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Prominent facies from the Lower/Middle Cambrian of the Dead Sea area (Jordan) and their palaeodepositional significance

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Key words. – Lower Cambrian, Middle Cambrian, Burj Formation, Jordan.

Abstract. – New carbonate facies types are reported from the Cambrian Burj Fm. (Bilbilian) of the southern Dead Sea area (Jordan). They indicate the existence of a large low energy lagoon, with restricted water circulation and higher salinity, behind a high energy oolite shoal or shoal complex (back-barrier system). The transition between shoal and lagoon is marked by the interfingering of sediments from both environments, caused by washover events from the shoal into the lagoon behind. The lagoon itself was characterized by a low sedimentation rate and entire bioturbation. In a shoreward direction, the lagoonal facies changed into a microbial-dominated tidal or sabkha flat environment from which sediments were periodically reworked and redeposited into the lagoon. Comparison of our results with investigations of subsurface Cambrian deposits in southeastern and northern Jordan shows that lagoonal environments were the predominant carbonate production centres in this area during the short marine phase in the Cambrian of the Dead Sea area.

Faciès du Cambrien inférieur et moyen de la mer Morte (Jordanie); signification paléoenvironmentale

Mots clés. – Cambrien inférieur, Cambrien moyen, Formation de Burj, Jordanie.

Résumé. – Certains faciès carbonatés sont décrits pour la première fois dans la formation de Burj (Cambrien, Bilbilie), au sud de la mer Morte (Jordanie). Ils indiquent l'existence d'un grand lagon de basse énergie, avec une circulation d'eau réduite et une salinité élevée, derrière un haut-fond oolitique de forte énergie ou un haut-fond complexe (système d'arrière-barrière). La transition entre le haut-fond et le lagon est marquée par des interdigitations de sédiments provenant des deux environnements, avec des phénomènes de débordements, du haut-fond sur le lagon situé en arrière. Le lagon lui-même est caractérisé par un faible taux de sédimentation et une totale bioturbation. En direction de la côte le faciès lagunaire se modifie en un environnement à calcimicrobes dominants, d'estran ou de sabkha, d'où les sédiments étaient périodiquement repris et redéposés dans le lagon. La comparaison avec les recherches sur les dépôts cambriens de subsurface dans le sud-est et le nord de la Jordanie démontrent que les faciès lagunaires étaient les centres prédominants de production de carbonates dans cette région pendant la courte phase marine du Cambrien de la mer Morte.

INTRODUCTION

The Jordan Cambrian (Ram Group, including up to Arenigian) consists of a sequence of continental siliciclastics (Salib Fm., early Cambrian), followed by shallow marine carbonates and siliciclastics (Burj Fm., higher early to ?middle Cambrian). The overlying continental siliciclastics (Umm Ishrin Fm., Disi Fm., Umm Sahm Fm.) span the ?late Cambrian to early Ordovician interval (fig. 1). The Burj Fm. carbonate succession represents a relatively short marine transgressive phase. Its exposed outcrops are at the NE edge of the Dead Sea, in some wadis near its southern end, and also some wadis further south. The field area for the results presented here is in the Wadi Tayan, east of the southern edge of the Dead Sea (fig. 2).

Cambrian sediments from the Dead Sea area have been known since the beginning of the last century [for a summary of research history see Elicki and Shinaq, 2000]. Most previous work was focused on fossil reports and on the Cambrian siliciclastics [summaries in Bender, 1968 ; Amireh, 1991 ; Amireh *et al.*, 1994 ; Elicki and Shinaq, 2000]. Some more intense work on the carbonate facies was undertaken during the 1990s [Shinaq, 1990 ; Shinaq and Bandel, 1992 ; Rushton and Powell, 1998]. Until now, there has been only one publication on detailed facies investigations of the carbonates – from a part of the succession in the Wadi Zerqa Main section at the NE end of the Dead Sea,

