Viséan transgression and reworking at Boudouda (NW Benahmed, western Moroccan Meseta)

Ralph Thomas BECKER[1], Pedro CÓZAR[2], Zhor Sarah ABOUSSALAM[1], Ahmed EL HASSANI[3], Lahssen BAIDDER[4] & Sven HARTENFELS[1]

1. Institut für Geologie und Paläontologie, WWU Münster, Corrensstraße 24, D-48149 Münster, Germany
rbecker@uni-muenster.de
2. Instituto de Geosciencias, Facultad de Medicina, C/Severo Ochoa 7, 28040 Madrid, Spain
3. Hassan II Academy of Science and Technology, Km 4 Avenue Mohammed VI Rabat, Morocco
4. Faculté des Sciences Aïn Chok, BP 5366 Maârif, Casablanca, Morocco

Fig. 1: View from the north on the upper Viséan Bioclastic Limestone Member of the Oued Ayada Formation (lower to middle parts), showing the alternation of solid minor limestone cliffs and intervening poorly exposed intervals, with Z. S. ABOUSSALAM and L. BAIDDER for scale. Conglomerates at electricity pole in the background.

Abstract. At Boudouda NW of Benahmed, upper Frasnian goniatite shales are in unconformable contact with massive, partly dolomitized conglomerate boulders of the new Oued Ayada Formation. They represent debris flow deposits of localized channels and contain reworked supposed Emsian reefal organisms and Frasnian to lower/?middle Famennian conodonts. Rare foraminifers prove upper Viséan (Upper Asbian) sedimentation. Laterally, a ca. 35 m thick sequence of bioclastic limestones with crinoids, mostly fragmented brachiopods or gastropod-rich forms a second member. Thin-sections show a dominance of variably sorted wacke-, pack- and grainstones with abundant coated grains (initial ooids) and subangular fine quartz sand. Biota include calcareous green algae, foraminifers, and various Algospongia (Aoujgaliidae and Palaeoberesellidae). Throughout the succession, there are reworked Frasnian to middle Tournaisian deeper-water conodonts, which shows that a probably small-sized pelagic platform existed once in the region, which had been uplifted during the Eovariscan 2 tectonic phase. A single, juvenile, originally pyritic goniatite gives limited evidence for an upper Tournaisian/lower Viséan goniatite shale, which has no equivalents elsewhere in the Meseta. Based on a rich record of foraminifers (more than 70 taxa) and stratigraphically meaningful other calcareous microfossils, polyphase erosion and re-deposition by storms occurred on a shallow-water, photic zone carbonate ramp in the upper Viséan. The Oued Ayada Formation correlates with the transgressive limestones of the basal Melilla Formation in the southern Mdakra Basin and the Bled Mekrach Formation in the NE Rehamna.

1. Introduction

The Carboniferous of the Benahmed region has been briefly described by ROCH (1950), who assumed that a lower Viséan limestone from the Oued Mellah area with *Spirifer bisulcatus* transgressed the Devonian, followed by a middle Viséan limestone with different brachiopods. He acknowledged the difficulty to distinguish both Viséan subdivisions in the absence of goniatites. The listed fauna includes ten species of spiriferids, productids, chonetids, athyrids, and orthotetids. *Spirifer bisulcatus* is a species from the upper Tournaisian and Viséan of Great Britain and was placed by ANGIOLINI et al. (2011) in the genus *Angiospirifer* LEGRAND-BLAIN, 1985, which occurs in southern Algeria, the eastern Anti-Atlas (MOTTEQUIN et al. 2017), and Meseta (e.g., DELEPINE 1933). However, old identifications should be treated with caution.

TERMIER & TERMIER (1951a) confirmed the unconformable contact with the underlying Devonian and, based on foraminifer and brachiopod data, also assumed a lower Viséan transgression that continued into the upper Viséan. They separated four main Viséan outcrop and lithofacies developments (I to IV), with Groups III and IV located in the NW of Benahmed. Group III included outcrops at Sidi Bou Chatah and Boudouda, Group IV the syncline of Dar Cheikh el Mfaddel to the west.

We logged and sampled in detail for conodonts, microfacies, foraminifers, and other calcareous microfossils the conglomerate boulders and limestone succession (Figs. 1-2) just north of the Frasnian section at Boudouda (see previous chapter; coordinates for section base = N33°10'43.7", W7°15'46.4"). Both are clearly in disconformable contact, as evident from a large stratigraphic gap, an intervening massive conglomerate (Fig. 3), and different orientation of the bedding. The Carboniferous limestones dip with ca. 40-50° to the west (Fig. 1). Since rich foraminifer faunas were already noted by TERMIER & TERMIER (1951a) and since Devonian conodonts were found in an initial spot sample, our study aimed to reconstruct the local Eovariscan reworking, the precise timing of transgression, and the previously unstudied microfacies of the Boudouda Viséan. This forms a base for regional comparisons (compare CÓZAR et al. 2020a). Our data show that a Frasnian to Tournaisian succession existed once, which was lost by pre-upper Viséan erosion.

The Boudouda Viséan succession is assigned to the new **Oued Ayada Formation**, named after the dry valley that runs roughly in parallel to the outcrop just slightly to the NE (see map in main Benahmed chapter). It is ca. 45 m thick and subdivided into the informal **Conglomerate** and **Bioclastic Limestone Members**. Both represent a neritic, shallow-water carbonate platform setting with erosional channels that transgressed deeper-water Devonian strata that were previously uplifted by Eovariscan block faulting. Late diagenetic dolomitization and the main Variscan deformation led to subsequent overprinting.

2. The Conglomerate Member

Adjacent to an electricity pole that can be used as a landmark (in the background of Fig. 1), there are thick boulders of coarse-grained, unsorted, polymict limestone conglomerate, which form a succession in the scale of 10 m or more (Fig. 2.1). Individual large blocks were variably affected by late diagenetic dolomitization and iron mineralization, causing partly an ochre or reddish weathering color (Fig. 3). There is a high variability of clast size (a few mm to 10 cm or more), the degree of rounding, and the amount of fine matrix. Since pebbles and clasts often float in matrix, deposition occurred as marine debris flows, within a channel that probably originated at an active fault scarp. Matrix-poor boulders may represent submarine rockfall at the same slope.

1

2

3

Fig. 2: The Conglomerate Member of the Oued Ajada Formation at Boudouda and its unclear relationships with the Bioclastic Limestone Member. **1.** View on the main conglomerate boulders looking from the south; **2.** Discontinuous outcrop between the last conglomerate boulders (ca. 1 m thick) and the measured section in the background; **3.** View from the piste at the northern end of the conglomerate boulders, with overlying strongly dolomitic, irregularly-bedded marls exposed in the roadcut (at the hammer).

Within several blocks, Devonian reefal fossils were found, including complete stromatopores (Fig. 4.1), massive (Fig. 4.4.), favositid (Fig. 4.2), and rare thamnoporid tabulate corals. In thin-section (Fig. 4.3), cross-sections of trilobites were observed in micritic to microsparitic mudstone matrix. The direct association of large stromatopores and tabulate corals proves for some blocks (Fig. 4.2) a reefal origin, while others contain mostly macrofossil-poor micrites or crinoidal limestones. In the context of the regional geology (see main Benahmed chapter), it is likely that the reef clasts derived from the Emsian rather than from the Middle Devonian; the latter interval is developed close-by at Dar Cheik el Mfaddel in deep neritic to shallow pelagic facies.

