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C. R. Palevol 4 (2005) 569–582

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Systematic Palaeontology (Micropalaeontology)

Calcimicrobial cap rocks from the basal Triassic units: western Taurus occurrences (SW Turkey)

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Received 13 October 2004; accepted after revision 28 February 2005

Available online 22 April 2005

Written on invitation of the Editorial Board

Abstract

A post-extinction calcimicrobial cap rock occurs above the giant Permian skeletal carbonate platform exposed in the western Taurus Mountains (southern Turkey). It was formed during the main step of a very rapid and large-scale platform flooding (Earliest Triassic) and has been found also in other Tethyan localities. This calcimicrobial cap rock, 20 to 40 m thick, consists of thrombolitic and stromatolitic build-ups at the base and most oolitic grainstone in the upper part. It was terminated by a sudden input of fine terrigenous sediments. The domal, columnar and conical stromatolites are 'anachronistic' deposits as are the abundant botryoidal and fanning aragonite crystal pseudomorphs. This again shows the uniqueness of the Earliest Triassic period and indicates a delayed biotic recovery. ***To cite this article: A. Baud et al., C. R. Palevol 4 (2005)***.

Résumé

Un chapeau calcimicrobien dans les unités basales du Trias : occurrences dans le Taurus occidental (Turquie du Sud-Ouest). Un chapeau calcimicrobien post-extinction recouvre la plate-forme carbonatée permienne affleurant dans le Taurus occidental (Turquie méridionale) ; il a été reconnu dans d'autres régions téthysiennes. La croissance de ce chapeau s'effectue durant la phase d'inondation principale du Trias basal. D'une épaisseur de 20 à 40 m, ce chapeau est constitué d'une interdigitation de constructions thrombolitiques et de stromatolites, en sa partie inférieure, et principalement de calcarénites oolitiques, au-dessus. Il se termine abruptement avec l'arrivée d'un détritisme terrigène fin. Avec des constructions thrombolitiques et de stromatolites variés ainsi que des ciments aragonitiques abondants, ce dépôt microbien est considéré comme anachronique. Cet apparent retour dans le passé de la sédimentation biogénique montre une des particularités singulières de la période du Trias précoce. Elle est ici le signe d'une radiation retardée. ***Pour citer cet article : A. Baud et al., C. R. Palevol 4 (2005)***.

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1631-0683/$ - see front matter
doi:10.1016/j.crpv.2005.03.001

Keywords: Permian; Triassic; Taurus; Microbialites; Thrombolites; Stromatolites; Anachronistic

Mots clés : Permien ; Trias ; Taurus ; Calcaires microbiens ; Thrombolites ; Stromatolites ; Anachronique

1. Introduction

After the end-Permian mass extinction, primitive groups of microbial communities emerged from stressed palaeoenvironments to recolonise the normal marine area of the Tethys as they do along the western Pantalassa margin [41]. The prolific Upper Palaeozoic skeletal carbonate factory was abruptly replaced by a non-skeletal carbonate factory [9].

During the main step of the very rapid and large-scale end Permian-basal Triassic flooding of the giant Permian carbonate platforms of western and central Tethys [12], we note in different areas (southern Alps, Taurus, Turkey, southern Armenia, eastern Elburz, Iran, Central Iran and northern Oman) the growth of domal stromatolites, thrombolites and/or microbial mats [11].

Previous studies have documented the widespread occurrence of microbialites following the end-Permian mass extinction in eastern Tethys from the basal Triassic of China [15,24–27] and also from Iran [19,20]. Here new data are presented, built on previous studies of the Lower Triassic of western and central Tethys [3,37] as well as earlier microbialite studies [9].

As shown by one of us [37], thrombolites and stromatolites associated with thrombolites show strong carbon isotopic differentiation between their different fabrics. The relationship between the very important extension of these microbial structures in the Lower Triassic deposits [6] and the large carbon isotopic fluctuations throughout this period [34,37] are under study.

Concerning nomenclature, we are following the definitions of microbialites presented by Shapiro [42], who recognized different fabrics (mega-, macro-, meso-, and microstructural). The mesostructure category described internal textures of macrostructural elements that are visible in the field. From the three most common groups of microbialite, two are described here: laminated mesostructure (stromatolites) and clotted mesostructure (thrombolites). For the thrombolites, we found in the studied area two categories of Riding [38]:

- (1) calcified microbial thrombolites;
- (2) tufa-like build-ups.

2. Geological and stratigraphical settings (Figs. 1,2)

Part of the giant carbonate platform crops out in the western Taurus range (southern Turkey) within different thrusted units of the upper Antalya Nappes [29] (Fig. 1). The Permian shallow carbonate limestones belong to the Pamucak Formation and the Triassic calcimicrobial rocks to the Lower Kokarkuyu Formation. To the east, in the Ala dag Nappes, Permian sediments belong to the Çekiç dag Formation and the Triassic one to the Gevne Formation [33,37].

One of the best exposure is at the Çürük dag locality at which a 650-m thick section of shallow water carbonates (Middle to Upper Permian–Lower Triassic) is situated at about 15 km northwest of Kemer [8–11,30,31,37] (Figs. 2,3,5). In this section, the Pamucak Formation is represented by a thick (400 to 600 m) cyclic succession of inner to outer platform facies (Guadalupian to Lopingian). The upper part of the formation is made up of black nodular limestones locally with chert (Changhsingian in age). These limestones are rich in calcareous algae (Dasycladacea) and in small foraminifera (mainly Milliolidae), with intervals containing brachiopods, echinoderms and crinoids. The microfacies consists of bioclastic wackestones deposited under low energy (algal biomicrites, Fig. 3, microfacies **4**). Upward, the facies and the microfacies change abruptly (seeming paraconformity) into high-energy grainstones, then into oolitic grainstones (Fig. 3, microfacies **3**), with echinoderms, bivalves and foraminifera of Changhsingian age. The top of the Pamucak Formation shows a strong diagenetic recrystallisation interpreted to have been formed in close proximity to a subaerial surface. The lower Kokarkuyu Formation, that is the calcimicrobial cap rock, consists of about 40 m of microbial and oolitic limestones dated by conodonts of the *isarcica* zone (Early Induan, basal Triassic).

Approximately 10 km to the northeast of the Çürük dag locality is the Kopuk dag section (Figs. 1,2,5). The calcimicrobial cap rock that overlies the Late Permian oolitic grainstone is about 42 m thick [37].

About 100 km to the east, near Alanya, a similar but thinner (20 m) calcimicrobial cap rock exists in the