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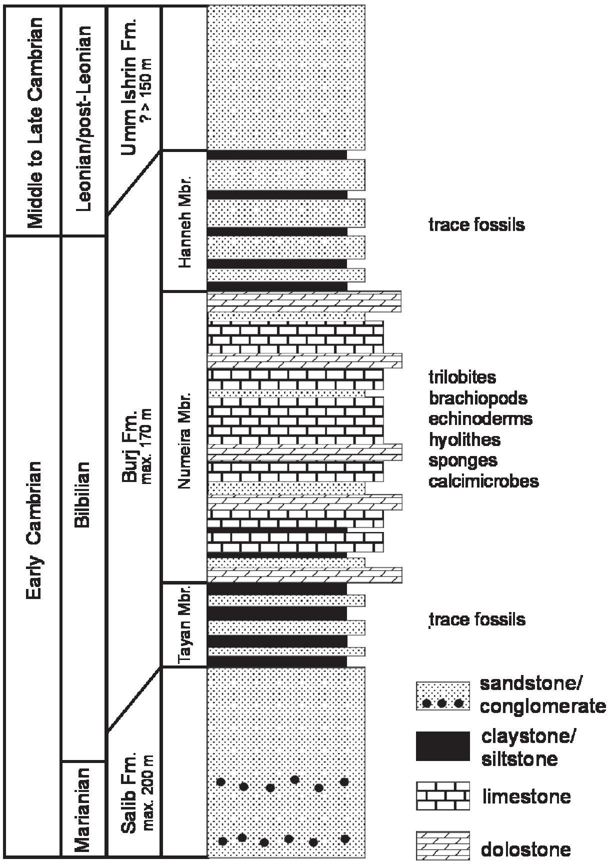


FIG. 1. – Simplified general geological column of the Jordan Cambrian.
FIG. 1. – *Colonne géologique générale simplifiée de la succession cambrienne de Jordanie.*

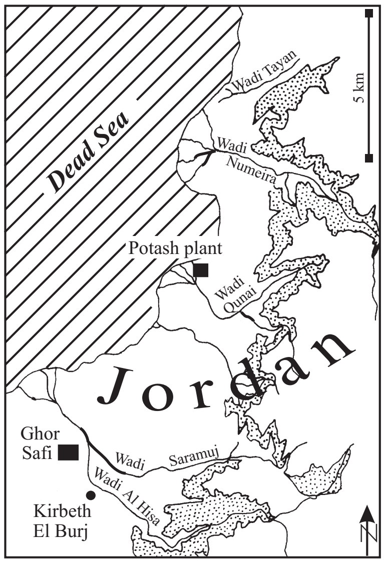


FIG. 2. – Regional site map of the working area at southern Dead Sea (after Rushton and Powell [1998, modified]).
FIG. 2. – *Carte des sites de la région étudiée au sud de la mer Morte (d'après Rushton et Powell [1998, modifiée]).*

and from two test wells in middle and southeastern Jordan [Shinaq and Bandel, 1992]. Rushton and Powell [1998] discussed the facies of the carbonates in connection with a biostratigraphic review of the trilobite fauna.

CARBONATE FACIES

Carbonate facies types, already described from surface and subsurface outcrops, include mainly grainstones and rudstones (oolitic, peloidic, bioclastic or oncolitic), indicating higher energy regimes. The bioclast allochems came from trilobites, echinoderms, hyolithes and brachiopods. Only subordinate and rare low-energy mudstones and wackestones (sometimes together with calcimicrobes) are reported from middle and SE Jordan [Shinaq and Bandel, 1992].

In the study area for the southern Dead Sea region, new carbonate facies types have been observed : (i) peloid grainstone, (ii) algal-lump/pseudopeloid float-/grainstone, and (iii) oncoid/ooid float-/grainstone.

(i) peloid grainstone facies (pl. I, fig. 1A)

This facies is characterized by uniform grain sizes and by lack of internal sedimentary structures. The principal components are very small peloids (round and oval fecal pellets, mostly less than 0,1 mm in diameter). Other components (extremely rare single ooids and bioclast relicts) are practically absent. No terrigenous influx was observed. This facies is disconformably overlain by type (ii).