The relationships between the conglomerate and the main section of the Oued Ayada Formation are somewhat uncertain. There is a small covered interval between both members (Figs. 2.2-3) but conglomerate boulders lie roughly on strike with the main section (Fig. 2.2). As pointed out above, they represent a channel with very high depositional energy within the lower Oued Ayada Formation. The foraminifer data give no significant age difference between both members (see below). To the south, the conglomerate contacts without clear fault evidence the steeply southwards dipping, upper Frasnian Boudouda Formation. In the adjacent Dar Cheik el Mfaddel area (Dar Baati, Termier & Termier 1951a, p. 71), a similar conglomerate with clasts ranging from 1 mm to 10 cm yielded Emsian brachiopods. It is said to be separated from Viséan limestones by a band of Strunian (uppermost Famennian) age. It seems to represent a second individual channel.

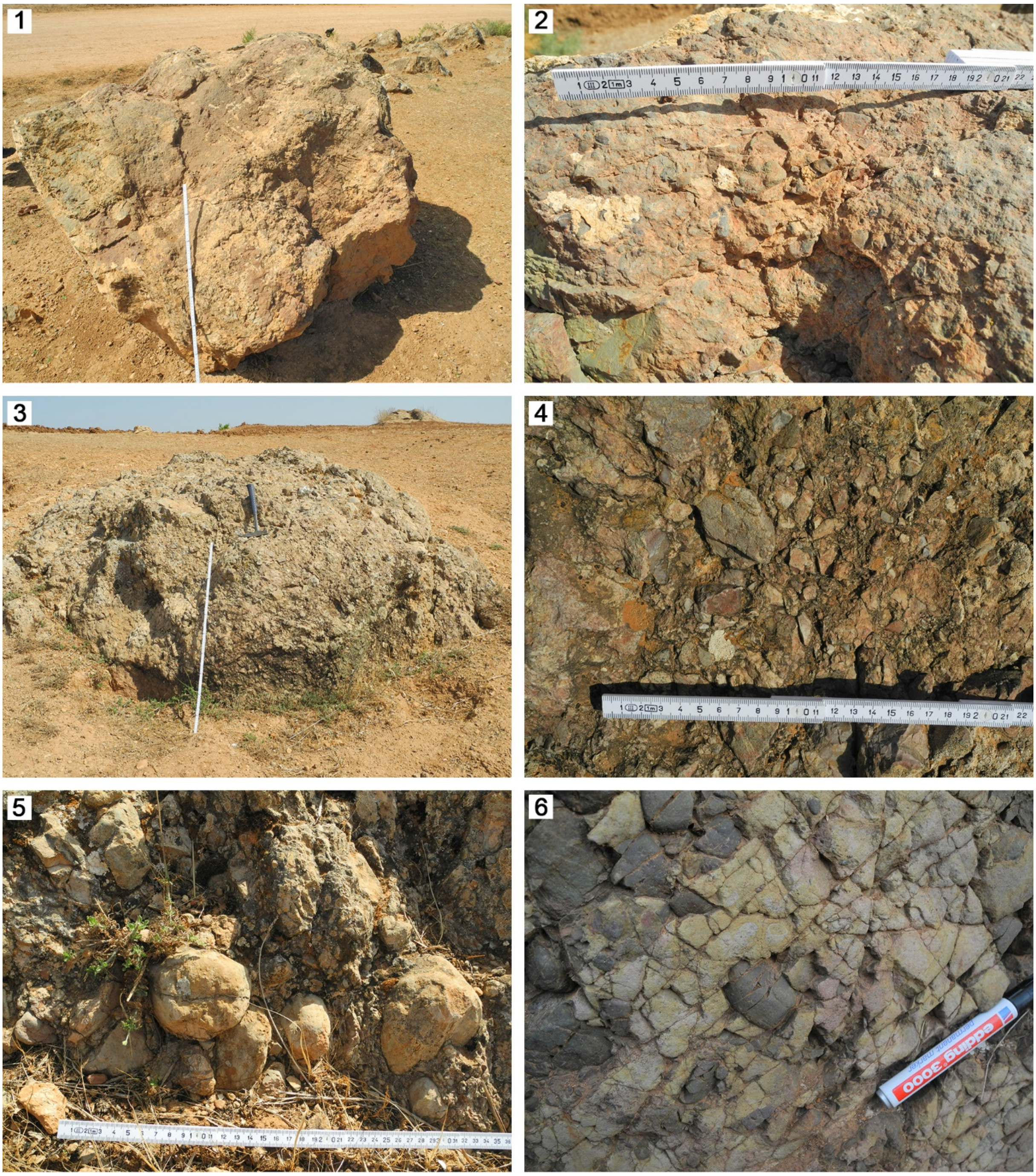

Fig. 3: Field photos of the Conglomerate Member of the new Oued Ayada Formation at Boudouda. **1.** Strongly dolomitized Block 1; **2.** Nodular, yellowish to orange weathering Block 2 with cm-sized subangular pebbles; **3.** Overview of massive Block 2, composed of mostly small-sized pebbles; **4.** Third conglomerate block with mostly subangular, strongly unsorted, often dolomitized clasts and a low amount of fine matrix; **5.** Strongly unsorted conglomerate with well-rounded to subangular, mostly dolomitized, yellowish weathering pebbles, up to 10 cm in diameter, sitting in a matrix of fine pebbles/clasts; **6.** Partly matrix-rich and densely fractured conglomerate with well-rounded, grey pebbles of highly variable size.

