



# Discovery of a Mississippian Reef in Turkey: The Upper Viséan Microbial-Sponge-Bryozoan-Coral Bioherm From Kongul Yayla (Taurides, S Turkey)

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**Abstract:** For the first time, a Mississippian reef is described from Turkey. This microbial-sponge-bryozoan-coral bioherm has been discovered in the Central Taurides (South Turkey), at Kongul Yayla located between Hadım and Taşkent. The bioherm contains a rich and diversified fauna: sponges and rugose corals are of particular interest. The bioherm shows four main facies reflecting distinct growth stages from the base to the top: (1) the basal bioclastic beds, (2) the core facies formed of framestone comprising rugose corals, lithistid sponges, fistuliporid bryozoans and microbial boundstone, (3) the crest facies with large colonies of cerioid rugose corals and chaetetid sponges, and (4) the bioclastic facies containing reworked material from the bioherm in lateral and overlying positions to it. The entire bioherm is topped by siltstones with thin bioclastic horizons, often slumped. *Siphonodendron pauciradiale* and *Lithostrotion maccoyanum* are the guide taxa for the RC7β biozone and indicate an upper Asbian age for the bioherm. The Kongul Yayla bioherm resembles most the Cracoean reefs from northern England. It confirms the position of this buildup type along the platform margins and edges in the Palaeotethyan realm as seen in the British Isles, Belgium, southern France, southern Spain and North Africa. Facies and the coral fauna argue for a European affinity of the Anatolian terrane.

**Key Words:** Mississippian, Viséan, Asbian, sponges, rugose corals, bioherm, microbialite, Kongul Yayla, Anatolide, Tauride, Bolkar Dağı, Hocalar Nappes, Kongul Formation, Zindancık Formation

## Bir Mississipiyan Resifi'nin Türkiye'de İlk Kez Bulunuşu: Kongul Yaylası'ndan (Toroslar, G Türkiye) Üst Viziyen Mikrobiyal-Bryozoa-Mercan Biyohermi

**Özet:** Bir Mississipiyan resifi Türkiye'de ilk kez tanımlanmıştır. Bu mikrobiyal-sünger-bryozoa-mercan biyohermi Orta Toroslar'da (Güney Türkiye) Hadım ve Taşkent arasında yer alan Kongul Yaylası'nda bulunmuştur. Biyoherm zengin ve çeşitlenmiş bir fauna içerir: bu çalışmada süngerler ve rugosa mercanlara yoğunlaşmıştır. Biyoherm alttan üste belirgin büyüme evrelerini yansıtan dört ana fasiyesi içerir: (1) biyoklastik taban katmanları, (2) rugosa mercan, lithistid sünger ve fistuliporid bryozoa içeren çatıtaşı ve mikrobiyal bağlamtaşıdan oluşan çekirdek fasiyesi, (3) büyük cerioid rugosa mercan ve chaetetid sünger kolonileri içeren tepe fasiyesi, (4) altta ve stratigrafik olarak aynı düzeylerde bulunan biyohermlerden türeme işlenmiş malzeme içeren biyoklastik fasiyesi.

Tüm biyoherm, ince biyoklastik düzeyler ve çoğunlukla slump yapıları içeren silttaşları tarafından üzerlenir. *Siphonodendron pauciradiale* ve *Lithostrotion maccoyanum* RC7β biyozonunu işaret eden kılavuz taksonlardır ve biyohermin geç Asbiyen yaşlı olduğunu gösterirler. Kongul Yayla biyohermi kuzey İngiltere'deki Crocoean resiflerine büyük benzerlik sunar. Biyoherm, Britanya Adaları, Belçika, güney Fransa, güney İspanya ve Kuzey Afrika'da gözlemlendiği gibi bu tip yığılımların Paleotetis alanının platform kenarlarında geliştiği görüşünü doğrular. Fasiyes ve mercan faunası Anadolu tektonik birliklerinin Avrupa'ya benzer olduğunu gösterir.

**Anahtar Sözcükler:** Mississipiyan, Viziyen, Asbiyen, sünger, rugosa mercan, biyoherm, mikrobiyalite, Kongul Yayla, Anatolid, Torid, Bolkar Dağı, Hocalar Napı, Kongul Formasyonu, Zindancık Formasyonu

## Introduction

The Waulsortian mounds are the traditional examples of Dinantian (Mississippian) bioconstructions in

NW Europe (e.g., Lees & Miller 1995). However, they are only a fraction of the well diversified and widely distributed spectrum of Mississippian

bioconstructions (e.g., Aretz & Herbig 2003a). Viséan and Serpukhovian bioconstructions ranging from microbial buildups to coral reefs with very diversified fauna and flora have been documented in Western Europe, in Belgium (Mucchez *et al.* 1990; Aretz & Chevalier 2007), Southern France (Aretz & Herbig 2003a), North Wales (Bancroft *et al.* 1988), South Wales (Aretz & Herbig 2003b), Northern England (Mundy 1994), Ireland (Somerville *et al.* 1996), South-western Spain (Rodríguez-Martínez *et al.* 2003), and also in Northern Africa (Bourque *et al.* 1995; Bourque 2007; Aretz & Herbig 2008), United States (Lord & Walker 2009), Eastern Australia (Webb 1999) and Japan (Sugiyama & Nagai 1994; Sugiyama & Nagai 1994).

The Mississippian of Southern Turkey is relatively poorly known. Apart from large-scale tectonostratigraphic studies (Şengör & Yılmaz 1981; Kozur & Göncüoğlu 1998; Stampfli 2000; Göncüoğlu *et al.* 2007; Moix *et al.* 2008) only a few studies of the regional geology and tectonics described sections in the Mississippian of the Taurides (Özgül 1997; Altiner & Özgül 2001). Only very limited data on Mississippian macrofossils are available from the Taurus (Unsalaner-Kiragli 1958; Minato & Kato 1977).

The present paper gives a first description of a microbial-sponge-bryozoan-coral reef discovered in the Hadim region in the Taurides. It aims (1) to give a preliminary description of the reef facies, (2) to characterize the biotic association, (3) to date the reef by rugose coral biostratigraphy, and (4) to compare the Turkish reef with other well known Mississippian buildups.

