Carbonate Microfacies Analysis of Sinjar Formation from Qara Dagh Mountains, South–West of Sulaimani City, Kurdistan Region, Iraq

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Abstract**—**The paper describes the carbonate microfacies identified in the Sinjar Formation (Late Paleocene–Early Eocene) cropping out in Qara Dagh Mountain, near Sulekan Village approximately 20km south–west of Sulaimani (Iraq). One section (62m thick) has been measured in the field and closely sampled to undertake detailed microfaciesal and micropalaeontological studies to determine the formation's age and environment of deposition. A number of 93 samples were collected illustrating all the lithological changes along the section. The limestone in the studied area is hard and extremely rich in large foraminifers (soritids, rotaliids, nummulites, miliolids) and green algae (dasycladales). The investigation of the thin sections allowed us to identify the carbonate microfacies (18 types and subtypes) and the micropaleontological association (foraminifers and green algae), to determine the age of formation and to reconstruct the paleoenvironment of deposition (fore-reef, reef, back-reef). Based on the field observations and the studied thin sections, we determined three Units of a carbonate platform (I, II and III) from the base to the top of the section: Unit I with coralgal associations, Unit II is dominated by larger foraminifers and characterized by the absence of coralgal associations, while Unit III is dominated by small foraminifers (mostly miliolids), peloids and green algae. It is partially dolomitized.

Keywords**—**Facies analysis, Late Paleocene–Early Eocene, Sinjar Formation, SW Sulaimani (Iraq).

I. INTRODUCTION

THE limestone cropping out in Qara Dagh, near Sulekan Village belongs to the Sinjar Formation that is present in the Foot Hill Zone of the High Folded Zone, within the unstable shelf area. It develops as centimetric to metric banks, grey in colour and generally showing a massive texture. The profile is located at about 1 km west of Sulekan Village (Figs. 1, 2), at coordinates N 35^o 22' 40"; E 45^o 29' 07"; according to [1], this latitude belongs to the middle paleolatitude region (above 30^o), which contains carbonate platforms - all of them being located along the northern rim of the Tethys area. The Sinjar Formation was first described from the Jabal Sinjar area (near Mantissa village) by Keller, 1941 in [2]. In its type area, it comprises 176 m of limestone formation [3], which in Derbendikhan area is 120 m thick [4], in the Foot Hill Zone - 213 m thick, while in some wells it reaches 337 m thick (Sufaya-A2 well). The formation was deposited predominantly in shallow marine environment [2], in shallow water, reef, fore-reef and lagoon [3]. Reference [5] considered the Sinjar Formation in the type section to be the single section which contains three different facies indicating the reef (algae facies), back-reef (miliolids) and fore-reef (nummulites and discocyclinids). The age of this formation is considered to be Palaeocene-Early Eocene [3], or Early Eocene [6]. An Early Eocene age is confirmed for the Sinjar Formation in Derbendikhan area of north-east Iraq [4].

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Generally, the Sinjar Formation is overlain by Gercus Formation [3] and underlain by clastic Kolosh Formation [7]. The contact between Sinjar and Gercus Formations is gradational [4]. In the studied area, this contact is represented by siliciclastic components in uppermost part of the section, while the contact between Sinjar and Kolosh Formations is conformable [7], but it is covered by soil in the studied section. In other localities, the Sinjar Formation was described by [8]–[9]–[10]–[11]–[12]–[13]–[14]–[15]–[16]–[17]. The formation is probably thickest near the Iraq-Syria-Turkey triple border point and it extends into Syria, where it is known as Sinjar Limestone [18]–[19]. It is developed in similar facies in south-east Turkey, under the name of Becirman Formation [20]. In Iran the formation is equivalent to the lower part of the Jarum Formation [21] and of the Taleh Zang Formation [22].

II. MICROFOSSILS

The architecture for establishing the chronostratigraphic framework is provided especially by the biostratigraphy of benthic foraminifera and dasycladacean algae. Along a total measured section of 62 m thickness (Fig. 3), 93 samples were collected and analysed. In this study, the recorded distributions of benthic foraminifera and dasycladacean algae allowed us to determine the age of the investigated Sinjar Formation section in the study area. In some levels within the section, the calcareous algae (dasycladacean) are mostly associated with larger foraminifera like rotaliids, orbitolits and nummulitids. The most frequently recognized dasycladacean are: *Cymopolia ellongata* Defrance (Pl. III, photo 2, 10), *Cymopolia sp.* (Pl. III, photo 8, Pl. IV, photo 4, 5). These species of *Cymopolia* were identified in the Adriatic carbonate platform along the Dubrovnik Coast by [23]. *Acroporella*? *sp*. (Pl. III, photo 4), *Uteria sp.* 1 (Pl. III, photo 5; Pl. IV, photo 5), *Uteria sp.* 2 (Pl. III, photo 9) are known from Paleocene-Lower Eocene deposits [24]. *Trinocladus perplexus* Elliot indicates shallow subtidal, open platforms (Late Paleocene), (Pl. III, photo 6), (Pl. III, photo 7); *Trinocladus sp.* (Pl. III, photo 11, 12; Pl. IV, photo 1, 2, 11), *Dissocladella*? (Pl. III, photo 12), *Acicularia sp.* (Pl. IV, photo 3), and *Broekella belgica* Morellet (Pl. IV, photo 6) indicate a Paleocene age [24]; *Hamulusella* (Pl. IV, photo 13) was also described by [25] from Paleocene deposits within the Kolosh Formation in the same region. Besides, red algae represented by *Parachaetetes* (Pl. IV, photo 9) and *Solenopora* (Pl. I, photo 1) were identified. The foraminifera assemblages consists of: *Orbitolites complanatus* (Pl. V, photo 1, 5); *Mardinella shirazensis* Rahaghi (Pl. I, photo 4) which has first been found in Thanetian sedimentary rocks from the Shiraz area, West Iran; however, the same forms have been observed in the benthic foraminifer-rich limestones of Thanetian age in the NE Mardin area, SE Turkey [26]; *Biloculina* (Pl. V, photo 2); *Kathina* (Pl. V, photo 3);