(ii) algal-lump/pseudopeloid float-/grainstone facies (pl. I, fig. 1B-3)

Large algal lumps (up to 5 mm) within a grainstone matrix of pseudopeloids are the typical textural features of this facies type. The base is erosive; no other sedimentary layering is visible, but bioturbation is common. The pseudopeloids are distinctly larger (around 0,5 mm) than in type (i) and irregular in shape, so that a lithoclast nature is strongly indicated. Further components are single glauconite grains and a distinct amount of quartz. Bioclasts (trilobite and undeterminable shelly remains) occur infrequently. The algal lumps are cloud-shaped and float irregularly within the grainy matrix. Ooids were not observed.

(iii) oncoid/ooid float-/grainstone facies (pl. I, fig. 4-8)

The main textural feature of this bioturbated facies type is the occurrence of very large ("giant") oncoids up to 40 mm in diameter, embedded within an ooid grainstone matrix. The oncoids constitute about 30 percent of the rock. Their cores are made up of different components (intraclasts of the grainstone matrix; smaller oncoids; or aggregate grains [algal lumps]). The microbial envelopes are mostly clearly visible and represent *Girvanella*-type cyanobacteria (a morphological group of ?oscillatoriacean affinity). Furthermore, redeposited stromatolites (domed-subspherical) of similar size as the oncoids occur. The ooids of the grainstone matrix are between 0,2 mm and 0,5 mm in diameter. Mostly they show an intact radial internal structure. However, some are collapsed (distorted ooids) because of early dissolution of the cores and subsequent compaction. Disarticulated bioclasts (brachiopods, echinoderms, trilobites) are frequent and have oncolitic coatings. Algal lumps (several millimeters in diameter) are rather rare. Lithoclasts (grainstone intraclasts) are common, and

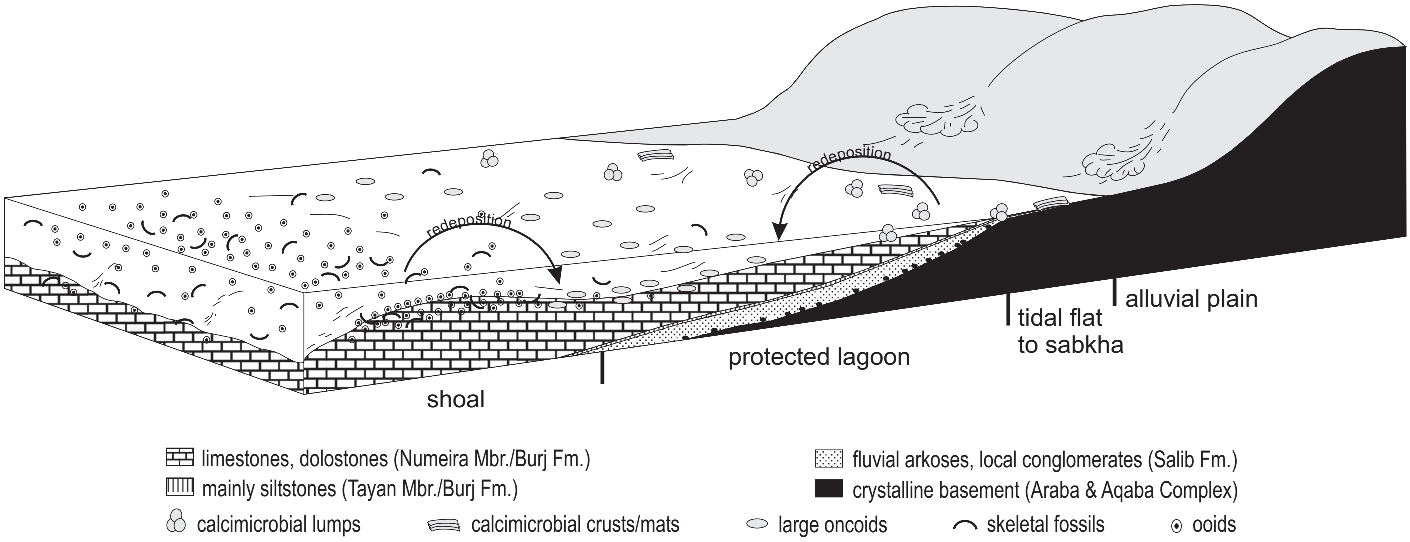


FIG. 3. – Reconstruction of the depositional environment of the marine Burj Fm. (Numeira Mbr.).
FIG. 3. – *Reconstruction des milieux de dépôt de la formation marine de Burj (Membre de Numeira).*

