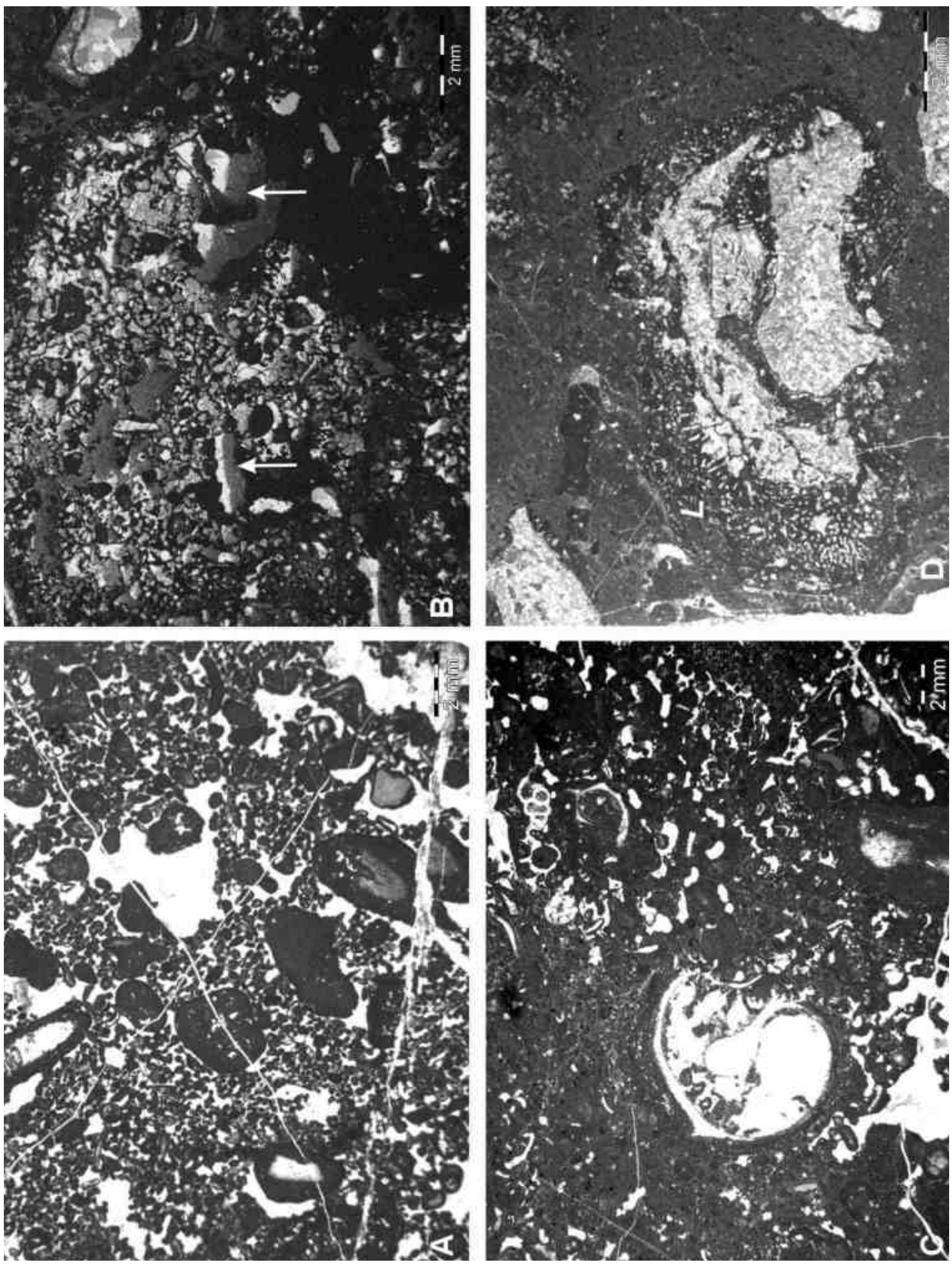

A
B
C
D
L
2 mm

**Table 4.59**. Examples of microfacies from KE section, Ay-Petri Massif, bedded limestones, Tithonian

A – peloidal-intraclastic-oncoidal packstone with fenestre structures, sample KE 8

B – *Bacinella* bindstone with geopetal infillings (arrows), sample KE 4b

C – bioclastic-peloidal packstone, sample KE 12

D – sponge floatstone, in the central part segment of the sponge (?*Cladocoropsis*) with *Lithocodium aggregatum* (*L*), sample KD 12 b

## 4.3.14. The KF section (Ay-Petri Massif, Tithonian-Lower Berriasian, bedded limestones)

### LOCATION AND STRATIGRAPHY

The KF section is positioned at the upper edge of the Ay-Petri Massif, between the characteristic Chaka-Tysh and Nishan-Kaja rock complexes located in the lower parts of the slopes (Figs 4.1, 4.18). The sequence is about 50 meters thick (Fig. 4.17). Beneath the studied sequence the slopes are covered with rock fragments detached and gravitationally transported downslope from higher part of the massif. Larger rock complexes located in the lower part of the slopes are presumably the isolated fragments and have not been studied so far.

Examination of foraminifer assemblage suggest the Tithonian to Berriasian age of the KF sediments. The following taxa were identified: *Palaeogaudryina magharaensis* (Late Kimmeridgian-Middle Berriasian), *Verneuilinoides polonicus* (Tithonian-Early Valanginian), *Nautiloculina bronnimanni* (Berriasian-Hauterivian), *Nautiloculina oolithica* (Late Oxfordian-Berriasian), *Everticyclamina paraekelleri* (Kimmeridgian-Tithonian), *Meandrospira favrei* (Berriasian-Hauterivian) and *Amijella amiji* (Liassic-Berriasian, Krajewski, Olszewska 2007).

### MICROFACIES

The KF section includes macroscopically and microfaciesly monotonous, bedded limestones arranged as several succeeding depositional sequences of bioclastic wackestones and oncoidal packstones (Fig. 4.17). In the wackestones mostly the foraminifers, fragments of echinoderms and gastropods were identified, embedded within the micritic matrix (Tab. 4.60A, C). Other common fossils are fragments of bivalves and sponges. Packstones are fine-grained sediments composed mostly of oncoids, peloids, bioclasts (chiefly foraminifers) and intraclasts (Tab. 4.60B, C). Moreover, sediments are cut by veins, up to several centimeters thick, filled with micrite and fine peloids. Common are also fine-detrital, oncoidal packstones built of fine oncoids of poorly visible internal structure, accompanied by peloids and fine bioclasts. In the uppermost part of the sequence, at the edge of karstic plateau, limestones of local clotted structure contain abundant *Cladocoropsis* floatstones, in which numerous fragments of transported sponges can be observed embedded within micritic matrix (see Tab. 4.61).

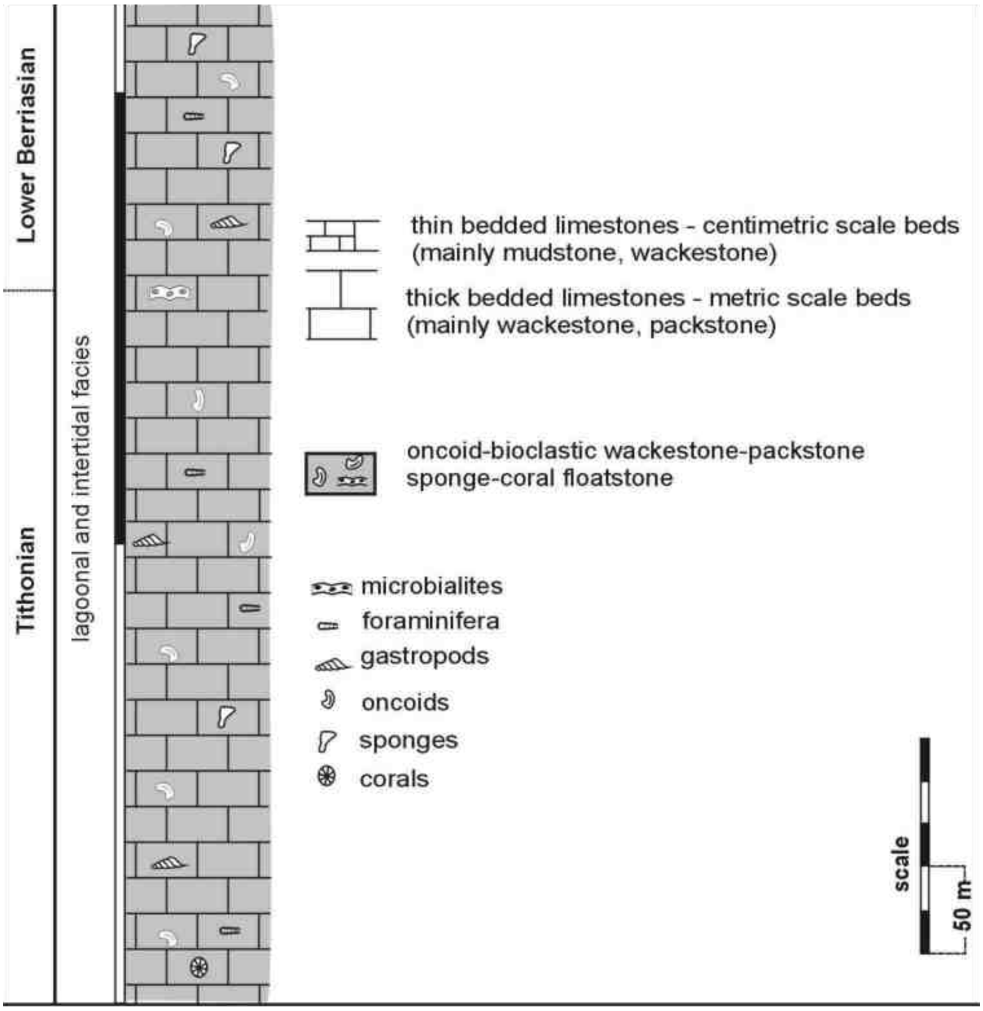



**Fig. 4.17.** Schematic lithological log of the KF section
(Ay-Petri Massif, Tithonian-Berriasian, bedded limestones)

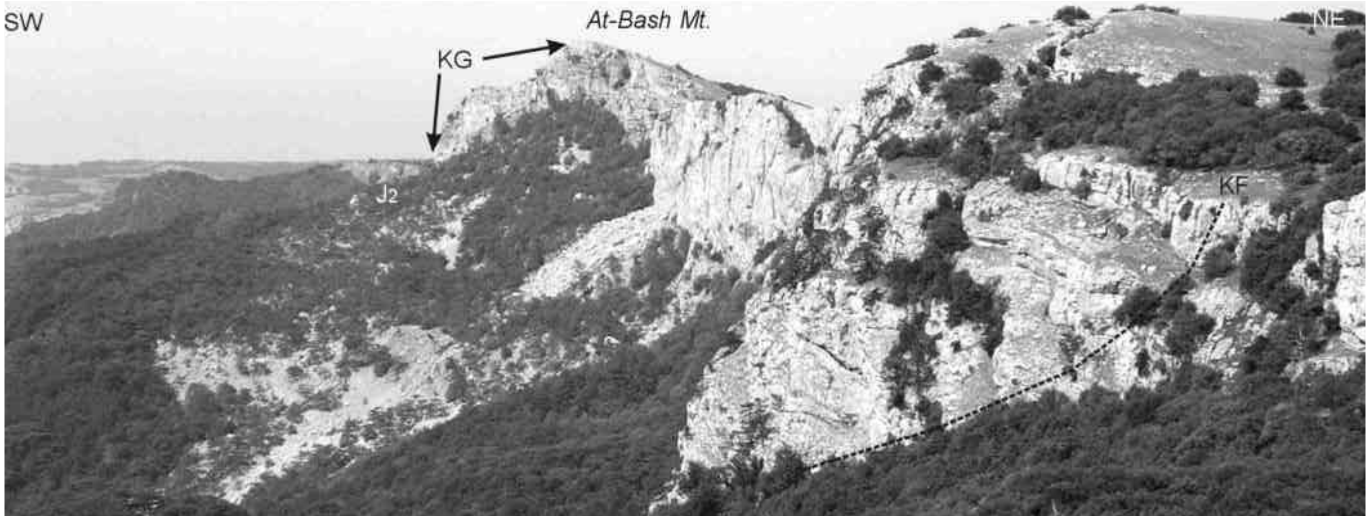



**Fig. 4.18.** Location of the sections KF and KG. The thickness of the Upper Jurassic and Lower Cretaceous sediments of the southern escarpment of the Ay-Petri Massif gradually decreases from ~600 m in the Ay-Petri Mountain to ~200 m in the At-Bash Mountain, see also Fig. 4.20

## INTERPRETATION

Monotonous development together with fossil assemblage indicate deposition in an intra-platform depressions. The observed succession from wackestones to packstones reflects small, periodical oscillations of sea level. Relatively low diversity of fauna and sporadic appearance of typical microencrusters, so common in other sequences, point out to restricted lagoon environment. The presence of more abundant sponge floatstones in the upper parts of the sequence evidences the change in deposition conditions and intensive development of *Cladocoropsis* meadow in a more open lagoon. These strata rest upon the older sediments with small angular unconformity.

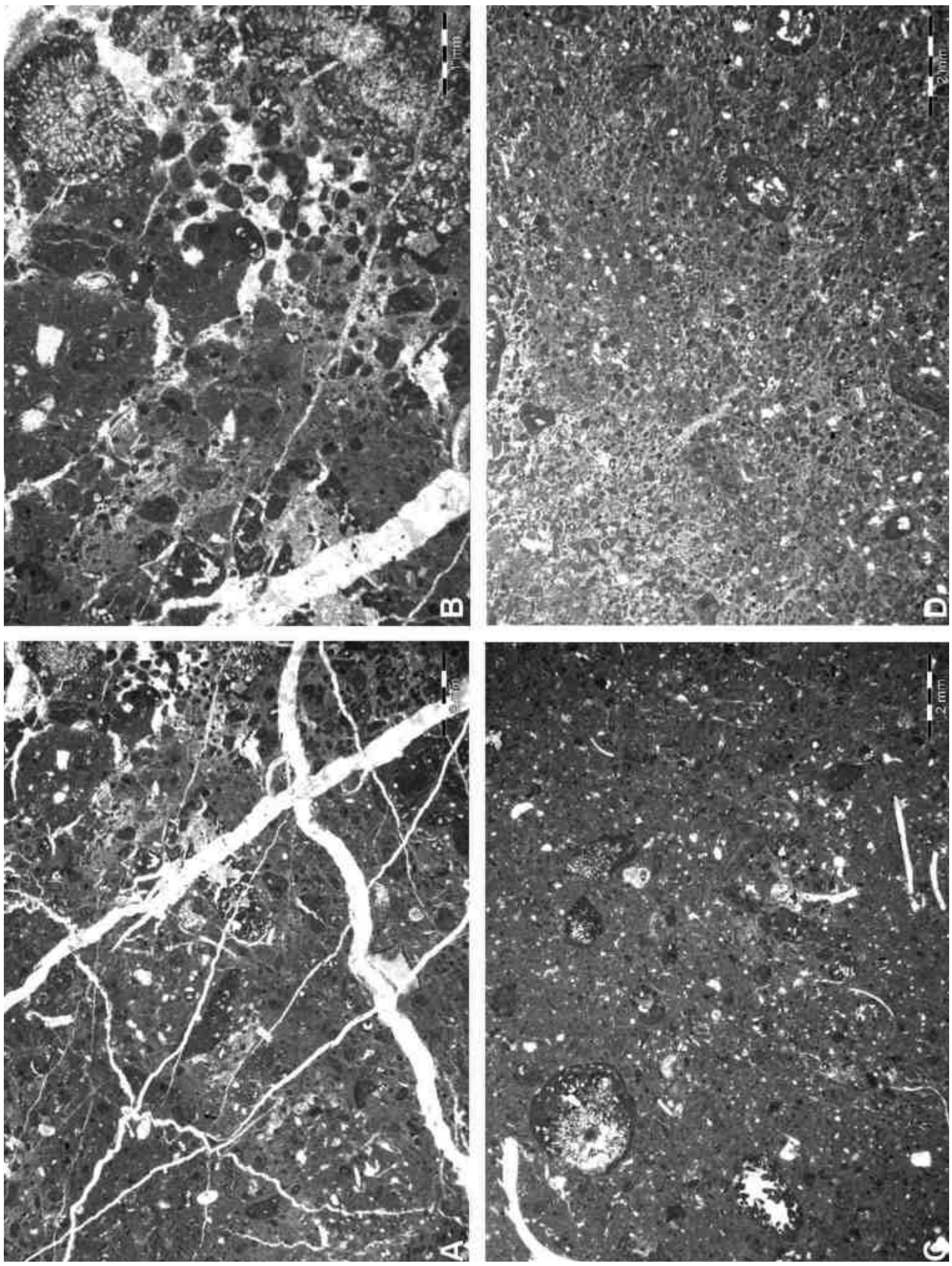

A
B
1 mm
C
2 mm
D
2 mm

**Table 4.60.** Examples of microfacies from KF section, Ay-Petri Massif, bedded limestones, Tithonian

A, B – bioclastic wackestone-packstone, samples KF 1a, KF 1c

C – foraminiferal wackestone, sample KF 3

D – peloidal packstone, sample KF 5

### 4.3.15. The KD section (Ay-Petri Massif, Plateau, Upper Tithonian-Lower Berriasian, bedded limestones)

#### LOCATION AND STRATIGRAPHY

The KD section is representative of sediments from the southern edge of the Ay-Petri Massif, between the Ay-Petri and the At-Bas mountains (Fig. 4.1). The north-west samples were collected from several sites extending as far as to the Besh-Tekne Depression, from sets including from a few to a dozen or so of beds. Similar to the KL section, such sampling pattern aimed to recognize lateral facies variability in the crest of the Ay-Petri Massif. However, due to collection of samples from various sites the comprehensive sedimentologic column has not been drawn.