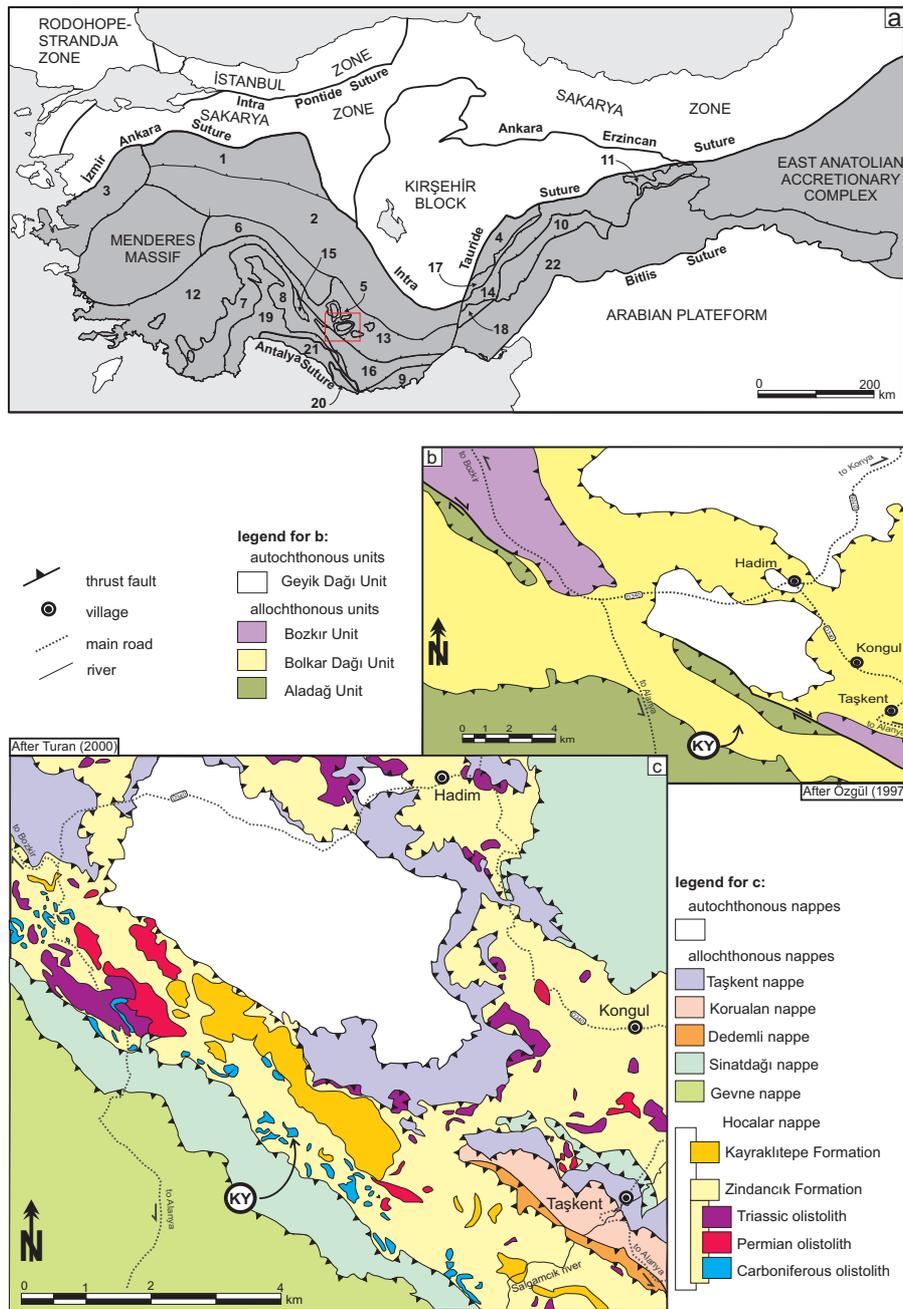
## Settings

The Turkish landmass is made of several continental fragments (terranes) juxtaposed during the Alpine orogeny (Middle Triassic–Late Eocene, Şengör 1984) and separated by complex suture zones. These are, from North to South, Rhodope-Strandja Zone, İstanbul Zone, Sakarya Zone, Kırşehir Block, Menderes Massif, Anatolide-Tauride Block and the Arabian Platform (Okay & Tüysüz 1999). Despite many years of researches on tectonics, stratigraphy and palaeogeography, a huge number

of controversies persists about the time and intensity of the deformation, and the boundaries of the continental and oceanic entities (see Görür & Tüysüz 2001). Moreover, there is no consensus about the denomination and classification of these units (see Robertson 2000; Moix *et al.* 2008). The southern part of Turkey corresponds mainly to the Anatolide-Tauride Block (Özgül 1984) – also named the Anatolide-Tauride Platform (Şengör & Yılmaz 1981), the Anatolide-Tauride Composite Terrane (Göncüoğlu *et al.* 2000) or the Menderes-Taurus Platform (Görür & Tüysüz 2001) – which corresponds to an assemblage of tectono-stratigraphic units, elongated E–W and bounded by major faults (Figure 1a). Traditionally, the whole Anatolide-Tauride Block is said to have originated at the northern margin of Gondwana (Okay *et al.* 2006), but recent works separated the Anatolian terranes of Eurasian affinity, from the Taurus Terrane (the ‘Cimmerian blocks’ of Şengör 1984) with a Gondwanan origin (see Moix *et al.* 2008).

In the Western Taurides, Özgül (1984, 1997) recognized six tectono-stratigraphic units. The Geyik Dağı unit, in a central position, is considered to be autochthonous. All other units, namely the Bozkır, Bolkar Dağı and Aladağ units in the north, and the Antalya and Alanya units in the south (Figure 1b) are allochthonous. In the Hadim region between the city of Konya and the town of Alanya, the Mississippian crops out in the Aladağ and Bolkar Dağı units (Figure 1b). In the latter, the Mississippian succession consists of shallow-water limestones intercalated with siltstone deposits integrated in the Zindancık Member of the Kongul Formation (Figure 2a). Özgül (1997) and Altiner & Özgül (2001) attributed a Viséan–Serpukhovian age to the limestones and concluded that they are intercalated with contemporaneous siltstone. Ekmekçi & Kozur (1999) concluded a Moscovian age for the entire formation based on conodonts from a single sampled locality.

Turan (2000, 2001) distinguished, in the same area, an autochthonous group (Jurassic to Eocene) and an allochthonous group made of six units or tectonic nappes. These are the Korualan, Dedemli, Taşkent, Hocalar, Sinatdağı and Gevne nappes (Figure 1c). The last one corresponds to the Aladağ Unit of Özgül



**Figure 1.** (a) General structural map of Turkey, redrawn and modified after Okay & Tüysüz (1999) and Şengör (1984). The Anatolide-Tauride Block is presented in grey. The numbers refer to the tectono-stratigraphic (sub-)units of the Anatolide-Tauride Block (after Okay & Tüysüz 1999). Legend: 1- Tavşanlı Zone; 2- Afyon Zone; 3- Bornova Flysch Zone; 4- Bolkar Dağı Unit; 5- Hadim Nappes; 6- Sultan Dağ; 7- Beydağları; 8- Anamas Dağ; 9- Alanya Nappes; 10- Geyik Dağ Unit; 11- Munzur Dağları; 12- Lycian Nappes; 13-14- Bozkır Unit; 15- Beyşehir-Hoyran Nappes; 16-18- Aladağ Unit; 19- Antalya Unit; 20- Alanya Tectonic Window; 21- Alanya Nappes; 22- Biltis-Pörtürge Unit. Red squares correspond to the enlarged zones in Figure (b) and (c). (b) Simplified tectonic map of the Hadim area, redrawn after Özgül (1997) showing the tectonostratigraphic units of Özgül (1984, 1997). The formations are not presented. (c) Simplified tectonic map of the Hadim area, redrawn after Turan (2000) showing the tectonostratigraphic units (nappes) of Turan (2000). The formations are detailed only for the Hocalar Nappe. In (b) and (c), the Kongul Yayla section is indicated with 'KY'. Maps (b) and (c) are not at the same scale and do not cover exactly the same areas.

(1984) while the Hocalar Nappes are included in the Bolkar Dağı unit. In the Hocalar nappes, Turan (2000) described two formations: the Kayarklitepe Formation (Triassic quartzites and sandstones) and the Zindancık Formation (Figure 2b). The latter is formed of a thick siltstone and sandstone succession with limestone blocks interpreted as olistoliths ('metaolistormu' of this author) within a flysch sequence of supposed Triassic age. On its maps, Turan (2000, Figure 1c) indicates Carboniferous, Permian and Triassic blocks. The limestones cropping out in the Kongul Yayla section are presented by this author as olistoliths.