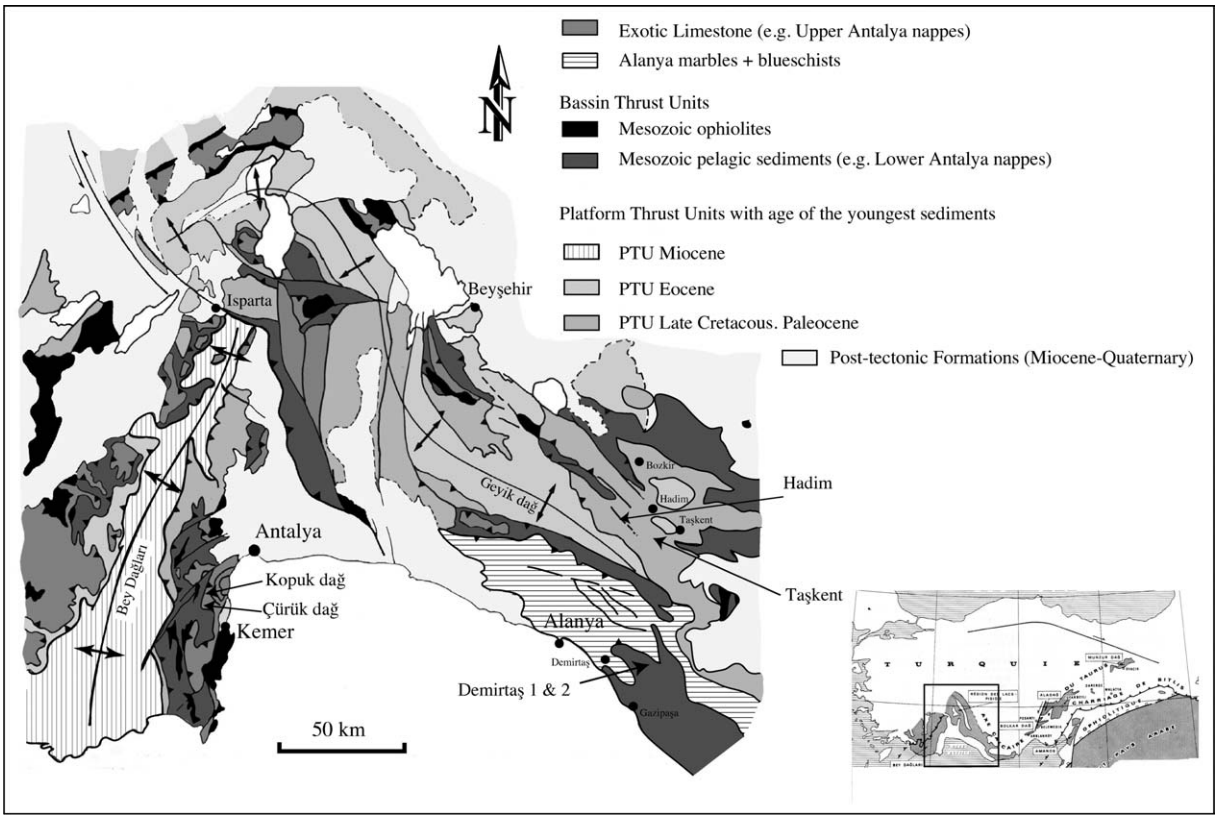

Fig. 1. Geological sketch of the Western Taurus with location of the studied sections [29,32,33,37] and place of the Taurus in a sketch map of Turkey. Çürük dag, N36°41′32″–E30°27′40″, alt. 1425 m; Kopuk dag N36°42′82″; E30°30′21″; alt. 1180 m; Demirtas 1 N36°28′96″, E32°14′99″, alt. 150 m; Demirtas 2 N36°27′35″, E32°14′86″, alt. 140 m; Taskent N36°50′58″, E032°30′04″, alt. 1800 m; Hadim N36°52′52″, E32°25′29″, alt. ~1900 m.

Fig. 1. Esquisse géologique du Taurus septentrional, avec la position des profils étudiés [29,32,33,37] et son emplacement de la région dans une esquisse de la Turquie (cadre à droite).

Antalya Nappes, which belong to the Demirtas windows (Demirtas sections 1 and 2, Fig. 1,2, [37]).

In the Ala dag unit of the Hadim area, the calcimicrobial cap rock is 41 m thick in the Taskent section (Figs. 1,2,4), and 35 m in the Hadim sections [37]).

To the east, in the Pinarbasi area of Central Taurus [2,3], a stromatolitic unit has been described at the base of the Triassic shallow carbonate succession.

3. The onset of the calcimicrobial cap rock

In the analysed sections as in other sections of the Taurus Mountains to the east, the onset of the calcimicrobial cap rock follows the deposition of a thin (0.2–0.6 m) oolitic-grainstone unit (Fig. 3, microfacies **3**) in the Çürük dag section [9,30,37], in the Demirtas, Taskent and Hadim sections [37] and in the Ala dag units [45]. The contact between the oolitic grainstones and the calcimicrobial cap rock is a bedding plane, stylolite (Fig. 4D) or clay seam. According to Ünal [45] (Fig. 8), it corresponds to an unconformity and a gap of short duration in the Ala dag unit. However, if an unconformity exists, we will place it more likely at the base of the oolite unit, because this unit is overlying different Upper Permian deposits. Concerning the time gap, we know that the base of the stromatolites belong to the second conodont zone of the Triassic, but we are missing Upper Permian diagnostic fossils in the oolitic beds and in the underlying sediments to evaluate the exact duration of the gap. A Late Wujiapingian–Changhsingian is inferred from the foraminiferal assemblage (*Paradagmarita* zone).

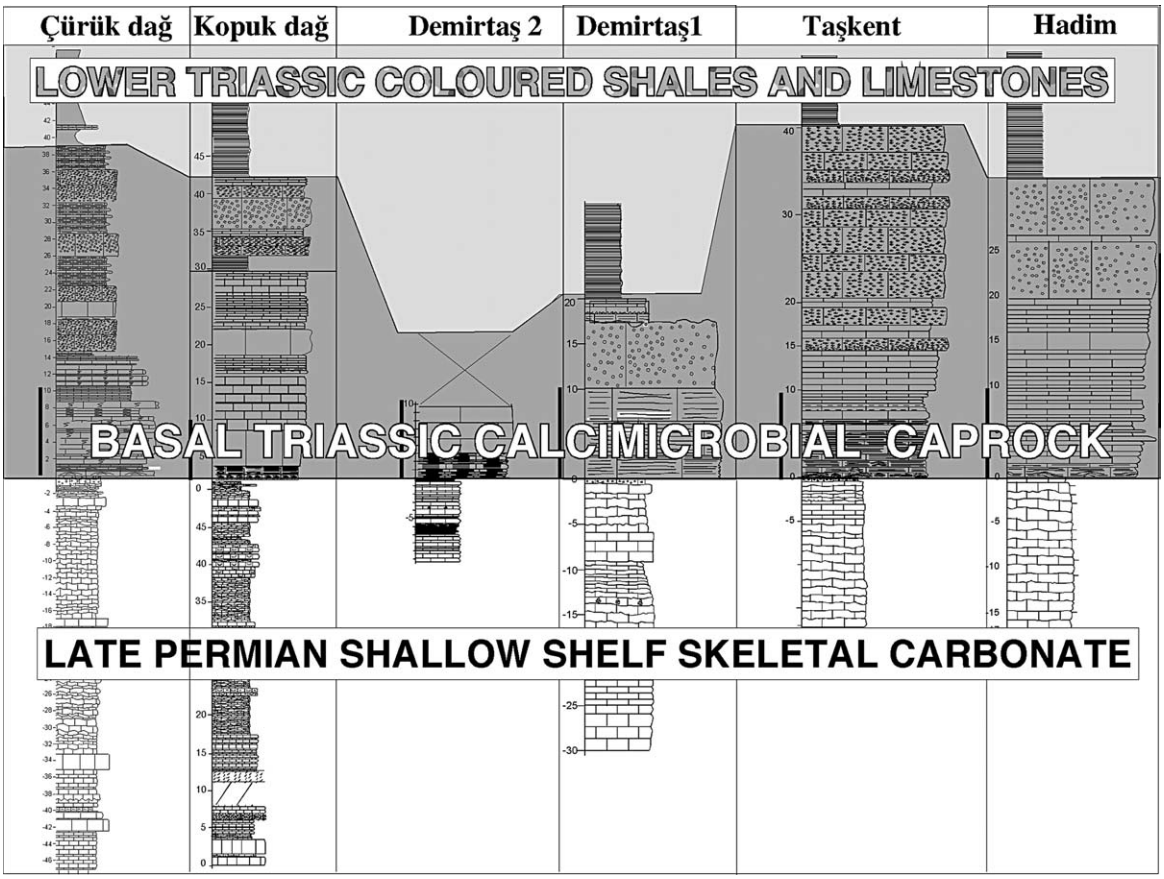

Fig. 2. Stratigraphic profiles of the six studied sections [35] showing calcimicrobial cap rock development above the Late Permian skeletal carbonate. Thickness in meters, scale vertical bar = 10 m.

Fig. 2. Profils stratigraphiques des six sections étudiées [37] avec la position et l'épaisseur des calcaires microbiens de la base du Trias en « chapeau », ou couverture sur les calcaires squelettiques du Permien supérieur. Échelle en mètres, barre verticale noire = 10 m.