Similar to the karst plateau of the Ay-Petri and the Yalta massifs, the crest part of the Ay-Petri Massif are built of grey, thin-bedded, rarely thick-bedded limestones which form several sets of variable thickness. Some limestones show characteristic, nodular structures. Beds dip to the north at a dozen or so of degrees. Some sediments rest with angular unconformity upon the strata forming the south-facing walls of the Ay-Petri Massif .

Studies of microfauna revealed the presence of foraminifer assemblage with *Paleogaudryina varsoviensis* (Late Oxfordian-Tithonian), *Verneuilinoides polonicus* (Tithonian-Early Valanginian), *Nautiloculina bronnimanni* (Berriasian-Hauterivian), *Nautiloculina oolithica* (Late Oxfordian-Berriasian), *Everticyclammina kelleri* (Berriasian-Valanginian) and *Meandrospira favrei* (Late Berriasian-Hauterivian, Krajewski, Olszewska 2007). Ranges of these species suggest the Upper Tithonian and Lower Berriasian ages of sediments from the southern edge of the Ay-Petri Massif.

#### MICROFACIES

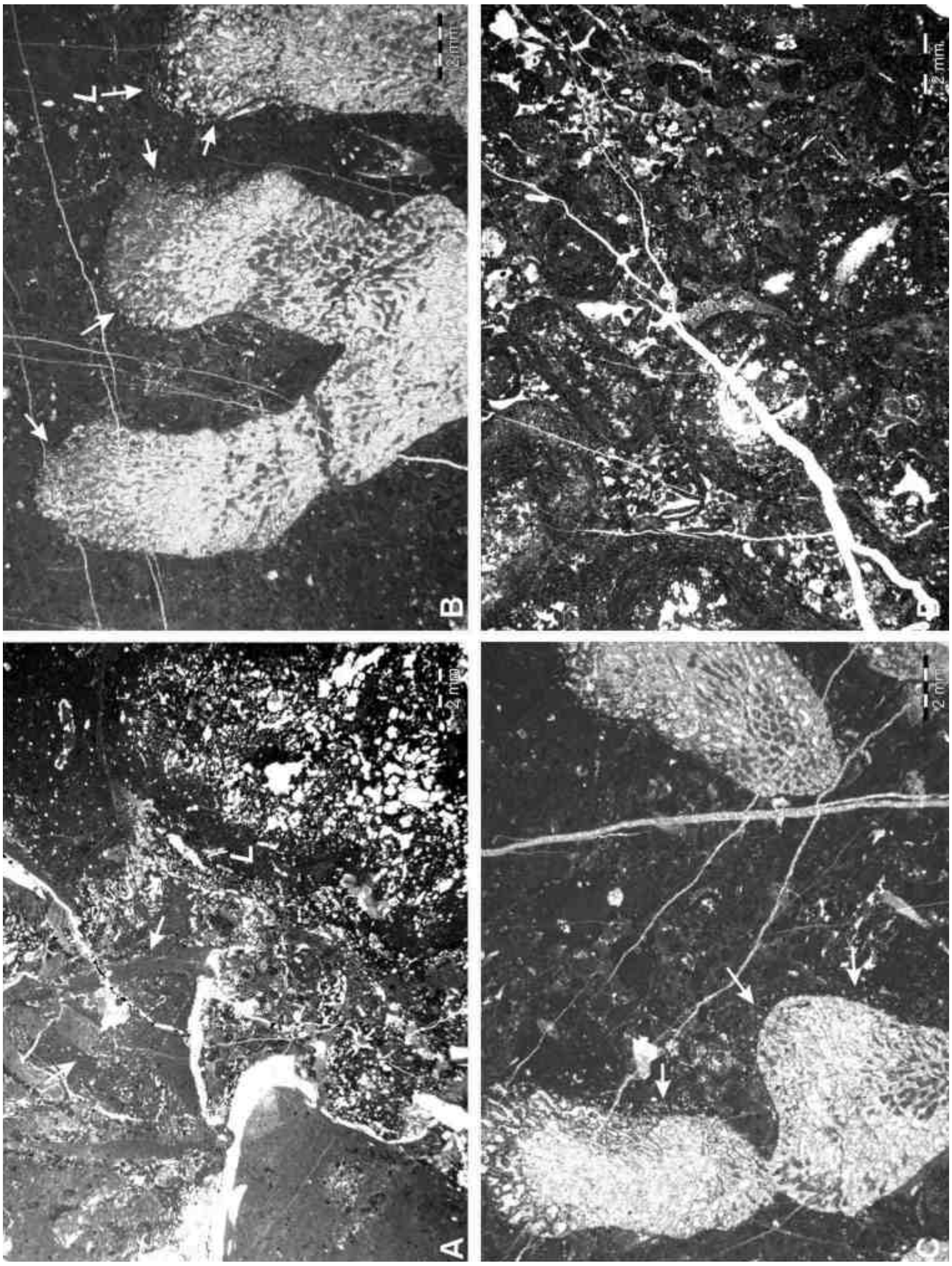
Similar to other sequences described from the crest part of the Ay-Petri Massif, several microfacies varieties indentified under the microscope can be related to the thicknesses of beds. The thin-bedded limestones are mostly bioclastic wackestones and mudstones with numerous foraminifers. Thicker beds are oncoidal-peloidal packstones-rudstones (Tab. 4.61A, D). Apart from commonly observed, small, oval oncoids also large *Lithocodium-Bacinella* forms were observed. Nuclei of oncoids are often bioclasts of sponges, algae, foraminifers and bivalve shells. *Lithocodium aggregatum* grows immediately onto larger bioclasts, followed by successive micritic laminae and *Bacinella irregularis* (Tab. 4.62A).

Moreover, numerous sponge floatstones-packstones were found (Tabs 4.61B, D, 4.62B–D). These varieties are particularly common in sediments forming the edge of the plateau and the south-facing rock walls. Macroscopically, the sediments reveal distinct, clotted structures. In a micritic matrix most common are numerous fragments of *Cladocoropsis* scattered within the sediments as single segments and larger fragments composed of several segments cemented with microencrusters (Tab. 4.62B). Most sponges have thin beds of microencrusters (mostly *Lithocodium aggregatum*) coating their outer surfaces but larger skeletal fragments show such beds mostly on upper surfaces. However, redeposited skeletal fragments reveal microencrusters covering their entire surface. Commonly, such redeposited fragments became nuclei of large oncoids.

**INTERPRETATION**

Sediments observed in the KD section were presumably deposited at the Jurassic/Cretaceous break. Initially, the *Cladocoropsis* floatstones-packstones were formed in shallow, subtidal, back-reef and open-lagoon environments of moderate or low energy. Under such conditions sponge meadows developed, which can be included into the *Cladocoropsis* zone (Leinfelder *et al*., 2005). During high-energy episodes sponge skeletons were disintegrated and scattered over the sea floor. The larger fragments preserved in life position as well as microencrusters developed on their surfaces indicate that *Lithocodium aggregatum* probably grew only onto the upper, better illuminated surfaces of densly packed *Cladocoropsis*. However, during storm episodes when intensive erosion affected the *Cladocoropsis* meadows these were disintegrated and scattered over the floor before *Lithocodium aggregatum* could have developed on their surfaces. Hence, light-depended *Lithocodium aggregatum* might have grown onto various parts of skeletons.

The oncoidal packstones represent back-reef to open lagoon environments. Together with bioclastic wackestones and mudstones these sediments form succeeding depositional sequences probably related to the changes of sea level. Their development is similar in other parts of the plateau represented by the KL, KK and KM sections. The only significant differences are the proportions of microfacies controlled by diversified morphology of the internal platform.



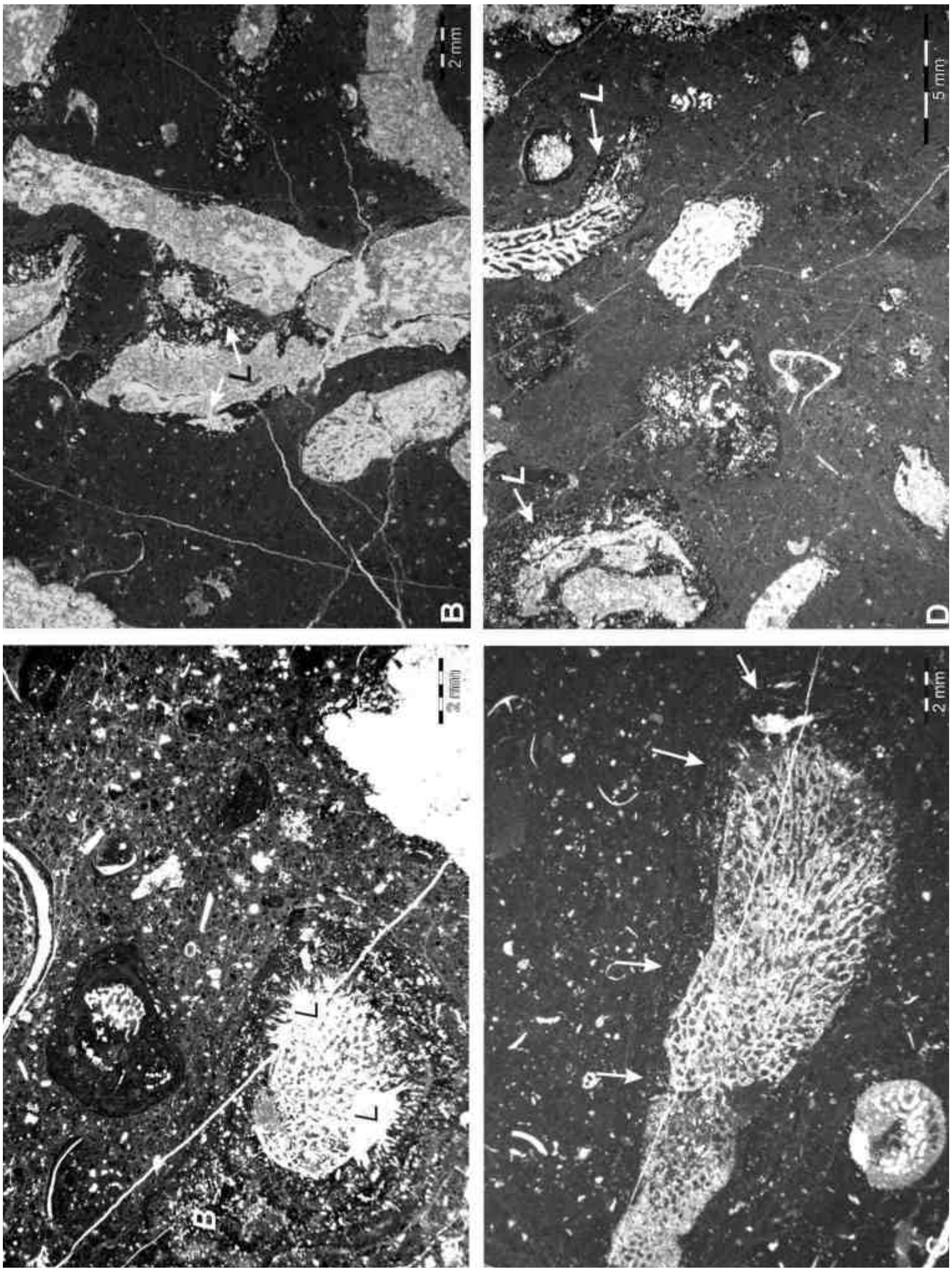
A
B
L
2 mm

**Table 4.61.** Examples of microfacies from KD section, Ay-Petri Massif, plateau, bedded limestones, Tithonian-Lower Berriasian

A – *Bacinella-Lithocodium* bindstone, in the left upper part borings, sample KD 4

B, C – sponge floatstone, on the upper part of the *Cladocoropsis* skeletons microencrusters are developed (arrows), sample KD 5f, KD 5e

D – *Bacinella* oncoid rudstone, sample KD 3a



B
D
L
2 mm
5 mm

**Table 4.62.** Examples of microfacies from KD section, Ay-Petri Massif, plateau, bedded limestones, Tithonian-Lower Berriasian

A – oncoid wackestone with fragment of *Cladocoropsis* sp., on the outer surfaces of the sponges *Lithocodium aggregatum* is visible, sample KD 11b

B – sponge floatstone, on the upper part of the *Cladocoropsis* skeletons *Lithocodium aggregatum* are visible, sample KD 12e

C, D – sponge floatstone, reworked fragment of the *Cladocoropsis* with microencrusters (arrows) on the upper part of the skeleton, samples KD 11f, KD 12b

### 4.3.16. The KG section (Ay-Petri Massif, At-Bash Mountain, Tithonian, bedded and massive limestones)

#### LOCATION AND STRATIGRAPHY

The KG section is situated in the southern wall of the At-Bash Mt. (Figs 4.1, 4.18). From the north this study area is bordered by a vast, karstic Besh-Tekne Depression in which numerous pinnacles and exposures of Upper Jurassic and Lower Cretaceous limestones occur.

The geological structure of the At-Bash Mt. is complicated. The Upper Jurassic sediments rest upon the Middle Jurassic strata and the Taurid Series, and are overlain by Upper Jurassic/Lower Cretaceous limestone succession. Similarly to other parts of the Ay-Petri Massif, two sedimentary complexes can be distinguished, dipping under different angles (Millev, Barabaskhin 1999). The lower complex, about 200 meters thick, forms the main part of the At-Bash southern wall, which is the subject of the study (Fig. 4.18). The At-Bash Massif occupies the same level as the Ay-Petri Massif, where thickness of the lower complex reaches 700 meters. To the west thickness of the lower complex decreases to about 200 meters in the vicinity of the At-Bash Massif. Above, towards the Besh-Tekne Depression, the second complex occurs, composed of Lower Cretaceous carbonates (cf. Millev, Baraboskhin 1999, Yudin 2008).

The KG section begins at the foot of the southern wall of the At-Bash Mt. (Fig. 4.18). Several foraminifers were indentified, e.g. *Palaeogaudryina magharaensis* (Late Kimmeridgian-Middle Berriasian), *Palaeogaudryina varsoviensis* (Late Oxfordian-Tithonian), *Nautiloculina oolithica* (Late Oxfordian-Berriasian), *Labirynthina mirabilis* (Latest Oxfordian-Early Tithonian) and *Dobrogelina ovidi* (Tithonian-Berriasian, Krajewski, Olszewska 2007). Owing to foraminifer assemblage, stratigraphic position of the most part of the At-Bash Massif corresponds to the Tithonian (Krajewski, Olszewska 2007). Considering the microfossil assemblage and lithology, it is concluded that the age of the At-Bash Massif is similar to the upper part of the Ay-Petri Massif.

#### MICROFACIES

The studied sediments are thick-, medium- and thin-bedded, grey limestones (Fig. 4.18). Locally, beding is poorly marked or disappears. Commonly, the sediments are strongly fractured and fractures are filled with sparite. Macroscopically, the sediments are monotonous and contain mostly gastropods and bivalves.

Microfacies observations enabled the author to distinguish five varieties of studied sediments: sponge (chaetedid) framestones-packstones, sponge floatstones, mudstone-fine-pelitic packstones, bioclastic wackestones and intraclastic grainstones-rudstones (Tabs 4.63–4.66).

The lower parts of the KG section is mostly bioclastic wackestones-mudstones and fine-detrital, peloidal packstones (Fig. 4.19, Tab. 4.63). Fossils – mostly foraminifers and small bivalves – are rare. Above, strongly fractured succession of monotonous mudstones-wackestones occurs with rare fossils (mostly foraminifers). Sediments composed of intraclastic packstones-grainstones-rudstones. Intraclasts are fragments of peloidal packstones and mudstones-wackestones, identical to those observed in the lower part of the sequence (Tab. 4.64).