The nature of the limestone units (olistoliths versus lenses) are not well understood. Neither the regional literature (Hocalar nappe versus Bolkar Dağı unit), nor the local conditions of outcrop (highly tectonized and slightly metamorphosed), do not enable us to choose one of the two proposed models.

In the Kongul Yayla section (stratotype of the formation after Özgül 1997), three limestone units are exposed on Kongul hill, separated from each other by siltstone units. The northern limestone unit (NLU) is at least 120 m thick, and crops out near the path, north of the hill. It is well bedded and bedding mostly dips north. From north to south, the following succession has been observed (Figure 3). The lower half consists of 60 m of variegated shallow-water limestone facies, which are succeeded by 10 m of dark bioclastic limestone with corals, brachiopods and crinoids. The latter is topped by a 3-m-thick interval with abundant productid brachiopods, followed by a 10-m-thick unit of light oolitic grainstones with corals and brachiopods, with an uppermost 0.5-m-thick bed with many large *Lithostrotion araneum* colonies. The upper part comprises 25 m of various limestone facies poor in macrofossils. The contact with the surrounding siltstones is sharp and oblique to the bedding. Between this first unit and the next one, there are 100–120 m of non fossiliferous dark brown siltstones, and few centimetre- to metre-thick beds of pale quartzitic sandstone (Figure 3). The second unit, called the biohermal limestone unit (BLU), forms the main part of the hill, is approximately 50 m thick and dips southward. Its reef character was previously recognized by Özgül (1984, 1997). Its base is made up of 15 m of thin-bedded coarse crinoidal

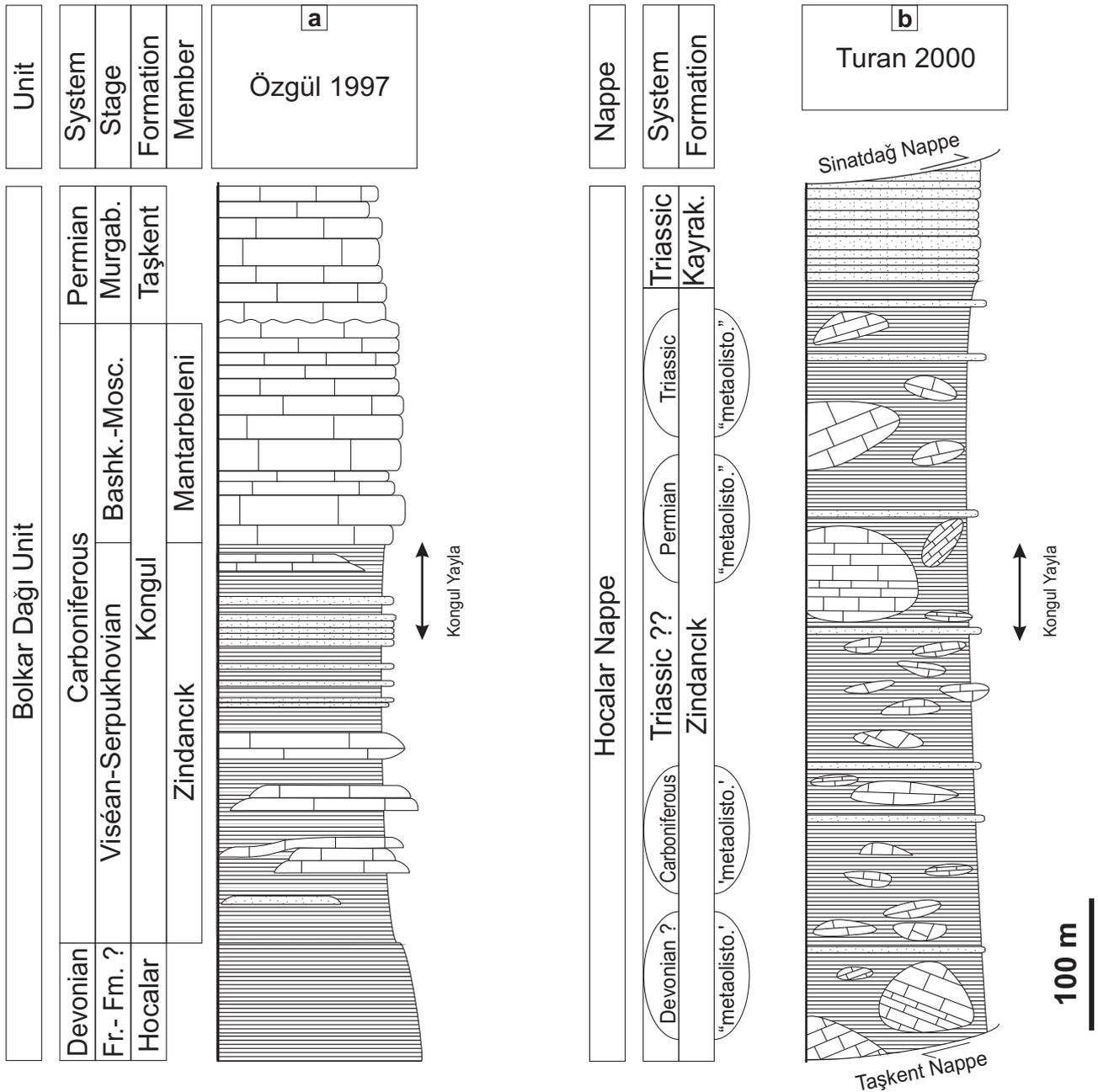
limestone with numerous bioclasts and fragments of corals, brachiopods, gastropods, pelecypods, etc. The top of this unit is a 0.6-cm-thick bed constructed by large colonies of *Siphonodendron pauciradiale* (Figure 4b). The bioherm *sensu stricto* begins above the *Siphonodendron* bed with a 25-m-thick massive pale limestone rich in fossils, particularly at the top (Figure 4d, f). The latter is overlain by 5- to 8-m-thick thickly bedded coarse bioclastic limestone containing stemmed echinoderms and other centimetre-size bioclasts. The overlying 25–30-m-thick package of dark shale still contains bioclasts (crinoids, corals and brachiopods) but is progressively silty and sandy up-section. Several levels within the shale (particularly the bioclastic levels) are folded by metre-scaled slumps (Figure 4e). The same black silty shale crops out, at least, over 50 m and is followed by a third, 20–25-m-thick, limestone block (southern limestone unit – SLU) which is overlain by a last siltstone unit with quartzitic sandstone beds (Figure 3).

## Materials and Methods

The material was collected in the Taurus mountains in August 2009. The sampling was mainly focused on the collection and analyses of the stratigraphical and lateral distribution of the rugose corals, with a particular interest for the biohermal unit. The section was preliminarily divided into lithological units (KY1 to KY16) which were logged but not sampled bed-by-bed. The biohermal unit was measured both on the top and in the flank of the hill. More than 50 samples were collected (both for corals and lithologies) and 90 thin sections were prepared (30x45 mm, 45x60 mm, 60x90 mm and 70x70 mm sized thin sections). The facies analysis is based on qualitative and semi-quantitative – field and thin sections – observations. The quality of the material did not permit neither a detailed sedimentological study nor cement analyses.