The base of the calcimicrobial cap rock at the Çürük dag section consists of a 0.2-m-thick bed with a thrombolitic texture (Fig. 3, microfacies **2**) and is overlain by 0.6 m of domal stromatolites (Fig. 6A and Fig. 3, microfacies **1**).

In the Kopuk dag section as in the Demirtas section, domal and undulose stromatolite biofacies immediately overlies the oolitic grainstone (Fig. 6C).

In the Taskent section of the Ala dag unit (Fig. 4), columnar stromatolites grew up to 0.1-m height in a thrombolitic matrix (Fig. 4B and C) directly at truncated oolitic grainstones (Fig. 4D). The truncation of ooids is due to pressure solution as shown by Fig. 4D and is not due to subaerial dissolution, as previously interpreted [45]. Locally a thrombolitic biofacies occurs (**t** in Fig. 4B), followed by a 14-m-thick succession of planar stromatolites (Fig. 4A).

4. Development of the calcimicrobial cap rock (Fig. 5)

In the studied sections, two different framestones make up the calcimicrobial cap rock. At the Çürük dag section, a lower, 14-m-thick portion consists of an interdigitation of massive beds or domes with a thrombolitic texture and thin-bedded laminar stromatolites (Fig. 5A,B). The upper part (25 m thick) is made of oolitic grainstone beds (0.1 to 0.3 m) with occasional calcimicrobial calcilutite and thrombolitic beds. Some beds within the lower part are very rich in ostracods of Palaeozoic affinity [13], micro-foraminifera [9] and micro-gastropods [37].

In the Kopuk dag profile, the lower stromatolite–thrombolite section (28 m thick) is separated from the oolitic upper part (12 m thick) by 3 m of marly lime-

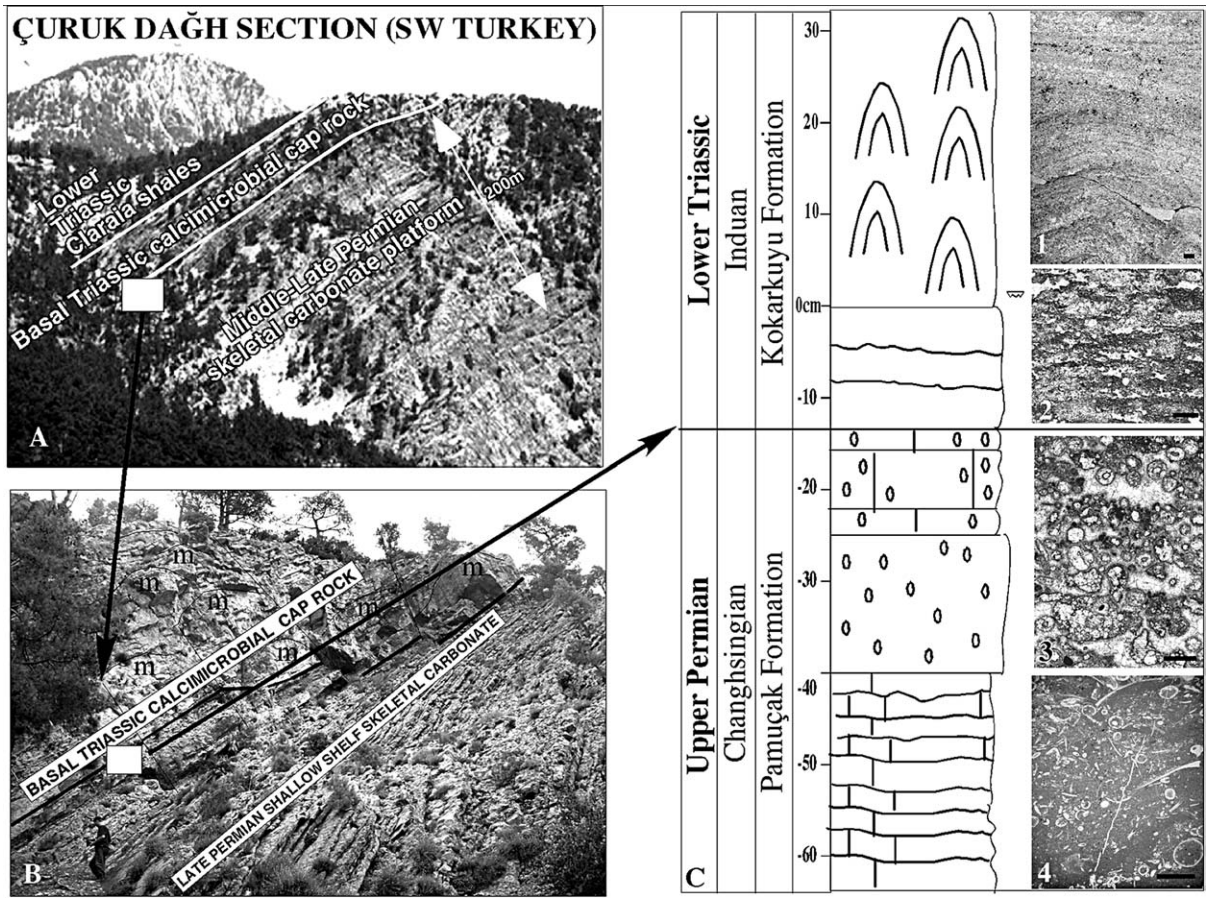

Fig. 3. Overview of the Çürük dag section. (**A**) The Çürük dag Mountain from the south, with the thick development of the Middle–Late Permian skeletal carbonate platform and the calcimicrobial cap rock at the top. (**B**) The Permian–Triassic boundary (black line) at the base of the calcimicrobial cap rock; m = thrombolite mound. The scale is given by S. Richoz at the lower left corner. (**C**) Lithological column (scale in centimetres) and microfacies (scale bar = 1 mm) of the Permian–Triassic transition with the onset of the calcimicrobial cap rock. **1**, The thin lamination of the domal stromatolite; **2**, fenestral clotted micrite of the basal thrombolite with geopetal microcavities filled by dark coccoidal peloids and drusy cement at the top; **3**, recrystallised and fenestral oolitic grainstone; **4**, skeletal wackestone with calcareous algae, bivalves and ostracods.

Fig. 3. La section du Çürük dag. (**A**) Vue du sud, avec la forte épaisseur des calcaires de plate-forme Permien moyen à supérieur et la couverture de calcaires microbiens au sommet. (**B**) La limite Permien–Trias (trait noir), surmontée par le chapeau de calcaires microbiens; m = monticule thrombolitique. L'échelle est donnée par S. Richoz dans le coin gauche inférieur. (**C**) Colonne lithologique (échelle en centimètres) et microfaciès (barre d'échelle = 1 mm) de la transition Permien–Trias et du démarrage des calcaires microbiens. **1**, laminites microbiennes des stromatolites en dômes ; **2**, micrite grumeleuse fenêtrée du thrombolite basal avec des microcavités à remplissage géopète de péloïdes coccoïdaux et de calcite géodique ; **3**, *grainstone* oolitique recristallisé à microcavités ; **4**, *wackestone* squelettique à algues calcaires, bivalves et ostracodes.

stones. Tufa-like thrombolite domes up to 1 m high occur within medium bedded calcilutite, between 22 and 25 m above the base (Fig. 8A,C). A short description of these unusual build-ups is given below (§ 4.3)

In the Demirtas section, the lower portion (10 m thick) consists essentially of domal and flat laminated stromatolites. The upper part is made of cross-bedded oolitical grainstones (7 m thick) followed by 1.5 m of laminated microbial limestone with a ferruginous hardground at the top.

The Taskent section is comprised of a 14-m-thick lower portion with columnar stromatolites and thrombolites at the base and is overlain by a flat laminar stromatolite (Fig. 4). The upper part consists of about 25 m of bedded oolitic grainstones.