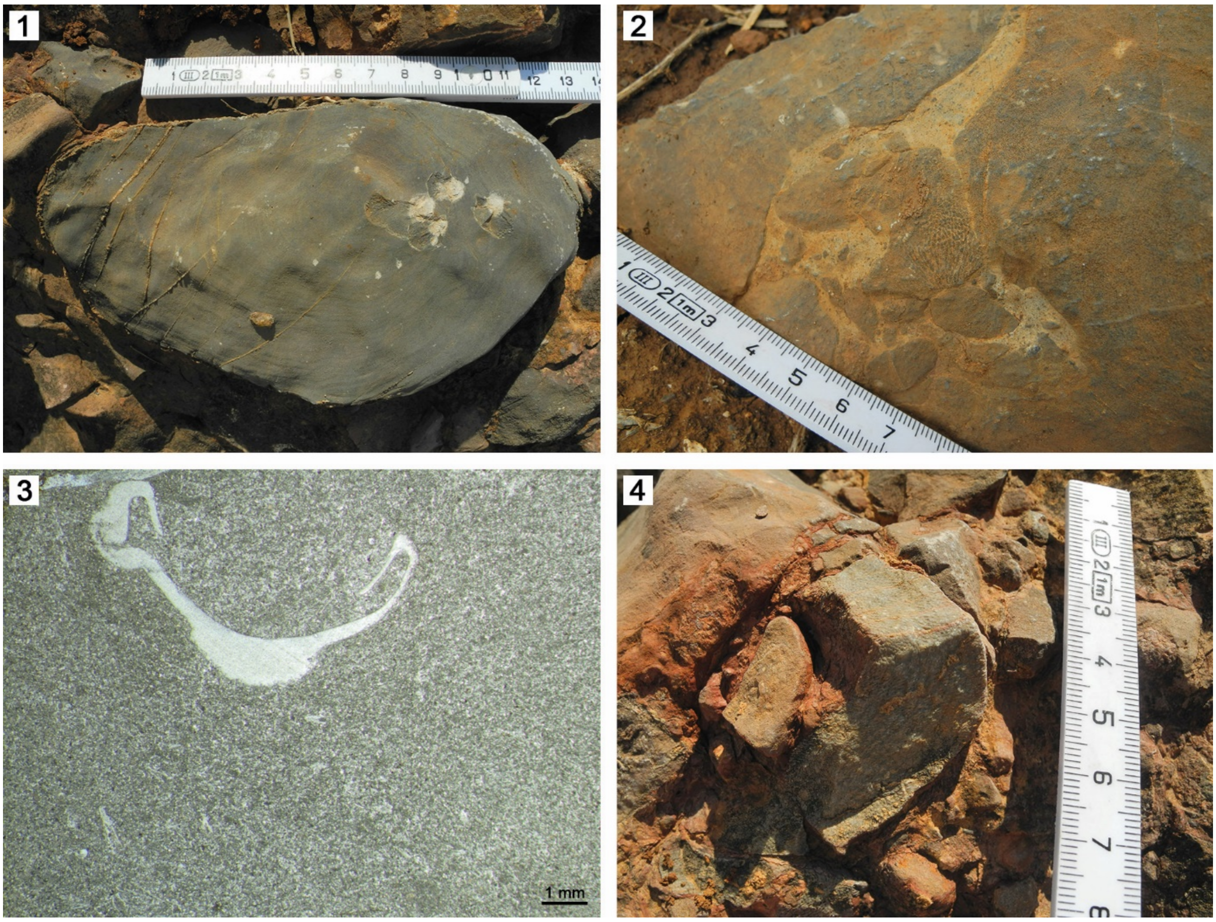

Fig. 4: Shallow-water Devonian fauna observed in the Viséan conglomerate boulders at Boudouda. **1.** Large, complete stromatopore; **2.** Favositid coral (center) lying adjacent to a large stromatopore (right); **3.** Thin-section of a mudstone pebble with the complete cross-section of a trilobite; **4.** Pebble consisting of a massive tabulate coral.

3. Bioclastic Limestone Member

The fields east of the ca. N-S running piste expose with interruptions a ca. 35 m thick alternation of thin- to thick-bedded bioclastic limestones (Figs. 1, 5). Covered intervals are either deeply weathered marls or thinly bedded limestones while solid beds stick out prominently and can be traced along strike. The prominent beds are concentrated in the middle part of the section (Beds 7a to 36). Most limestones are light-grey, crinoidal, and contain fragmentary brachiopods (Fig. 6.1). More complete specimens are rare (Fig. 6.2). Bed 36 is peculiar because of its abundance of gastropods (Fig. 6.3). There are nearly planispiral euomphalids (*Straparollus*), involute bellerophontids, and higher spired, partly large forms (Fig. 6.5). Associated are partly thick-shelled brachiopods. Other beds yielded fragmented bryozoans, corals, algae, and various microproblematica (Tab. 1). Only a few beds (e.g., Bed 8b) display strong, macroscopic hummocky-type cross-bedding, as typical for tempestites (Fig. 6.4). The member formed on a shallow current- and storm-ridden platform, where constant and strong water- and sediment movements prevented the settling of reefal fauna, such as rugose and tabulate corals. Crinoid meadows and brachiopod populations must have lived originally in close-by more protected zones.

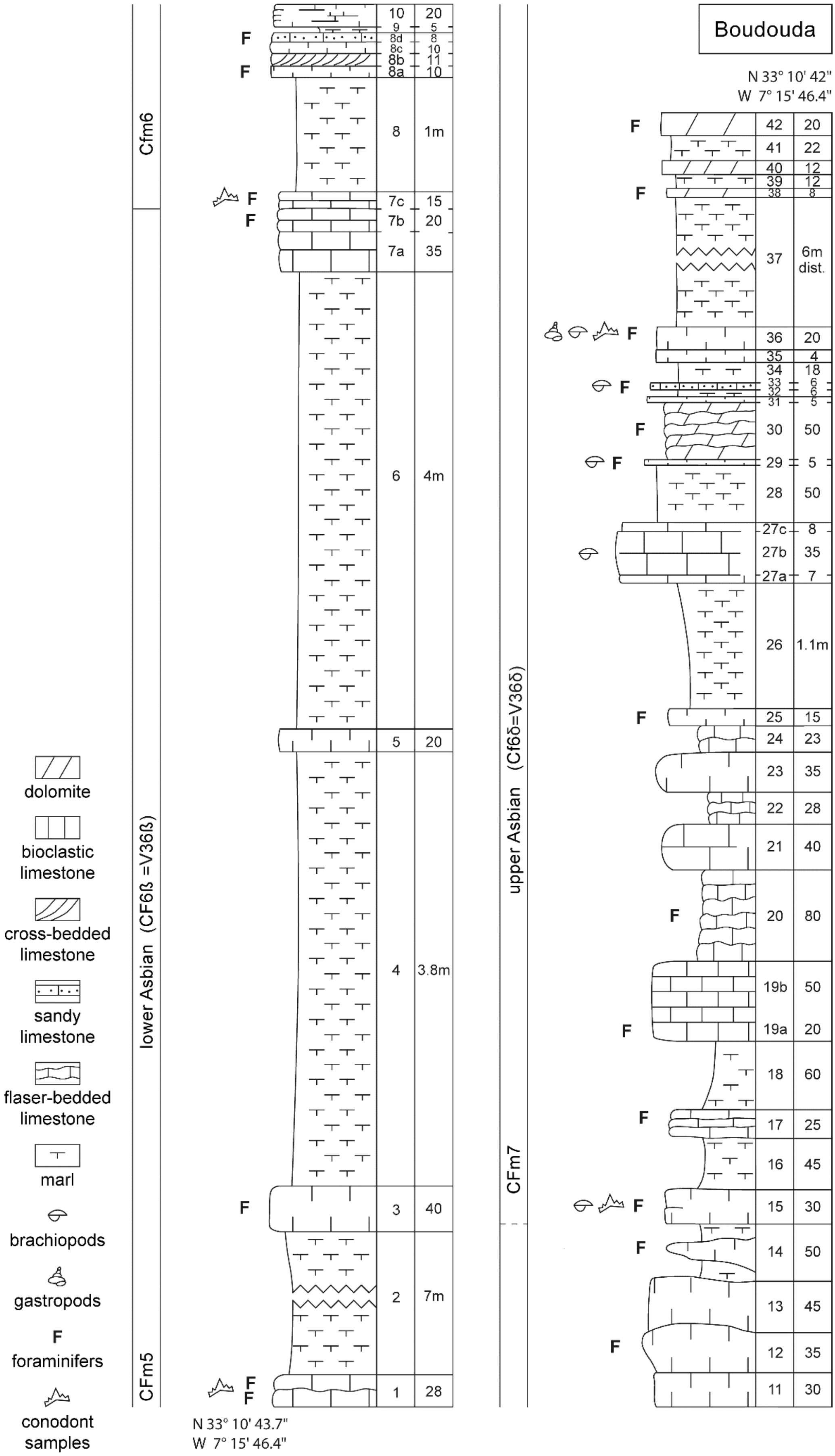

Fig. 5: Section log for the Bioclastic Limestone Member of the new Oued Ayada Formation at Boudouda, showing the position of conodont samples and foraminifer beds (thicknesses in cm if not stated otherwise).