## Biostratigraphy

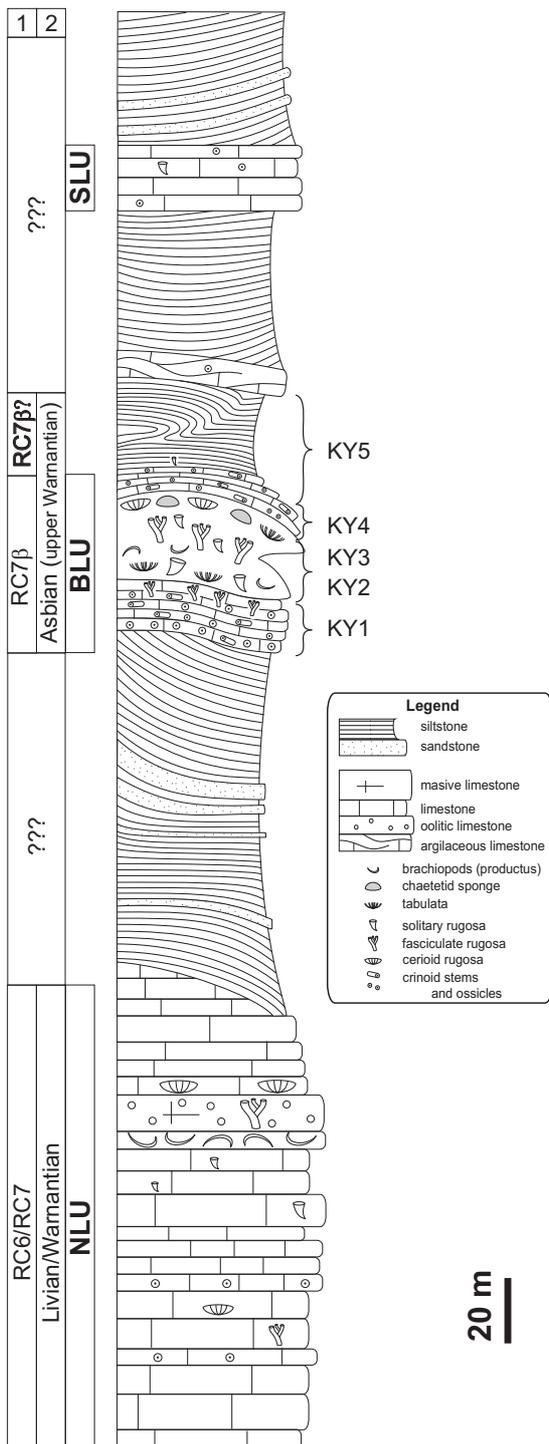
Özgül (1997) indicated a Viséan to Serpukhovian age for the Zindancık Member of the Kongul Formation (Figure 2a), based on basic identification of a few foraminifera from various limestone levels. He did not propose any age for the siltstones. Turan (2000)



**Figure 2.** Comparison between the two lithostratigraphic interpretations of the Viséan formations in the Hadim area. (a) Lithological succession of the Kongul Formation with limestone lenses interbedded in siltstone-sandstone, after Özgül (1997). (b) Lithological succession of the Zindancık Formation with Carboniferous olistholiths in siltstone-sandstone matrix, after Turan (2000). For both lithostratigraphic logs, 'Kongul Yayla' corresponds to the supposed stratigraphic position of the Kongul Yayla section within the formations (see Figure 3). Legend: Fr.- Frasnian; Fm.- Famennian; Bashk.- Bashkirian; Mosc.- Moscovian; Murgab.- Murgabian; Kayar.- Kayraklıtepe Formation; 'metaolisto.'- 'metaolistostomu' of Turan (2000). See Figure 3 for the legend of lithologies.

identified a few foraminifera and macrofossils and concluded to a Carboniferous age for some olistholiths of the Zindancık Formation (Figure 2b). The supposed

age of the siltstones (and for the whole formation) is Triassic. This surprising age is not discussed by this author and remains questionable.



**Figure 3.** Schematic log of the Kongul Yayla section. SLU– southern limestone unit, BLU– biohermal limestone unit, NLU– northern limestone unit. KY1 to KY5 corresponds to the lithological units described in the main text. Legend: 1– Rugose coral zones after Poty *et al.* (2006); 2– Viséan sub-stages (Belgium-British Isles).

In the present work, biostratigraphic dating is based on rugose corals. The northern limestone unit (NLU) provided few corals, among them *Axophyllum* aff. *pseudokirsopianum* and *Lithostrotion araneum*, which both have rather long stratigraphic ranges. The youngest age for the NLU is Warnantian (RC7 biozone of Poty *et al.* 2006) and the oldest age is Livian (RC6). The biohermal unit (BLU) is richer in fauna. The occurrence of *Siphonodendron pauciradiale* at the base and of *Lithostrotion maccoyanum* at the top, in the absence of younger fauna, is sufficient to indicate a Warnantian age (Asbian, RC7 $\beta$  biozone of Poty *et al.* 2006). The bioclastic rudite (KY4) and the siltstones above the BLU are also Viséan in age because *Soshkineophyllum* sp. has been collected near the contact with the reef. The southern unit (SLU) provided no diagnostic taxa for precise biostratigraphy; only *Clisiophyllum* sp. indicated a Mississippian age (Figure 3). Further investigation with foraminifera should allow more precise dating of each block, as well as the whole formation.