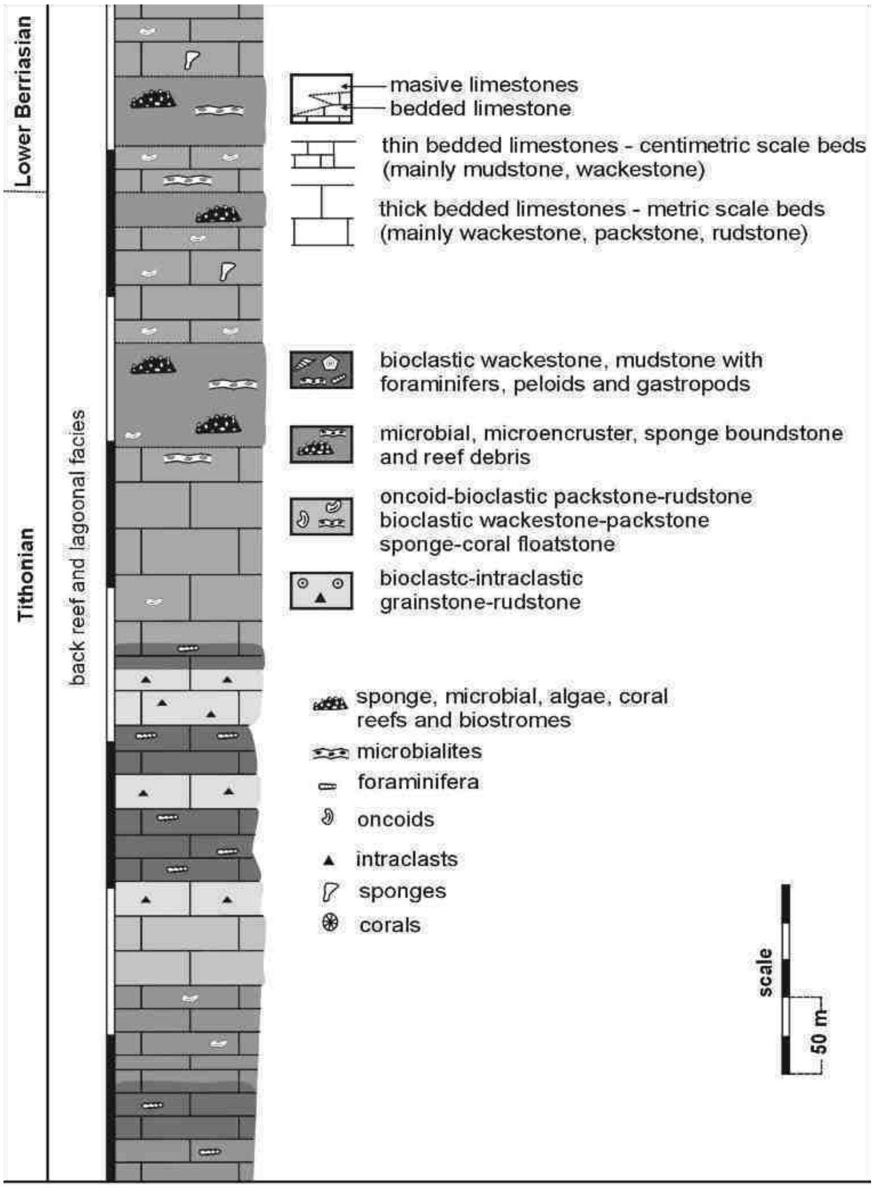



**Fig. 4.19.** Schematic lithological log of the KG section (Ay-Petri Massif, Tithonian, bedded and massive limestones)

The upper parts of the KG section is different – there are chiefly oncoidal packstones-rudstones and sponge-microbial (chaetetids) framestones (Tabs 4.65, 4.66). Common are lateral and vertical successions of both microfacies varieties. Biolithites are composed mostly of the fragments of sponge skeletons and of *Bacinella irregularis*, which form clusters within oncoidal-bioclastic packstones. In the intraskeletal spaces and beneath the skeletons *Bacinella irregularis* is usually observed whereas at the upper surfaces of skeletons thin microbial crusts are developed together with microencrusters (including *Lithocodium aggregatum*). Skeletons belong mostly to chaetetids (?*Chaetetopsis spengleri* (KOECHLIN)) as well as to *Actinostromaria* with radial-fibrous (actinostromid) wall structure (Fig. 65A, B). Oncoids are mostly built of concentric microbial crusts enveloping the nucleus, which is usually micritic, rarely formed by various bioclasts.

In the top part of the KG section, close to the edge of the plateau common are sponge floatstones with numerous, disseminated fragments of *Cladocoropsis*. Rarely, these are large skeletal fragments embedded within micritic or fine-detrital matrix. Most of skeletons host *Lithocodium aggregatum* with *Troglotella incrustans* on their surfaces. Abundant are also foraminifers, bivalves and gastropods (see section KD, Tab. 4.62B).

## INTERPRETATION

The interpretation of the KG section brings some problems due to rare fossils. Lithology is dominated by bioclastic wackestones and mudstones with numerous foraminifers, which grade up the sequence to peloidal packstones. Studied samples do not contain fossils typical of shallow environment. However, considering microfacies development and comparison to other sequences and sediments located higher in the sequence, it is suggested that these sediments presumably represent the inner platform environment. Commonly observed peloidal packstones and mudstones-wackestones were probably deposited in shallow, quiet and restricted parts of the platform. The breccia horizons are composed mostly of intraclasts which are redeposited fragments of peloidal packstones as well as mudstones-wackestones observed in this sequences. Thus, it can be suggested that intraclastic grainstones originated from the erosion of underlying sediments. Similar upward succession – from mudstones-wackestones and peloidal packstones to intraclastic grainstones-packstones-rudstones – is common in the middle part of the sequence. Such succession may indicate periodical erosion caused by changes sea level and temporary emergences. Observations from adjacent sequences (KE, KF) also demonstrate deposition in intertidal environments and erosion of sediments.

The sponge framestones and oncoidal packstones noticed in the KG section suggest deposition in more open, periodically higher-energy environment. Characteristic is the common occurrence of *Bacinella irregularis* and much rare *Lithocodium aggregatum*, which points out to shallow but higher-energy conditions related to shallow subtidal environment with abundant sponges (mostly chaetetid patch-reefs and biostromes). These sediments were laid down during the rise of sea level and indicate deposition of peri-reefal environments. In the upper part the sediments grade into *Cladocoropsis* floatstones, reflecting the open lagoon environments. Skeletal fragments are commonly occupied by *Lithocodium aggregatum* which indicates shallow, oligotrophic conditions.

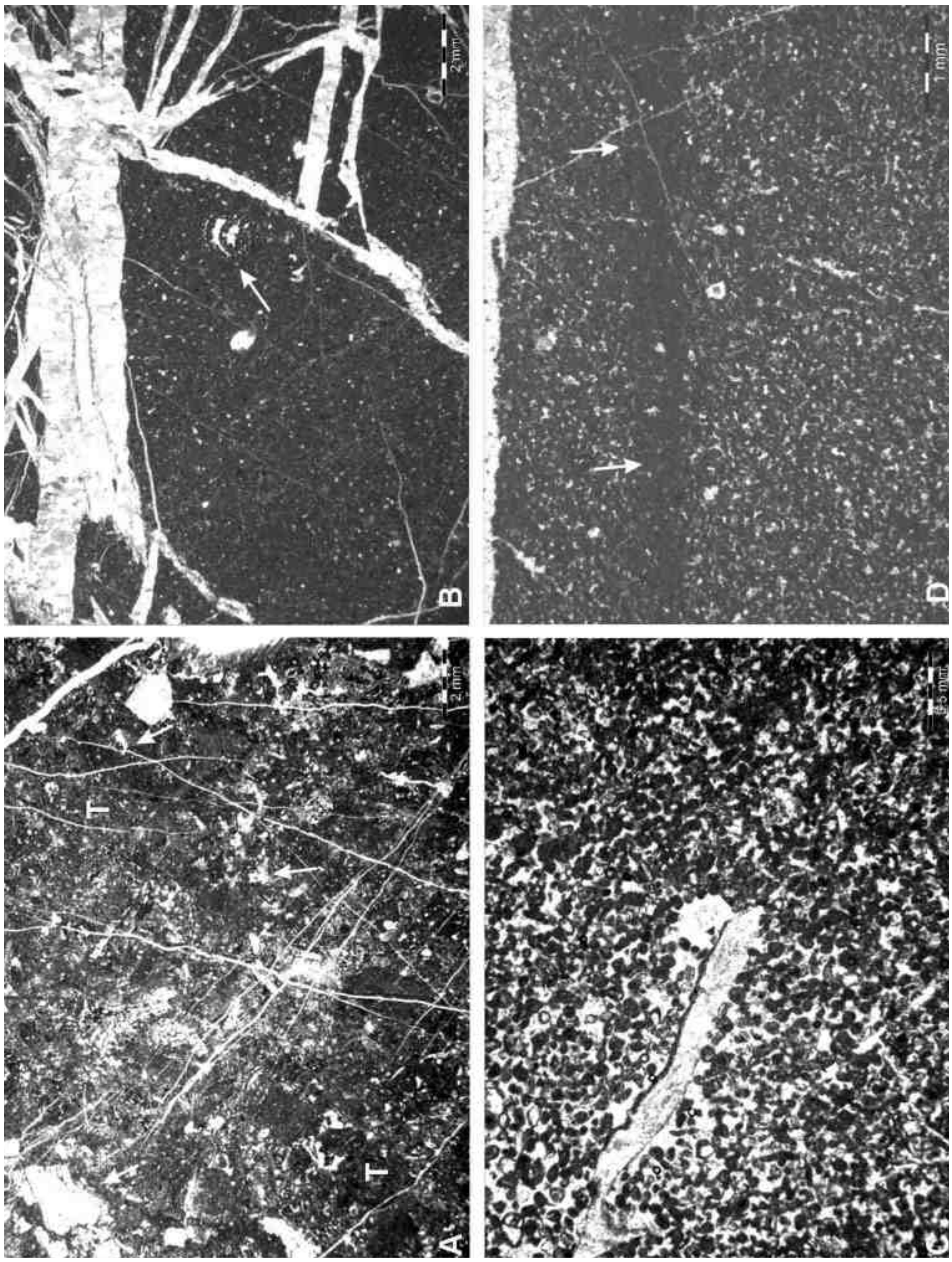

A
B
C
D
T
T
2 mm
2 mm
1 mm

**Table 4.63.** Examples of microfacies from KG section, Ay-Petri Massif, At-Bash Mt., bedded limestones, Tithonian

A – thrombolitic (T) bindstone with small geopetal infilled caverns (arrows), sample KG 1

B – mudstone with foraminifers (arrow), sample KG 9

C – peloidal packstone, sample KG 11a

D – peloidal packstone stabilized by microbial crust (arrows), sample KG 11c

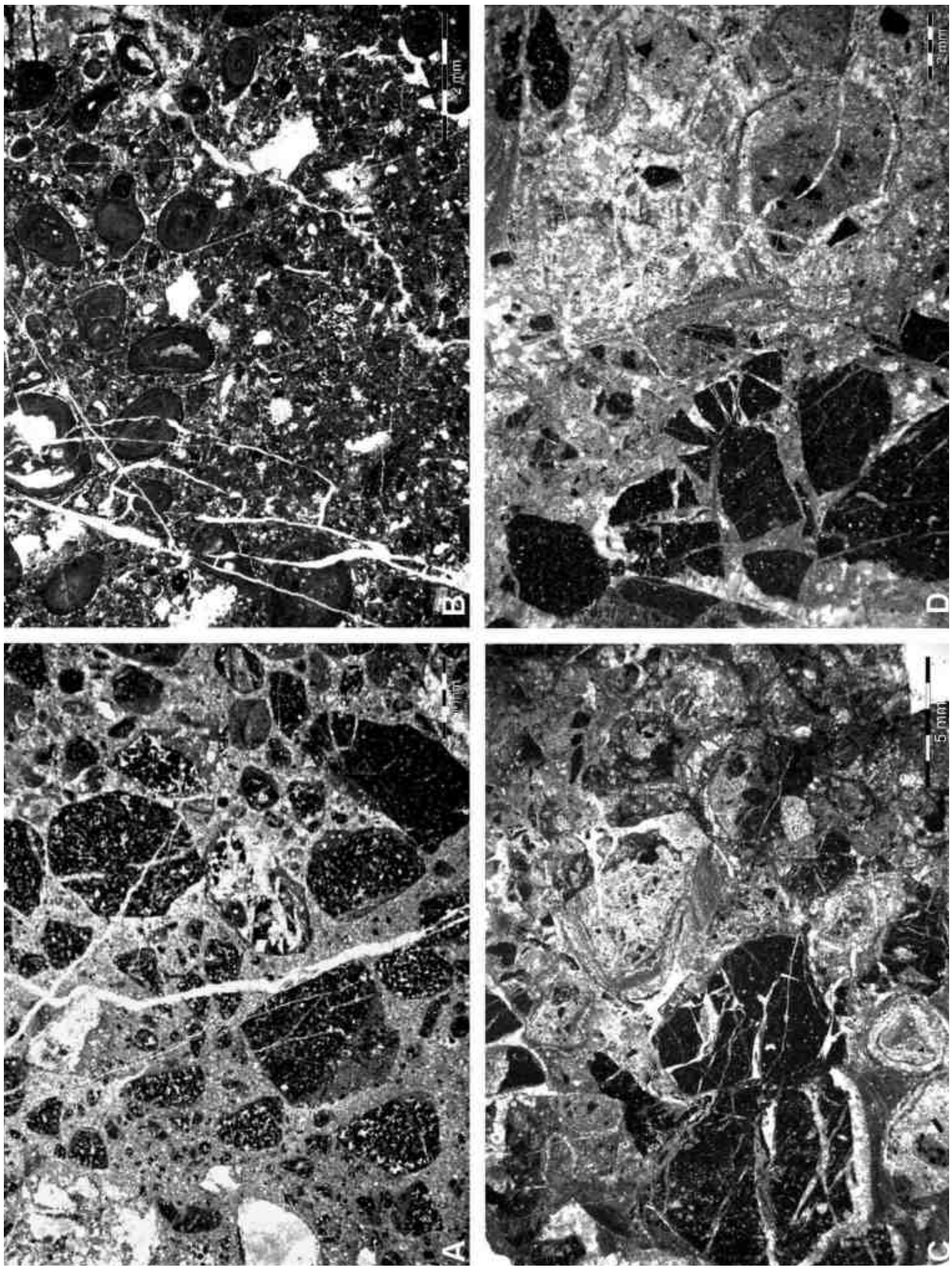

A
B
2 mm
C
5 mm
D
2 mm

**Table 4.64.** Examples of microfacies from KG section, Ay-Petri Massif, At-Bash Mt., bedded limestones, Tithonian

A – intraclastic grainstone, sample KG 4 a

B – oncoidal-bioclastic packstone, sample KG 2a

C, D – breccias consist of lithoclasts and cement, samples KG 10, KG 10a

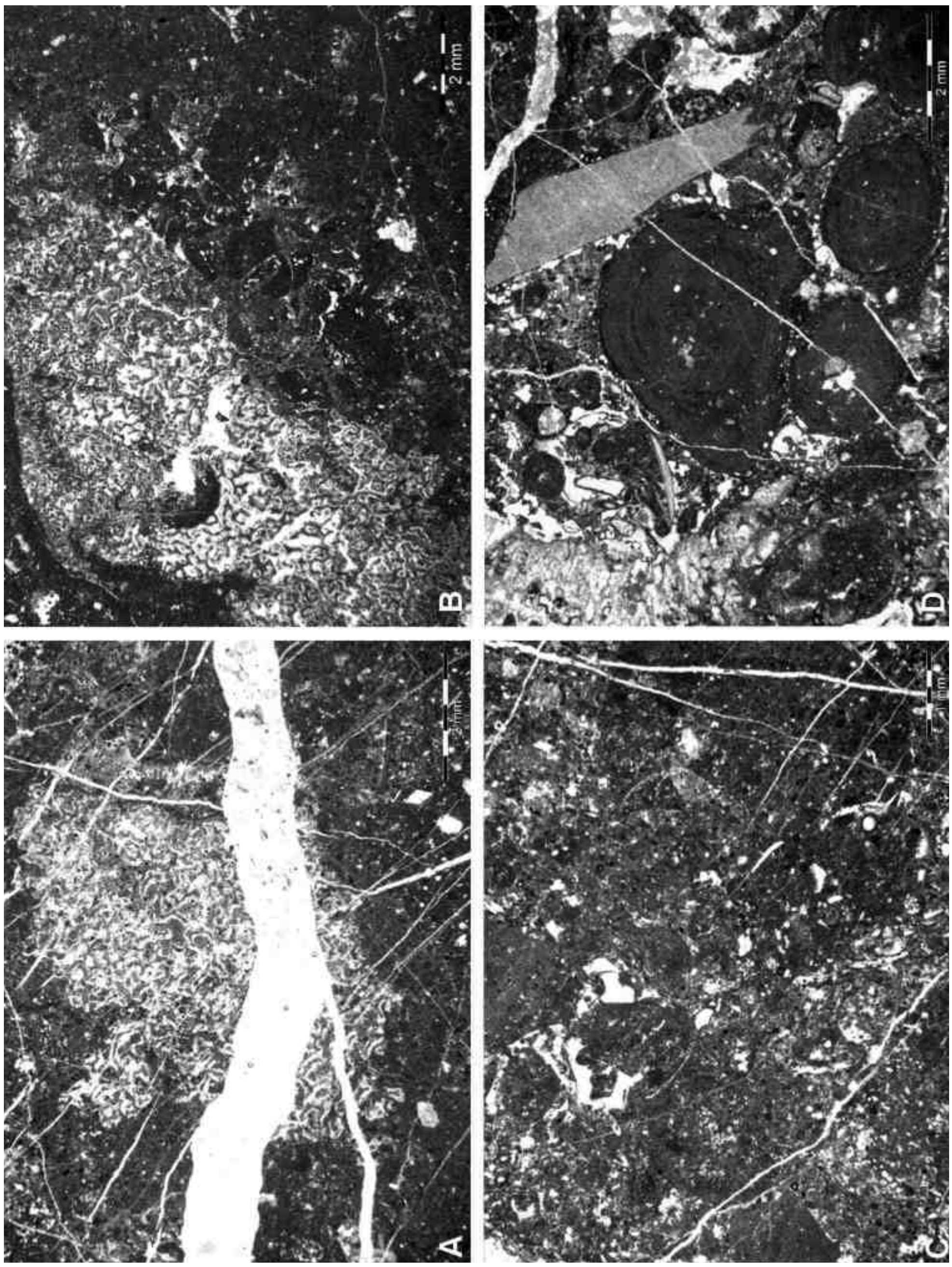

A
B
C
D
2 mm
2 mm

**Table 4.65.** Microfacies from the upper part of KG section, Ay-Petri Massif, At-Bash Mt., bedded and massive limestones