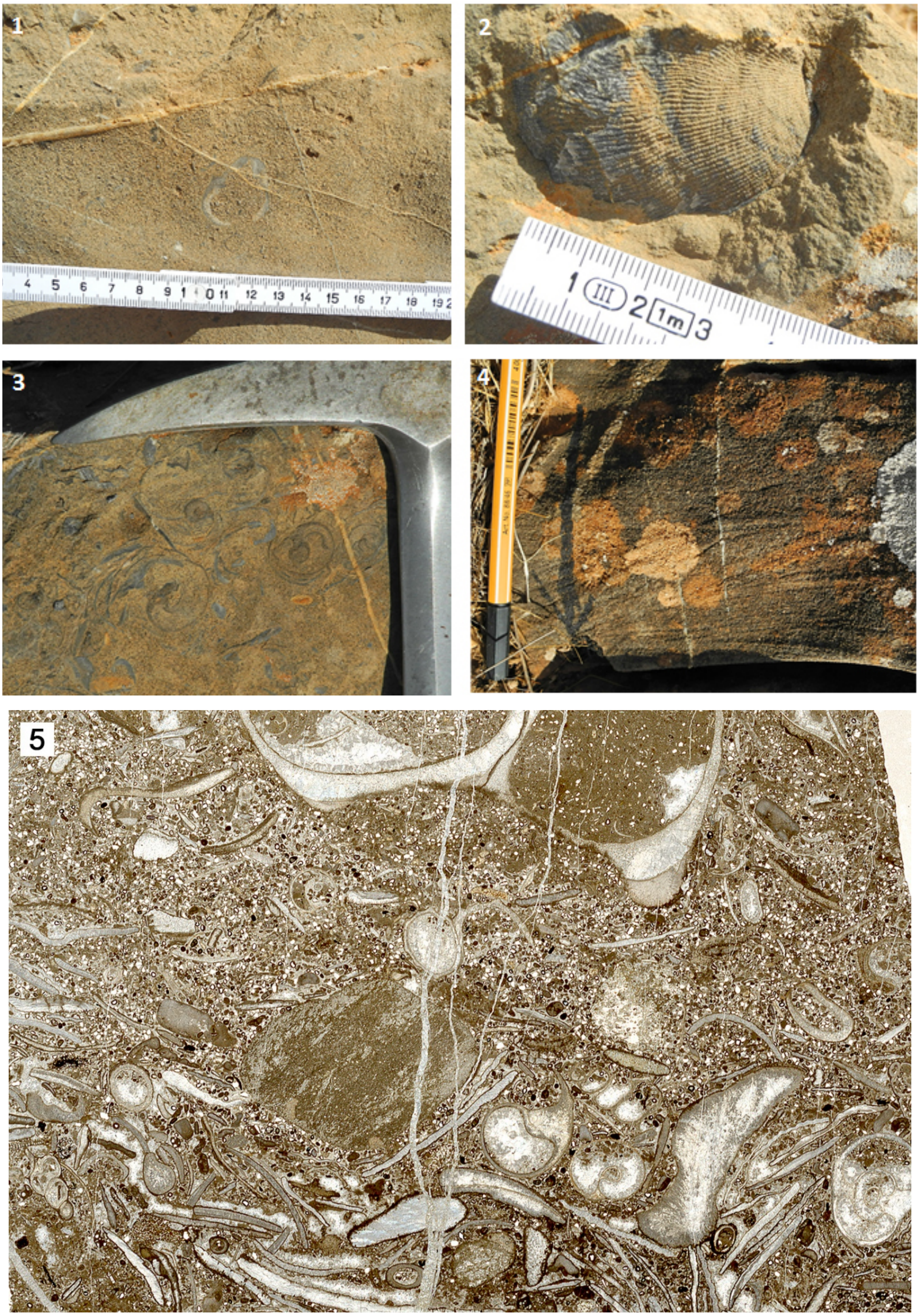

Fig. 6: Sedimentary and faunal characteristic of the Bioclastic Limestone Member (Oued Ayada Formation) at Boudouda. **1.** Fine-grained crinoidal limestone with brachiopod cross-section, Bed 27b; **2.** Detail of near-complete productid brachiopod, Bed 27b; **3.** Gastropod-rich limestone with fragmentary brachiopods, Bed 36; **4.** Cross-bedded, tempestitic crinoidal limestone, Bed 8b; **5.** Thin-section of Bed 36, with brachiopod shells, bellerophontid (lower right corner), euomphalids (lower left), other, partly large snails (e.g., upper center), different types of (sub)rounded extraclasts (recrystallized mudstones, coated grains), and sandy micrite/sparite matrix (picture width ca. 7 cm).