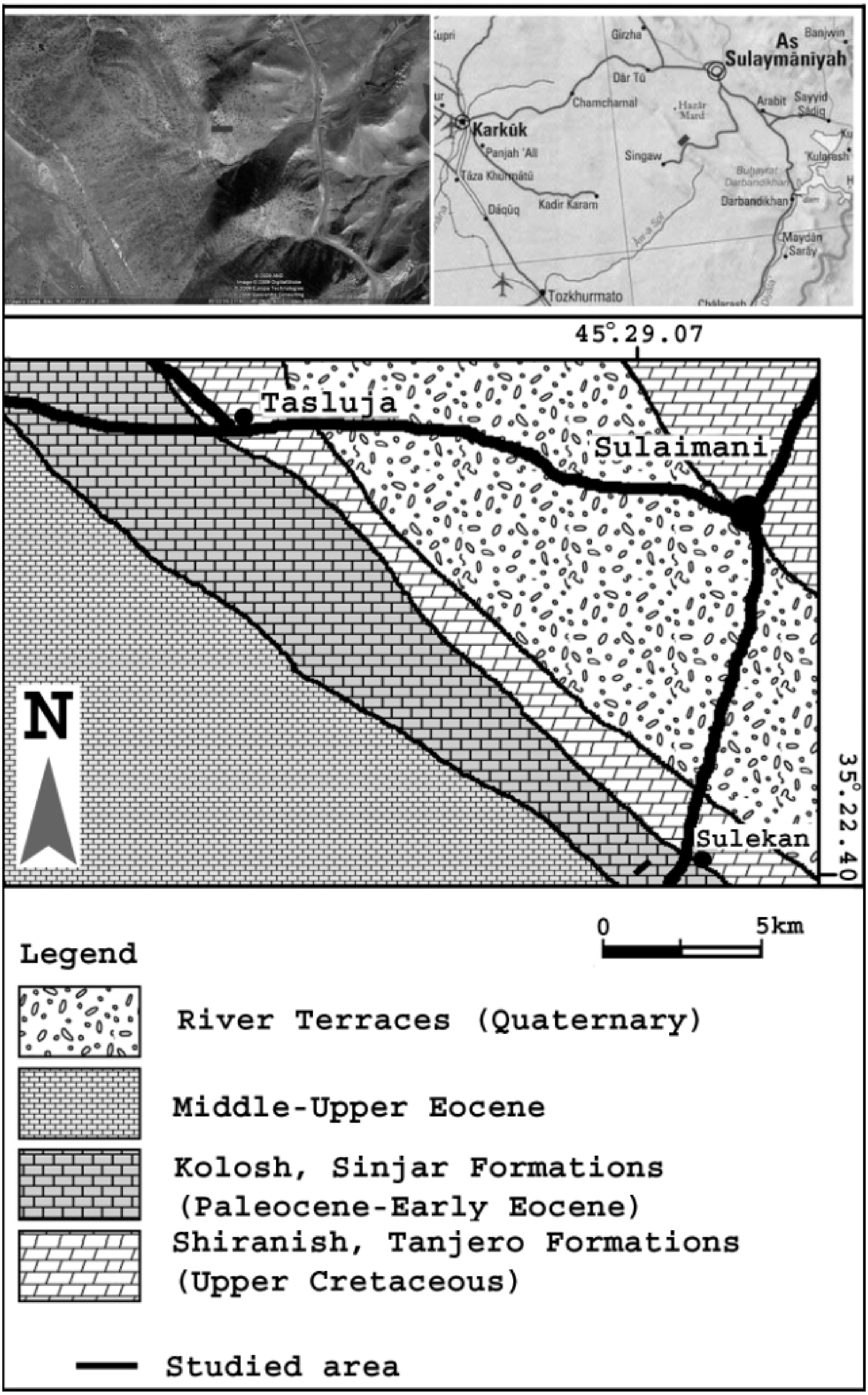

Fig.1.Location of the studied section

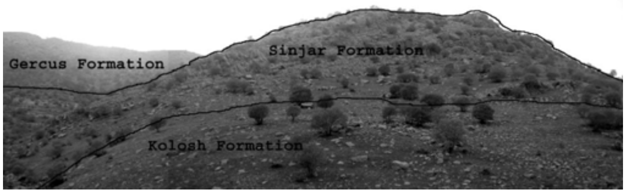

Fig. 2. Studied Section of the Sinjar Formation overlain by Kolosh Formation and underlain by Gercus Formation

Operculina subsalsa Davies and Pinfold (Pl. V, photo 6); *Opertorbitolites transitorius* Hottinger (Pl. V, photo 7); *Cuvillierina sireli* Inan (Pl. V, photo 8); *Idalina sinjarica* Grimsdale (Pl. V, photo 9); *Koskinolina* (Pl. V, photo 10); *Operculina heberti* Munier-Chalmas (Pl. V, photo 11) has also been found in the Late Paleocene deposits of the Hayamana-Polatli Basin, central Turkey by [27]; *Assilina sp*. (Pl. V, photo 12); *Saudia labyrinthica* Grimsdale (Pl. V, photo 13); *Penarchaias glynnjonesi*? Henson (Pl. V, photo 14, 15);*Textularia* (Pl. V, photo 16); *Cibicides* and *Quinqueloculina*. On the basis of this faunal assemblage, a Late Paleocene–Early Eocene age of the formation has been confirmed.

III. MICROFACIES

Four main microfacies types have been recognized: grainstone, packstone, wackestone and boundstone. Each of them is subdivided into several subtypes, thus in total 18 microfacies types are described. The distinction between various microfacies types was based on relative frequencies of components and fabric criteria (sorting, packing and orientation):

I. **Grainstone** is characterized by well-sorted and densely packed fabric. It usually contains large benthic foraminifers consisting of soritids and rotaliids. Besides, peloids, green and red algae, gastropods and ostracods are present. Seven subtypes were described:

─Bioclastic grainstone (G1) appears only at one level of the section and consists of red algae fragments, peloids, intraclasts, coral fragments and green algae. Generally, the corals are surrounded by fine micrite;

─Peloidal grainstone (G2) consists of peloids, red algae, some foraminifers, small dasycladales and echinoid plates (Pl. I, photo 7). Sometimes the ostracods shells are filled by peloids;

─Miliolids and rotaliids grainstone (G3) mostly consists of miliolids and rotaliids with green algae and echinoid plates (Pl. I, photo 2);