A, B – sponge-microbial boundstone with *Actionstromaria* sp., samples KG 1a, KG 1b

C –microbial bindstone, sample KG 16

D – oncoidal rudstone with numerous bioclasts and fragment of sponges (upper left side of the photo, sample KG 2a

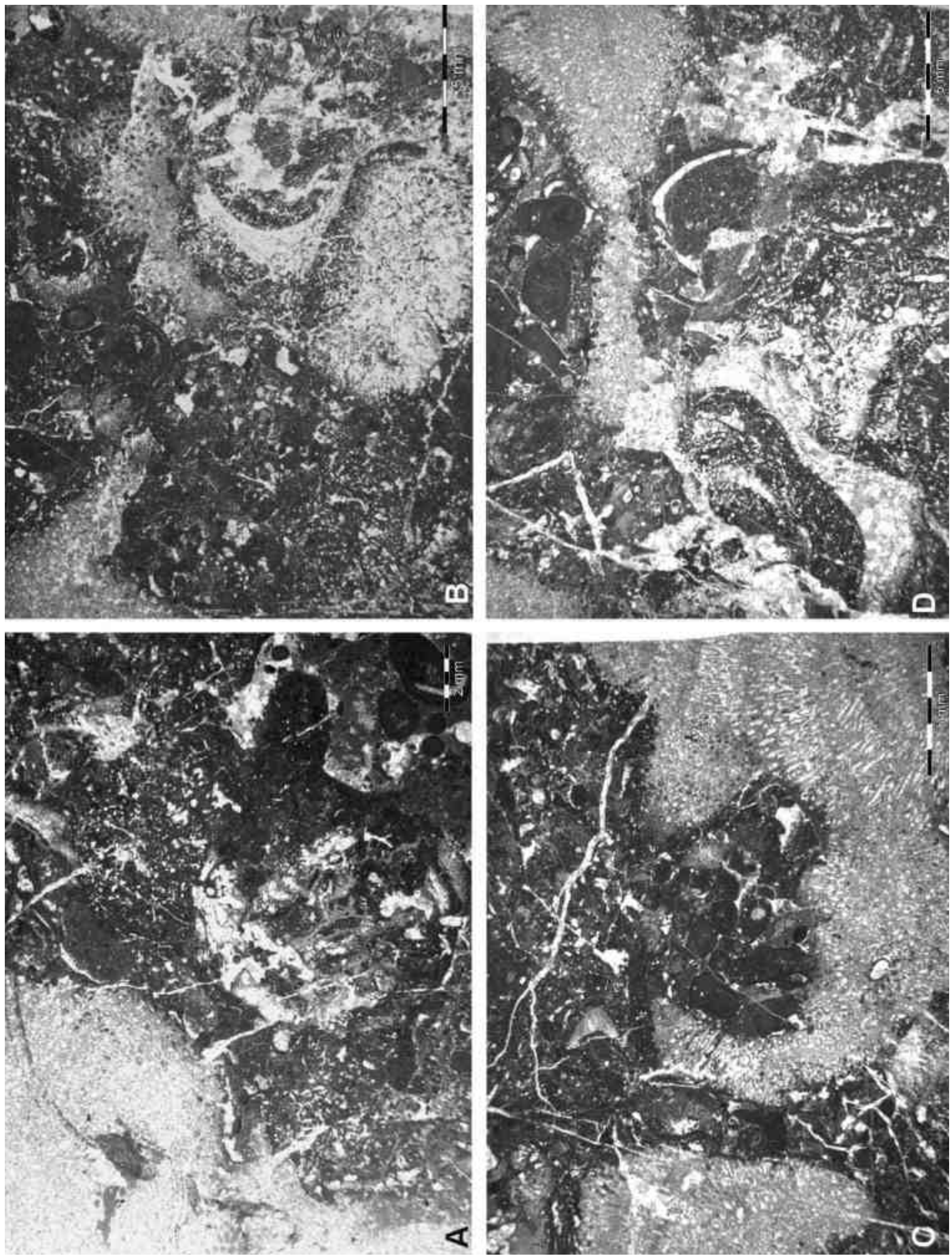

A
B
C
D

**Table 4.66.** Microfacies from the upper part of KG section, Ay-Petri Massif, At-Bash Mt., bedded and massive limestones

A, B – sponge-algae-microbial framestone, samples KG 2c, KG 2e

C, D – sponge-*Bacinella* framestone, in the upper part oncoidal packstone, samples KG 2 d, KG 2a

## 4.4. Facies development of the Yalta and the Ay-Petri massifs

### 4.4.1. Remarks on the tectonics disturbing the recent facies pattern

Depositional sequences recently observed in the investigated parts of the massifs have been tectonically disturbed. Thus, comparison of particular sections may cause problems. It is especially true for the Yalta Massif and, to less extent, also for the Ay-Petri Massif.

In many older papers the Crimean Mts. were described as relatively uniform, uplifted block in which Upper Jurassic sediments were stratigraphically continuous and attained total thickness of even 2–3 kilometers (e.g., Muratov 1960, 1973, Permyakov et al., 1991, 1993, Leshukh *et al*., 1999, Dorotyak 2006). This concept has been called into question in modern studies and it was proposed that significant thicknesses of carbonate deposits resulted from tectonic stacking of strata (e.g., Popadyuk, Smirnov 1996, Yudin 1999a, b, Millev, Baraboskhin, 1999, cf. Gintov, Borisenko, 1999). Unfortunately, the available literature provides only very general data, insufficient to precise the character and amount of tectonic transport. Basing upon the field observations and the literature analysis, the field studies were organized in such a way that examined sections belonged to the same tectonic blocks. Hence, for some sequences (KM, KN, KP and KO) observations were carried on only in the upper part of rock walls, for which the partial sequences were described. Numerous tectonic disturbances encountered in the study area include vertical or high-angle (some tens of degrees) surfaces with well-visible slickensides and angular unconformity exposed along the southern edge of the plateau (Tabs 3.1, 4.29a).

During field studies some vertical faults, commonly perpendicular to the strike of beds, were found particular in the Yalta Massif (Tab. 4.16D). Distinct similarities of facies and microfacies development of sediments in both blocks of the faults, as seen e.g. in the KN section, indicate low throws of these faults. Larger displacements should result in disturbances of lithology and stratigraphy of the affected successions. However, no such large tectonic displacements of sequences were observed (Fig. 3.1). The only high-throw faults accompanied by extended tectonic breccias were encountered along the southern edge of the Ay-Petri Massif (Tab. 4.29F) but this fault system shows different structural directions and does not disturb the studied sediments (Fig. 3.1).

In some parts of sequences located in the vicinity of the Iograf Ridge, which itself is an isolated block of complicated tectonic pattern, high-angle faults were found (Tab. 4.13B). These are presumably minor displacements caused by insignificant, lower-rank movements resulted from gravitational sliding of lithologically diversified blocks along the interfaces with soft sediments. Thus, these displacements do not disturb remarkably the sedimentological successions. Some of such high-angle faults seen e.g., in the Ioraf Ridge, may represent the older, Early Cretaceous movements, Tertiary movements as well as the younger displacements. Continuity of sediments in the Iograf Ridge was tectonically disturbed and depositional sequences perhaps were repeated due to sucessive overthrusting (Millev, Baraboskhin 1999, V. Yudin, pers. comm.). It must be emphasized that sediments from the Iograf Ridge were included into the stratotype representative of sedimentary sequences of both the Yalta and the Ay-Petri massifs although tectonic events have not been taken into consideration (e.g., Permyakov *et al*., 1993, Leshukh *et al*., 1999). Hence, for the KJ section more general sedimentological conclusions and comparison with the other sequences were limited mostly to the lower portions of the sequence where both the succession and the development of strata have not been considerably tectonically disturbed (according to authors observations) and, thus, their comparison with other sequences can be made.

A characteristic feature observed in various parts of the Yalta and the Ay-Petri massifs is the distinct, angular unconformity, which separates sediments belonging to two tectonic units: the lower unit, which represents deposits building the southern walls of the massifs (sections KJ, KM, KN, KP, KO, KS, KR, KA, KB, KC, KE, KF and KG), and the upper one, which includes sediments covering the vast karstic plateau (sequences KK, KL, KD, Figs 3.2, 4.19). Basing on stratigraphic observations, it can be proposed that sediments from the uppermost part of sequences located on the southern slopes of the massif and those from the sequences located on the plateau represent two tectonic units of similar age (mostly Uppermost Tithonian-Lower Berriasian).

In the Ay-Petri Massif, sediments observed in the KC, KB and KA sections together with angular unconformity found along the southern edge of the massif correspond to the final stage of development and the erosion of the Ay-Petri reef complex. This coincidence leads to the conclusion that, due to Cimmerian movements at the Jurassic/Cretaceous break, development of the Ay-Petri reef complex has been halted and the emerged sediments were subjected to intensive erosion. Then, the Early Cretaceous marine ingression unconformably laid down the new deposits onto the surface of the older strata. These new sediments were mostly thin-bedded, lagoonal limestones. Such conclusion may concur the earlier concepts, after which sediments in the whole massif are stratigraphically continuous (e.g., Muratov 1973, Permyakov *et al*., 1993, Leshukh *et al*., 1999, Dorotyak 2006). However, such interpretation appears to be doubtful if the new observations are considered, i.e., there exist overthrusts, which are evident from the uppermost parts of the massifs exposed on the plateau (e.g. Popadyuk, Smirnov 1996, Yudin 1999a, b, Nikishin *et al*., 1998, 2001). In authors opinion, at the present stage of geological studies of the Crimean Mts. tectonic movements at the Tithonian/Berriasian break can not be precluded. These movements are responsible for the formation of recently observed angular unconformity. Consequently, the question arises whether slabs of Middle Jurassic sediments sanwiched between the two tectonic units, e.g. in the vicinity of the At-Bash Mountain (Millev, Baraboskhin 1999, Yudin 2008) are fragments emplaced during the main stage of the formation of the Crimean Mts. allochthone or are rather fragments of older rocks displaced from adjacent, uplifting land during the earlier (Jurassic/Cretaceous boundary) tectonic movements.

Concluding, the author assumes that sediments encountered in most of studied sequences (excluding KK, KL and KD) belong to the same, first-rank tectonic block (Fig. 3.1). Vertical tectonic surfaces commonly observed in the study area do not disturb significantly the stratigraphic continuity of sediments even if they slightly displace the strata. Hence, it is evident that sedimentological observations made in the studied sequences are valid and that comparisons between the sequences in the Yalta and Ay-Petri massifs are possible. Moreover, it is proposed that most of the southern portion of the massifs is a relatively uniform tectonic block. Therefore, sedimentological conclusions presented in this paper are based only on data from some parts of the massif. Another important problem, which requires new studies is the comparison of sediments from the study area with: (i) those building the vast karstic plateau in the uppermost portion of the massif and (ii) with the remaining parts of the Crimean Mts., which are separate tectonic blocks (Yudin 1999a, b).

### 4.4.2. Facies

Basing on lithological criteria, several facies varieties were distinguished in the studied sediments, probably belonging to the three main types of platform environments: (i) platform slope, (ii) platform margin reefs and ooidal shoals, and (iii) internal platform lagoons and tidal flats. All identified facies varities were deposited in a shallow-marine basin of depth from several to a dozen of meters, with a maximum depth of some tens of meters. Moreover, some depositional sequences reveal strong influence of adjacent land, as documented by siliciclastic and mixed, carbonate-siliciclastic successions.

#### PLATFORM SLOPE FACIES

Facies representing the platform slope occur in the lower portions of KJ, KR, KC and KB sections. However, in some parts of the massifs such facies were observed also in the upper portions (e.g KJ section), may be due to tectonics. Estimated thickness of platform slope facies varies from some tens to 100 meters and can be diversified in various portions of the massifs due to syndepositional movements and Late Jurassic/ Early Cretaceous erosion. In studied sequences no gravity flow sediments were observed, which indicates low angle of platform slopes.

#### Facies 1 – Bioclastic wackestones-packstones with microbilites (thick-bedded and massive limestones, e.g. Tabs 4.6, 4.51A)

This facies variety is dominated by monotonous sediments composed mostly of bioclasts and peloids. Some deposits, particularly peloidal packstones are locally stabilized by micriobialites. Occassionally, thrombolite-*Crescientella* bindstones were found. Both the development of sediment and the lack of typical, shallow-marine fauna enable the author to locate this facies in a deeper (some tens of meters) parts of low-angle platform slopes.

**Facies 2 – *Microsolena*-microbial-sponge boundstones-floatstones (thick-bedded and massive limestones, e.g. Tabs 4.3C, D, 4.30)**

In this microfacies typical is the presence of platy *Microsolena*, which forms biostromes with abundant thrombolitic structures and *Crescientella-Terebella* association. These organisms together with the character of sediments indicate somewhat deeper environment but still within the range of photic zone or, alternatively, shallower environment of increased trophic conditions related to the close proximity of the land. In the Ay-Petri reef complexes biolithites were observed composed of thrombolites, particularly *Crescientella*, which often forms microframework (Krajewski 2008, Schlagintweit, Gawlik 2008).

**PLATFORM MARGIN FACIES**

Facies representing the platform margin are related to the growth of carbonate buildups with contribution from peri-reefal deposits and ooidal-bioclastic shoals. Such facies were observed mostly in the sequences localized in the areas of the Ay-Petri Mt. (KA, KB and KC sections), the At-Bash Mt. (KG section) and in the lower parts of the Iograf Ridge (KJ section). Thickness of sediments dominated by these facies reaches 400 meters in the Ay-Petri Mt. and from a dozen to some tens of meters in the other areas. Sediments of the platform margin environments form numerous, alternating horizons composed of ooid facies and carbonate buildups, of thicknesses from a dozen to some tens of meters, which indicates mobile character of the platform with oscillations of the sea level.

**Facies 3 – Ooidal-cortoid-bioclastic grainstones-rudstones (massive limestones, e.g. Tabs 4.34A, C, 4.52, 4.54B, D)**

This facies variety is common in the KB and KC sections located in the Ay-Petri reef complex where it forms several horizons representing the ooid-cortoid-bioclastic shoals. Frequently, intergranular spaces are filled with early diagenetic phreatic cements. Thickness of this facies variety usually does not exceed a dozen of meters.

**Facies 4 – Sponge-microencruster-algal-coral-microbial boundstones (massive limestones, e.g. Tabs 4.34B, 4.36, 4.40, 4.41, 4.42, 4.46, 4.48)**

The fourth variety is represented by small but abudant patch-reefs and biostromes built by various organisms and peri-reefal detritus. Their maximum diversity was noticed in the massive limestones of the Ay-Petri reef complex as well as in the thick-bedded limestones of the Yalta and the Ay-Petri massifs. Such buildups were formed in shallow-marine environments, as indicated by fossils: algae, sponges and corals, and by most typical microproblematic associations: *Lithocodium-Bacinella* or green algae *Thaumatoporella*. Several types of structures were observed: from sponge-microbial-algal reefs representing the shallow subtidal buildups growing in high-energy, oligotrophic environment to sponge-microbial or coral-microbial reefs. The latter were initially formed in shallow environment, as revealed by *Lithocodium* growing onto the skeletons. At the second stage the interskeletal spaces as well as the whole surfaces of the reefs were intensively inhabitated by thrombolites, which is interpreted as an effect of crisis and change of trophic conditions. Maximum thickness of sediments dominated by this facies only exceptionally exceeds 100 meters.

### INTERNAL PLATFORM FACIES (OPEN/RESTRICTED LAGOON AND TIDAL FLAT)

The internal platform facies were encountered in all sequences (particularly in the Ay-Petri Massif), in the upper part of other massifs and on the plateau. Usually, these facies form several, thin depositional sequences composed of thin- and medium--bedded limestones genetically related to low-energy environments and probably slight oscillations of sea level.

#### Facies 5 – *Bacinella*-oncoidal-bioclastic packstones-rudstones (bedded, and massive limestones, e.g. Tabs 4.14B, D, 4.17D, 4.18, 4.21C, D, 4.22, 4.45)

This facies variety occurs mostly in the uppermost part of studied sequences and includes thick- and medium-bedded limestones composed of both the oval, fine, micritized oncoids and various, well-developed, large oncoids formed by microbial crusts and *Bacinella*. The facies is typical of the internal platform and represents the open lagoon environment. *Bacinella* oncoids formed mainly during the episodes of higher sea level, in the moderate-energy environment.

#### Facies 6 – Sponge-coral floatstones (bedded limestones, e.g. Tabs 4.8, 4.9, 4.50, 4.57, 4.62)

This facies variety is most common in the uppermost part of the massifs. The rock is composed of very abundant but highly dissolved skeletons, both in the life position and redeposited, embedded in mudstone or wackestone with numerous foraminifers. The upper surfaces of skeletons are usually covered with microencrusters, mostly *Lithocodium*, typical of the open-lagoon environment. In some horizons abudant skeletons may lead to erroneous classification of such rock as a biostrome.

#### Facies 7 – Foraminiferal-gastropod wackestones-mudstones (thin-bedded limestones, e.g. Tabs 4.14C, 4.15, 4.28B)

This facies is represented by thin-bedded limestones deposited in a restricted lagoon environment. Development of sediments is monotonous and their fossils show poor taxonomic diversity. Fossil assemblage is dominated by foraminifers, gastropods and echinoid clast, typical of the internal platform.