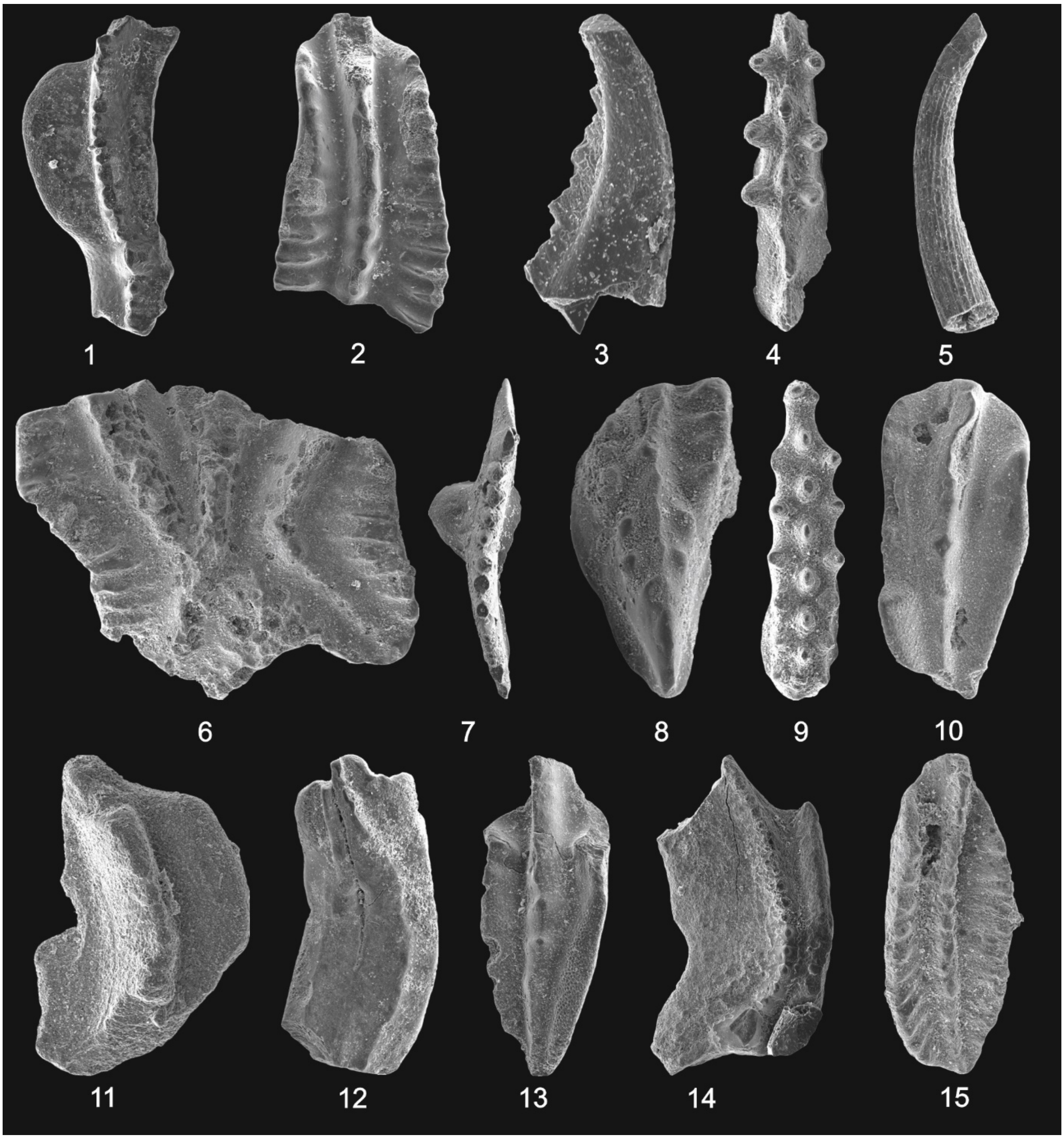

Fig. 7: Reworked Frasnian to Tournaisian conodonts from the Viséan Oued Ayada Formation at Boudouda (1-2 from conglomerate Block 1, 3-5 from conglomerate Block 2, 6 from Bed 1, 7-12 from Bed 7c, 13-15 from Bed 15, 16-18 from Bed 36), GMM B4C.2.93-107. **1.** *Palmatolepis glabra prima*, incomplete specimen with typical outer anterior platform ear, x 75; **2.** Cf. *Polygnathus webbi*, posterior end broken off, x 75; **3.** *Belodella resima*, juvenile, x 150; **4.** *Icriodus* cf. *vitabilis*, juvenile, x 140; **5.** *Neopanderodus perlineatus*, x 120; **6.** *Ancyrodella curvata* late morphotype, large-sized fragment, x 40; **7.** *Branmehla inornata*, anterior part broken off, x 85; **8.** *Gnathodus delicatus*, incomplete, x 110; **9.** *I.* cf. *plurinodosus*, small specimen, x 85; **10.** *Neopolygnathus communis communis*, with anterior platform collar preserved on right side only, x 95; **11.** *Palmatolepis* fragment, probably of the *tenuipunctata-glabra* Group, x 85; **12.** *Siphonodella (Eosiphonodella) bransoni*, aboral view showing the typical basal cavity, x 70; **13.** *Neo. communis communis*, with anterior platform collar, left platform margin partly broken off, x 90; **14.** *Pa. glabra pectinata* or *distorta*, fragment, x 70; **15.** *Polygnathus* sp., resembling a Tournaisian specimen figured as *Po. perplana* in Youngquist & Patterson (1949: pl. 17, fig. 11), which differs clearly from the *perplana* holotype, x 100.

4. Reworking of Frasnian to Tournaisian conodonts

All conodont samples yielded reworked, partly numerous, mostly broken and eroded to rounded, brownish to light-grey specimens (CAI 2-3), often too incomplete for even generic identification. Fish scales and teeth are associated. There must have been a conodont-rich sand that included the fine quartz material of residues.

Bulk conodont samples from conglomerate boulders were only partly productive. Block 1 yielded a fragmentary *Palmatolepis glabra prima* (Fig. 7.1) and an incomplete polygnathid that probably belongs to *Po. webbi* (Fig. 7.2). The first is the index species of the *glabra prima* Zone high in the lower Famennian and typical for pelagic facies, the second is restricted to the top-Givetian (see ABOUSSALAM & BECKER 2007) to topmost Frasnian. A sample from Block 2 yielded three conodonts that all can have been derived from Frasnian neritic facies: *Icriodus* cf. *vitabilis* (Fig. 7.4), *Belodella resima* (Fig. 7.3), and *Neopanderodus perlineatus* (Fig. 7.5). The latter two taxa have a much lower range, starting in the Anti-Atlas deep in the Lower Devonian (e.g., ABOUSSALAM et al. 2015). The restricted evidence shows that Emsian to lower Famennian limestones were uplifted by Eovariscan block faulting prior to the onset of Viséan debris flow re-deposition. The seismic trigger can be roughly aligned with the Eovariscan 2 phase of MICHARD et al. (2008).

Widely spaced sampling of the Bioclastic Limestone Member shows that the erosion and re-deposition of uplifted Frasnian to Tournaisian limestones continued regionally and continuously for a long time. Bed 1 yielded a large fragment of the late morphotype of *Ancyrodella curvata* (Fig. 7.6), which ranges from the top-middle Frasnian (*Pa. plana* Zone = MN Zone 10, see KLAPPER 1997) to the Frasnian/Famennian boundary. Associated are *Polygnathus* fragments, a fish scale, and pyritic, minute *Ammodiscus* foraminifers; the latter are probably not reworked. There is one irregularly coiled *Glomospira* and one *Hyperammina*.

Bed 7c yielded a mixture of Famennian to middle Tournaisian pelagic taxa. *Branmehla inornata* (Fig. 7.7) ranges from the middle Famennian *marginifera utahensis* Zone ca. to the top of the lower Tournaisian (e.g., HARTENFELS 2011; SPALLETTA et al. 2017). The entry of *Gnathodus delicatus* (Fig. 7.8) defines in North America the second zone of the middle Tournaisian (e.g., BOARDMAN et al. 2013), which is also characterized by the coincident appearance of the first true *Gn. typicus* (= M1). In their type region, both species do not reach the upper Tournaisian. LANE et al. (1980) depicted for *Gn. delicatus* a range up to the middle of the *anchoralis* Zone but their figured specimens are not conspecific with the type material or our specimens.

One specimen from Bed 7c resembles *I. plurinodosus* described by WANG et al. (2016) from the top-lower to early middle Famennian of the Junggar Basin in NW China. Our specimen lacks a posterior thorn, which excludes the otherwise similar German *I. ballbergensis* LÜDDECKE, HARTENFELS & BECKER, 2017. The associated *Neopolygnathus communis communis* ranges from the lower Famennian to the upper Tournaisian (e.g., WEBSTER & GROESSENS 1990; HARTENFELS 2011; WANG et al. 2016, SPALLETTA et al. 2017), possibly even into the basal Viséan (LANE et al. 1980). The syntype series of BRANSON & MEHL (1934) included the two figured specimens (no lectotype selected) with smooth platform and an anterior platform collar, partly only on one side. In this respect, our specimens agree well, but in the literature a range of deviating forms has been assigned to the subspecies.

There is a second palmatolepid fragment that probably belongs to the *Pa. tenuipunctata-glabra* Group (Fig. 7.11), which is most

common in the lower but ranging into the middle Famennian. *Siphonodella (Eosiphonodella) bransoni* (Fig. 7.12) is the index species of the lower Tournaisian *bransoni* Zone (Ji 1985) but the species ranged higher, almost to the top of the substage (Sandberg et al. 1978; Kaiser et al. 2017).