─Large foraminifers Rudstone (G4) consists of large foraminifers (large orbitolits), gastropods, rotaliids, miliolids, green algae, echinoid plates, nummulites and red algae fragments (Pl. II, photos 3, 5). Sometimes the gastropod shells are filled with dasycladales; some skeletal foraminifers have been fractured by microfaults, probably during late diagenesis. The miliolids become predominant in the upper part of this facies (towards the upper part of the section);

─Rotaliids grainstone (G5) mostly consists of rotaliids but sometimes miliolids, small nummulites and green algae appear too (Pl. I, photo 6; Pl. II, photo 8). In the uppermost part of the section, terrigenous materials and red algae fragments occur and probably the Sinjar Formation gradually transforms into the Gercus Formation;

─Green algae and soritids grainstone (G6) consists of dasycladales and large foraminifera (Pl. II, photo 2);

─Miliolids and green algae grainstone (G7) contains mostly miliolids, green algae, gastropods, rotaliids and it is partially dolomitized;

─Soritids grainstones (G8) mostly composed of medium to small orbitolits with other foraminifers such as miliolids, rotaliids, additionally with peloids, little green algae and echinoid plates. In the upper part, dolomitization processes were also identified.

II. **Packstone**; this facies type is characterized by the dominance of diverse (sessile benthonic and plutonic) foraminifers. Fragments of red algae, plates and spines of echinoids, gastropods and ostracods are common, the green algae being abundant at some levels. Five subtypes of packstone facies were identified:

─Bioclastic packstone (P1) consists of red algae fragments, ostracods, foraminifers, plates of echinoids, and small gastropods (Pl. I, photo 3; Pl. III, photo 1). Sometimes the bioclasts are transformed into blocky cement;

─Rotaliids packstone (P2) mainly consisting of rotaliids. Besides, red algae fragments, little green algae, fragments of corals, plates and spines of echinoids, fragments of ostracods with some other foraminifers (Pl. II, photo 6) are also present. This facies appears in the lower part and towards the upper part of the section;

─Foraminiferal packstone (P3) consists of diverse benthic foraminifers (rotaliids, soritids, nummulites and miliolids) and plutonic foraminifers (globigerinids), red algae (complete forms and fragments), little green algae. In some levels the shells of gastropods are filled with peloids;

─Green algae packstone (P4) mostly consists of green algae (dasycladales);

─Soritids packstone (P5) consists of soritids, green algae, rotaliids and miliolids (Pl. I, photo 5);

III. **Wackestones** are characterized by the presence of moderately sorted, randomly oriented, and mostly well-preserved foraminifers, represented by rotaliids, miliolids, soritids; besides, green algae and in the upper part terrigeneous materials appear too. Four subtypes of this facies were described:

─Rotaliids wackestone (W1) consists of rotaliids, miliolids, green algae (in the upper part) and rare nummulites. Sometimes it is dolomitized in the upper part;

─Soritids wackestone (W2) consists of soritids with some miliolids and rotaliids (Pl. II, photo 1);

─Green algae wackestone (W3) contains green algae and terrigeneous materials (Pl. II, photo 7);

─Dolomitized wackestone (W4) with terrigeneous materials. Both latter microfacies types (W3 and W4) that occur at the top of the section are characterized by siliciclastic input, which indicates a relative sea level fall. Probably this represented the end of deposition for the Sinjar Formation. Concordantly, on its top, the Gercus Formation started to become sedimented.

Boundstone and **bindstone** (B1, B2) consist predominantly of well-preserved solenoporacean algae that are not affected by fragmentation and dendroid corals (Pl. I, photo 1). Corals are commonly encrusted by sessile foraminifers and other bioclasts. Generally, this facies builds-up a reef framework with sizes larger than one square meter.