**Facies 8 – Intertidal mudstones-microbial bindstones (thin-bedded limestones, e.g. Tabs 4.10D, 4.56B, 4.58B, C)**

This facies variety is related to numerous, thin sequences of carbonate muds with rare foraminifers and to microbial mats. Typical features are fenestral structures. Cavities are usually filled geopetally with vadose silt.

**Facies 9 – Mixed, siliciclastic-carbonate and pure siliciclastic facies (e.g. Fig. 4.5, Tabs 4.7, 4.11, 4.26, 4.53A)**

In both the Yalta and the Ay-Petri massifs, particularly in their lower portions, siliciclastic sediments were observed. The detrital material was supplied from the adjacent land and originated from the erosion of both the Middle Jurassic clastics and the Taurid Flysch sediments, similar to those occurring in the immediate basement of the massifs. In the lower part of the KJ, KC and KB sections siliciclastic sediments appear at the same elevation and in the same lithologic succession. This may suggest that these sediments formed at the Kimmeridgian/Tithonian boundary, in the same, main episode related to the break or restriction of carbonate sedimentation and to erosion. Up the sequences siliciclastics are less common and they are mixed, siliciclastic-carbonate deposits related to the later influence of land, much less intensive and extended in comparison with the earlier episode. Moreover, siliciclastics were found in the upper portion of the KP section, at the southern edge of the plateau, within the clotted limestones. Siliciclastic facies appear in some horizons and presumably reflect phases of tectonic movements (which uplifted the adjacent land) as well as bathymetric and climatic changes.

### 4.4.3. Facies relationships among the sequences

Studies of the southern part of the Yalta and the Ay-Petri massifs led to the identification of several facies varieties of limestones and mixed, siliciclastic-carbonate sediments. Their characterization and biostratigraphic data enabled the author to recognize facies relationships and variability between the investigated sequences.

It was found that the lower portion of sequences located in the Yalta and the Ay-Petri massifs are similar in their facies and microfacies development, and form similar successions of depositional sequences. Hence, it is proposed that to lower portions of sequences a very simplified, classic stratigraphy based upon stratotype from the Iogaf Ridge is applicable but their stratigraphic position mentioned in some publications should be modified (cf., Muratov 1973, Leshukh *et al*., 1999, Dorotyak 2006, Anikeyeva, Zhabina 2009). Examples are lower portions of the KJ, KC and KB sections, where sediments are similar and include, among others, *Microsolena*-microbial-sponge biostromes and bioclastic wackestones-packstones with microbialites, whereas microencrusters are dominated by *Crescientella moronnensis*. These sediments grade into shallower facies where abundant are branched corals, sponges, chaetetids and algae. Higher up in the sequence oolitic and siliciclastic horizons appear. Generally, depositional variability observed up the sequence resulted from both the diversity of sea bottom relief and the platform evolution. Thus, the study area was divided into two main parts: Yalta and Ay-Petri massifs.

**THE AY-PETRI MASSIF**

In the area of the Ay-Petri Mt. deposition of a vast reef complex has proceeded as early as in the lowermost portions of the massif. This reef complex includes several, succeeding, shallow-marine depositional sequences, which recently appear as strongly cemented, massive limestones. In the exposures alternations of carbonate buildups with oncoidal and ooidal facies can be observed. Moreover, numerous sedimentary gaps and evidences of emergence are clear. Microfacies analysis of massive limestones from the Ay-Petri reef complex reveals a high vertical and lateral variability of sediments. Distances between particular sequences are about several hundred meters, which evidences that limestone facies may change laterally within such short intervals. Most similar are the lowermost portions of profile of presumed Kimmeridgian/Lower Tithonian age. These sediments are microbial biolithites with *Microsolena*, sponges and *Crescientella* deposited in somewhat deeper and more trophic environment. However, siliciclastics also encountered in the lower portions of sequences may suggest other explanation – the proximity of land – which might have strongly modified depositional environment. This stage of deposition can be observed in various sequences from other parts of massifs and is interpreted as the initial phase of development of platform margin which relief was modified in the time, e.g. due to the growth of reef complexes. Higher in the sequences (particularly in the KC and KB ones) a strong diversification of facies becomes obvious. Starting roughly from the level of siliciclastic horizons, the KC section is dominated by ooidal-bioclastic shoals facies of rather limited extent, same as the KB section. At the same position the sponge-coral-algae patch-reefs are prevailing. Furthermore, towards the the KR section oncoidal facies related to the back-reef – lagoon transition, which are common in other sequences located in to northeast become abudant. It seems that similar regularity occurs in the western part, towards the At-Bash Mt. where bioclastic wackestones-packstones dominate. In the uppermost portion of studied sequences the character of deposition again becomes uniform, i.e., it is represented by prevailing open, sometimes more restricted lagoonal facies. To the northeast massive limestone grade laterally into thick-bedded, then into thin-bedded limestones, representing the internal platform facies (KS, KP, KO sections).

Comparison of sedimentary complexes from e.g. the Ay-Petri Mt. with those located southwest, towards the At-Bash Mt., reveals similarities in their stratigraphic position and some resemblances, especially of sponge framestones observed at the same levels. However, contrary to the Ay-Petri, the At-Bash succession is incomplete and much thinner. In the KG section of the At-Bash Mt. microbial-*Microsolena*-sponge facies observed in the lower protion of the KB, KC and KJ sections are absent. A possible explanation is that in the At-Bash area big parts of these sequences could not be preserved due to tectonic events. However, field observations did not reveal large, vertical tectonic disturbances between both areas. On the other side, similar stratigraphic position of higher portions of sequences in both areas along with the presence of strongly brecciated, intraclastic packstones-grainstones in the At-Bash succession may suggest significant sedimentary breaks and erosion. Such interpretation is supported by microfacies data from the adjacent KF and KE sections where common are sediments deposited in lagoonal and intertidal environments. In such exteremely shallow waters deposition rates were low and sediments were subjected to erosion during the periods of sea level drops. Hence, at that stage of At-Bash history marine deposition was ended and erosion took place.

For such interpretation important is the position and development of carbonate complexes between the Ay-Petri and the At-Bash, referred to the basement relief (Fig. 4.20). In this area the surface of pre-Upper Jurassic basement was significantly uplifted. Thickness of Jurassic deposits in the lower tectonic unit, which builds the southern edge of the massif changes from ~600 meters in the Ay-Petri area to ~200 meters in the At-Bash vicinity and is even lower southwestward Fig. 3.1, Tab. 3.1C, D). Thus, there exists a similarity between the facies development and the basement morphology. Results of sedimentological studies may suggest that such similarity is not an effect of tectonic events. Instead, it is proposed that during both the Kimmeridgian and the Early Tithonian the At-Bash area was a land and was subjected to erosion and thus sediments from the Ay-Petri Massif remain *in situ* and the only displaced element is the upper complex building the karst plateau and separated from the rest of the massif by angular unconformity observed at many sites in the massif. Taking into account the concept of allochthonous origin of the Crimean Mts., the four assumptions can be proposed concerning the relationships of the Ay-Petri Massif to its basement: (i) sediments from the lowermost portion of the massif remain *in situ* whereas sediments from the uppermost portions (plateau) were overthrusted, (ii) sediments were overthrusted along a short distance (as referred in the literature) and the character of the basement was similar to that recently observed in the studied area, (iii) the immediate basement is para-allochthonous and was partly overthrusted together with overlying carbonate complexes, which preserved the primary structure of the platform, (iv) the observed relationships are purely casual. At the present stage of knowledge the problem is far from a final solution. The four hypotheses proposed above ought to be verified by more detailed sedimentological and structural investigations.

### THE YALTA MASSIF

Sedimentary successions distinguished in the Yalta Massif represent chiefly the internal platform environments. These are similarly developed in most parts of sequences and their similar facies varieties reveal significant lateral extent. These are thick- and/or thin-bedded limestones of facies variability controlled by diversified relief of the platform. Simplifying, in the northeastern part of the massif (KJ, KM and KN sections) more common are thick-bedded limestones developed as oncoidal packstone of lagoonal origin whereas in the southwestern part (KO and KP sections) sediments are developed in thin-bedded facies.

**PLATEAU OF THE YALTA AND THE AY-PETRI MASSIFS**

On the contrary to the southern walls of the Ay-Petri and the Yalta Massifs, where significant facies variability is observed, deposits forming the uppermost portions of the massifs (i.e., karstic plateau) are similarly developed (KK, KL and KD sections as well as the uppermost part of KO section). Outcrops of microfaciesly similar limestones can be examined over long distances. These sediments represent internal platform facies and contain several, cyclic, shallow-marine depositional sequences related probably to small oscillations of the sea level.

### 4.4.4. Development of deposition on carbonate platform of the Crimean Mts. in the areas of the Yalta and the Ay-Petri massifs

Studies of facies diversity and biostratigraphy enabled the author to reconstruct the sedimentation conditions and to distinguish most important stages of the evolution of the Crimean Mts. carbonate platform in the vicinity of the Yalta and the Ay-Petri massifs (Fig. 4.20). Taking into account the allochthonous character of the Crimean Mts., poor stratigraphic data and still controversial interpretation of geological structure of the area, it is difficult to prove to what extent the sediments building both the Yalta and the Ay-Petri massifs represent the carbonate platform. Simplifying so far, three principal stages of geological evolution of the Crimean Mts. platform can be distinguished: (i) first stage – Kimmeridgian-Early Tithonian, (ii) second stage – most part of the Tithonian and (iii) third stage – Late Tithonian-Early Berriasian (Fig. 4.21, cf. Bendukidze 1982, Leshukh *et al.*, 1999, Bucur, Săsăran 2005, Săsăran 2006, Ivanova *et al.*, 2008).

In various levels of most studied sequences from the Ay-Petri Massif sedimentary breccias, fenestral structures, hardgrounds and dissolutions of macrofossils were observed (Krajewski, Olszewska 2006, Krajewski 2008). It seems that many depositional sequences might have been erosionally reduced and that younger sediments might have been deposited onto various members of older sequences. Undoubtedly, there were several emergence episodes but their duration is difficult to estimate. In some cases precise definition of boundaries of particular sequences is complex due to hardly accessible exposures and poor macroscopic variability of massive limestones. In the reefs strong cementation of various rocks took place under shallow-marine conditions, at high flow rates and low deposition rates. As a result of all these processes, a huge monolith of massive limestones has formed, subsequently sculptured by erosion into the recent Yalta and Ay-Petri massifs.

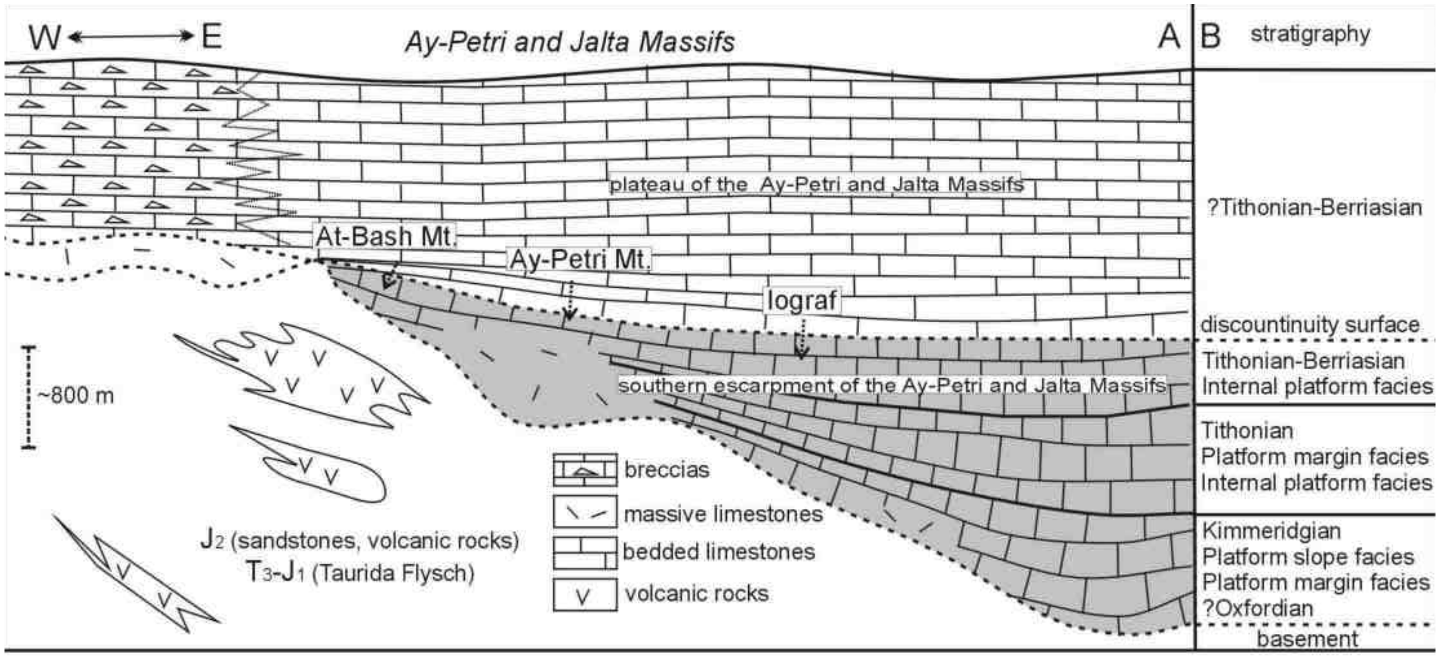



**Fig. 4.20.** A – Simplified model which shows present position of the Upper Jurassic-Lower Cretaceous Yalta and Ay-Petri Massifs in relationship to morphology of the bed-rock, after Muratov 1960, simplified and modified, not to scale. B – Simplified stratigraphic position of the sediments from the present area. Some of the rocks complexes from the Yalta Massif maybe tectonic disturbed and do not fit to the stratigraphic succesion presented in the model. In gray, sedimentary sequences which forms the main southern escarpment of the massifspresented in this paper. Thickness of the studied interval (shaded in gray) gradually decreasfrom the ~800 m at the Yalta and Ay-Petri Massif to ~200 at the At-Bash Mountain. Farther to the west sediments of the study tectonic unit are thinning out, cf. Yudin 2008

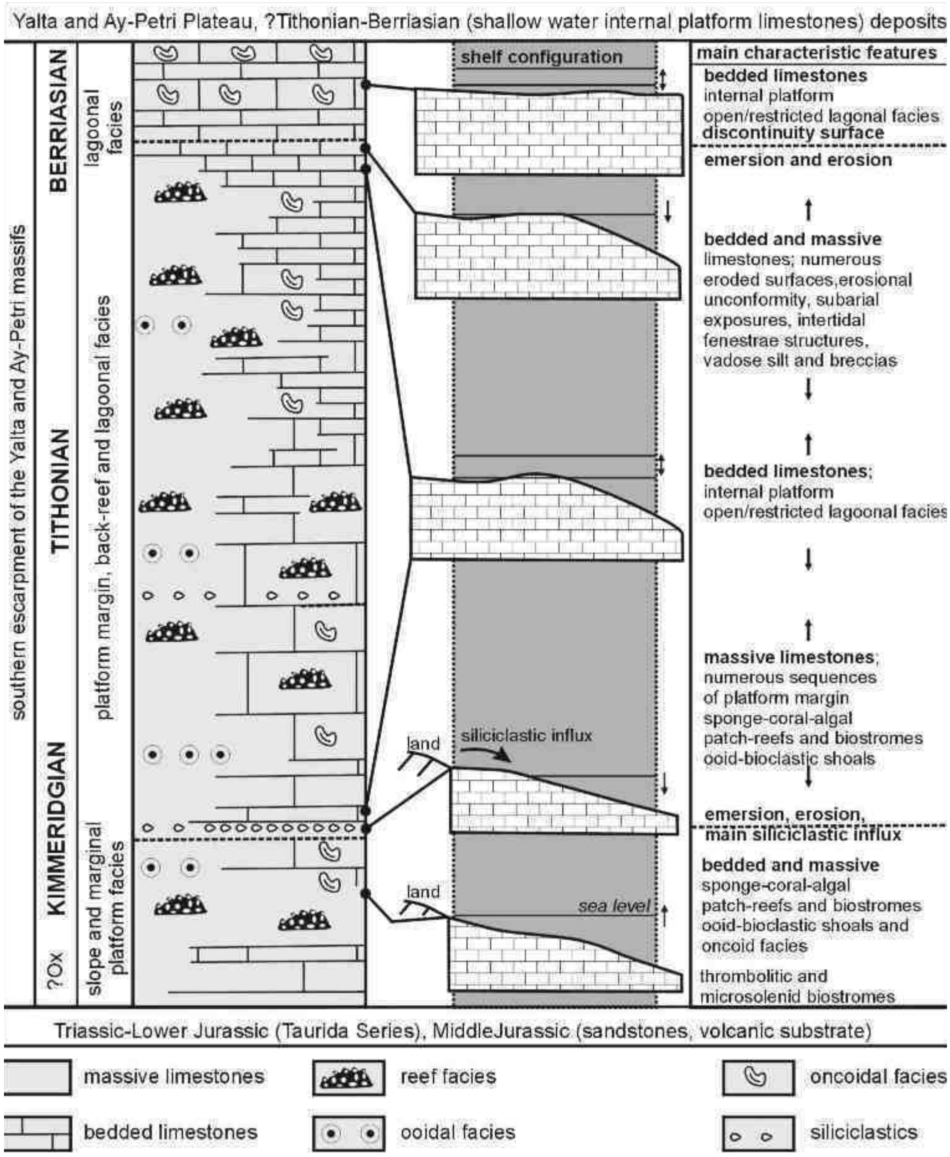



**Fig. 4.21.** The simplified model with sedimentary succession of the main stages of development of Crimean carbonate platform in study area of the Yalta and Ay-Petri massifs

All sediments encountered in the Yalta and the Ay-Petri massifs are products of shallow-marine deposition in various environments related to succeeding evolution stages of the Crimean Mts carbonate platform, from platform slope to platform margin reefs and ooid bars, back-reef, lagoonal and intertidal. Total thickness of sediments at the final stage of this evolution (before tectonic movements forming the allochthonous series of the Crimean Mts.) was probably less than about 1000 meters. Much higher present thicknesses observed in some parts of carbonate massifs perhaps are the effect of tectonic stacking of strata. The studied sediments of the Yalta and the Ay-Petri massifs rest unconformably upon the Middle Jurassic sediments and the Taurid flysch (Triassic-Lower Jurassic). In the top surface the studied sediments contact the Tithonian and Berriasian strata, which perhaps belong to other tectonic blocks (Yudin, 2008).