peloids sometimes occur. Terrigenous input was very low ; represented only by some clay accumulation in pressure solution sutures.

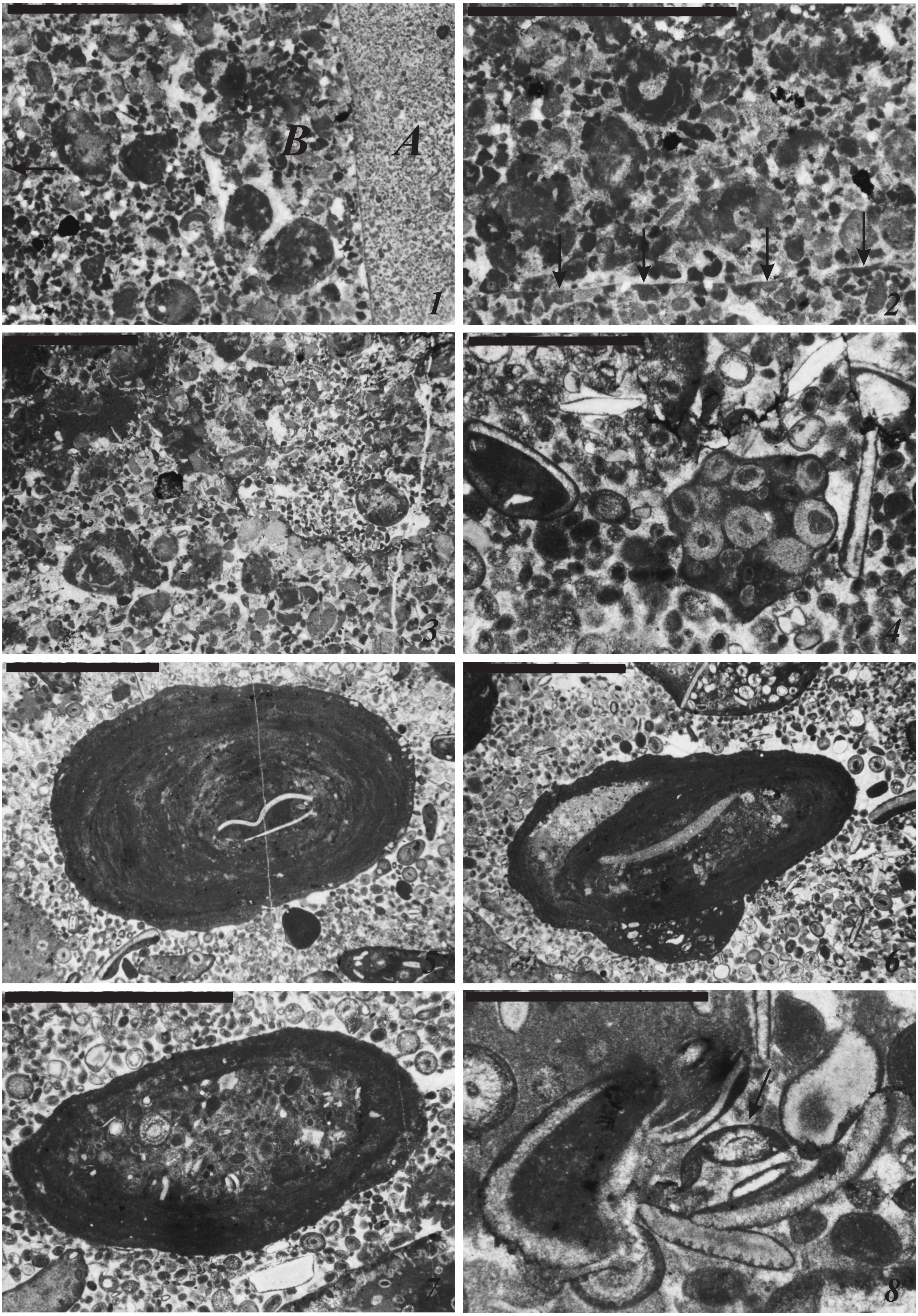
DEPOSITIONAL AND PALAEOGEOGRAPHIC DISCUSSION

The study area was thoroughly checked for carbonate facies types, permitting a more complete and comprehensive reconstruction of the marine depositional system than those given by Amireh *et al*. [1994] and Rushton and Powell [1998]. The investigations led to recognition of some distinct lithologies that allow interpretation of the main sedimentary processes in context with the previously recognized facies belts.

The monotonous, unlayered peloid grainstone facies (i), with its overwhelming abundance of fecal pellets and the total lack of muddy matrix, points to a nearly complete sediment-recycling by non-skeletal invertebrates typical for some lagoonal environments. The small amount of fine terrigenous material was brought in by aeolian transport only; there was no fluvial input. The environment is interpreted as lagoonal, with low energy and low sedimentation rate, and perhaps with reduced water circulation.

In contrast, the algal-lump pseudopeloid float-/grainstone facies (ii) shows a distinctly wider variety of components. Especially, the large algal lumps point to shallow and low energy conditions within a protected area with a low sedimentation rate [tidal flat, ?sabkha ; Flügel, 1978 ; Scholle *et al*., 1991]. Life forms are mainly represented by calcimicrobes and non-skeletal invertebrates. Glauconite grains occur. They are commonly interpreted to form in mid-shelf to upper slope positions [e.g. Bathurst, 1971 ; Rösler, 1980 ; for discussion see Chafetz and Reid, 2000]. Many authors, in contrast, pointed out that such a mineral formation is also possible in deeper environments during times of low sedimentation rates [e.g. Tucker and Wright, 1990]. Chafetz and Reid [2000], however, report glauconite from a Cambro-Ordovician (?higher salinity) tidal flat environment in Texas and New Mexico. Life conditions documented in the facies of the Jordan material seem to be only acceptable for calcimicrobes and some