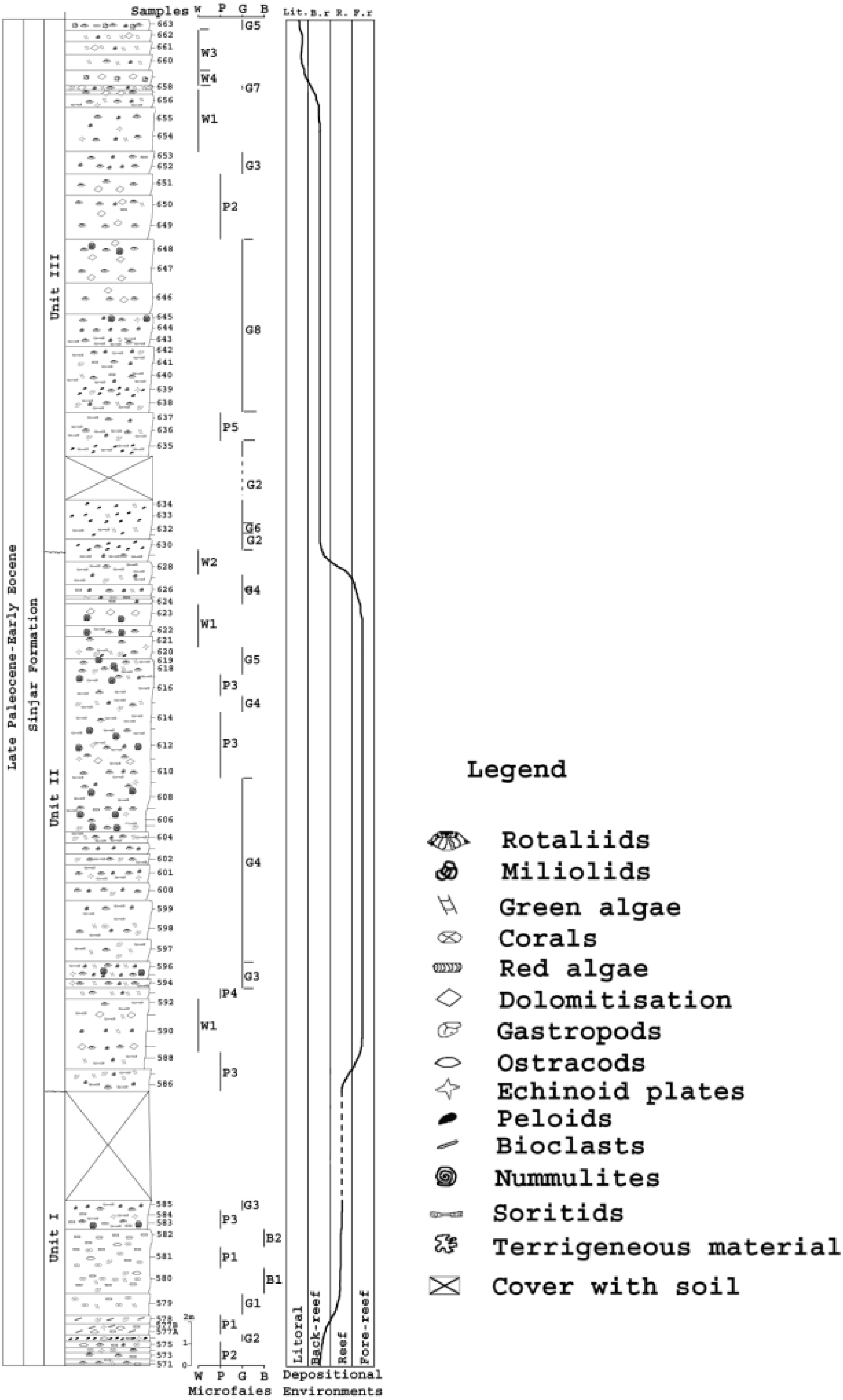

Fig. 3. Stratigraphic column of studied section showing microfacies and depositional environments

Green algae (dasycladales), gastropods, ostracods, red algal fragments and echinoid plates are commonly dispersed in the micritic matrix, in the interspaces between algae and corals. The bindstone is mostly composed of red algae transformed into sparite. Micrite forms infillings of cavities and interspaces between components; it is dark brown in colour.

IV. PALEOENVIRONMENTAL DEPOSITION

Previous studies have shown that the Sinjar Formation was deposited in a reef environment [28]. Reference [3] have determined three depositional environments (backreef, reef and forereef) in the type section. Locally, variations of the sedimentary environment of the Sinjar Formation have been recorded, as proven by studies on algae and benthonic foraminifers [13]. According to the results of the present study, the vertical changes of the microfacies and the diversity of bio-components point to cyclic sedimentation caused by successive transgressions-regressions. These led to the formation of limestones in various depositional environments: back-reef (in the lowermost part of the section), followed by reef (about 6 m thick), fore-reef (middle part), back-reef (upper part) and ending with littoral environment with input of clastic material that belongs to the Gercus Formation. The latter deposits are conformably overlaying the Sinjar Formation and they mark the end of limestones deposition with the Sinjar Formation.

The **reef** deposits are represented by red algae and corals (solenoporaceans, parachaetetes, and dendroid corals) boundstone building-up massive, metric limestone banks in the base of the section, as well as bank reefs associated with foraminifers. Solenoporacean framestones are characterized by the preservation of autochthonous small-scale algal banks, deposited in a setting below the fair-weather wave base [29].

The **fore-reef** was identified in the proximal area of the reef towards the open sea; it is characterized by microfacies types such as large foraminiferal rudstone, rotaliids grainstone, foraminiferal packstone, and rotaliids wackestone. Foraminifers are relatively large and they are represented by rotaliids, discocyclinids, soritids and nummulitids associated in the lower part with miliolids and green algae typical for shallow waters [30]. Similar foraminiferal communities were identified and summarized in a carbonate ramp by [31] on the north-western Adriatic Carbonate Platform during the Late Paleocene–earliest Eocene. On the other hand, the occurrence or increasing abundance of larger foraminiferal specimens, especially as species of orbitolits were interpreted to indicate shallow-marine waters in the photic zone [32]. The rudstone microfacies in front of the reefs form mainly due to storm activity. The hydrodynamic energy and light intensity may both be reflected in the shell morphology of the benthic foraminifers; these organisms build more robust shells in high energy environments [33]. This facies was identified in the medium part of the section.

In the top of the section, microfacies types such as miliolids packstone, dasycladal packstone, foraminiferal packstone, peloidal grainstone, rotaliids grainstone, bioclastic packstone, bioclastic grainstone, soritids grainstone and wackestone are typical for **bac-kreef** environments represented by restrictive, protected and lagoons environments located between the reef and the littoral. These microfacies types include smaller foraminifers with thinner test walls, especially represented by miliolids and peneroplids. As a rule, peneroplids are present in the vicinity of the reef, while miliolids are typical for the distal, towards the littoral area [28]–[34]–[35]. Additionally, small orbitolits, textularids and rotaliids with thin walls were identified, pointing to high salinity and quiet environments [33]. They are accompanied by whole tests of fragments or gastropods and ostracods that characterize back reef environments. The associations of small miliolids and rotaliids are typical for shallow water environments behind the reef [36]. Dasycladales are frequent and diversified, pointing to shallow environments [37]–[38]; they occur in lagoons, in foraminifer-rich banks and protected environments in shallow marine water [39]. The richest assemblages of dasycladales species have been also found in the Paleocene of some regions in Europe such as: Belgium (Mons Basin), France (Aquitaine-Pyrénées area and Paris Basin), Italy (Sardinia), former Yugoslavia (Slovenia), former Czechoslovakia (Carpathian Mountains); in the Middle East (Iraq, Iran) and China (Tibet); in the Eocene of France (Paris Basin, Brittany), southern England (Sussex), Hungary and China (Xizang); and in the Miocene of Romania and Poland [40]. Optimal conditions for the development of the dasycladales have occurred during the Early-Middle Eocene [41]. Peloidal grainstone, another microfacies characteristic for shallow and agitated waters was also identified as interlayers among the other microfacies types. In other words, the presence of calcareous algae (dasycladales and red algae), small gastropods, ostracods and peloids are all arguments for the fact that these microfacies types were deposited in shallow, subtidal waters in the frame of the internal carbonate platform, in restricted areas, in tropical and subtropical climates.

The upper part of the profile consists of green algae wackestone, dolomitized wackestone and rotaliid grainstone microfacies types, associated with terrigenous material. These latter layers of the section including clastic fragments pointing to the proximity of the **shore** can be probably assigned to the Gercus Formation, conformably overlaying the Sinjar Formation.

In the studied profile, based on the field observations and the studied thin sections we can introduce three Units of a carbonate platform (I, II and III) from the base to the top of the section: Unit I with coralgal associations, consisting of corals and red algae, Unit II is dominated by larger foraminifers and characterized by the absence of coralgal associations, while Unit III is dominated by small foraminifers (mostly miliolids), peloids and green algae. It is partially dolomitized. The first two Units are similar to those first and second platform stages (I, II) identified by [42] in Paleocene–Eocene deposits of Egypt.