**(i) The Kimmeridgian-Early Tithonian stage**

The oldest, Kimmeridgian sediments are genetically related to the gentle slope of the platform, just forming at the continental margin (Fig. 4.21). Initially, the sediments were mostly *Microsolena*-microbial boundstones, thrombolitic-*Crescentiella* bindstones and bioclastic wackestones, which may indicate more deeper (microbial-sponge) or more shallower environments with increased trophic characteristics related to the influence of the adjacent land. Moreover, the *Crescentiella* microframeworks observed in the sequences are also related to the platform slope (Schlagintweit, Gawlick 2008). Up the sequences the above discussed facies grade at short distance into shallow, subtidal ones represented by sponge-coral-algal biostromes and patch-reefs with fossil assemblage typical of shallow-marine environments, and with siliciclastic horizons. These horizons observed in many parts of the massif close the first stage of platform evolution. Their wide distribution in the study area reflects regional changes in depositonal environments presumably related to tectonic movements, fall of sea level and climatic fluctuations (e.g. Strasser *et al*., 1999, Flügel 2004).

**(ii) The Tithonian stage**

This stage of platform evolution is represented by deposits laid down on the upper slope, reef-front, back-reef and in the lagoon, all resulting from the Tithonian transgression (Fig. 4.21). This is the period of full development of the platform and strong facies diversification, from various facies related to sponge, coral, algal, microbial bioconstructions, ooidal-bioclastic shoals representing the platform margin facies up to internal-platform oncoidal packstones, bioclastic wackestones and fenestral mudstones-bindstones. The sediments were deposited in shallow subtidal environments affected to bathymetric changes. Numerous erosional deposits, hardgrounds and borings indicate common deposition breaks whereas many horizons reflect changeable sedimentation, which points out to mobile character of the platform and common bathymetric changes. At this stage no significant influence of adjacent land was observed.

**(iii) The Late Tithonian-Early Berriasian stage**

The last evolution stage of the platform is dominated by internal platform facies and significant reduction of carbonate buildup growth. Instead, the buildups were subjected to common emergences and erosion. Sediments deposited at this stage represent several facies varieties of limestones; their origin was controlled by diversified morphology of the internal platform (Fig. 4.21). Usually, the buildups are scattered patch-reefs and sponge-coral meadows. Sometimes, siliciclastic deposits appear, supplied from emerged and eroded land. A part of older, larger carbonate buildups, e.g. the Ay-Petri reef, were emerged and subjected to erosion. Facies varieties are mostly mudstones-wackestones with numerous foraminifers rudists and gastropods, oncoidal packstones-rudstones and sponge-coral floatstones. In the study area carbonate sedimentation ceased perhaps in the Early Cretaceous due to Cimmerian orogenic movements followed by the formation of allochthonous Crimean Mts (e.g., Millev *et al*., 1995, 2006, Yudin 2000, 2006, Afanasenkov *et al*., 2007).

## 4.5. Selected aspects of development and evolution of carbonate platform deposition in the Crimean Mts

### 4.5.1. General remarks

Results of microfacies studies combined with controversial geological structure of the Crimean Mts. rise a number of questions concerning the influence of stratigraphy, facies development and tectonic controls on recent facies distribution, paleogeography and others (e.g., Popadyuk, Smirnov 1996, Gintov, Borisenko 1999, Yudin 1999a, b, Millev, Baraboskhin 1999, Afanasenkov *et al*., 2007, and many others).

Studies completed up to date by the author, including the results of microfacies analysis, provide a general recognition of microfacies development of Upper Jurassic-Lowermost Cretaceous sediments of the Crimean Mts. in their small but important fragment – the Ay-Petri and the Yalta massifs. Important difficulty is the geological structure of the Crimean Mts., which is still unknown in details, disputable and contradictorily interpreted by various authors. One of the basic questions is: does the Crimean Mts. rest *in situ* or were overthrusted as a whole? Although as early as at the beginning of the XXth century the allochthonous structure of the Crimean Mts. was proposed, at the end of that century most of the authors advocated the hypothesis that both the Upper Jurassic and the Lower Cretaceous sediments rest *in situ* and are stratigraphically continuous. Recently, most geologists support the allochthonous origin of the Crimean Mts. but substantial controversies exist concerning the direction of overthrusting, amount of tectonic transport and its mechanism (e.g., Popadyuk, Smirnov 1996, Yudin 1999a, b, Millev, Baraboskhin 1999, Afanasenkov *et al*., 2007). Moreover, the problem has been raised whether all parts of the massifs built of Upper Jurassic carbonates were overthrusted. It is possible that some of these parts remain *in situ* because logical stratigraphic and lithologic successions were observed, even if locally disturbed by fault tectonics. Another question is: are significant thicknesses of sediments observed in most part of study area the effects of tectonic repetition (e.g. Millev, Baraboskhin 1999) of the same depositional sequences? And the next problem: what are the mutual relationships of particular massifs of the Crimean Mts. and which are isolated tectonic blocks of different morphology, lithology and stratigraphy? Unfortunately, the analysis of available literature does not help very much because in most publications basic data on location of observations and on collected materials are only very general, thus, difficult to be verified (e.g., Leshukh *et al.*, 1999). Moreover, these data are partly citations of even older papers, which were based on materials now mostly inaccessible. Recent studies may provide at least partial solutions of this problem. Apart from basic geological questions, another important issue is the necessity of new sedimentological studies based upon microfacies analysis and extension of limited knowledge of microfacies development of Upper Jurassic and Lower Cretaceous carbonate complexes in the Crimean Mts.

### 4.5.2. Stratigraphic problems of the Yalta and the Ay-Petri massifs

Analysis of foraminifer assemblages together with observations of facies and microfacies diversity of sediments lead to suggestion that most of studied sediments represent time span from the Kimmeridgian through the Tithonian to the Earliest Berriasian (e.g. Millev, Baraboskhin 1999, Krajewski, Olszewska 2007). Hence, stratigraphic data presented in some publications (e.g., Permyakov *et al.*, 1991 1993, Leshukh *et al.*, 1999, Dorotyak 2006, 2007, Anikeyeva, Zhabina 2009), which suggested the Oxfordian age of these strata cannot be supported by the author. Due to the absence of ammonite fauna, the age determinations were based only upon foraminifers and are not precise (e.g., Kuznetsova, Gorbachik 1985, Krajewski, Olszewska 2007, Dorotyak 2007, Anikeyeva, Zhabina 2009). Consequently, it is difficult to estimate how much Kimmeridgian and Berriasian deposits were preserved in particular areas. Undoubtedly, the main part of studied sediments belongs to the Tithonian. Most of them were deposited in shallow-marine environments where even minor bathymetric changes might have stopped deposition and triggered erosion. This may result in the presence of stratigraphic gaps.

Recently observed sequence of carbonate platform sediments of the Crimean Mts. in the range of the Yalta and the Ay-Petri massifs is perhaps partly tectonically disturbed (e.g. Millev, Baraboskhin 1999, Yudin 1999a, b, cf. Gintov, Borisenko 1999). The overthrusting might have resulted in repetition of particular successions, which impedes recognition of stratigraphy in the studied parts of the Crimean Mts. and implies the necessity of detailed tectonic analysis. As the tectonic features are commonly poorly recognizable in the field, it is not surprising that in both the older and in some recent publications thicknesses of sediments were quoted to be about 2–3 kilometers (Muratov 1973, Leshukh *et al*., 1999, Dorotyak 2006). In author's opinion the true thickness of these strata does not exceed ~1000 meters (see also Millev, Baraboskhin 1999, Yudin 2006), as observed, e.g., in massive limestones of the Ay-Petri Mt. which is a single tectonic block (Yudin 2008). Good example of tectonics-controlled disturbances in stratigraphic continuity of studied sediments is the sequence of the Iograf Ridge (Millev, Baraboskhin 1999, V. Yudin pers. comm.). It must be emphasized that the stratotype representative of the whole Yalta Series was based on the Iograf Ridge (e.g., Leshukh *et al*., 1999, cf. Millev, Baraboskhin 1999, Krajewski, Olszewska 2007). In the lowermost parts of this sequence the oldest, Kimmeridgian and Tithonian sediments occur. In the upper portion of the sequence, within the thin-bedded limestones the ammonite assemblage was found indicative of the Kimmeridgian and the Tithonian (Oviechkin 1956, Leshukh *et al*., 1999, cf. Rogov *et al*., 2005). It is possible that the "classic" stratigraphy of the area, in which the age of underlying sediments was determined as the Oxfordian or even the Callovian, has resulted from comparison with other successions in the Crimean Mts. located at the same elevations a.s.l. and from the presence of sediments dated with ammonite fauna in the upper parts of the Iograf Ridge (Oviechkin 1956, Leshukh *et al*., 1999, Dorotyak 2006, 2007, cf. Rogov *et al*., 2005). In fact, some papers provide lists of ammonites documenting the existence of older sediments but it must be emphasized that these papers lack the relevant illustrations and locations of sampling sites, and that the specimens are only partly available, which precludes the verification of data (e.g., Leshukh *et al*., 1999). Moreover, the most commonly published lists of ammonites are compiled from the older papers, in which factual details are absent (M. Rogov, pers. comm.). Also analysis of available literature does not provide easy solution. The ambiguity of stratigraphic position of the Ay-Petri sediments, confirmed by this study, has already been proven by many earlier stratigraphic investigations in the Crimean Mts., in which sediments from the Yalta and the Ay-Petri massifs were determined as Tithonian and where the opinions expressed in older stratigraphic publications were questioned (e.g., Kuznetsova, Gorbachik 1985, Millev, Baraboskhin 1999).

### 4.5.3. Remarks on the structure of reefs – examples from the Ay-Petri reef complex

In the recent morphology of the Crimean Mts. the Ay-Petri reef complex forms a huge, homogeneous block of non-porous massive limestones commonly described in the literature as a vast, "classic" coral reef (e.g., Muratov 1973, Peremyakov 1984, Yudin 2006, and many others). Horizontally, the reef complex grades into thin- and thick-bedded limestones of back-reef and lagoonal facies (Fig. 4.12). The size of the Ay-Petri complex and the concept that it was built mostly of corals implies its comparison to recent coral reefs (e.g. Muratov 1973, Permyakov 1984, Leshukh *et al*., 1999, Dulub *et al*., 1985, Dorotyak 2006). However, basing upon the results of microfacies analysis, it is clear that the complex includes several, faciesly diversified horizons, which represent ooidal barriers and small, shallow-marine patch-reefs and biostromes formed mostly by sponges, algae, corals, microbialites and microencrusters (Krajewski, Olszewska 2005, 2006, Krajewski 2008). These organisms built a stripe of scattered carbonate buildups between which detrital sediments were laid down. The buildups grew mainly in shallow subtidal environments, under various conditions controlled by depth, deposition rate and trophic regime. Most of these buildups show gentle relief controlled by accomodations space and permanent emergences. Detrital sediments deposited between the buildups were binded mostly by microbialites, microencrusters and by early-diagenetic cementations under phreatic conditions. As a result, both the biolithites and the grainstones were quickly lithified and now these rocks resemble homogeneous, massive limestones. Deposition of such sediments has presumably lasted quite long, being controlled by subsidence rate and deepening of the basin. As a result, a complex of massive limestones, several hudred meters thick, was formed. Later tectonic movements and erosion exhumed large part of the complex as a large, seemingly homogeneous body. Probably, similar scheme is valid also for the Caucasus Mts., from which comparable, thick reef complexes were described (e.g., Bendukidze 1982). Taking into accout these facts, it is concluded that the Ay-Petri reef consists of a number of small patch-reefs and early-cemented grainstones; their deposition was controlled by bathymetric changes. Results of microfacies analysis evidence that the interpretation of the Ay-Petri Mt. as a coral reef is misleading because although corals are common fossils in the Ay-Petri limestones, other reef-builders are more abundant (Krajewski 2008, Anikeyeva, Zhabina 2009).

Corals: Microsolenidae, Latomeandridae, Thamnasteriidae, Montlivaltiidae, Stylinidae and Cladophylliidae were identified in thick-bedded limestones in the KJ section, and in massive limestones of the KA, KB, KC and KR sections. In the remaining sequences corals are common only in some specific horizons composed of wackestones, packstones, and biolithites associated with microbialites and microencrusters. In the massive limestones from the Ay-Petri reef complex corals are less frequent that other reef-builders: sponges, microbialites and microencrusters, although they still contribute to the growth of bioconstructions together with other organisms. This conclusion was somewhat surprising to the author because in the literature the Ay-Petri Massif was usually described as a typical example of coral reef, although sedimentological details were not satisfactorily presented. Moreover, abundant assemblage of corals was described from the adjacent parts of the Crimean Mts. (e.g. Sudak area) and also from the Caucasus Mts., which seemed to support the predominance of coral-related facies in formation of carbonate buildups in both regions (e.g., Bendukidze 1982). Particularly, studies in the Caucasus Mts. provided abundant data on corals, which formed vast reef complexes extending from the Caucasus towards the Crimean Peninsula (e.g., Muratov 1960, 1973, Bendukidze 1982, Permyakov 1984, Leshukh *et al.*, 1999, Afanasenkov *et al.*, 2007, and others). Moreover, the coral assemblage as well as the types of carbonate buildups and facies relationships recognized in the Caucasus Mts. resemble those observed in the Crimean reefs. Therefore, the fact that in sediments commonly accepted as coral facies corals are less common that other reef-builders needs some general comments.

Corals are most abundant in the KJ section, but only at some specific levels. In the lower part of the sequence corals are frequent and form biostromes in which Microsolenidae were identified, i.e. corals typical of somewhat deeper or more trophic depositional environment (e.g., Insalco 1996, Lathuiliére *et al.*, 2005, Morycowa, Roniewicz 2005, Roniewicz 2008). Higher up in the section, corals occur in thick-bedded limestones where horizons with numerous *Stylosmilia* were encountered. Abundant benthic fossils suggest the presence of biostromes, however microscopic observations proved that these are transported fragments of corals embedded in the carbonate mud.

In the massive limestones distribution of corals is different. Similarly to the KJ, in the KB and KC sections biostromes dominated by *Microsolena* occur in the lower part of both sections. Above, coral patch-reefs were sometimes encountered but usually corals build patch-reefs and biostromes together with other reef-builders. Moreover, coral fragments were found in grainstones. Hence, contrary to data from the literature, it is concluded that corals, although common, are not the main reef-builders in the Ay-Petri massive limestones (e.g., Muratov 1973, Permyakov 1984, Leshukh *et al.*, 1999, cf. Krajewski, Olszewska 2006, Krajewski 2008).

The questions arise how to explain the fact that in this study corals were encountered rarely in comparison with the literature and what could be expected from initial macroscopic observations of strata in which macrofossils were common? The location of investigated sequences was preceded by macroscopic field observations and analysis of literature, in order to find sequences representative of the Yalta and the Ay-Petri massifs, i.e. such that comprise extremely diversified sediments. Certainly, the sections were located at sites where coral facies should be the most common, i.e., in the massive limestones representing the carbonate buildups as well as in the thick-bedded limestones commonly forming biostromes. In the massive limestones frequent process is the dissolution of skeletons and their replacement by the cement. However, the preserved relics of primary internal structures compared with those of the other organisms and their morphology enable the author to conclude that relics left after dissolved skeletons only partly belong to corals and, more often, represent other organisms i.e., sponges, which are evidently more common in the studied sediments.

The results of following studies revealed the presence of several, shallow-marine depositional sequences in massive limestones: from shallow, subtidal to intertidal and supratidal, with frequently encountered traces of intensive erosion, terrestrial influences, siliciclastic beds and numerous emergences. Results of microfacies analysis enabled the author to suggest that abundant occurrence of corals is related to more deeper environments of moderate-energy but still within the photic zone. In the studied sequences gradations were commonly observed along short distances from relatively deeper or shallower, but still more trophic, deposition to extremely shallow one. In such a narrow interval maximum quantities of corals were observed. Usually, above facies rich in corals the sediments were observed with numerous algae, sometimes with siliciclastics and detrital sediments representative of ooidal barriers, as well as breccias and intraclasts typical of abrasional environment. Consequently, it is supposed that the "coral window" optimal for growth of corals was limited to relatively narrow time intervals. Microfacies development of the Ay-Petri massive limestones indicates mostly the shallow and abrasional environments, probable unfavourable for the growth of the reef-forming corals.