resistant bioturbating invertebrates. The environment can most probably be interpreted as a relatively low energy – but higher than type (i) – proximal and restricted-lagoonal to tidal flat/sabkha area [compare Flügel, 1978 ; Reineck and Singh, 1986 ; Tucker and Wright, 1990 ; Demicco and Hardie, 1994]. However, the preservation of the algal lumps (sometimes torn to pieces) and the common occurrence of erosive surfaces (very distinct at the base but also common within this facies type) where the bioturbation traces start, indicates periodic redeposition from the proximal lagoonal or tidal flat/sabkha environment into the lagoon.

The oncoid/ooid float-/grainstone facies contrasts strongly with the other types described. Most ooids are radially structured, indicating a moderate rather than a low or high energy regime [shallow shelf or lagoon, for discussion see Flügel, 1978]. The radial internal structure may also point to a higher salinity [Bathurst, 1971]. The water energy was higher than in types (i) and (ii), but not as strong as in a shoal environment (where cross bedded ooids occur). This energy index is consistent with the origin of the "giant" oncoids, typical for lagoons [Elicki, 1999]. The occurrence of distorted ooids may be a further argument for higher salinity because early dissolution of the cores is more understandable if they were sulfate-rich. In contrast, the normal-marine skeletal fossils, as well as the few occurrences of cross-bedded ooids, came from a higher energy and more open area (shoal). Thus, the depositional environment indicates an infingering of low energy lagoonal and high energy shoal sediments. Such interactions are characteristic for intertidal-lagoonal back-barrier systems [Read, 1985]. Within such facies realms, washover events, transporting shoal material into the quiet-water lagoon behind, are common. During these processes a mixing of the components from the different environments usually took place, however during more infrequent stronger events (storms),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lagoonal and shoal layers characteristically alternate [Tucker and Wright, 1990].