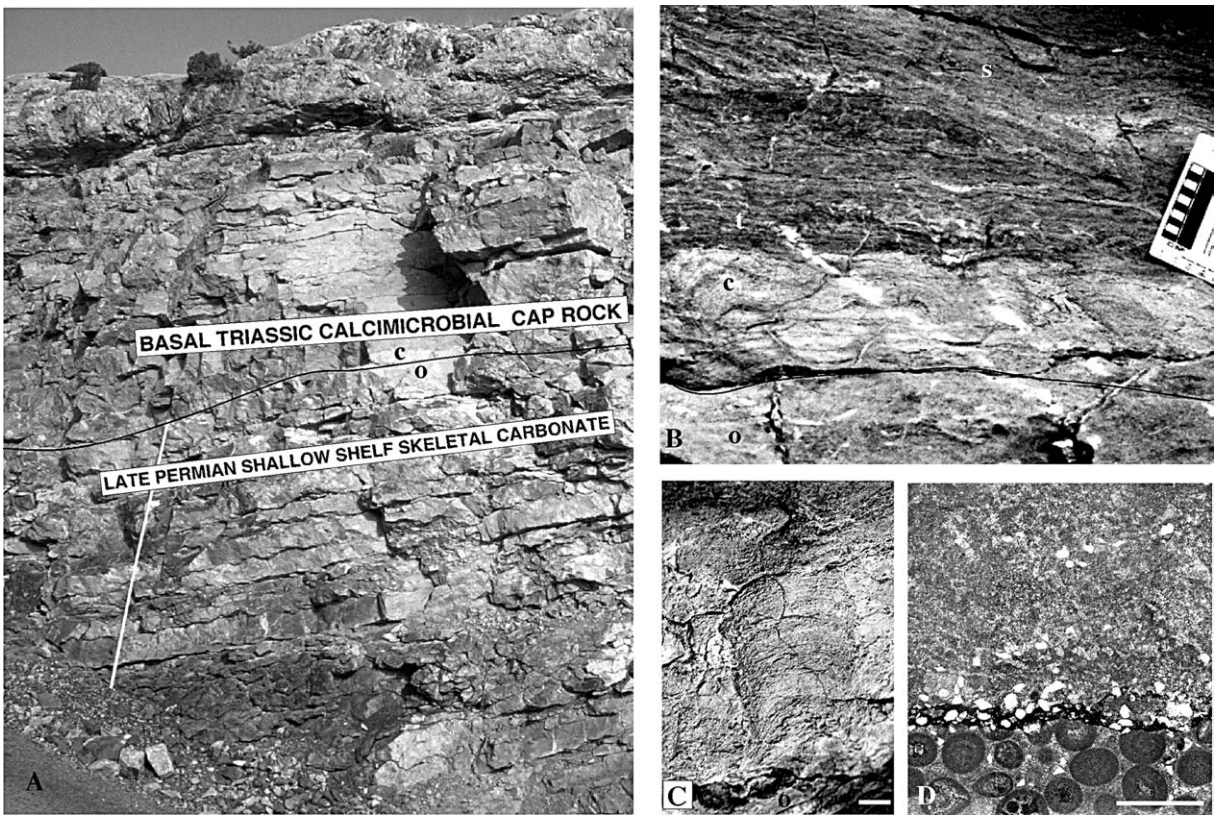

Fig. 4. The Permian–Triassic boundary at the Taskent section. (**A**) Overview of the outcrop with the Boundary (black line) at the base of the Calcimicrobial cap rock; **o** = oolitic grainstone beds; **c** = columnar stromatolites. Scale given by the double meters (in white). (**B**) Detail of the onset of calcimicrobial cap rock: **o** = oolitic grainstone bed; **c** = columnar stromatolites bed; **t** = thrombolite; **s** = planar stromatolite. Scale = 10 cm. (**C**) Outcrop view of a columnar stromatolite in a clotted micrite matrix. Scale bar = 1 cm. (**D**) Thin section of the contact between the oolitic grainstone and the clotted micrite matrix of the columnar stromatolite with a quartz-grain concentration along the pressure solution clay seams (Permian–Triassic boundary?, see comment in § 3). Scale bar = 1 mm.

Fig. 4. La limite Permien–Trias dans la section de Taskent. (**A**) Vue de l'affleurement avec la limite (trait noir) surmonté par la couverture de calcaires microbiens; **o** = niveaux de *grainstone* oolitique; **c** = niveau de stromatolites en colonnettes. Le double mètre (ligne blanche subverticale) donne l'échelle. (**B**) Détail de la mise en place du chapeau de calcaires microbiens: **o** = niveau de *grainstone* oolitique; **c** = niveau de stromatolites en colonnettes; t = thrombolite; s = stromatolites plans. Barre d'échelle de 10 cm. (**C**) stromatolite en colonnettes à l'affleurement dans une matrice de calcilutite grumeleuse. Barre d'échelle = 1 cm. (**D**) Lame mince du contact entre les oolites et la micrite grumeleuse de la matrice des stromatolites en colonnettes. Des grains de quartz se concentrent le long des filonnets argileux de dissolution sous pression (limite Permien–Trias?, voir commentaires, § 3). La troncature des ooïdes se fait par dissolution sous pression et non pas par dissolution subaérienne comme présenté dans [45]. Barre d'échelle = 1 mm.

A sudden influx of fine terrigenous sediments terminated the formation of the calcimicrobial cap rock. We think that the clay influx durably prevent the microbial calcification and the carbonate production. Up section, above the shales and marly deposits, the microbial influence on the carbonate sedimentation is again present, particularly in the development of oolitical shoals in the Ala dag units.

4.1. The stromatolite facies, macro-, meso-, and microstructures

At least four types of stromatolite facies are recorded in the post-extinction sediments.

- (1) The small-columnar stromatolites range from 3–5 cm in diameter and the columns are up to 10–15 cm high (Fig. 4C). In the central Taurus (Ala