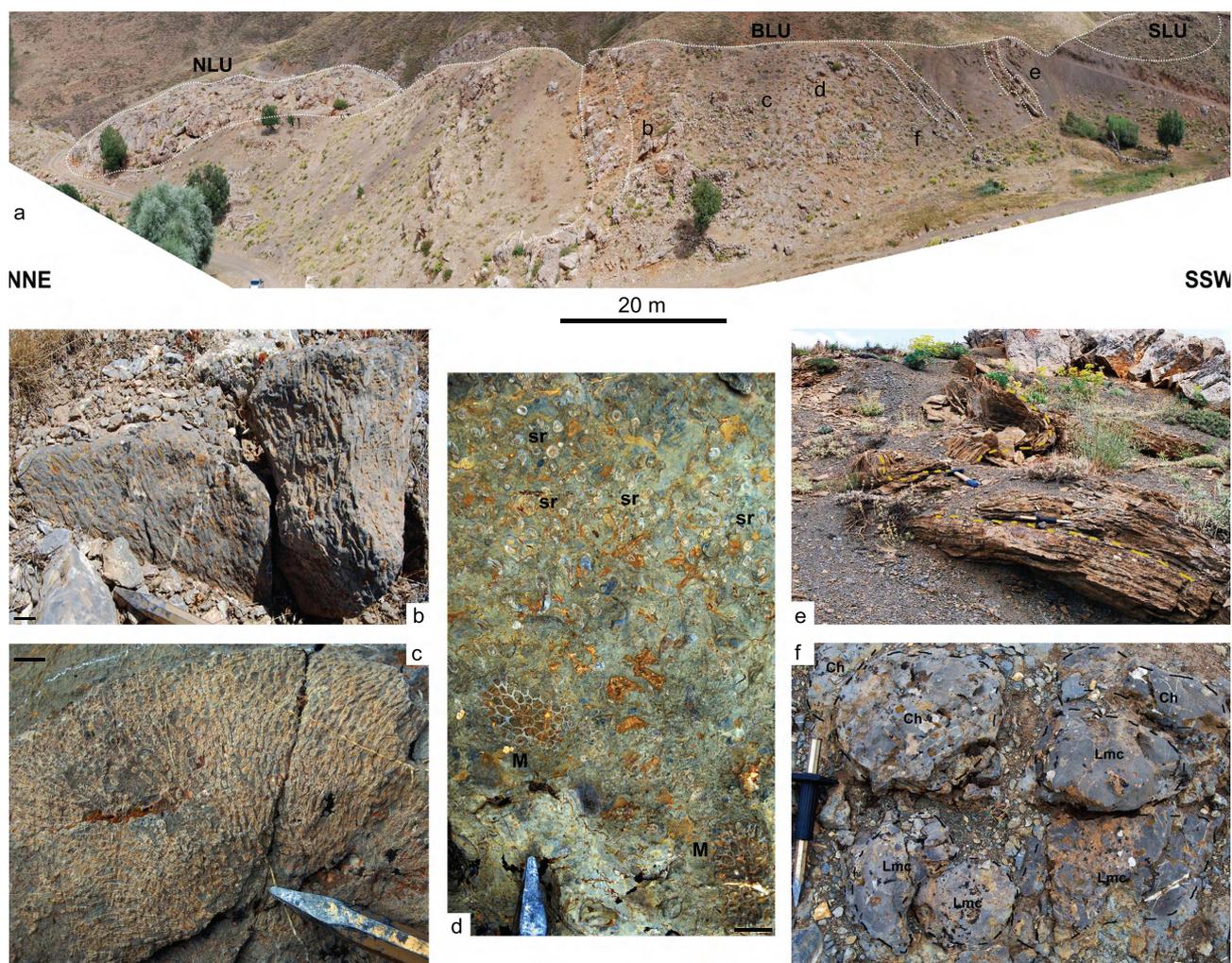
## Reef Facies

### Basal Facies

The sole of the bioherm (KY1 on Figure 2) is made of 15 m of cm- to dm-thick beds of poorly sorted coarse bioclastic rudstone very rich in stemmed echinoderms (up to 10 cm-long stems and 2 cm-large ossicles) and brachiopods debris. Minor components are gastropods and corals fragments, bryozoans, foraminifera, ostracods and trilobites. The matrix is neomorphosed to pseudospar and dolospar, usually weathered in a yellowish opaque ferruginous dolomite. The upper part of this bioclastic unit is a 0.6-m-thick bed containing *Siphonodendron pauciradiale* (Figure 4b). The colonies form a laterally continuous bafflestone in which there are small colonies of tabulate corals (multithecoporids), brachiopods and foraminifera (*Tetrataxis* attached to the corallites of *S. pauciradiale*). Although the matrix is often dolomitized and opaque, some small bioclasts (bryozoans and brachiopods) have been observed. The matrix is also rich in detrital quartz grains.

### Core Facies

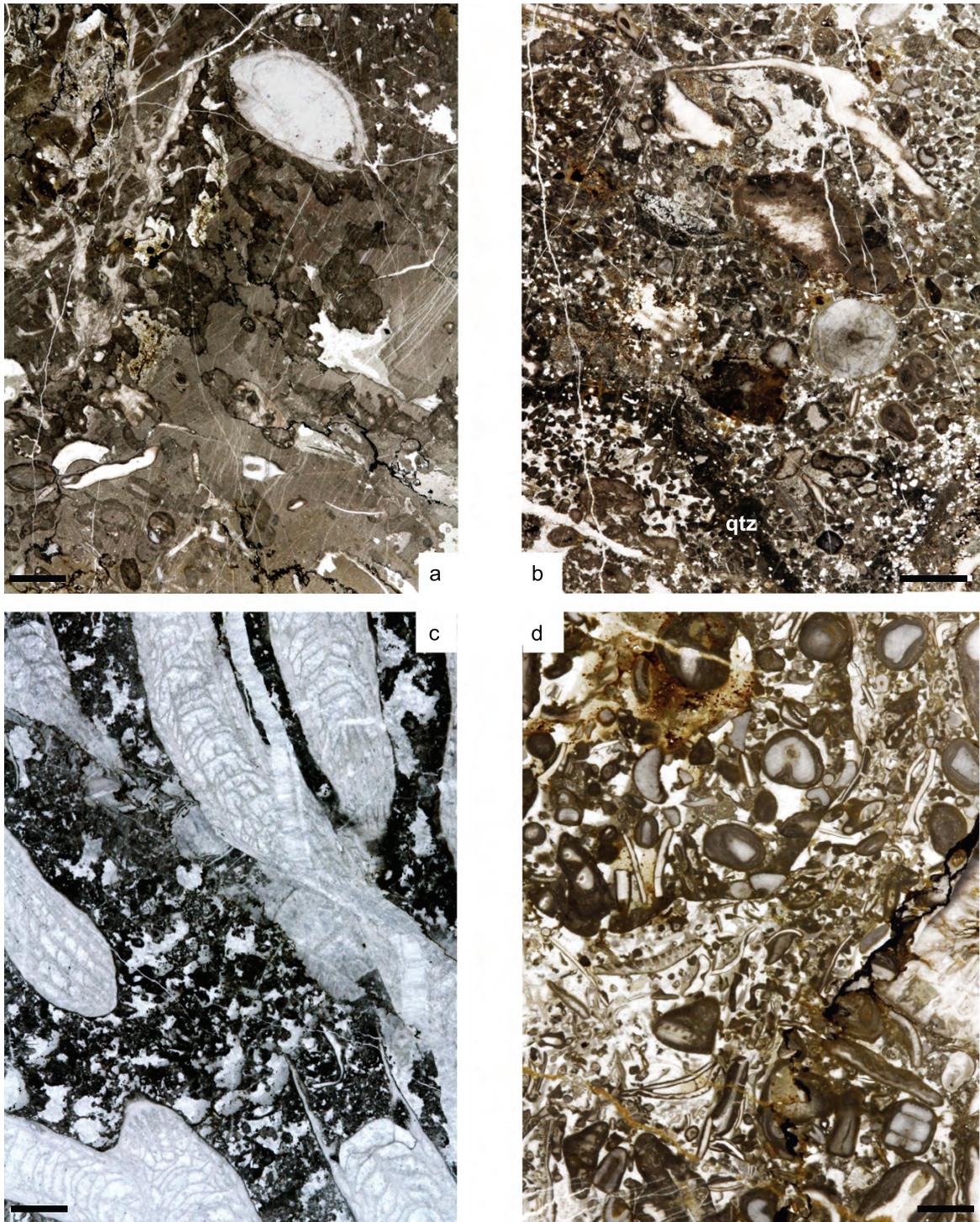
The first constructed facies attributable to the bioherm (KY2) is a matrix supported floatstone passing



**Figure 4.** Lithologies of Kongul Yayla section. (a) General view of the section with the three limestone units and the siltstone units. Legend: NLU– northern limestone unit (part.), BLU– biohermal limestone unit, SLU– southern limestone unit. The units circled with dotted lines are those exposed in Figure 2. b–f refer to the following pictures. Scale bar 20 m. (b) Bed constructed by *Siphonodendron pauciradiale* at the base of the bioherm. (c) Large colony of *Espiella* sp. from the core of the bioherm. (d) Microbial boundstone with numerous small solitary undisseminated rugose corals (sr) and michelinids tabulate corals (‘M’) from the top of the bioherm. Scale bar for B–D= 2 cm. (e) Slumped siltstone and calcareous shale overlying the bioherm. (f) Large colonies of *Lithostrotion maccoyanum* (‘Lmc’) and chaetid sponges (‘Ch’) forming the capping bed of the bioherm (photography parallel to the bedding). Scale for e–f given by the chisel (30 cm).