These newly discovered carbonate facies types from the Wadi Tayan area indicate the existence of a large low energy lagoon with restricted water circulation and higher salinity behind a high energy oolite shoal or shoal complex (back-barrier system). The transitional area between shoal and lagoon is characterized by an infingering of the different sediment types caused by washover events from the shoal into the quiet water behind. In the lagoon, the sedimentation rate was low and the sediment was fully bioturbated. Shoreward, the lagoonal facies changed into a microbial dominated tidal or sabkha flat environment from which the sediments were periodically reworked and redeposited into the lagoon (fig. 3).

Generally, the Jordan Cambrian represents a braided-stream-dominated coastal system unconformable on the Proterozoic Arabian-Nubian Shield, and burying a distinct palaeorelief [Bender, 1968, 1975 ; Segev, 1984]. From south to north some characteristic facies belts have developed : proximal alluvial fans, braided river sand flats, a distal braidplain, and marine facies [tidal flats/sabkhas, lagoons, ramp carbonates; Amireh *et al*., 1994]. The source area for the terrigenous material was probably only some tens of kilometers east of the present outcrops [Schneider *et al*., 1984 ; Amireh, 1987, 1991]. The marine phase within the Jordan Cambrian was geologically very short (early Bilbilian). Because of the trilobite content, this depositional area was seen as the westernmost part of the Pacific faunal province by Richter and Richter [1941].

CONCLUSIONS

Newly described carbonate facies from the marine Cambrian of the southern Dead Sea region (Jordan) enable a more detailed insight into the sedimentary processes and regional palaeogeography of this area for early Bilbilian time. All described facies types indicate a large lagoonal environment.

An unlayered peloid grainstone facies consists nearly completely of fecal pellets and was deposited within a low energy lagoon with a low sedimentation rate. It is disconformably overlain by an algal-lump/pseudopeloid float-/grainstone facies which indicates a microbial dominated protected lagoonal environment (tidal flat or sabkha), but with a little higher energy level. The sedimentation rate most possibly was low so that an entire recycling of the sediment has taken place. Broken fossils and internal erosive surfaces indicate periodic redepositional processes. An oncoid/ooid float-/grainstone facies was deposited within a moderate energy lagoon with higher salinity. Mixed (by washover events and storms) low energy lagoonal and high energy shoal sediments, characteristic for intertidal-lagoonal back-barrier systems are typical for these deposits. Thus, the existence of deposition controlled by a predominant lagoonal environment is demonstrated for this palaeogeographic region. Comparing these results with

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PLATE 1/PLANCHE 1

1. – Very distinctive erosional contact between inner-lagoonal (fecal-) peloid grainstone (right : A) and tidal- to sabkha-flat algal-lump pseudopeloid float-/grainstone (left : B). The fecal pellets of (A) are round to oval and very small. Other components are practically absent. The overlying layer (B) is characterized by many microbial lumps and small lithoclasts (pseudopeloids). Scale bar is 5 mm; arrow points to the top.

1. – *Limite d'érosion très nette entre les grainstones à péloïdes de lagon interne (à la base :* A) *et des pseudograinstones tidaux ou des fragments aplatis d'agrégats algaires. Les pelotes fécales de la couche inférieure sont rondes ou ovales et très petites. Les autres composants sont pratiquement absents. La couche qui les recouvre est caractérisée par un grand nombre d'agrégats microbiens et de petits lithoclastes (pseudopeloïdes). Échelle : 5 mm ; flèche dirigée vers le haut.*

2. – Algal-lump/pseudopeloid float-/grainstone. Typical algal-lump facies. The lumps are floating within a grainstone of pseudopeloids. Note the distinct erosive surface in the lower part of the photograph (arrows). Scale bar is 5 mm.