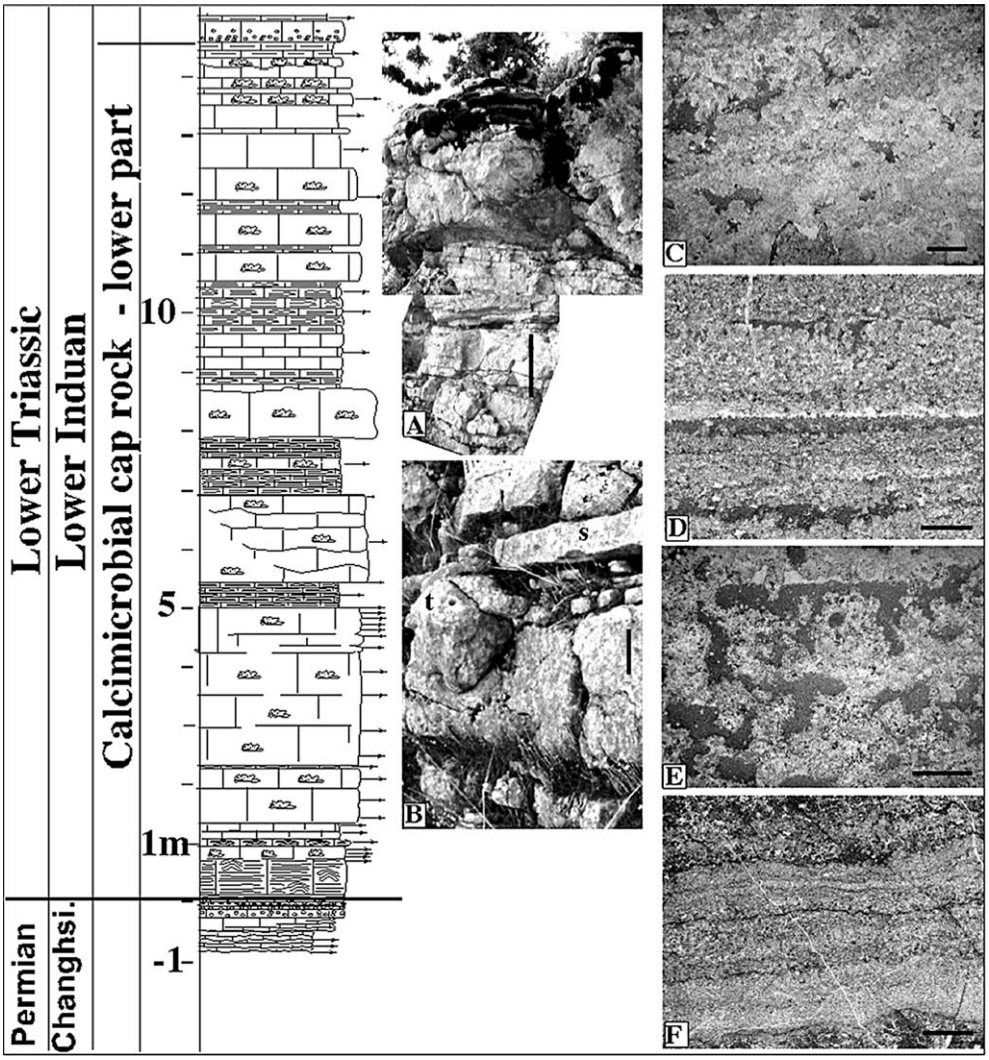

Fig. 5. Lithology, stratigraphy, facies and microfacies of the Çürük dag lower calcimicrobial cap rock. (**A**) Superposition of lower thrombolitic beds, laminated planar stromatolitic beds in the middle and an upper thrombolitic mound. Scale vertical bar = 1 m. (**B**) A thrombolitic bed (**t**) in the middle between planar stromatolitic beds. Scale vertical bar = 10 cm. (**C** to **F**) Thin sections, Scale bar = 1 mm. (**C**) Fenestral grumous micrite and microsparite of the thrombolite mound with geopetal micro-cavities filled by dark coccoidal peloids and a drusy cement at the top. (**D**) Stromatolite laminites made up of diagenetic altered fanning aragonite crystal pseudomorphs and geopetal micro-stromatactis sheets filled by dark coccoidal peloids and drusy cement at the top. (**E**) Clotted micrite and microsparite of a thrombolite bed with a network of geopetal filled cavities by dark coccoidal peloids and a drusy cement at the top. (**F**) Stromatolite laminites of calcilutite and calcisiltite with micro-peloids (grumous texture).

Fig. 5. Profil stratigraphique, faciès et microfaciès de la partie inférieure du chapeau de calcaires microbiens du Çürük dag. (**A**) Vue d'une superposition de bancs thrombolitiques dans la partie inférieure, de calcaires laminés stromatolitiques dans la partie médiane et d'un monticule thrombolitique au sommet. Barre d'échelle verticale = 1 m. (**B**) Banc thrombolitique (**t**) massif entre de petits bancs stromatolitiques. Barre d'échelle verticale = 10 cm. (**C** à **F**) microfaciès, Barre d'échelle = 1 mm. (**C**) Micrite et microsparite grumeleuse fenêtrée du monticule thrombolitique avec des micro-cavités à remplissage géopète de péloïdes coccoïdaux et de calcite géodique. (**D**) Alternance de laminites composées par des planchers de cristaux d'aragonite pseudomorphosés et altérés diagénétiquement et de micro-cavités en feuillets (stromatactis) à remplissage géopète de péloïdes coccoïdaux et de calcite géodique. (**E**) Micrite et microsparite grumeleuse, avec un réseau de cavités à remplissage géopète de péloïdes coccoïdaux et de calcite géodique. (**F**) Laminites stromatolitiques de calcilutites et de calcisiltites à micro-péloïdes (texture grumeleuse).

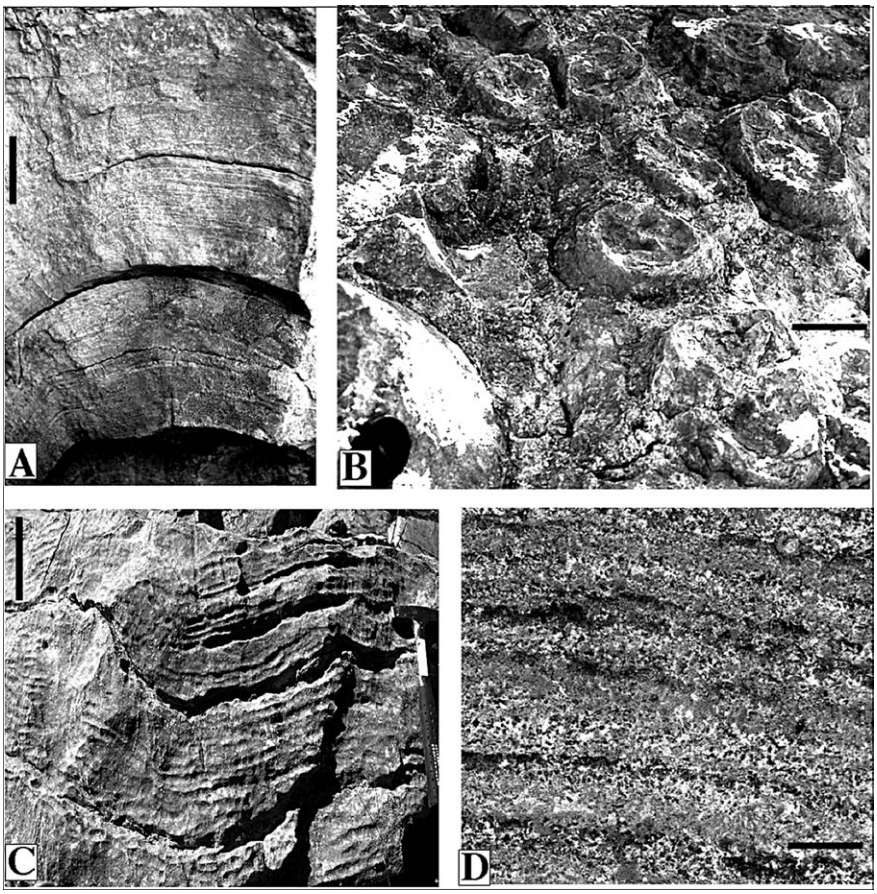

Fig. 6. Main meso- and microstructures of the stromatolite facies. Scale bar of the microfacies (MF) is 1 mm. (**A**) The domal stromatolite from the Çürük dag basal calcimicrobial cap rock (microfacies **1** in Fig. 3). Scale vertical bar = 10 cm. (**B**) The conical stromatolites viewed from above. Scale bar = 10 cm. (**C**) Undulose stromatolite from the basal calcimicrobial cap rock, Demirtas 1 section. Scale vertical bar = 10 cm. (**D**) MF: undulose stromatolite with silty to peloidal laminites.

Fig. 6. Méso- et microstructures principales des faciès stromatolitiques. La barre d'échelle des microfaciès (MF) est de 1 mm. (**A**) Stromatolites en dôme de la base du chapeau de calcaires microbiens du Çürük dag Barre d'échelle verticale = 10 cm. (**B**) Stromatolites coniques vues du haut, section du Kopuk dag, base du chapeau calcimicrobien. Barre d'échelle = 10 cm. (**C**) Stromatolites onduleux de la section de Demirtas 1, base du chapeau calcimicrobien. Barre d'échelle = 10 cm. (**D**) MF: alternance de laminites calci-silteuses et péloïdales d'un stromatolite onduleux.

dag unit) they overlie a Latest Permian diagenetically altered ooid grainstone (Fig. 4D) and are overlain by tabular undulose stromatolites.