Bed 15 contained another *Neo. communis communis* (Fig. 7.13), the Frasnian *Po. paradecorosus* and *Po. webbi*, a questionable fragment of *Pa. distorta* (a middle Famennian taxon, see Spalletta et al. 2017) or *Pa. glabra pectinata* (Fig. 7.14), and a juvenile supposed polygnathid (Fig. 7.15) that does not fit any named species. Distinctive are the oblique ribs in the posterior part of the leaf-shaped platform. To some extent it resembles a specimen figured as *Po. perplana* from the middle Tournaisian of Iowa (Prospect Hill Member, Youngquist & Patterson 1949). But it is also rather close to juvenile *Siphonodella cooperi* as illustrated by Świś & Dzik (2020, fig. 2) from the lower Tournaisian of Poland.

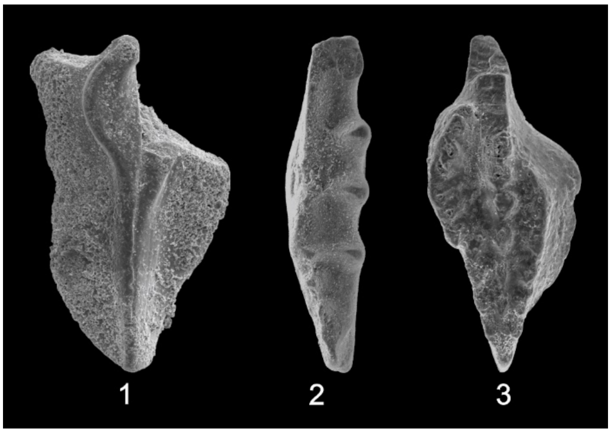

Fig. 8: Reworked conodonts from Boudouda, Bed 36, GMM B7A.12.108-110. **1.** *Pseudopolygnathus* sp., aboral view showing the wide basal pit, x 90; **2.** *Bispathodus aculeatus aculeatus*, x 80; **3.** *Gnathodus delicatus*, x 85.

Three incomplete conodonts from Bed 36 derived from the upper Famennian to middle Tournaisian interval. The pseudopolygnathid (Fig. 8.1) is too incomplete for species identification. *Bispathodus aculeatus aculeatus* is the index species for an upper Famennian zone but ranges higher, into the basal middle Tournaisian (Clausen et al. 1989; Izart & Vieslet 1988). It is not known to overlap with the higher middle Tournaisian *Gn. delicatus* (Fig. 8.3), which proves a heterochronic reworking. The conodonts may derive from the extraclasts recognized within the bed (Fig. 6.5).

Despite restricted conodont sampling, it could be proven that there was a long-term re-deposition of Frasnian to middle Tournaisian taxa. Most or all Famennian and Tournaisian species represent pelagic biofacies, which is not known in outcrop from the Benahmed region. It seems that a small pelagic platform has been lost by erosion, which straddled the Devonian-Carboniferous Boundary and the global Lower Alum Shale Event at the lower/middle Tournaisian boundary. The latter caused in the Anti-Atlas a complete interruption of carbonate sedimentation (Becker et al. 2006; Kaiser et al. 2011). In the Sidi Bettache Basin NE of Boudouda, a middle Tournaisian limestone is known from Sidi Jilali (Izart & Vieslet 1988). But definite lower Tournaisian conodont taxa, such as *S. (Eo.) bransoni*, were so far unknown in the Meseta.

The evidence of locally lost strata is deepened by a single juvenile, goethitic goniatite (Fig. 9) that combines an involute, globose early stage with sutures as in upper Tournaisian or lower Viséan taxa. It may represent the juvenile of an *Eurites* or of a related genus, such as *Trimorphoceras*. Such forms are known from cratonic North Africa (e.g., Ebbighausen et al. 2010). Based on unpublished specimens from the Anti-Atlas (southern Tafilalt) and the Northview Shale of Missouri, the median E_1-lobe is longer than the secondary external side lobes in early juvenile *Xinjiangites* and *Muensteroceras*. The sutures alone exclude any Frasnian to main middle Tournaisian genus, while upper Viséan taxa developed more advanced goniatitic sutures at small size. The originally pyritic preservation

suggests that the specimen came from a hypoxic goniatite shale or marl, which was so far unknown for the time interval under question in all of the Meseta. FADLI (1990, 1994b) described SSW of Sidi bou Chatah an alternation of black shales and dark bioclastic limestones, which could be a possible source. However, the unit was assigned to the upper part of the middle Viséan (V3a), the limestone includes possible upper Viséan taxa, and the general knowledge is too poor to draw any definite conclusions.

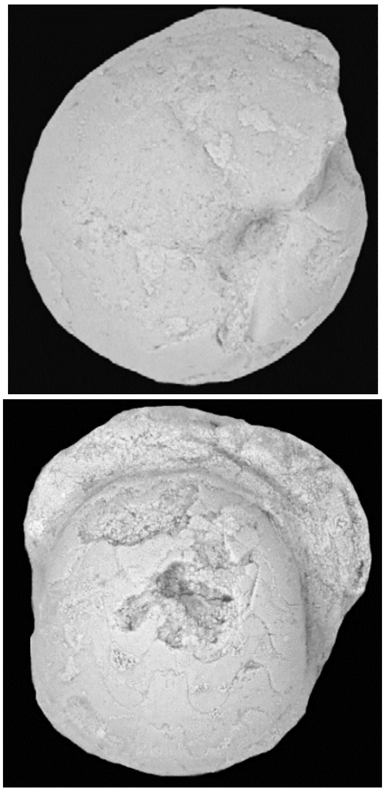

Fig. 9: Involute and globular, slightly deformed juvenile (4.8 mm diameter) goniatite (*?Eurites* sp.) with sutures as in upper Tournaisian/lower Viséan forms, found loose in scree of the upper Frasnian Boudouda Formation, lateral and adoral views, showing the subdivided E-lobe, GMM B6C.54.182.

4. Microfacies of Bioclastic Limestone Member

A set of 22 thin-section reveals the microfacies patterns and microfaunas. Dominant are variably sandy, bioclastic and intraclastic wacke, pack- and grainstones with abundant coated grains that represent initial ooids. Typical ooids are rare; common are thin micritic envelopes around rounded to angular quartz grains of mostly 0.1-0.2 mm diameter (fine sand), crinoid debris, brachiopod fragments, or micritic intraclasts. Several beds contain common large, fragmented brachiopod shells (e.g., Figs. 10.1-2, 10.8, 11.1, 11.5) that are sometimes obliquely imbedded. They are often thick, which indicates fragmentation under high-energy conditions. The sorting of the limestones is very variable, poor (brachiopod-rich beds, Figs. 10.1-2, 10.8, 11.5, 12.1), median (Fig. 11.4, 11.8), or relatively good, especially when the sand content is very high (Figs. 10.3-4, 11.2; 11.4, 12.3). There are some isolated crinoid ossicles (Figs. 10.1, 12.1), fragmentary bryozoa (Beds 1, 14, 19a), ostracods, fragmentary corals (Beds 14-15, 29), and a wide range of microfossils (Tabs. 1-2), especially foraminifers (Figs. 10.4, 11.6, 12.6). Indicators for the photic zone are calcareous algae, such as dasycladaceans (*Koninckopora*, present in most beds, and *Nanopora*, Beds 1, 29, 33, 36), red algae (*Solenopora*, Bed 36), and some of the Algospongia (sensu VACHARD & CÓZAR 2010: aoujgaliids, palaeoberesellids). Dolomitization occurs in several beds and becomes dominant in Beds 30-42 (Figs. 12.7, 13.5-6). Dolomicrites display strong bioturbation (Beds 38 and 42, Figs. 13.5-6).