The results of studies allow the author to conclude that coral facies appear to be less common in the study area than it was described in the literature (e.g., Muratov 1973, Leshukh *et al.*, 1999). It can be explained by the results of studies run in other regions. Characterization of Jurassic corals demonstrated that these organisms had different ecological preferences than recent reef corals, to which comparisons are made (see Roniewicz 2004, 2008). The recent reef-building corals reveal high degree of integration of individual polyps within the colony and high regeneration abilities whereas the Jurassic corals were mostly pseudocolonial or non-colonial organisms growing chiefly in low-energy environments with low bioerosion, as revealed by matrix sediments. In the case of patch-reefs, in their vicinity usually micrite, wackestones or packstones are observed, which fill the interskeletal spaces and indicate deposition under low-energy conditions. Some skeletons do not contain epifauna or such organisms grow only onto the uppermost parts of skeletons, which may evidence partial burial of skeletal material within the sediments. Jurassic corals occur mostly in single beds or as skeletal fragments scattered within detrital sediments, and only occasionally form small buildups, from which typical reef taluses are absent. Recent corals grow mainly in waters of higher agitation, under oligotrophic conditions and show high regenerative potential. On the contrary, Jurassic corals had low regenerative potential for mechanical destruction. Usually, Jurassic corals formed coral meadows in the photic zone but below or outside the areas of high water energy (e.g., Roniewicz 2004, 2008, Lathuiliére *et al.*, 2005). Their growth forms and hosting sediments indicate low to moderate hydrodynamic conditions, only temporary grading into higher water agitation.

Summing up, it is suggested that in the study area more abundant growth of corals was limited to specific intervals because during evolution of the basin conditions unfavourable for such organisms prevailed. It seems that an important factor limiting the growth of corals under optimal, oligotrophic, moderate-energy conditions was the proximity of land, strongly affecting the environment conditions. Moreover, common abrasional processes and permanent emergences also hampered the growth of corals.

### 4.5.4. The role of selected microencrusters as important reef-builders

Microencrusters were observed in most of studied sequences. These organisms are common in carbonate buildups of massive limestones and thick-bedded limestones represented by oncoidal packstones-rudstones as well as sponge and coral floatstones. In some parts of the sections microencrusters are important microframework builders, hence, these are crucial rock-forming organisms. In last years microencrusters and their environmental preferences were described from Jurassic and Cretaceous sediments from various areas (e.g., Leinfelder *et al*., 1996, Schmid 1995, 1996, Dupraz, Strasser 1999, Shirashi, Kano 2004, Matyszkiewicz, Słomka 2004, Cherchi, Schroeder 2006, Schlagintweit, Gawlick 2008, Senowbari-Daryan *et al*., 2008, Rameil *et al*., 2010 and many others). Simultaneously, these numerous publications demonstrate that microencrusters are still one of the most enigmatic and controversial groups of organisms. On the other hand, their abundance in Jurassic and Cretaceous strata makes their detailed characterization one of the leading research problems of Upper Jurassic and Lower Cretaceous sediments. Commonly, microencrusters are among the most important inhabitants of carbonate buildups and, with the progress in studies of Jurassic and Cretaceous systems, these organisms appear to be still more important reef-builders in comparison to traditional "bioconstructors", as e.g sponges or corals (e.g., Ourribane *et al*., 2000, Krajewski 2008, Schlagintweit, Gawlick 2008, Rameil *et al*., 2010). Microencrusters are also important for paleoecology, particularly if the other organisms indicative of depositional environments are absent or rare (Leinfelder *et al*. 1996, Schmid 1996). Usually, microencrusters occur in associations ascribed to specific depositional environments. In the studied se-diments microencrusters associations are particularly important for characterization of sedimentation conditions due to often controversial depositional environments. Among numerous microencrusters found in the studied sediments the most abundant are: *Lithocodium aggregatum*, *Bacinella irregularis*, *Thaumatoporella parvovesiculifera* and *Crescentiella morronensis* (*„Tubiphytes"*, Senowbari-Daryan *et al*. 2008), thus, special attention was paid to these species.

***Lithocodium aggregatum***

In the studied limestones of the Ay-Petri Massif *Lithocodium aggregatum* is very common, but it is particularly abundant in massive limestones and less frequent in thick- and medium-bedded limestones surrounding the reefs. On the contrary, in sediments from the Yalta Massif *Lithocodium* was rarely observed so far. *Lithocodium* lived in various sedimentary environments. In massive limestones, which are fragments of carbonate buildups, *Lithocodium* usually grew immediately onto the outer surfaces of sponges or corals as thin but extended crusts covering significant parts of skeletons (e.g., Tab. 4.67A) Moreover, it grew also onto other, hard elements deposited at the sea floor, e.g., bivalve shells. In some parts of the massifs *Bacinella-Lithocodium* oncoids are common; normally there were growing in the back-reef or open lagoon. Sometimes, *Lithocodium* contributed to lithification of fossil skeletons (Tab. 4.67A).

Recent, *Lithocodium aggregatum* inhabitates oligotrophic, shallow, reef and lagoonal environments of normal salinity and moderate or high energy of waters (e.g., Schmid, Leinfelder 1996, Schmid 1996, Dupraz, Strasser 1999, Rameil *et al*., 2010). Studies revealed that sediments were laid down in shallow-marine environments, at depths rarely exceeding a dozen or so of meters, usually even less. The predominance of forms developed as thin crusts on skeletal fragments allows the author to suggest that periods optimal for the growth of *Lithocodium aggregatum* were relatively short and were followed by intensive expansion of microbialites or other microencrusters, e.g. *Bacinella irregularis* or *Crescentiella morronensis* living in similarly shallow but more mesotrophic environments. It seems that important controlling factor was deposition rate. Occassionally, *Lithocodium* grew only onto the upper parts of skeletons whereas the interskeletal spaces were filled exclusively with detrital sediments, which indicates that development of some macroorganisms was probably controlled by deposition rates, limiting the chance for microencruster growth (cf. Rameil *et al*., 2010).

***Thaumatoporella parvovesiculifera***

Another important microencruster is green alga *Thaumatoporella parvovesiculifera* regarded as an indicator of shallow, subtidal, oligotrophic conditions (e.g., Schmid 1996, Leinfelder *et al*., 1996, e.g., Tab. 4.67C, D). In studied sediments *Thaumatoporella parvovesiculifera* was observed only in the Ay-Petri massive limestones, practically exclusively in sponge-algal-coral patch-reefs and biostromes. Most commonly it forms characteristic binds connecting the adjacent skeletal fragments (both remaining *in situ* and displaced), which stabilizes the skeleton (Krajewski 2008). Spaces between *Thaumatoporella* individuals are filled geopetally with fine sediments or by *Bacinella* and *Crescentiella.*

***Bacinella irregularis***

In sediments of the Yalta and the Ay-Petri massifs the most important and most widespread microencruster is cyanobacteria *Bacinella irregularis* (e.g. Tab. 67B). It was found in various sediments representing platform slope, margin reefs, back-reef and lagoonal environments, and it contributed significantly to the binding of sediment components. In reefs and biostromes, where skeletons are densly packed, *Bacinella irregularis* closely fills the interskeletal spaces, which binds and stabilizes the framework. In these parts of buildups where macrofossils are less effectively binded by microencrusters the skeletal fragments are more often displaced and damaged. Another examples of important role played by miroencrusters is the binding of clastic framework. In both the massive and the thick-bedded limestones the grainstones are one of the most common microfacies varieties, similarly to biolithites composed mostly of thrombolites and stromatolites, which bind together grainstones and contribute to the development of bindstones. *Bacinella irregularis* binds the framework by filling the intergranular spaces and *Bacinella*-microbial bindstones commonly form stable basement suitable for settlement by other benthic organisms. Moreover, *Bacinella irregularis* is commonly observed as large oncoids.

***Crescentiella morronensis***

*Crescentiella morronensis* ("Tubiphytes" Senowbari-Daryan *et al*., 2008 e.g. Tab. 4.68), together with *Bacinella irregularis* are the most widespread microencrusters in studied limestones. It occurs in somewhat deeper environments where it forms *Microsolena*-sponge-microbial biostromes or floatstones as well as in shallow subtidal ones, in which *Crescentiella morronensis,* is common in the lower parts of skeletons, growing under more cryptic conditions (Fig. 12E, 39D, E, 67E). Similarly to *Bacinella irregularis*, it contributes to binding and stabilization of the framework (e.g., Schmid 1996, Krajewski 2008, Schlagintweit, Gawlick 2008). Moreover, in the KJ, KB and KC section some sediments are composed mostly of *Crescentiella morronensis*. The particular importance is *Crescentiella* which grows in "colonies", over a dozen of centimeters in diameter, forming *Crescentiella*-microbial-cement microframework (Krajewski 2008, Schlagintweit*,* Gawlik 2008, Senowbari-Daryan *et al*., 2008, Tab. 4.68). Size of single forms may reach 1 centimeter across. Most of such forms are elongated and thin. Spaces between *Crescentiella* are usually about a few millimeters long and are occupied by microbial peloids, thrombolites or cement. Both large and small forms of the organism are observed representing various stages of development. Moreover, in peloidal matrix tubes are observed, which resemble chambers of *Crescientella*. Such forms may be referred to recently described, enigmatic, tube-like organisms of unknow systematic position (see Schlaginweit*,* Gawlik 2009). Depositional environment of cement-microencruster boundstones is currently linked to the upper fore-reef slope, between coral-sponge patch-reefs and microsolenid floatstones. Such model fits well to observations made in the KB and KC sections where similar forms occur. In the recent literature the genesis of *Crescentiella morronensis* is a matter of discussion (e.g., Schlagintweit, Gawlik 2008, Senowbari-Daryan *et al*., 2008). The organism is interpreted as symbiotic between cyanobacteria and foraminifers, and shows tubular structure.

Summing up, in studied reef limestones of the Yalta and the Ay-Petri massifs microencrusters are common constituents of both the massive and the thick-bedded limestones but are practically absent from the thin-bedded carbonates (despite some exceptions). Microencrusters occur in a variety of forms and proportions, which:

- encrust hard skeletal fragments of macrofossils filling the interskeletal spaces and contributing to their binding,
- together with microbialites bind wackestones and grainstones, sometimes filling the intergranular spaces,
- participate in formation of large oncoids,
- form microframework.

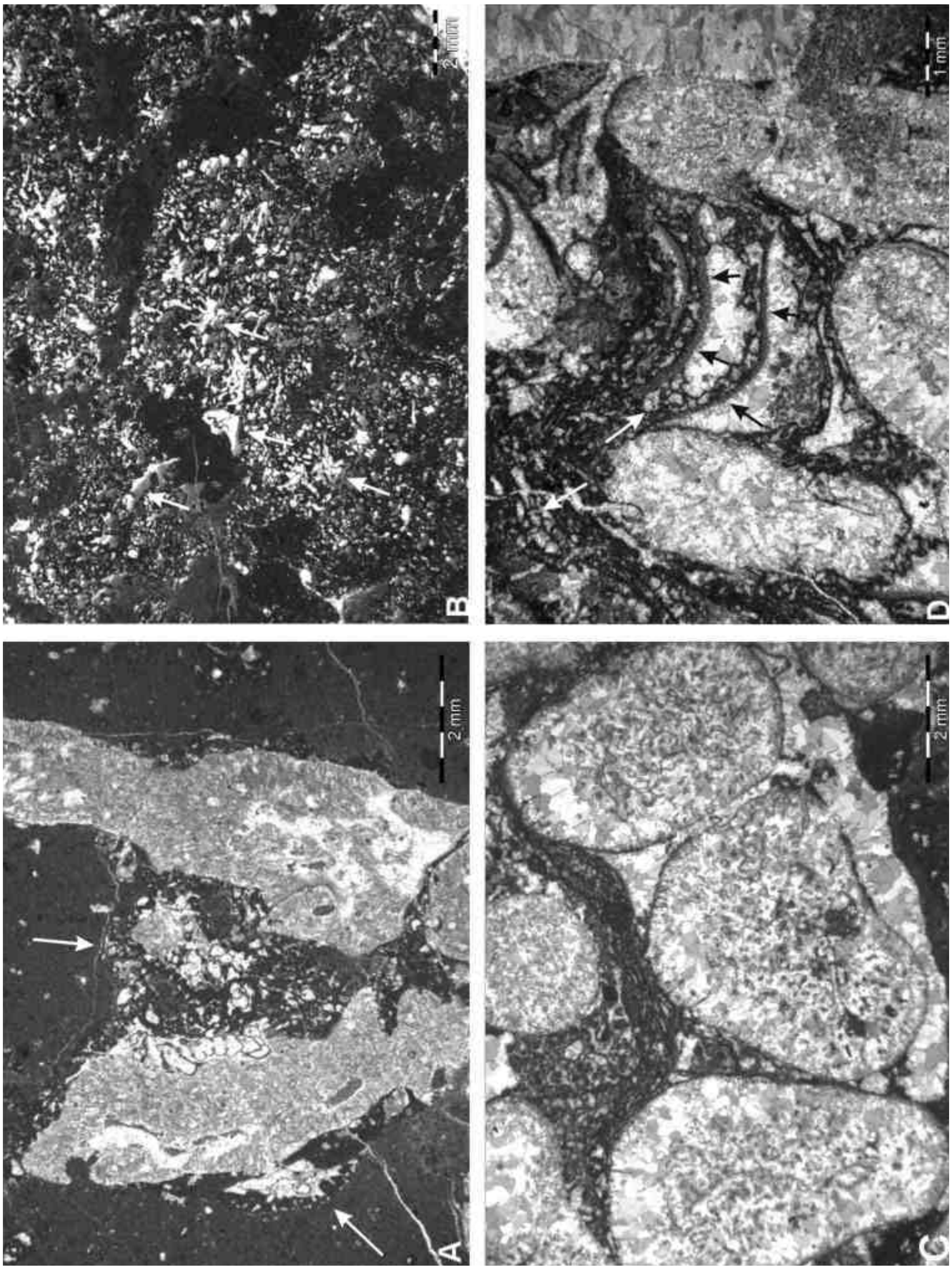

A
2 mm
B
2 mm
C
2 mm
D
1 mm

**Table 4.67.** Examples of the microincrusters from massive and thick bedded limestones of the Ay-Petri Massif

A – *Cladocoropsis* floatstone. Individual segments of the skeletons are lithified by consortium of *Lithocodium aggregatum-Troglotella incrustans* (white arrows), sample KD 12 e

B – *Bacinella*-microbial bindstone with geopetal internal infillings (white arrows), sample KE 7

C, D – dissolved skeletons of the macroorganisms. Among skeletons numerous binding filaments with *Thaumatoporella parvovesiculifera* green algae and *Bacinella irregularis* samples KB 51h, KB 7f

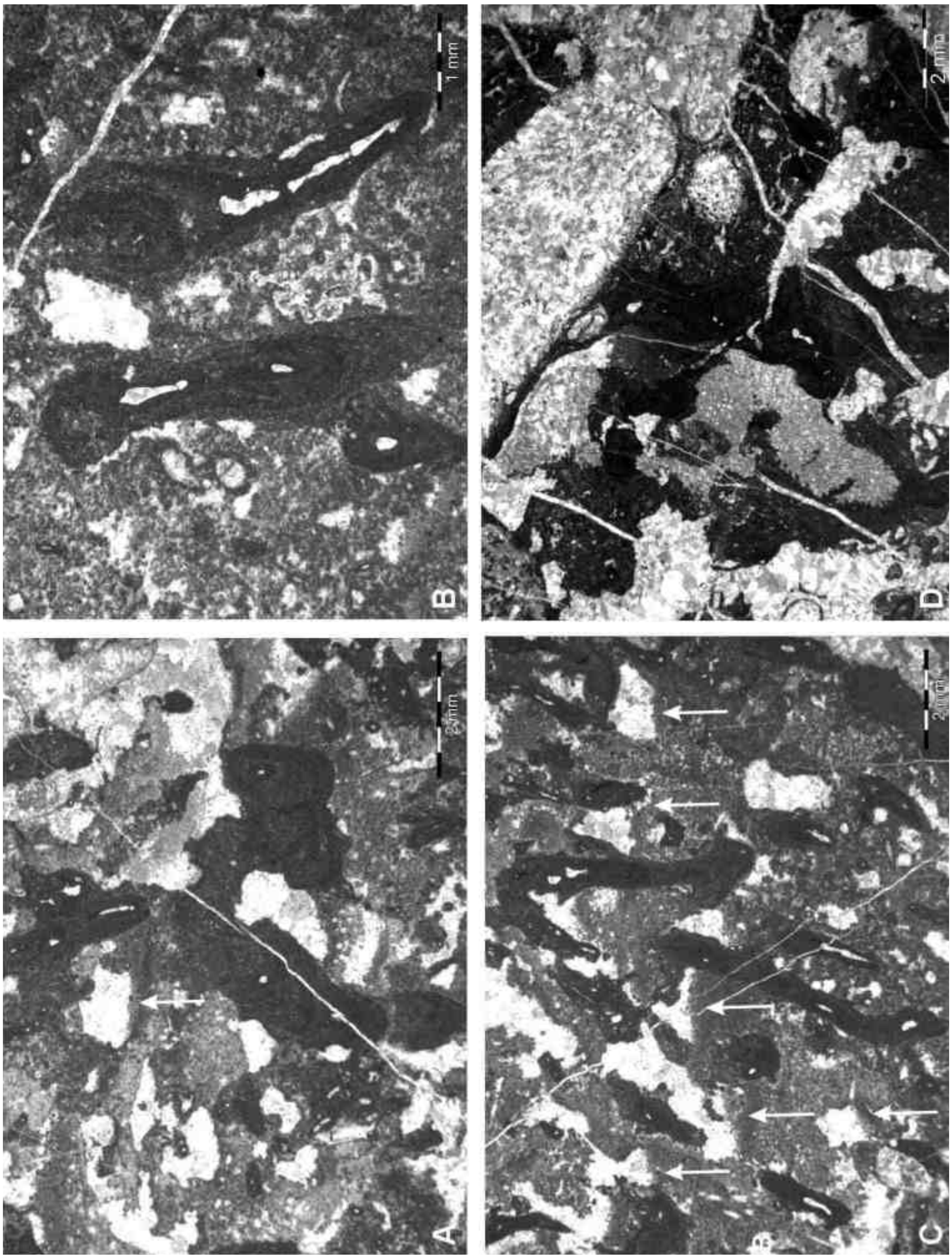

A
B
C
D
1 mm
2 mm
2 mm
2 mm

**Table 4.68.** Examples of the microencrusters from the Ay-Petri Massif, Ay-Petri reef, massive limestones

A, C – microframework composed of numerous *Crescientella moronensis* („*Tubiphytes*", Senowbari-Daryan *et al*., 2008) and matrix consist of microbial peloids, microbialites and cements. Common small caverns with geopetal infillings are visible (white arrows), sample KC 7 F, KC 7e

B – *Crescientella moronensis* with well visible internal structure, sample KC 7d

D – fragment of the sponge-coral patch reef; among dissolved macroorganisms numerous fragments of *Crescientella* (C) contribute to binding of the framework, sample KB 38l

### 4.5.5. Remarks on the reefs complexes from the Crimean Peninsula and the Caucasus Mts

Massive reef limestones and their development, stratigraphy, origin and paleogeographic position are still poorly known (e.g., Muratov 1973, Dulub *et al.* 1985, Arkad'ev, Bugrova 1999, Leshukh *et al.*, 1999, Krajewski, Olszewska 2006, Krajewski 2008). The origin of the Ay-Petri reef complex is difficult to explain due to possibility of the allochthonous structure of the Crimean Mts. However, the presence of such a large reef complex, which is the geological rarity in the Crimean Mts., inevitably raises the genetic discussion. Considering both the complicated structure and still controversial geological history of the Crimean Mts., various concepts can be proposed. Facies diversity of carbonate platforms usually results from various factors including the syndepositional tectonics and/or the basement structure (e.g., Flügel 2004, Matyszkiewicz *et al.*, 2006).