V. CONCLUSIONS

Eighteen microfacies types of the Sinjar Formation were identified. Main components are benthic foraminifers (large and small) represented by soritids, rotaliids, miliolids, and nummulitids, green and red algae (dasycladales and solenoporacean), corals, peloids, echinoid plates, gastropods and ostracod fragments. The typical feature is the considerable vertical facies variation. Thus the depositional environment consisted of a wide spectrum of facies types, from fore–reef containing large foraminifers, reef with coralgal bioconstructions forming biostromes and small scale banks, back–reef towards the open or restricted lagoons and protected environments with small foraminifers, green algae, gastropods and ostracods and finally, shore environment. These latter layers of the section including clastic fragments can be probably assigned to the Gercus Formation, conformably overlaying the Sinjar Formation. Along the depth-related environmental gradient linked to water energy, they point to high energy in front of the reef represented by rudstone microfacies with good sorting and lack of the micrite matrix, and moderate to low energy in the reef towards the littoral where the matrix micrite is predominant. Water depths obviously remained very shallow throughout the deposition of the Sinjar Formation. Facies types and assemblages allowed us to determine three Units of a carbonate platform (I, II, III) from the base to the top of section. Based on the green algae and foraminifer species identified; the deposits in the studied area can be assigned to the Late Paleocene-Early Eocene interval.

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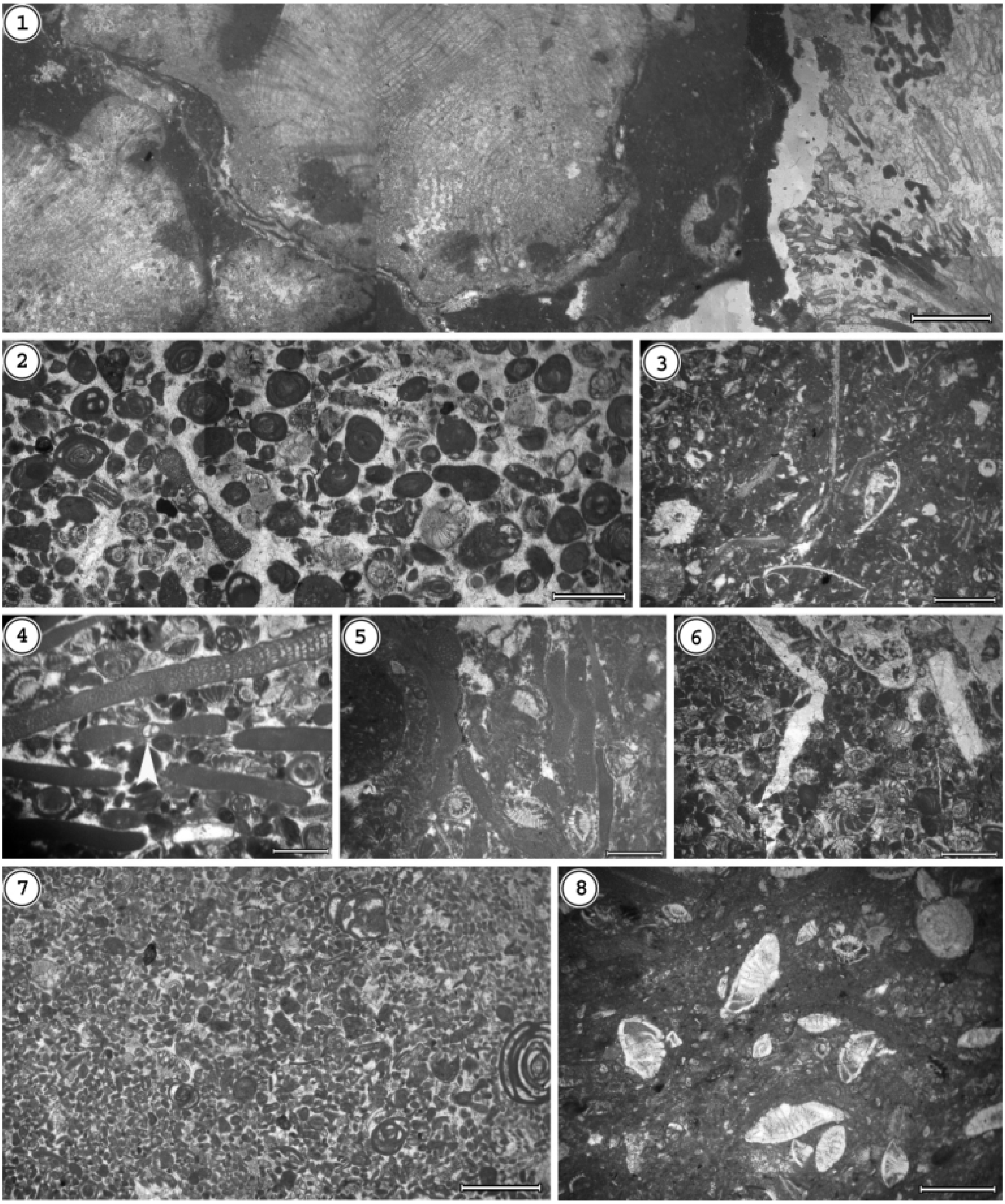

Plate I—1. Solenoporacean boundstone. *Solenopora* (arrow) together with dendroid corals (left part) form a reef framework with sizes larger than one square meter (S. 580); 2. Miliolids and rotaliids grainstone. The miliolids are micritized (S. 585); 3. Bioclastic packstone consisting of fragments of red algae, ostracods, foraminifers, and echinoid plates (S. 577A); 4. Soritids and rotaliids grainstone. The arrow points to *Mardinella shirazensis* Rahaghi (S. 604); 5. Soritids packstone mostly composed of large soritids (S. 616); 6. Rotaliids grainstone consisting mostly of rotaliids, besides gastropods, miliolids, green algae and nummulites (S. 618); 7. Peloidal grainstone. The intraclasts, some foraminifers and green algae are also presents (S. 634);
8. Nummulitic wackestone with *Operculina heberti* and *Assilina sp*. (S. 662). Note: The bar scale is 1mm