- (2) The individual domal stromatolites (5 cm) form bioherms up to 1 m thick with a relief and a diameter of 10–15 cm (Fig. 6A). This facies is common in the Antalya Nappes. The most frequent microfacies shows laminated microbial films with remains of twisted filaments and with cocoidal peloids and pseudo-peloids, resulting from dismantling of microbial filamentous mats alternating with layers of fringe crystals. Drusy cements infill the fenestral porosity due to the degradation of the microbial mucilage (Fig. 3, microfacies **1**).
- (3) The conical stromatolites form truncated cone-up structures with a synoptic relief of 10 cm and a basal diameter of 20 cm. This facies has been found in the Kopuk dag section (Fig. 6B).
- (4) The flat laminated to undulose stromatolites form tabular bodies from 0.1 to 2 m thick and are generally laterally continuous (Fig. 6C). They are common in all the investigated area. The stromatolite microfacies consists of microbialite laminae of dark fine-grained bioclastic micrite containing peloids,

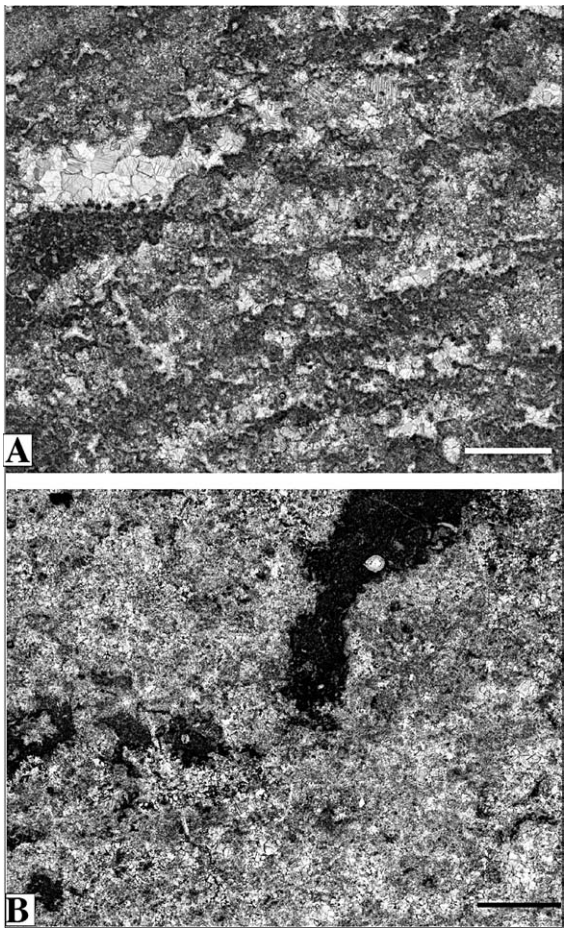

Fig. 7. Microstructures of the thrombolite facies. Scale bar of the microfacies (MF) is 1 mm. (**A**) Geopetal cavity filled by dark coccoidal peloids and drusy cement at the top within the fenestral clotted microsparite of the basal Çürük dag thrombolite. (**B**) MF: clotted microsparite with cavities compactly filled by dark coccoidal peloids and rare ostracod valves of a Çürük dag thrombolite mound.

Fig. 7. Méso- et microstructures principales des faciès thrombolitiques. La barre d'échelle des microfaciès (MF) est de 1 mm. (**A**) MF : Cavité à remplissage géopète de péloïdes coccoïdaux et de calcite géodique dans la microsparite grumeleuse et fenêtrée du thrombolite basal de la coupe du Çürük dag. (**B**) MF : Microsparite grumeleuse, avec cavités à remplissage noir de péloïdes coccoïdaux et rares valves d'ostracodes, monticule thrombolitique du Çürük dag.

ostracods, micro-foraminifera, and/or clotted micrite with fenestral fabric alternately with layers formed by elongated crystals growing in fringes and in fan arrays (Figs. 6D, 9C, D, E). In some part, micro-gastropods, ostracods, foraminifera and Earlandia are trapped within the crystal layer. Spherulitic aragonite crystal pseudormorphs also occur in a micritic matrix, as shown in Fig. 9F.

4.2. The thrombolite bioherms, macro- and microstructures

The thrombolite bioherms are well developed, particularly in the Çürük dag section (Fig. 5). They consist of bedded limestone or of mounds from 0.2 up to 2 m thick and extend laterally up to 10–20 m. They are intercalated with the thinly laminated stromatolitic limestones (Fig. 5A,B). No mesostructures are visible in the field. The microfacies are illustrated in the Fig. 7A,B and in Fig. 5C,E. A microsparitic matrix with patches or drums of micrite is showing abundant millimetric to centimetric cavities with geopetal textures filled by dark peloids or micrite and cemented by blocky calcite. In some case, a first generation of acicular fringe cement precedes the final blocky calcite. Micro-ostracods are found within the dark peloids infilling and within the clotted recrystallised microsparitic matrix, accompanied by micro-foraminifera.

4.3. The tufa-like build-ups

These unusual lithoherms have been found in two localities, the Kopuk dag section (Fig. 8A) near Kemer, and the Demirtas section near Alanya. These build-ups consist of a domal, tuffa-like framework from 0.1 to up 1 m high and 0.2 to 1 m in diameter (Fig. 8B,D). The large one (Fig. 8B) is built around a tube about 5 cm in diameter and 20 cm high (Fig. 8C chimney?). The mesostructures are clearly laminated and made of sub-vertical crystal needles (Fig. 8D,F). The tufa aspect is due to a high porosity, but we consider the build-up to be marine. In thin section, the main feature is the fibrous fabric given by thin elongated crystals and by filaments with patches of residual micrite and microsparite (Fig. 8E). The lamination is caused by colour changes (Fig. 8G). A detailed description of this very peculiar facies is in preparation.

4.4. The carbonate crystal lithoherms

Precipitate? carbonates which look like mounds made of spar (Fig. 9A) occur laterally or interbedded with the thrombolite bioherms. These consist of botryoidal and spherulitic crystal masses surrounding milli-