to wackestone with various bioclasts, fenestellid bryozoans and brachiopods (Figure 5a). The matrix is dark peloidal micrite of microbial origin and intraclastic peloidal clots. Millimetre-scaled cement-filled cavities are present within the peloidal matrix. This facies passes vertically into more bioclastic packstone-grainstone with stemmed echinoderms ossicles, ostracods, bryozoans and numerous small foraminifera (Figure 5b). The two microfacies are rich

in coated and micriticized grains varying in size from 0.05 to 2 mm. The larger skeletal grains (fenestellid and stenoporid bryozoans, stemmed echinoderms, brachiopod shells) are involved in oncoids-bearing mm-thick crusts of dark peloidal or laminated microbial micrite. Inside this initial reef core facies, fasciculate colonial corals, 0.5 m in diameter (Figure 4c) are commonly grouped in patches or clusters. These patches are several metres apart. The space



**Figure 5.** Microfacies of the bioherm. (a) micritic boundstone with coated brachiopods from the lower part of the biostrome (KY2.3). (b) bioclastic grainstone with small oncoids, crinoids and quartz grains ('qtz') from the base of the bioherm (thin section KY2.2). (c) Bafflestone with *Siphonodendron pauciradiale* with microbial pelloids between the corallites, block from lower part of the bioherm (KYB.4). (d) Bioclastic rudstone with crinoids, brachiopods, rugose corals and bryozoan debris, coated and forming microbial oncoids. Bioclastic beds overlying the bioherm (KY4.6). Scale bar for a–d= 2 mm.

between the coral corallites is usually filled by peloidal micrite with irregular fenestral porosity (peloidal microbialite fragments). This microbialite-coral boundstone shows a good example of combination between skeletal constructors and non-skeletal elements acting as stabilizers and secondary constructors. Microbialite facies forms the upper part of the bioherm (KY3): microbial boundstone with dark peloidal matrix as the dominant form, but some microbial coating and crust are also common around macrofossils. The local formation of microbial-coral boundstones, resulting from coatings and crusts of microbial laminae, and in thickets of small solitary undissepimented rugose corals (Figure 4d & 6a) was observed in this part of the bioherm. These corals (*Rotiphyllum densum*) are bound in growth position by the microbialite encrustations, and, to a lesser extent, by lithistid sponges and fistuliporid bryozoa. The crusts are heterogeneous and commonly made of alternating microbial laminae, sponge and clotted dark micrite. The space between the encrusted corals is filled with peloidal micrite and small cemented fenestral cavities.

Many multi-encrusted bodies have been observed in this facies. They consist of several superposed crusts of different organisms (Figure 6d, e) forming sub-spherical, bulbous or columnar centimetre-large bodies. The main contributors to these bodies are stenoporid and fistuliporid bryozoans, auloporid tabulate corals, lithistid sponges and micritic microbial laminae. Foraminifera (*Tetrataxis*) and fenestellid bryozoans are also commonly involved. The size of such bodies varies from 5 mm up to 10 cm. They do not play a dominant construction role at the reef scale but seem to be local carbonate-producing centres.

In this part of the bioherm (KY3), the fauna is rich and diversified and includes large productid and spiriferid brachiopods, gastropods, stemmed echinoderms (large stems), foraminifera attached to various skeletal grains, ramose rhabdomesid bryozoans, reticulate fenestrate fenestellids, massive stenoporids (*Tabulipora* sp., Figure 6d), massive encrusting fistuliporids (*Fistulipora* sp., Figure 6e), very abundant lithistids (Figure 6b) and other calcareous sponges (complete or only scattered spicules), tabulate corals (michelinid, syringoporid, multithecoporid) and rugose

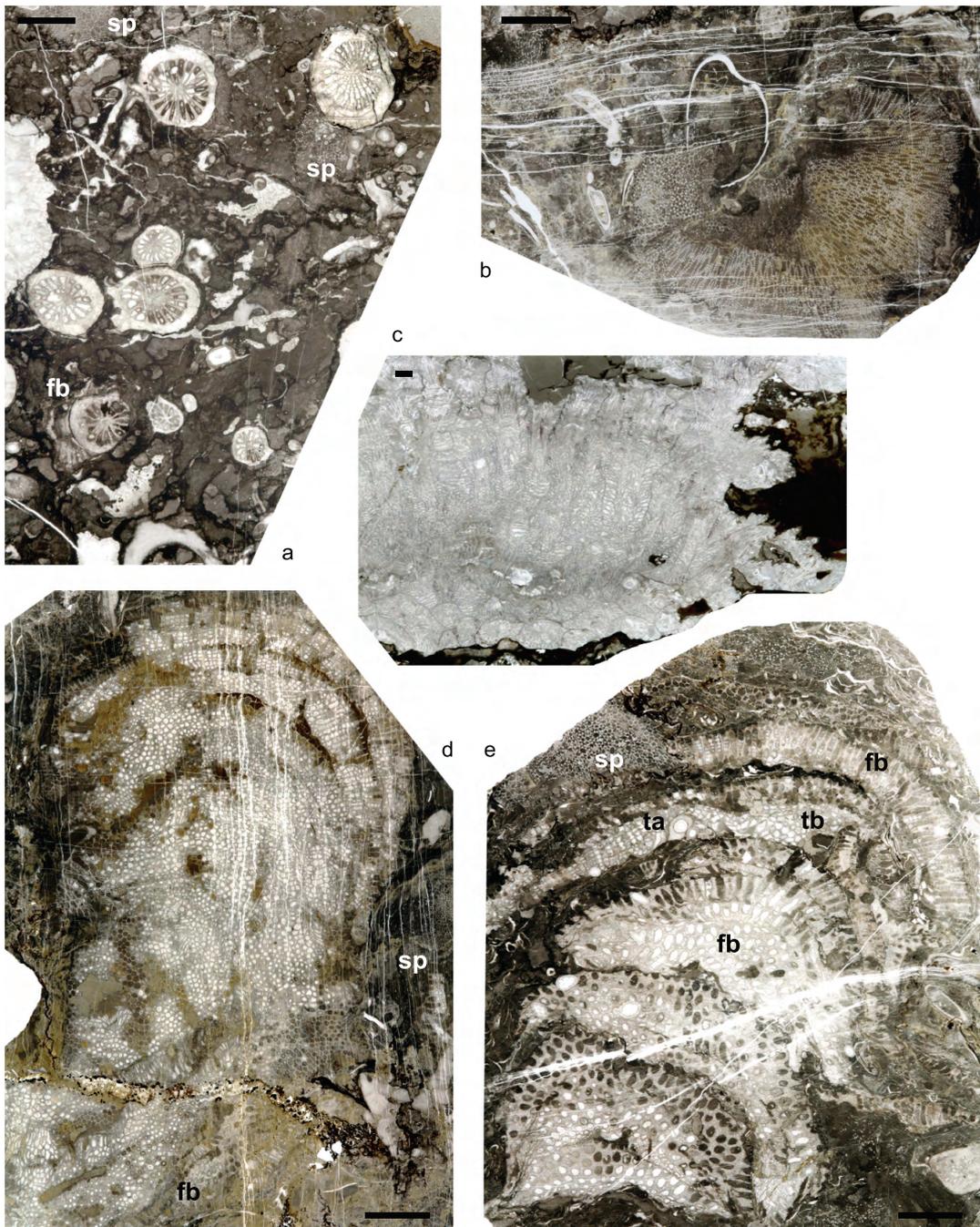
corals. The most common rugose corals are *Axophyllum* aff. *pseudokirsopianum*, *Axophyllum* sp., *Gangamophyllum* sp., *Amygdalophyllum* sp., *Palaeosmia murchisoni*, *Palaeosmia multiseptata* (up to 10 cm in diameter), *Siphonodendron irregulare*, *Siphonodendron pauciradiale*, *Espiella* sp. (Figure 4c) and small solitary undissepimented rugose corals (*Rotiphyllum densum*, *Amplexocarinia* aff. *cravenense*).