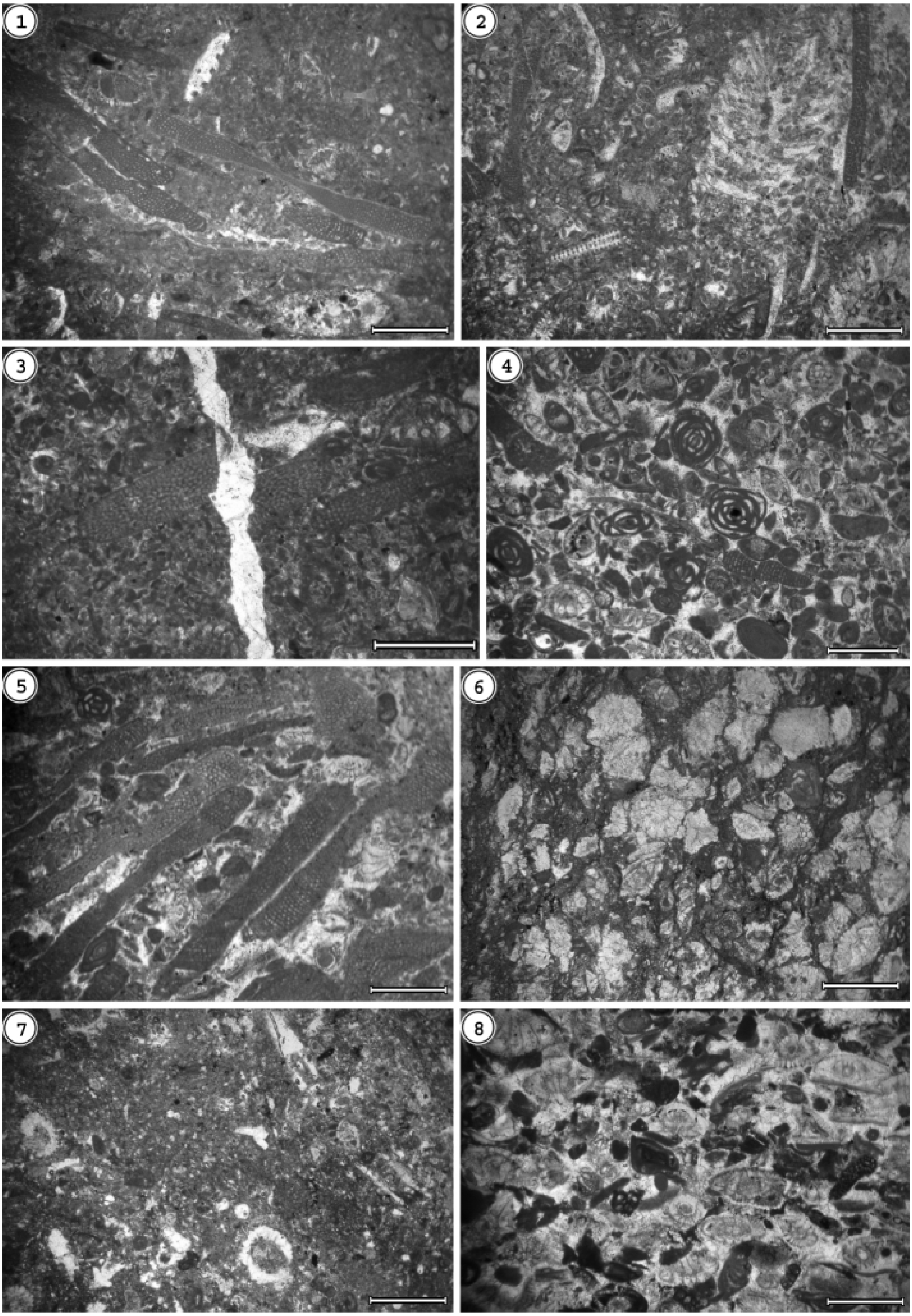

Plate II— 1. Soritids wackestone (S. 628); 2. Green algae and soritids grainstone (S. 632); 3. Large foraminifers rudstone, consisting of large foraminifers (orbitolits, rotaliids), green algae and peloids. The large fracture is a microfault through a soritid (S. 638); 4. Miliolids and rotaliids grainstone (S. 641); 5. Large foraminiferal rudstone contains more than 60 % large soritids (S. 643); 6. Rotaliids packstone, partially dolomitized (S. 646); 7. Green algae wackestone. The algae are dasycladales and gymnocodiaceans. This is partially dolomitized (S. 662); 8. Rotaliids grainstone with detrital material. This facies represents the end of the Sinjar Formation and probably passes into the Gercus Formation, as illustrated by the terrigeneous material (S. 663) Note: The bar scale is 1mm