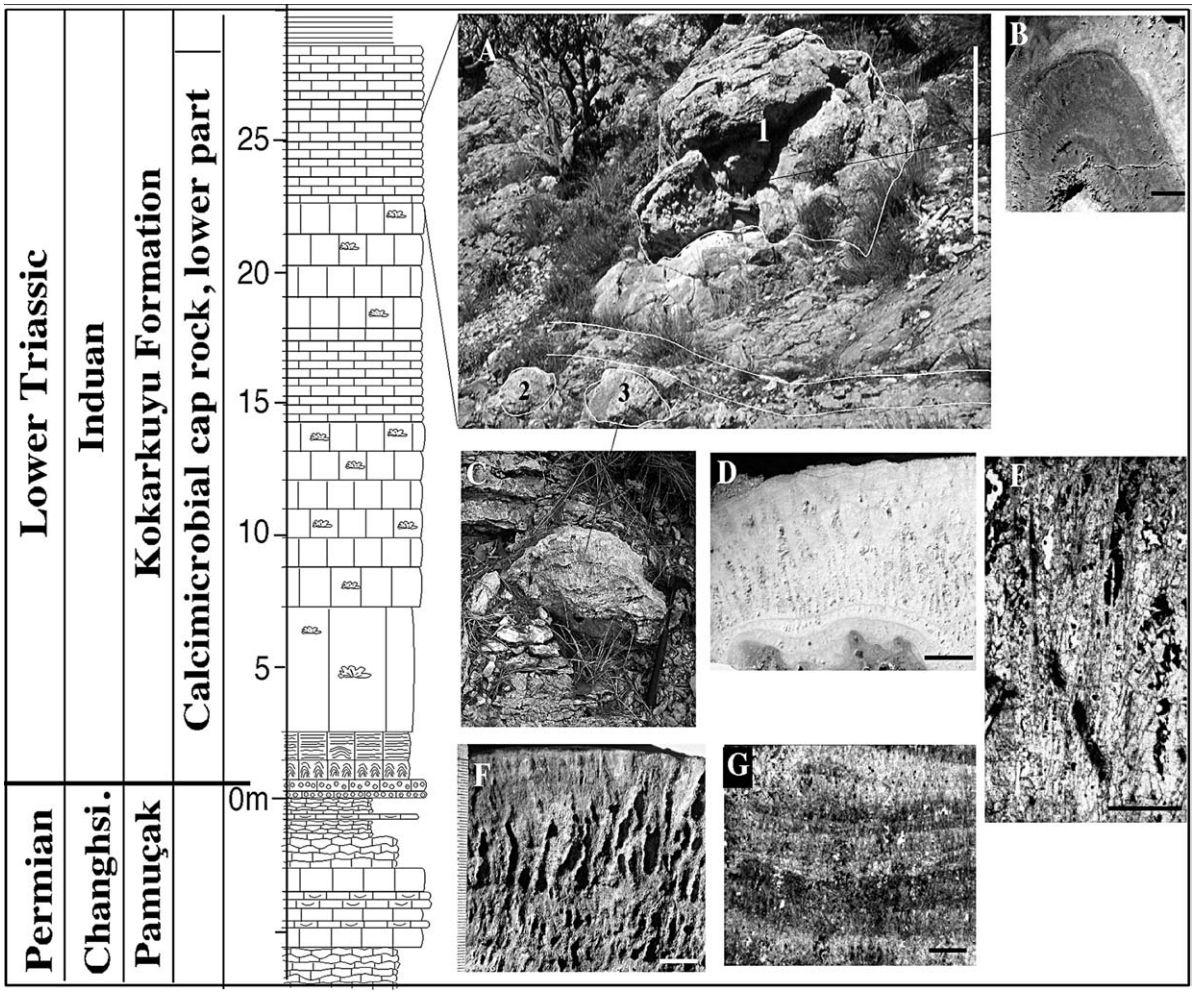

Fig. 8. Macro, meso and microstructures of the tufa-like microbial build-ups with its stratigraphical position in the lower Kopuk dag calcimicrobial cap rock. (**A**) Macrostructure of the microbial build-ups; **1**, large mound; **2** and **3**, smaller mounds; scale vertical bar = 1 m. (**B**) Laminated, conical mesostructure of the heart of the mound 1 in (**A**). (**C**) Closer view of the mound 3 in (**A**) within thin-bedded limestones. Scale is given by the hammer. (**D**) Polished surface of the laminated, tufa-like mesostructure of the mound 3. Scale bar = 1 cm. (**E**) Microfacies showing the subvertical filaments in calcitic matrix. Scale bar = 1 mm. (**F**) Mesostructure of the finely laminated mound 3. Scale bar = 1 cm. (**G**) Microfacies of (**F**), showing the laminations in the calcitic crystal matrix. Scale bar = 1 mm.

Fig. 8. Macro-, méso- et microstructure des constructions calcimicrobiennes à aspect de tuf, avec leur position stratigraphique dans le chapeau de calcaires microbiens de la coupe du Kopuk dag. (**A**) Vue des constructions calcimicrobiennes à aspect de tuf ; **1**, dôme principal ; **2** et **3**, monticules annexes. Barre d'échelle verticale = 1 m. (**B**) Cœur du dôme 1, mésostructure conique laminée de type tuf. Barre d'échelle = 1 cm. (**C**) Monticule 3 pris dans des calcaires en petits bancs. Le marteau donne l'échelle. (**D**) Surface polie, montrant la structure laminée de type tuf. Barre d'échelle = 1 cm. (**E**) Microfaciès de la surface précédente montrant de nombreux filaments subverticaux pris dans la masse calcitique. Barre d'échelle = 1 mm. (**F**) Surface du monticule 3 montrant un aspect finement laminé. Barre d'échelle = 1 cm. (**G**) Lame mince de l'échantillon précédant montrant le détail des laminations claires et foncées de coloration de la masse des cristaux calcitiques. Barre d'échelle = 1 mm.

metric to centimetric cavities filled by micrite or peloidal micrite and/or drusy cements. Some of the cavities are bordered by microspherulitic cements (Rivularia-like microbial colony, see [9], Fig. 4) and aragonite needles (Fig. 9B).

Pseudomorphs of aragonite sea floor cement occur in part of the domal and flat laminated stromatolites. Millimetric fanning and botryoidal crystal fringes illustrated in Fig. 9C, D, E, are superposed to form laminated centimetric up to decimetric lithoherms.

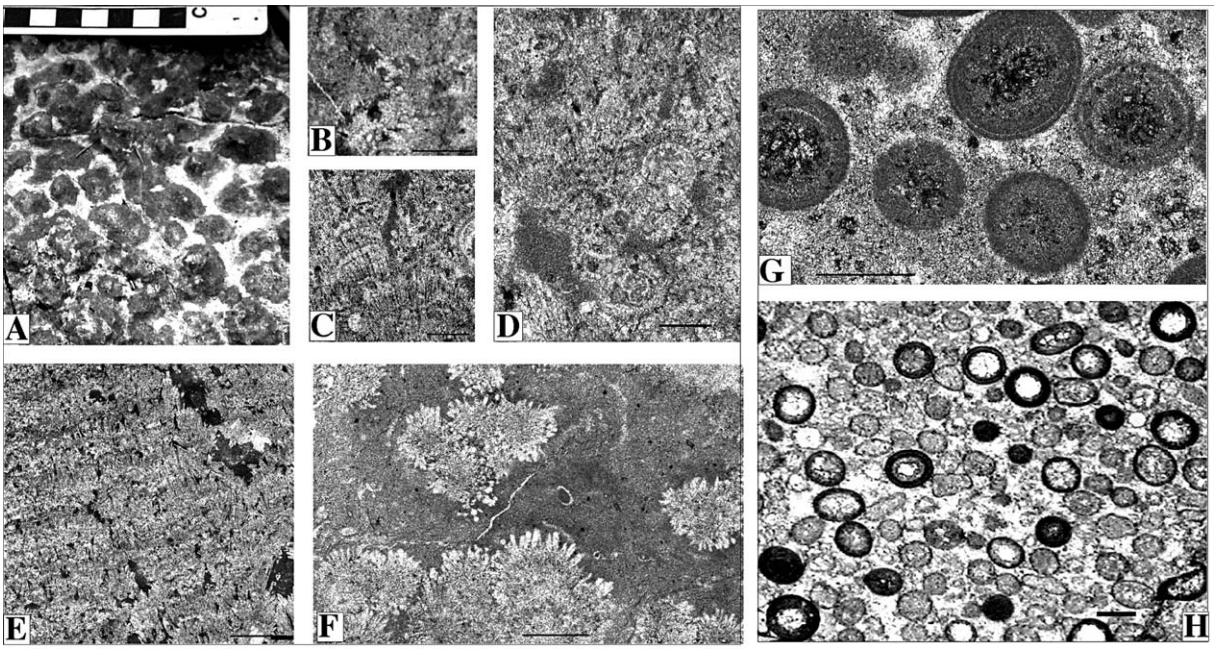

Fig. 9. Main meso- and microstructures of the crystal lithoherms and the oolitic facies. Scale bar of the microfacies (MF) is 1 mm. (**A**) Mesostructure of a spherulitic crystal masses (grey–black) surrounded by white drusy cements cropping out laterally to a Çürük dag thrombolite mound. Scale black bars in cm. (**B**) MF: pseudomorphs of a spherulitic aragonite crystal needles from the previous mesostructure. (**C**) MF: Pseudomorphs of fanning aragonite crystals occurring in the stromatolite facies of the Çürük dag lower calcimicrobial cap rock. (**D**) MF: Diagenetically altered pseudomorphs of aragonitic fans and fringes around microgastropod shells, thrombolitic bed of the Çürük dag lower calcimicrobial cap rock. (**E**) MF: Couplets of fanning aragonite crystals pseudomorphs with a fenestral fabric filled by micro-peloids occurring in the stromatolite facies of the Çürük dag lower calcimicrobial cap rock. (**F**) MF: Spherulites of aragonite crystals pseudomorphs in a micritic matrix with ostracod shells, stromatolite facies of the Çürük dag lower calcimicrobial cap rock. (**G**) MF: Detail of the oolite, with a preserved concentric texture from the Çürük dag upper calcimicrobial cap rock. (**H**) MF: Diagenetically altered oolitic grainstone from the Çürük dag upper calcimicrobial cap rock.