#### *Reef-Crest Facies*

The uppermost part of the bioherm is a coral-chaetetid capping bed mainly formed by large (1 m-scale) colonies of *Lithostrotion maccoyanum* and chaetetid sponges (Figure 4f) forming a metre-scaled framestone. Despite their exceptional size, the colonies seem to have fought against sediment fouling and burial, because many of them show disrupting growth on the topmost surface of the colonies and rejuvenescence features (Figure 6c). The space between the colonies is filled with a fine bioclastic wackestone containing bryozoans, echinoderm stems, gastropod shells and scattered sponge spicules. The matrix is a peloidal micrite with small millimetre-scaled cemented fenestral cavities. The sediment is usually argillaceous and weathered in an opaque ferruginous dolomite.

#### *Flank Facies*

The 5–8 m of limestone overlying the bioherm (KY4) comprise dm-thick beds of bioclastic grainstone to rudstone with coarse and badly sorted stemmed echinoderm ossicles, brachiopod shells and coral fragments, bryozoans and foraminifera. Moreover, centimetre-sized lithoclasts are common in this facies (Figure 5d). They show the same (or very similar) microfacies as the whole rock: a coarse bioclastic grainstone-rudstone with coated and micriticized grains. The presence of a microbial coating and crust around skeletal grains, as well as faunal similarities with previous reef assemblages indicates their para-autochthonous character, linked to flank deposition. Above, the amount of coated grains is reduced and the stemmed echinoderm stems become dominant. At the base, microsparitic or pseudosparitic matrix is dominant and towards the top, becomes more argillaceous, and detrital quartz grains are abundant.



**Figure 6.** Microfacies of the bioherm. (a) Microbial boundstone with small solitary undissepimented rugose corals (*Rotiphyllum densum*) on which sponges ('sp') and fistuliporid bryozoans ('fb') have grown up. Upper part of the bioherm (KY3.9). (b) Transverse section through a lithistid sponge. Upper part of the bioherm (KY3.14.b). (c) Longitudinal section in a *Lithostrotion maccoyanum* colony showing rejuvenescence in the upper part of the colony, due to sediment fouling. Crest facies of the bioherm (KY3.8). (d) Multi-encrusted body mainly made of stenoporid bryozoans (*Tabulipora* sp.) with some sponges ('sp') and fistuliporid bryozoans ('fb', *Fistulipora* sp.). Upper part of the bioherm (KY3.13). (e) Multi-encrusted body involving fistuliporid bryozoans ('fb'), stenoporid bryozoans ('tb'), sponges ('sp') and auloporid tabulate corals ('ta'), several microbial micritic laminae are involved in the encrustment. Upper part of the bioherm (KY3.14). Scale bar for a–d= 2 mm.

The siltstones and calcareous shales overlying the limestones remain bioclastic, with stemmed echinoderms, solitary rugose corals and brachiopods in the lower 2–3 m (Figure 4).

### Interpretation

As in many Palaeozoic reefs, the sole of the Kongul Yayla bioherm (unit KY1) is made of crinoidal rudite ('pelmatozoan sand' of Aretz & Herbig 2003a). It formed a (hard) substrate with many possibilities for attachment, which enabled the initial growth of the constructors. The biostromal bed with *S. pauciradiale* at the base (unit KY2) of the reef is the first step of colonization by corals and the establishment of a skeletal frame. Micritic coatings and crusts around the bioclasts and fossils illustrate the microbial component in stabilising this structure. Sponges also first appeared at the base of the reef and remained very common in the other facies. The constructing organisms can be divided into two categories based on the importance of their role in the construction of the reef. The first category comprises the skeletal constructors, including the colonial rugose corals (both fasciculate and cerioid), chaetetid sponges, massive bryozoans and rare tabulate corals. They produce a framestone facies. The second category comprises the stabilizers and non-skeletal constructors, which form boundstones: these are solitary corals, bryozoans (fenestellids), sponges and, above all, microbial communities forming microbialites.

The apparent lack of green algae is one of the most striking features of the bioherm. The absence of photosynthetic multicellular organisms is traditionally allied with deep aphotic environments. However, the presence of highly diverse macrofaunal and microfaunal assemblages dominated by corals and sponges does not fit with deep aphotic conditions but more probably corresponds to dysphotic conditions (Madi *et al.* 1996). The reason is probably linked to water turbidity rather than depth (see discussions in Aretz & Herbig 2008; Aretz *et al.* 2010). Almost all facies described here above are quartz-bearing. The origin of the quartz is detrital and might record siliciclastic influx related to both sea-level fluctuations (Aretz & Herbig 2003a) and erosion of relief. This relief may have been a rising hinterland

in an initial phase of the Hercynian orogeny, but the latter has never been clearly documented in the Taurides (Okay & Tüysüz 1999; Okay *et al.* 2006). Göncüoğlu *et al.* (2000) attributed a volcanic origin to the siliciclastic influx.

Palaeobathymetry is not easily estimated because of the probable water turbidity and lack of guide organisms. Sea level fluctuations are also not easily recognized in the facies succession due to lateral variations of turbulence and the absence of clear high energy facies such as oolitic bars or erosion surfaces. The flank facies could alternatively be considered as post-reef bioclastic deposits caused by the onset of a relative sea-level increase.

If the hypothesis of interbedded limestone/siltstone formation is accepted, the stratigraphic succession of lithologies could be interpreted as the result of sea level changes. The siltstones should thus correspond to low sea level sediments whereas limestone units correspond to high sea level deposits. A detailed sequence stratigraphic analysis is needed for further precision.

The fossil assemblage shows a clear vertical distribution. In the basal bioclastic facies (KY1), the most common organisms are the stemmed echinoderms allied to bryozoans, brachiopods and fasciculate rugose corals (*S. irregulare* bed) which is comparable to the '*Plicatifera* community' of Mundy (2000). The base of the core facies (KY2) is marked by the development of lithistid sponges and fenestellid bryozoans with scattered solitary rugose corals. This stage corresponds to the '*Saharopteris* community' of Mundy (2000) and to Zone 6: 'sponge-fenestellid assemblage' and Zone 5: 'crinoid-fenestellid assemblage' of Madi *et al.* (1996). Both indicate a low to middle biodiversity developed in the storm wave zone but with aphotic conditions. The main core facies (KY3) belongs typically to Zone 4: 'colonial rugose coral-microbial encruster assemblage' of Madi *et al.* (1996), characterized by the intergrowth of fasciculate colonies and microbialite framework associated with solitary rugose and tabulate corals. It corresponds also to the '*Saharopteris* community' of Mundy (2000). Following the classification of Aretz (2010), the rugose coral association of the reef core (composed of *Siphonodendron*, *Espiella*, *Axophyllum*, *Gangamophyllum*, *Amygdalophyllum*, *Palaeosmilina*)

might be classified as D1 and, locally, D3 category: 'bioherm dwellers' to 'supported framework builders'. This assemblage is the most diversified for corals, brachiopods and bryozoans. The association of the crest facies (top KY3) composed of monospecific large cerioid colonies of *Lithostrotion maccoyanum* and chaetetid sponges is classified as D2 ('capping bed' of Aretz 2010). The overlying bioclastic flank facies fits with the definition of the '*Koninckopectens* community' of Mundy (2000) and Zone 2: 'crinoid-ramose bryozoan assemblage' of Madi *et al.* (1996). This latter zone is typically a high energy euphotic to dysphotic environment, but, in the Turkish case, it means also increasing turbidity of water.