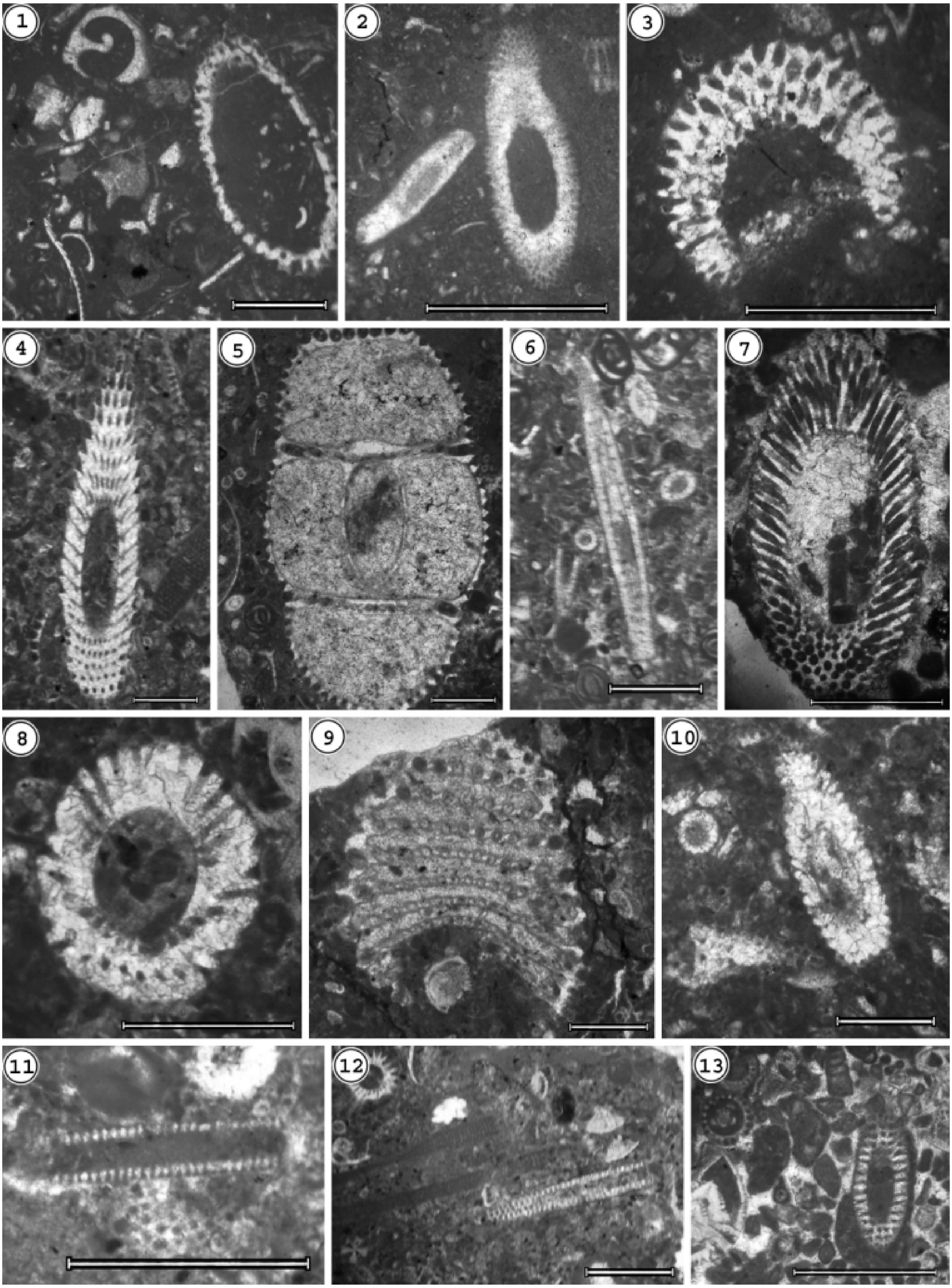

Plate III —1. Bioclastic packstone with green algae and gastropods (S. 578); 2. *Cymopolia ellongata* Defrance, oblique section (S. 580); 3. *Cymopolia?sp.* (S. 582); 4. *Acroporella*? *Sp*. (S. 586); 5. *Uteria sp.* 1 (S. 587); 6. *Trinocladus perplexus* Elliot (unsharp photo), longitudinal section, shallow subtidal open platform (S. 593); 7. Unknown dasycladal? (S. 595); 8. *Cymopolia sp*. (S. 586); 9. *Uteria sp.* 2 (S. 587); 10. *Cymopolia ellongata* Defrance (S. 593); 11, 12. *Trinocladus sp*. (S. 594, 588); 13. *Dissocladella*? (S. 596). Note: The bar scale is 1mm