Fig. 9. Méso- et microstructures principales des faciès de lithohermes de précipitation et des faciès oolitiques. La barre d'échelle des microfaciès (MF) est de 1 mm. (**A**) Masse sphérulitique de cristaux sombres entourés de calcite géodique claire: c'est un faciès latéral du monticule thrombolitique du Çürük dag. Échelle centimétrique. (**B**) MF : Sphérulite d'aiguilles aragonitiques pseudomorphosées provenant du faciès précédent. (**C**) MF : Pseudomorphose en calcite de cristaux d'aragonite en éventail provenant des calcaires stromatolitiques médians de la coupe du Çürük dag. (**D**) MF : Pseudomorphose en calcite de cristaux d'aragonite en éventail et aciculaires entourant des tests de microgastéropodes ; niveaux thrombolitiques médians de la coupe du Çürük dag. (**E**) MF : Succession verticale de cristaux d'aragonite en éventail, pseudomorphosés en calcite avec des micro-cavités remplies de micro-péloïdes coccoïdaux, calcaires stromatolitiques médians de la coupe du Çürük dag. (**F**) MF : Pseudomorphose en calcite de sphérulites de cristaux d'aragonite dans une matrice micritique avec tests d'ostracodes, calcaire stromatolitique basal de la coupe du Çürük dag. (**G**) MF : Détail des oolites concentriques provenant de la partie supérieure du chapeau de calcaires microbiens du Çürük dag. (**H**) MF : *grainstone* oolitique altéré diagénétiquement et provenant de la partie supérieure du chapeau de calcaires microbiens du Çürük dag.

4.5. The ooids facies

The upper part of the calcimicrobial cap rock consists mainly of oolitic beds with minor intercalation of microbial calcilutite and thrombolitic beds. In most cases the oolites are recrystallised (Fig. 9H), but in Fig. 9G the fine concentric laminations are still preserved.

It is interesting to note that this facies has been regarded as 'disaster deposits' that formed in the aftermath of the end-Permian mass extinction by Groves [18]. As shown by this author, we agree with the strong link between these microbial mediated deposits.

5. Comparison with Armenia, Iran and China

In Armenia, two sections have been sampled, Vedi and Sovetachen, and a short account on basal Triassic

microbialites is given in Baud et al. [9,11]. In the adjacent northwestern Iran (Kuh e Ali Bashi and Zal sections) and in central Iran (Shareza and Abadeh sections), two of us (A.B. and S.R.) participated in fieldwork under the leadership of Prof. R. Brandner, in 2002. A detailed report on the Iranian calcimicrobial cap rock is in preparation. A short comparison with the Tauric microbialites is given in [11]. The first detailed description of the basal Triassic microbialites of the Abadeh section was published and illustrated by an Iranian–Japanese Working Group [21]. The authors described a 'stromatolite–thrombolite' unit about 2 m thick and illustrated the microfacies. In another work [4], this basal Triassic unit is called the 'Thrombolite zone'. This "Thrombolite zone" occurs also in the basal Dalan formation of the Zagros Range. In the Elburz Range (northern Iran), according to our field notes (see also [7,43]) laminated microbialites are widespread in the Lower Elika Formation (basal Triassic). In a recent study of the Abadeh section, the 'stromatolite–thrombolite' unit of the Iranian–Japanese R.G. has been interpreted as seafloor calcite precipitate [19]. Our own observations and thin sections favoured columnar stromatolite mound similar to those illustrated by Pratt and James [35] (Fig. 3).

The Permian–Triassic transitional succession is well exposed in southern China. In the Huaying Mountains (Sichuan Province), studies reveal an unusual crystalline carbonate crust, of possible microbial origin between the Latest Permian Changxing Formation and the Earliest Triassic bedded limestones of the Feixianguan Formation [24,25]. A microbialite framework of this carbonate crust was confirmed by Ezaki [15,16]. But in a comment, Kershaw gave questions to the Ezaki analysis and asked for responses [23].

To the south, in the Great Bank of Guizhou of the Nanpanjiang basin, an Early Triassic (Griesbachian) calcimicrobial succession is made of 'Renalcis' [26,27]. A comprehensive study of basal Triassic peloids from this area has been published [1].

A Panthalassa Permian–Triassic seamount exposed within the Chichibu Jurassic accretionary complex of southern Japan contains Griesbachian calcimicrobial bindstone overlying Changhsingian skeletal limestones [39].

6. Discussion: the post-extinction calcimicrobial cap rock

The calcimicrobial cap rock described here, but also found in other localities of the giant Lower Triassic Tethyan carbonate platforms, is interpreted as anachronistic in the sense that the thrombolites, the domal, columnar and conical stromatolites are similar to some of the facies described in Late Proterozoic and Early Palaeozoic shelf carbonate environments [5,32]. The botryoidal and fanning aragonite pseudomorphs look alike, but are smaller in shape than the Late Archean and Proterozoic aragonite seafloor cement, as illustrated in [44,46]. The Late Proterozoic cap carbonates [17] share some similarities with the described cap rock, including calcimicrobial development, seafloor precipitates and a strong carbon isotope shift [22,28]. But the Triassic calcimicrobial cap rock is neither overlying glacial deposits nor occurring after a 'snowball Earth' episode. This cap rock gives evidence of the uniqueness of the Earliest Triassic period.

Calcification of microbial mats needs specific environmental conditions such as warm water temperature, over concentration of dissolved carbon, alkalinity and other requirements [38]. The microbial explosion in the post-extinction level and at other specific times during the Early Triassic [6] up to the Spathian [36], in concert with the large carbon isotope excursions [34,37], opens the question of the gas hydrate capacitor hypothesis [14] applied to Early Triassic time, even if this hypothesis is dismissed in [34].

The non-skeletal carbonate factory, acting during the Lower Triassic metazoan-reef gap after the end-Permian mass extinction, can be interpreted as processes of carbonate production similar to those of earlier time [40]. In this sense, the basal Triassic calcimicrobial cap rock differs from most Upper Palaeozoic build-ups.

7. Conclusions: 'anachronistic' facies and calcimicrobial cap rock

- (1) On the giant Tethyan carbonate platform following the Late Permian mass extinction, the skeletal carbonate factory shift to a microbial carbonate factory.
- (2) A unique, microbial unit with stromatolites and/or thrombolites and oolites called here "calcimicrobial

cap rock" is well-dated to the post-extinction Earliest Triassic and occurs below the Upper Griesbachian coloured shales and marly-limestones, in the Taurus as in other areas of the central Tethys. Due to the presence of thick beds and mounds, this unit is forming cliffs in the landscape.

- (3) At the dawn of the Triassic, the inter-tropical Tethyan carbonate platforms and ramps were thrown into an 'anachronistic' microbialite world, with stromatolites, carbonate precipitate, thrombolites and oolites.
- (4) This seeming 'return to the past' is accompanied by a delayed biotic recovery, but a rapid return to high carbonate productivity by a non-skeletal carbonate factory. With the large carbon isotopic fluctuations, this again shows the uniqueness of the Earliest Triassic period.

Acknowledgements

Two of us (SR and AB) were funded by the Swiss National Foundation (projects Nos. 20-53787.98 and 67941.02), by the Geological Museum in Lausanne and by the Dr Joachim de Giacomi Foundation. One of us (JM) thanks the CNRS, UMR 7578 (Paris) for the fieldwork grant. We are grateful to the Demirel University of Isparta, particularly to Prof. F. Yagmurlu for the help with logistics and to N. Özgül for his help and advices in the field. Thanks to S-J. Jackett and S. Pruss for their useful corrections of the text and to S. Pruss and S. Kershaw for their constructive criticism of the manuscript.

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