The abundance of relatively well-sorted (similarly-sized) coated grains and quartz grains reflects a biphasic depositional history. First, silt to predominant fine sand and shell debris were sorted in a very shallow regime, with a long-term repetition of similar currents, and with sufficient calm interphases to enable the microbial micritization and coating. This nearshore material was partly swept away during later storms and re-deposited variably with much coarser shell fragments and with Devonian intraclasts derived from a near-by Eovariscan uplift block.

Fig. 10: Microfacies of Bioclastic Limestone Member, Oued Ayada Formation, at Boudouda , scale bar = 1 mm, part I. **1-2.** Poorly sorted wacke-packstone with abundant coated grains (including subangular, fine quartz sand), crinoid ossicles, large brachiopod fragments, and fine, bioturbated matrix, Samples 1a-b (Bed 1); **3-4.** Well-sorted kamaeniid packstone with foraminifers and brachiopod shells, Bed 3; **5-7.** Alternating coated grain wacke- and packstone layers, the latter with abundant fine, coated or non-coated quartz sand, Bed 7b; **8.** Poorly-sorted bio- and extraclastic pack-rudstone with coated grains, brachiopod fragments, micrite extraclasts, and abundant, fine quartz sand, partly dolomitic, Bed 8a.

Fig. 11: Microfacies of Bioclastic Limestone Member, Oued Ayada Formation, at Boudouda, scale bar = 1 mm, part II. **1.** Detail of Fig. 10.8, bio- and extraclastic packstone with brachiopod fragments, micrite extraclasts, and abundant, fine quartz sand; **2.** Well-sorted, fine-grained, calcareous sandstone with coated grains and micrite matrix, partly dolomitized, Bed 8d; **3.** Moderately-sorted coated grain wacke-packstone with quartz sand, Bed 12; **4.** Moderately-sorted grainstone with subangular quartz grains (coated or not), foraminifers, coated grains, and blocky cement, Bed 14; **5-6.** Poorly-sorted pack-grainstone with coated grains, subangular quartz, crinoid debris, brachiopod fragments, foraminifers, and extraclasts, Bed 15; **7.** Poorly sorted grainstone with coated grains, large micrite extraclasts, and fine quartz sand, Bed 17c, **8.** Overview of moderately sorted grainstone with coated grains, fine quartz sand, and bioclasts, Bed 19c.

Fig. 12: Microfacies of Bioclastic Limestone Member, Oued Ayada Formation, at Boudouda, scale bar = 1 mm, part III. **1-2.** Moderately sorted grainstone with layers variably rich in coated grains, fine quartz sand, and bioclasts, details of Bed 19c; **3-4.** Relatively well-sorted, sand-rich grainstone with abundant coated grains, Beds 20 and 25; **5-6.** Poorly sorted, sandy grainstone with abundant coated grains, grading into parts with more abundant brachiopod shells, crinoidal debris, foraminifers, and extraclasts; Bed 29; **7**. Granular dolomite, Bed 30; **8.** Sandy, bioclastic packstone with coated grains, micritic extraclasts, micrite matrix and some dolomitization, Bed 33.

(Figs. 10-13: thin-sections kept in the collection of P. CÓZAR)