Studies on Upper Jurassic sediments of the Crimean Mts. have initiated the search for identical or similar structures in the adjacent areas. Analysis of available literature leads to the conclusion that areas where such structures may occur are the Caucasus Mts., which reveal some similarities of geological structure to the Crimean Mts (Bendukidze 1982, Afanasenkov *et al.*, 2005, 2007, Krajewski 2008, Guo, Vincent 2009). In the Caucasus thick, faciesly diversified carbonate complexes occur, ranging in age from the Callovian to the Lower Cretaceous. Also, in the Caucasus studies were carried on corals and their role in the formation of coral-algal reefs (Bendukidze 1982). In the sediments both the small bioherms, biostromes and larger reefs are present. The buildups were investigated with special attention paid to the coral fauna but results of microfacies observations have not been published, as yet, and the internal structure of the reefs as well as other organisms inhabitating the environment still remains poorly known (Bendukidze 1982).

Simplifying, there are several, most important data concerning the development of carbonate buildups in the Caucasus Mts. and in the Crimean Peninsula but future paleogeographic studies must involve newly developed concepts of geological evolution of the regions, often substabtially different from the older ideas.

In the Caucasus area the barrier reefs are scattered along the margins of the geosynclinal Great Caucasus Trough (e.g., Bendukidze 1982, Nikishin *et al.*, 1998, Afanasenkov *et al.*, 2005, 2007). The northern reef stripe occupies the southern edge of the Scythian Platform behind which vast lagoonal facies were deposited. Similar pattern was observed along the southern edge of the Great Caucasus Trough (Bendukidze 1982). The age of coral reefs was determined as the Late Oxfordian, Kimmeridgian and Early Tithonian. Earlier, in the Late Callovian and the Early Oxfordian, the microbial-sponge buildups have developed, typical of the northen margins of the Tethys Ocean (e.g. Leinfelder *et al.*, 1996, Matyszkiewicz 1997).

Maximum development of reefs took place in the Kimmeridgian whereas the Tithonian was dominated by lagoonal facies and the reef growth was gradually ceasing (Bendukidze 1982). Recently, the Caucasian Upper Jurassic complexes underwent tectonic disturbances, probably similarly to the Crimean ones.

Three sub-formations were distinguished in carbonate buildups, depending on their paleogeographic position. The first includes buildups developed in the Great Caucasus Trough basin, the second embraces barrier reefs rimming the margins of the geosyncline and the third comprises buildups occupying vast, epicontinental lagoons behind the barrier reefs.

In the lagoonal environments large reef complexes are rare and include succeeding development stages of Microsolenidae biostromes, which formed the basement of the reefs, followed by atol reefs from which corals *Stylina, Heliocoenia, Thecosmilia, Isastraea, Calamophylliopsis* and *Montlivaltia* were described. In the lagoons, where deposition was dominated by oolitic facies and conditions were rather unfavourable for the corals, small colonies of *Stylina, Heliocoenia* or *Thecosmilia* were observed (Bendukidze 1982).

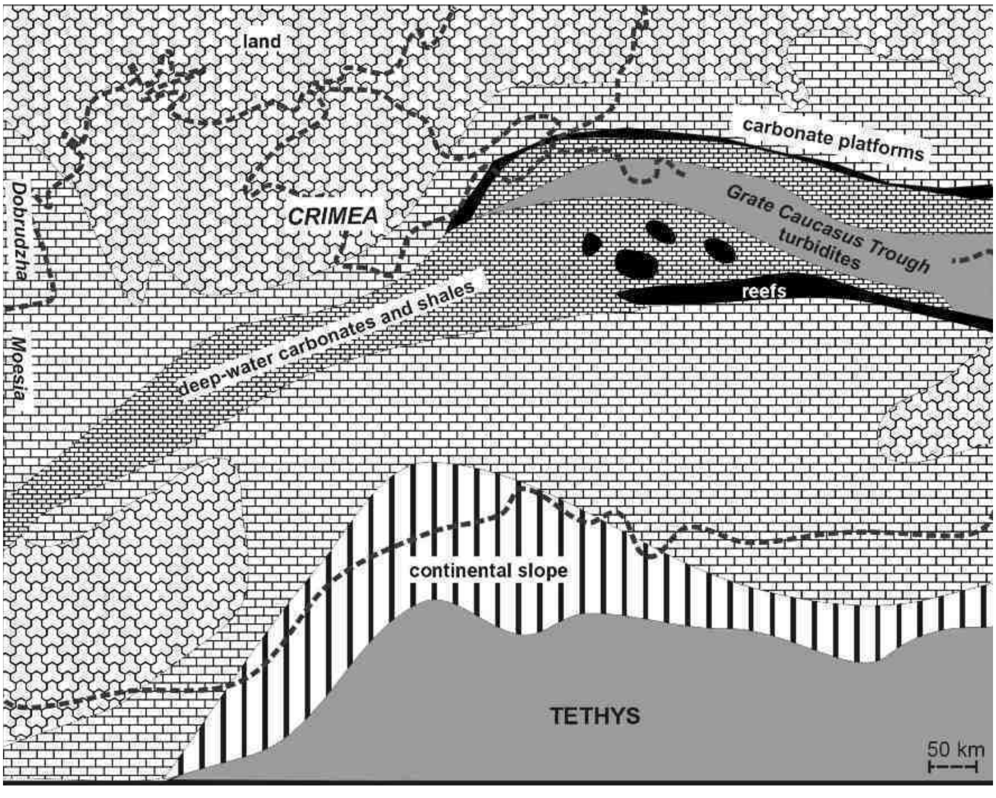



**Fig. 4.22.** Sketch shows the Late Jurassic paleotectonic situation on the Black Sea area, after Nikishin *et al*., 1998, Afanasenkov *et al*., 2007, simplified and modified

Particularly intensive growth of barrier reefs took place along the margins of the Great Caucasus Trough (Fig. 4.22). Examples can be the reef complexes known from the Terek Valley (Bendukidze 1982), where large, several hundred meter thick, massive structures are observed. These are composed of numerous, small buildups and detrital sediments (originating from reef erosion), and subsequently subjected to early diagenetic cementation. The main reef builders are there corals but algae and sponges were also identified. Among corals typical taxa are *Cladophyllia, Stylosmilia, Thecosmilia, Cryptocoenia, Stylina, Calamophylliopsis, Actinastraea, Istraea* and *Heliocoenia*. Up the sequences, the reef structures grade into massive and bedded, Upper Tithonian and Lower Cretaceous sediments. In most sequences Upper Cretaceous strata unconformably cover the reefs or fill the relief formed during the sub-aerial exposures (e.g., Bendukidze 1982). Both the northern and the southern Caucasian reef stripes continue to the northwest, rimming the geosyncline (Afanasenkov *et al.*, 2007, Fig. 4.22). The reef complexes encountered in this area are up to 800 meters thick and were formed mostly by corals *Stylosmilia, Stylina, Etallonia, Heliocoenia, Thecosmilia, Calamophylliopsis, Myriophyllia* and *Pachygyra* (Bendukidze 1982).

Analysis of the structure of Crimean Mts., combined with the results of this project and with data from literature, reveals many similarities in tectonics, stratigraphy, facies development, size and morphology of carbonate complexes from the Crimean Mts. and from the Caucasus, although further, more detailed studies are inevitable. It seems that sediments observed recently in the Crimean Mts. belonged to the same or similar system developed along the northwestern extension of structures observed in the Caucasus. For example, comparison of the reef complexes from the Ay-Petri Massif and the Terek Valley shows many similarities. In the Caucasus Mts. reef complexes were deposited mostly in the Kimmeridgian and, less commonly, in the Late Oxfordian and the Early Tithonian. Stratigraphic observations in the Ay-Petri Massif proved that the carbonate buildups were formed mostly during the Tithonian, less commonly in the Kimmeridgian and, may be, also during the Earliest Cretaceous (Krajewski, Olszewska 2006, 2007). Additionally, it must be emphasized that in the older literature and in some new publications the growth of the Ay-Petri reefs was related to the Oxfordian and the Kimmeridgian (e.g. Muratov 1960, 1973, Leshukh *et al.*, 1999 and others). This suggests that such differences may be the effects of still insufficient knowledge of stratigraphy of both regions. Attention must be paid to obvious similarities in size and morphology of massifs interpreted as reef complexes. Their dimensions reach several hundred meters across. The massifs are composed of numerous, small buildups accompanied by detrital sediments and subjected to cementation, which led to the formation of huge, massive limestones complexes. It seems that in both regions reefs grade into logoonal facies dominated by oncolitic sediments. These structures are commonly accepted as coral reefs but such interpretation seems to be an oversimplification as the bioconstructions were built by much wider group of reef-constructors. Although in the Ay-Petri complex only a small number of corals was be identified, these are mostly similar to those known from the Caucasian buildups. In the Ay-Petri Massif significant part of coral skeletons was dissolved, hence, at the present stage of studies more precise comparions are risky. According to the literature, the Caucasian bioconstructions are built by corals similar as in the Eastern Crimean Mts. (Sudak area). However, the results of this study and other projects run in the northern margin of the Tethys Ocean allow to suggest that more extended group of organisms: e.g., algae, sponges, microbialites and microencrusters contributed to the construction of what was traditionally called “coral reefs”, may be by analogy to the recent coral reef systems in the world. Solution will be provided by future microfacies studies run in both regions.

Some suggestions can be provided by the results of studies on the East Black Sea Basin, between the Crimean Peninsula and the Caucasus Mountains, in the area of the northern Shatsky Swell (Afanasenkov *et al*. 2005, 2007, Fig. 4.22). The comparative studies of adjacent areas (where drillings were completed) based on seismic data and data from the Caucasus Mts. led to the distinguishing of two types of Upper Jurassic structures: the Yuzhnyi Adler shelf carbonate platform and the system of isolated carbonate buildups developing towards the Crimean Peninsula and separated by a depression filled with younger deposits (Afanasenkov *et al*. 2005). Growth of these buildups is related to the Callovian rifting phase, known from both the South Crimea and the Caucasus regions. This rifting divided the Jurassic sea bottom into several tectonic blocks composed of pre-Callovian rocks. On such elevations the isolated reef complexes have started to grow. Their sizes are similar to those of the Ay-Petri reef. It cannot be precluded that the Ay-Petri reef belongs to this system or that it represents a similar system built along the northwestern extension of that block.

# 5. Final conclusions

In the study area the oldest Upper Jurassic sediments represent the Kimmeridgian; the presence of Oxfordian deposits suggested in some papers has not been confirmed by the author.

In the northeastern part of study area, especially in the Yalta Massif, sediments were tectonically disturbed. Thus, recently observed, apparent thickness of these strata reaching several kilometers is perhaps a result of allochthonous structure of the Crimean Mts. and tectonic repetition of sedimentary successions of the same age. On the other hand, studies reported in this paper were mostly in those parts of the massifs, which were the uniform tectonic blocks. The results enable the author to suggest that true thickness of carbonate platform sediments in the Crimean Mts. does not exceed about ~800 meters in the Ay-Petri Mt. area and gradually decreases towards the At-Bash Mt. Greater thicknesses found in the Yalta Massif probably are tectonically controlled.

The results of current studies enabled author to identify several facies and microfacies varieties of limestones, which represent several milestones of development of the Crimean carbonate platform. Sediments building the main part of the platform are contoured from the bottom and the top by tectonic unconformities.

The first stage of platform development is related to the Kimmeridgian/Tithonian turn. Two main facies varieties were deposited: bioclastic wackestones-packstones with microbolites and *Microsolena*-microbial-sponge boundstones-floatstones. Sedimentation proceeded at a gentle slope, close to the eroded land. The impact of this land reflected by supply of siliciclastic material strongly influenced depositional environment but facies diversity was similar at this stage of platform history.

The second stage took place during the Tithonian and is characterized by significant facies diversity of sediments deposited in the marginal platform environments: ooidal barriers and reefs built by various organisms: sponges, corals, algae, microbialites and microencrusters. The main facies varieties are: ooid-cortoid-bioclastic grainstones-rudstones (massive limestones), sponge-algal-coral-microbial boundstones (massive limestones), mixed, siliciclastic-carbonate and pure siliciclastic facies. Moreover, common are internal platform products: open and restricted lagoonal facies represented by foraminiferal mudstones-wackestones and oncoidal packstones-rudstones (bedded limestones). The sediments contain several, lower-rank depositional sequences probably related to small bathymetric oscillations.

The last, third stage of platform history (Upper Tithonian-Berriasian) is dominated by internal platfom facies represented by *Bacinella*-oncoidal packstones-rudstones (bedded and massive limestones), sponge-coral floatstones (bedded limestones), foraminiferal-gastropod wackestones-mudstones (thin-bedded limestones) and intertidal mudstones-microbial bindstones (thin-bedded limestones). At that stage further growth of the platform was halted due to Cimmerian movements and sediments were subjected to frequent episodes of emergence and erosion. During the final episode sediments of the carbonate platform were tectonically displaced.

Depositional sequences described in this paper represent shallow-marine environments of depths not exceeding some tens of meters (usually from several to a dozen od meters). In the sequences erosional gaps and deposits formed during episodes of emergence and erosion: breccias, vadose silt or fenestral structures. The platform developed at a continental margin and the land temporarily supplied clastic material. The main controlling factors for these shallow-marine environments were probably small oscillations of sea level resulting in cyclicity of deposition and changes in deposition rates.

Carbonate buildups of the Crimean Mts. were traditionally related mostly to the growth of corals. However, the author found that corals have not been the principal reef-builders. More important were other organisms: sponges, algae, microecrusters and microbialites. Microencrusters independently formed microframework or accompanied macroorganisms and, similarly to microbialites, contributed to stabilization and cementation of sediments. Less common occurrence of corals can be explained in terms of unfavourable conditions prevailing during the platform history, and precisely, high-energy environment, proximity of land and high deposition rates. Only in some thin horizons deposited under optimal conditions corals were more abundant. The coral reefs are more common and characteristics for Oxfordian deposits from Eastern Crimean Mts.

The important process in deposition of massive limestones was early diagenetic cementation. Detrital sediments were quickly cemented due to high-energy conditions and intensive water circulation. Then, during high sea level episodes, the hard, lithified bottom was settled by vigorously growing benthic organisms, which provided rigid framework. Such multiply repeating cycles led to the formation of the Ay-Petri reef complex, which consists of several horizons of ooidal-bioclastic and sponge-algal-coral facies. Recently, these sediments form a vast, monolitic block of non porous massive limestones but during sedimentation the low-relief platform surface was covered with numerous, small patch-reefs and peri-reefal detritus.

Sediments from the Yalta and the Ay-Petri massifs are products of a vast system of carbonate platforms extending from the Caucasus Mts. towards the Moesian Platform and the Dobrudzha. The Crimean Mts. platforms developed close to the land. Considering the available literature, it seems that most similar to the Crimean massifs in stratigraphy and development might have been the Caucasian carbonate complexes as well as structures and carbonate platforms known from the eastern part of the Black Sea coast.

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ISSN 0867-6631
ISBN 978-83-7464-337-5

12/7/2010