### Comparison

The Kongul Yayla bioherm has little in common with the classical Waulsortian mounds (Lees & Miller 1985, 1995). The latter are mud-mounds with a poorly diversified fauna, originating in deeper water and are older (upper Tournaisian–lower Viséan). As mud-mounds they lack skeletal and/or non-skeletal framebuilders.

Late Viséan to Serpukhovian bioherms are almost globally documented in the subtropical and tropical realm (see Introduction). Although only preliminary data are presented for the Turkish reef, it can easily be compared and integrated into the global spectrum (see Figure 7). The important role of microbial communities in the formation of these reefs has been highlighted in recent years (e.g., Webb 2002; Aretz & Chevalier 2007). The Kongul Yayla reef is not different in this respect, and it is well illustrated by the relative volumetric abundance of microbial boundstones, crusts and coatings in the reef core facies.

The important contribution of sponges to the formation of Viséan reefs and their good preservation has been noticed in various regions (England: Mundy 1994; Ireland: Labiaux 1996; Australia: Webb 1999; Algeria: Madi *et al.* 1996; Morocco: Aretz & Herbig 2008) and in this respect the Kongul Yayla reef shares many similarities to the above-mentioned localities. Taxonomic data on the single reefs are mostly insufficient, but overall relatively different sponges in changing abundances seem to contribute to reef

Features	Reef				
	Kongul Yayla	Jerada	Cracoe	Lion Creek	La Serre
Mixed siliciclastic-carbonated context	+	+	-	-	+
Basal bioclastic facies	+	-	+	-	-
Abundance of corals in the upper parts	+	+	+	-	+
Large scale coral framework	-	-	+	+	-
Small-scale patchy coral framework	+	+	-	-	+
Impoverished green algae flora	+	+	-	-	-
Biodiversity*	-	+	+	+	-
*biased by the intensity of sampling/study					

**Figure 7.** Summarized comparison of the Kongul Yayla reef with other Viséan reefs, based on characters described in the text (+ and - refer to presence/absence or high/low).

formation, and this is also so at Kongul Yayla. The same is true for the sizes of the sponges.

The setting of the Kongul Yayla reef is very similar to the microbial-sponge buildups at Jerada (Aretz & Herbig 2008) and in the Béchar Basin (Madi *et al.* 1996). In both regions a mixed siliciclastic-carbonate setting dominates. The occurrence of detrital quartz is recorded throughout the Kongul Yayla reef. Reduced light penetration as consequence of turbidity and the resulting impoverished (or, in the Turkish case, apparently absent) calcareous algal flora has been evoked for both regions. Differences can be reported from the base of the reefs. A bioclastic sole, as at Kongul Yayla is not documented in the Jerada reefs, where the base directly contains microbial boundstone facies. The formation of a coral biostrome at the base of the reef is a unique feature of Kongul Yayla, but Aretz & Chevalier (2007) already highlighted the individuality of every bioconstruction.

Aretz & Herbig (2008) noticed the great similarity of the Jerada microbial-sponge buildups to the Cracoean buildups (Mundy 1995, 2000). The same degree of similarity can be postulated for the Kongul Yayla reef, although the diversity of the reef fauna is currently much lower than in the Cracoean buildups. This can be explained partly because this is preliminary data for Kongul Yayla, and also by the

smaller size of the Kongul Yayla reef. It is interesting to note that in all three areas (Jerada, Cracoe, and Kongul Yayla) rugose corals become abundant and diversified in the top of the reefs, which can be explained with reef growth into shallower water and the preferred elevated position for these filter feeders (Aretz 2010). A further similarity of the rugose faunas is the inclusion of small undissipimented corals in the framework through microbial coatings and incrustations.

Although colonial rugose corals are abundant in the Kongul Yayla reef, they do not dominate in the reef core and the formation of a large-scale coral framework was not observed, and this is a major difference from the Welsh coral reef (Aretz & Herbig 2003a) or the Australian Lion Creek reefs (Webb 1989). The patchy occurrence of a coral framework resembles more the style of reefs such as La Serre in S France (Aretz & Herbig 2003b).

It is interesting to note that Cracoan-typed reefs formed along the margin of platforms and might even have played a crucial role in stabilizing them. The olistolith nature of the occurrences at Jerada and, questionably, Kongul Yayla result from the destruction of platform edges; which may also be so in SW Spain (see data in Cózar *et al.* 2003; Aretz & Herbig 2008). Further regional studies are needed for a better understanding of the tectonic settings of the Kongul Yayla reef along the margin of the platform and its putative olistolith nature. However, the Kongul Yayla reef is a further example of the extensive development of a Cracoan-typed reef in the western Palaeotethys.

## Conclusions

The Kongul Yayla reef is a bioherm constructed by skeletal and non-skeletal organisms. The former are mainly colonial rugose corals, tabulate corals, fistuliporid bryozoan and sponges (lithistid and chaetetid) producing framestone. The non-skeletal components are microbial communities well integrated in boundstones, oncoids, multi-encrusted bodies and pelloids facies. Three growth stages have been noticed: stabilization by stemmed echinoderms creating a solid sole for the following bioconstructors,

colonization by macro- and micro-organisms creating most of the buildup core, domination by the same organisms forming the upper part of the bioherm and showing the most abundant and diversified fauna. The latter is topped by coarse bioclastic facies containing reworked material from the reef. The whole reef is overlain by siltstones with bioclastic slumped levels interpreted as the burial effect of mud following or terminating the development of the reef.

The macrobiotic association is dominated by corals, bryozoan and sponges. *Siphonodendron*, *Lithostrotion* and *Espiella* are the main colonial rugose corals. *Palaeosmilia*, *Axophyllum*, *Gangamophyllum* and *Amygdallophyllum* are the most common solitary corals. Many small undissepimented solitary rugose corals (*Rotiphyllum*) were observed in the core facies, together with michelinid tabulate corals. Lithistid sponges are very abundant in the reef core and chaetetid sponges are mostly present at the top of the reef. Bryozoans are mainly represented by reticulate fenestrate fenestellids, ramose rhabdomesids, massive stenoporids, and massive encrusting fistuliporids.

*Siphonodendron pauciradiale* and *Lithostrotion maccoyanum* are the guide taxa for the RC7 $\beta$  biozone of Poty *et al.* 2006) and indicate an Asbian age (Warnantian, Upper Viséan).

The Kongul Yayla reef shares many similarities with contemporaneous reefs in Europe, N Africa and Australia, especially the incorporation of sponges and corals into a microbial framework. It can be assigned to the Cracoan-type reefs and possibly formed along the platform edge before being transported basinwards.

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