2. – *Floatstone/grainstone à agrégats algaires/pseudopeloïdes. Faciès typique d'agrégats algaires. Les agrégats flottent à l'intérieur d'un grainstone de pseudopéloïdes. Noter : la surface d'érosion à la partie inférieure de la photographie (flèches). Échelle : 5 mm.*

3. – Algal-lump/pseudopeloid float-/grainstone. At the upper right a large bioturbation structure, filled mainly with small oval fecal pellets, is well visible. Scale bar is 5 mm.

3. – *Floatstone/grainstone à agrégats algaires/pseudopeloïdes. À la partie supérieure droite une grande structure de bioturbation, remplie de nombreuses pelotes fécales ovales, est bien visible. Échelle : 5 mm.*

4. – Oncoid/ooid float-/grainstone – a mixed facies of lagoonal and shoal components. An aggregate grain consisting of several ooids and some peloids and enveloped by a thin microbial lamina is situated within a matrix of bioclasts, lithoclasts and other high energy grains. Scale bar is 2 mm.

4. – *Floatstone/grainstone à ooïdes/oncoïdes; faciès mixte d'éléments de lagon et de plate-forme; un agrégat de grains de plusieurs ooïdes et de quelques péloïdes, enveloppé par une mince lame microbienne se situe à l'intérieur d'une matrice de bioclastes, lithoclastes et autres constituants de haute énergie. Échelle : 2 mm.*

5. – Oncoid/ooid float-/grainstone. *Girvanella*-type large oncoid with a very thick microbial envelope within a matrix originated under higher energy conditions. As a core of the oncoid a trilobite carapace was used. Scale bar is 5 mm.

5. – *Floatstone/grainstone à ooïdes/oncoïdes; grandes oncoïdes – constituée par des Girvanella, avec une enveloppe microbienne dans une matrice formée dans des conditions de haute énergie. Une carapace de trilobite forme le noyau de l'oncoïde. Échelle : 5 mm.*

6. – Oncoid/ooid float-/grainstone – same as for fig. 5. Note the multiple *Girvanella*-type large oncoid. First, components were calcimicrobial connected with each other and then enveloped by algae. This first oncoid and further components were used later as a core for a second oncoid building stage. Scale bar is 5 mm.

6. – *Floatstone/grainstone à ooïdes/oncoïdes – comme sur la figure 5. Noter les multiples grandes oncoïdes – édifiées par des Girvanella. Les composants étaient d'abord des calcimicrobes interconnectés, puis ils ont été enveloppés par des algues. Ces premiers oncoïdes et les constituants ultérieurs ont été ensuite utilisés comme noyau au cours d'un second stade de construction oncoïdale. Échelle : 5 mm.*

7. – Oncoid/ooid float-/grainstone. *Girvanella*-type large oncoid with a litho-intraclast core (oolitic-pseudopeloidal) of the same material as the surrounding sediment. Scale bar is 5 mm.

7. – *Floatstone/grainstone à ooïdes/oncoïdes; grandes oncoïdes de Girvanella avec un noyau litho-intraclastique (oolitique-pseudopeloïdal) du même matériel que le sédiment encaissant. Échelle : 5 mm.*

8. – Oncoid/ooid float-/grainstone. Most of the components (mostly bioclasts as broken shells and disarticulated echinoderms, and ooids), show a thin microbial envelope. Note the distorted ooid in the middle (arrow) indicating the primary existence of a very easy-soluble (probably sulfate) ooid-core which was early solved, followed by the collapse due to compaction. Scale bar is 2 mm.

8. – *Floatstone/grainstone à ooïdes/oncoïdes. La plupart des bioclastes (surtout des coquilles brisées, des échinodermes désarticulés et des ooïdes) montrent une fine enveloppe microbienne. Noter l'ooïde déformée au milieu (flèche), indiquant l'existence initiale d'un noyau facilement soluble (probablement sulfaté) qui a été dissous très tôt, suivi par l'affaissement dû à la compaction. Échelle : 2 mm.*

other reports from subsurface deposits in southeastern and northern Jordan [Shinaq and Bandel, 1992], lagoonal environments were the most important and predominant carbonate production centres for much the maximum Cambrian marine transgressive phase in this area.

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