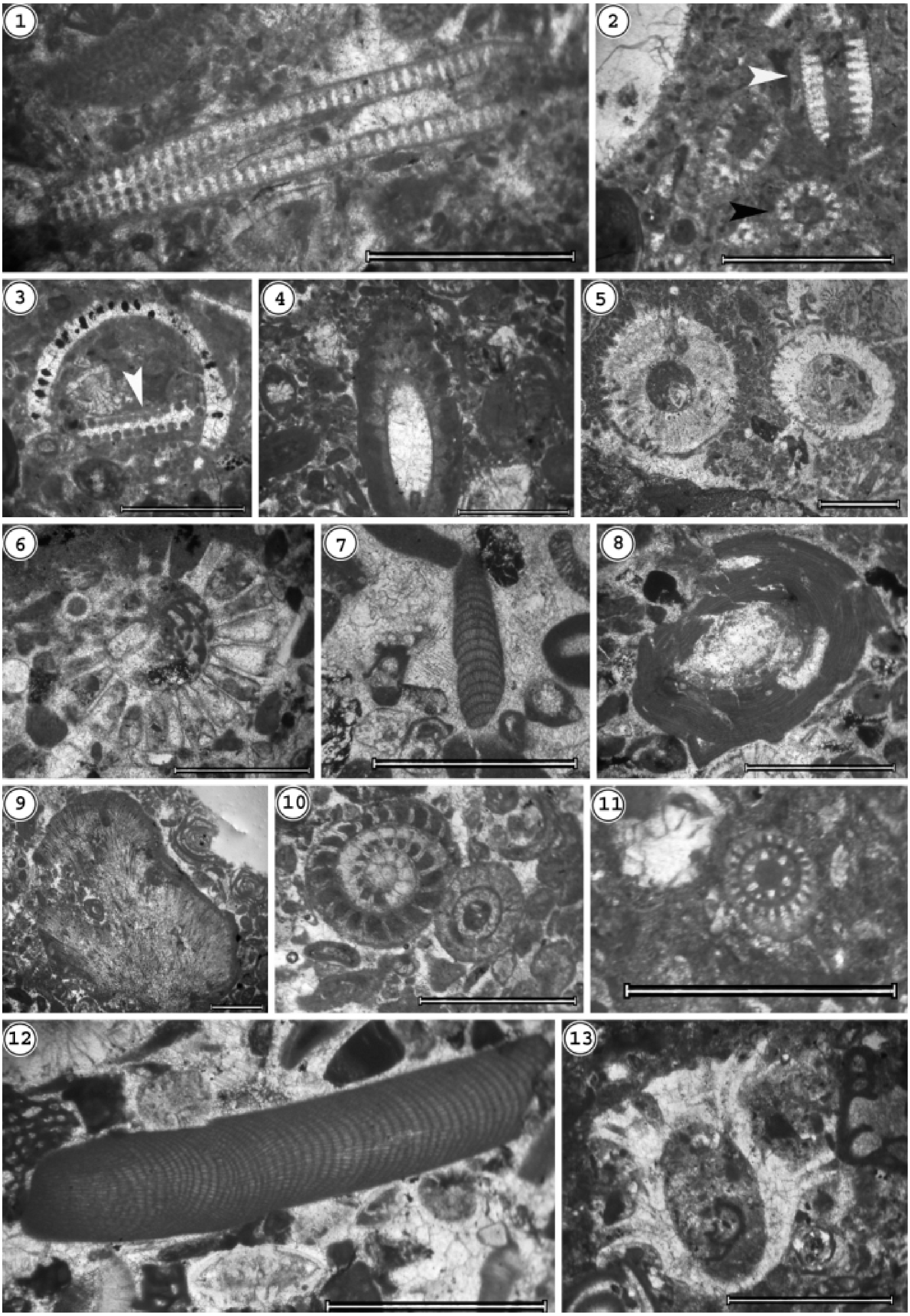

Plate IV—1. *Trinocladus* (S. 588); 2. *Trinocladus,* longitudinal section (white arrow), transversal section (black arrow), (S. 597); 3. *Acicularia sp.* (arrow), (S. 598); 4. *Cymopolia sp* (S. 609); 5. *Uteria sp*. 1 (left part) and *Cymopolia sp*. (right part), (S. 620); 6. *Broekella belgica* Morellet (S. 624); 7, 8, 12. Fragments of red algae (S. 626, 624, 663); 9. *Parachaetetes* (S. 641); 10. Nummulite (left part) and ?*Cymopolia* (right part) (S. 645); 11. ?*Trinocladus* (S. 654); 13. *Hamulusella* (S. 660). Note: The bar scale is 1mm

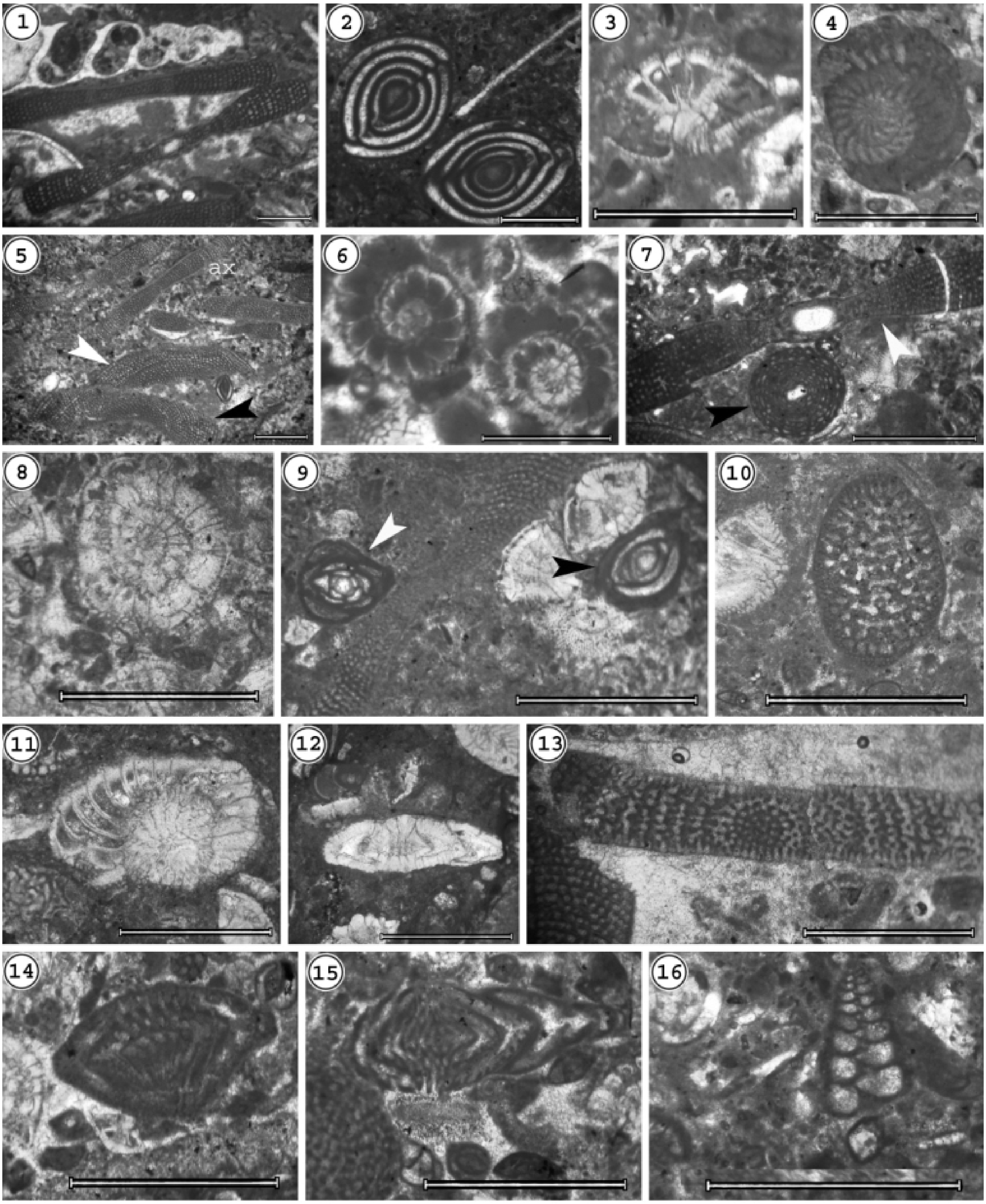

Plate V— 1. *Orbitolites complanatus* and gastropod (S. 586); 2. *Biloculina* (S. 588); 3. *Kathina*, axial section (S. 598); 4. Nummulite (S. 598); 5. *Orbitolites complanatus*, axial section (ax), portion of the peripheral parts of the equatorial section (white arrow) and portion of the equatorial section (black arrow), (S. 601); 6. *Operculina subsalsa* (S. 604); 7. *Opertorbitolites transitorius*, vertical section (white arrow) and transversal section (black arrow), (S. 607); 8. *Cuvillierina sireli* Inan (S. 615); 9. *Idalina sinjarica* Grimsdale, equatorial section (white arrow) and axial section (black arrow), (S. 616); 10. *Koskinolina* (S. 616); 11. *Operculina heberti* (S. 622); 12. *Assilina sp*. (S. 622); 13. *Saudia labyrinthica* (S. 642); 14. *Penarchaias glynnjonesi*? Henson, tangential section (S. 611); 15. *Penarchaias glynnjonesi*? Henson, a section parallel and close to the axis of coiling (S. 611); 16. *Textularia* (S. 660). Note: The bar scale is 1mm