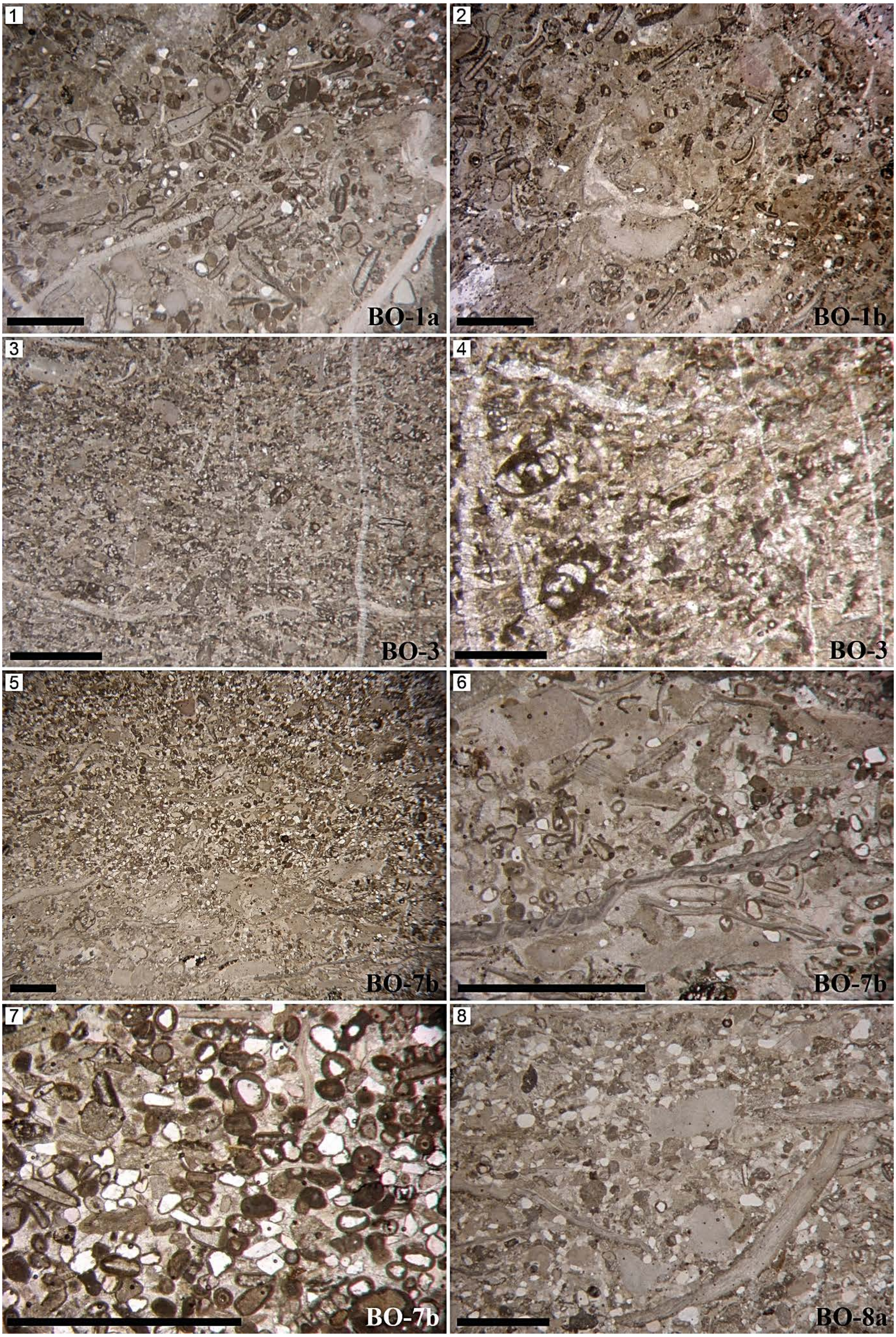

Fig. 10

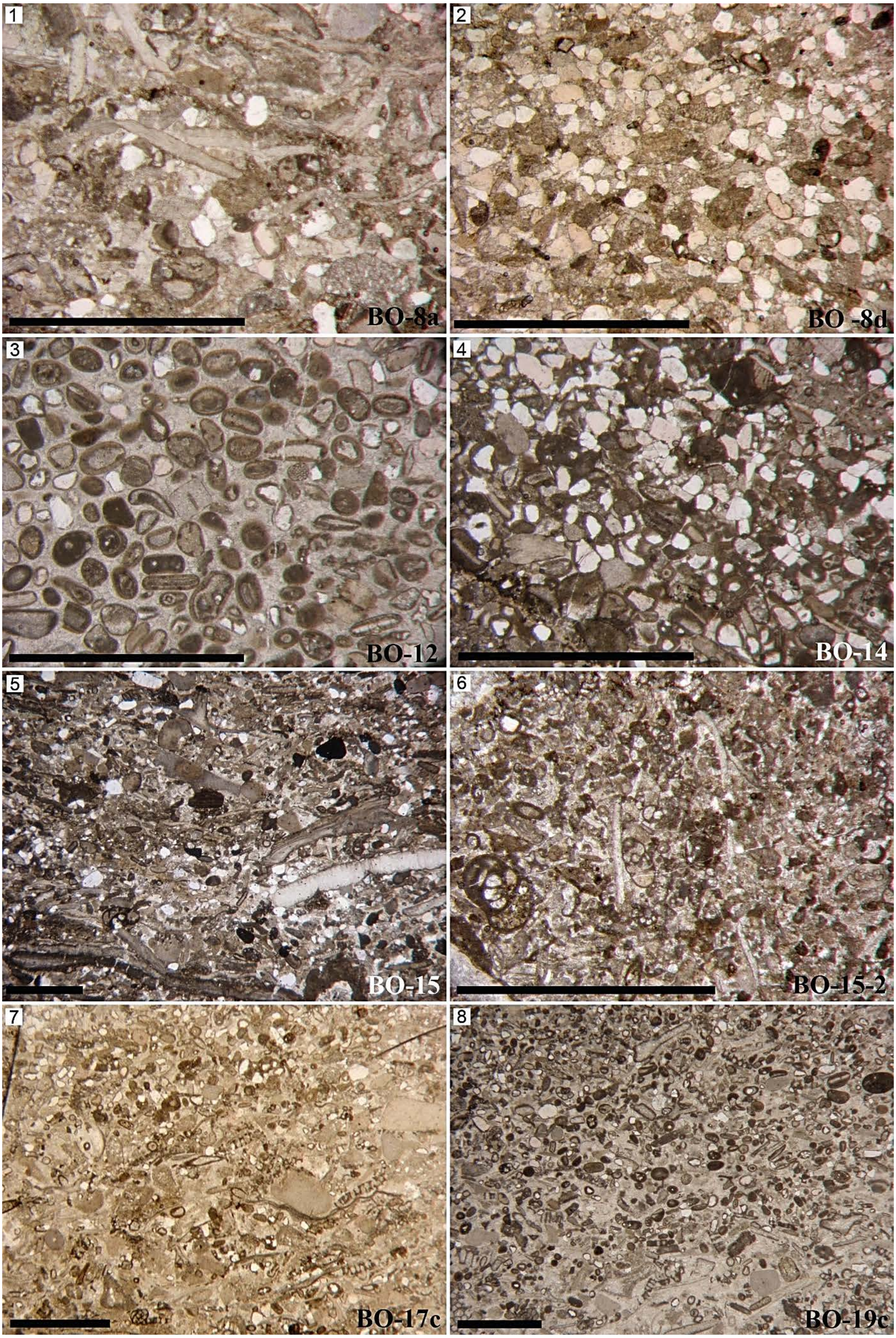

Fig. 11

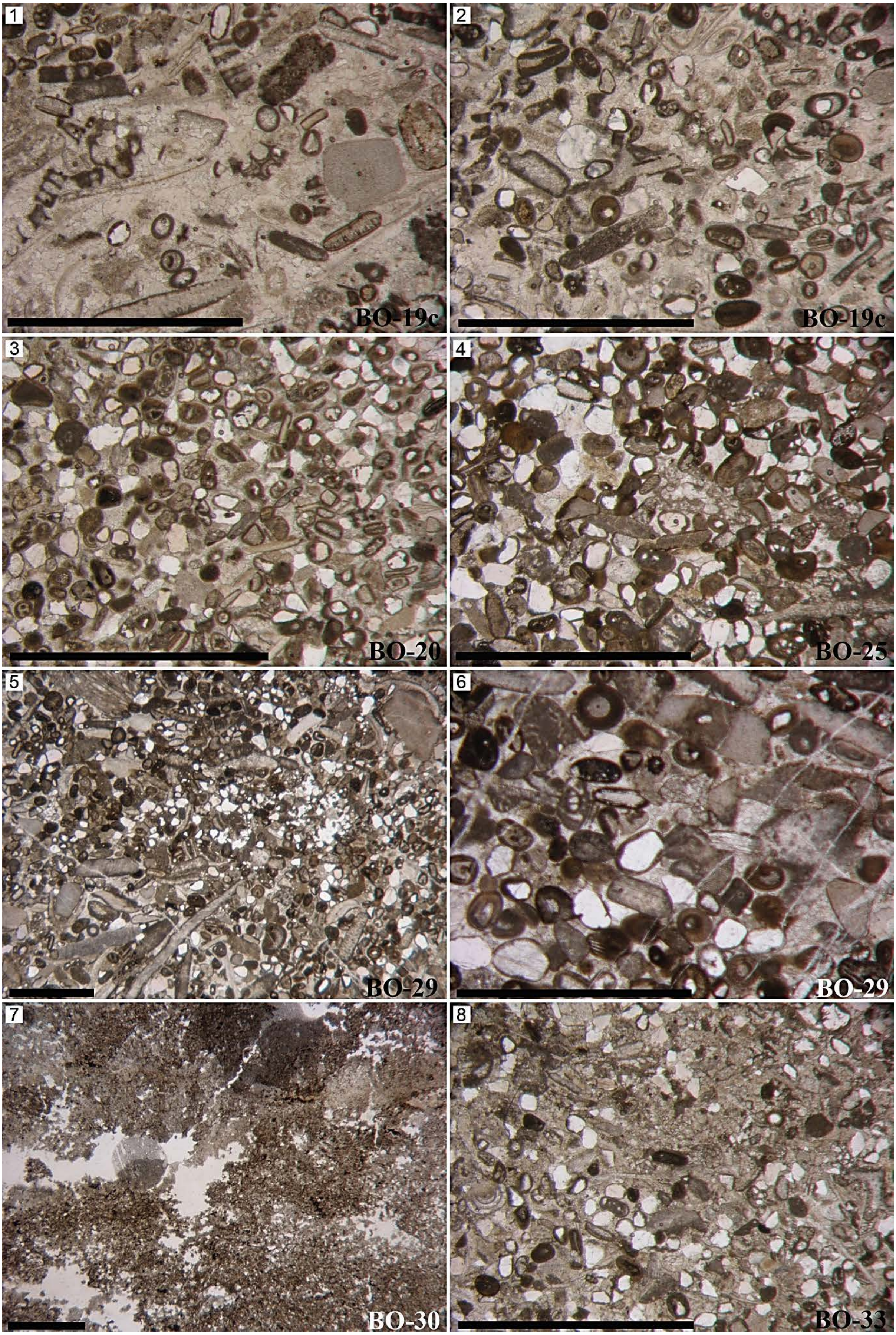

Fig. 12

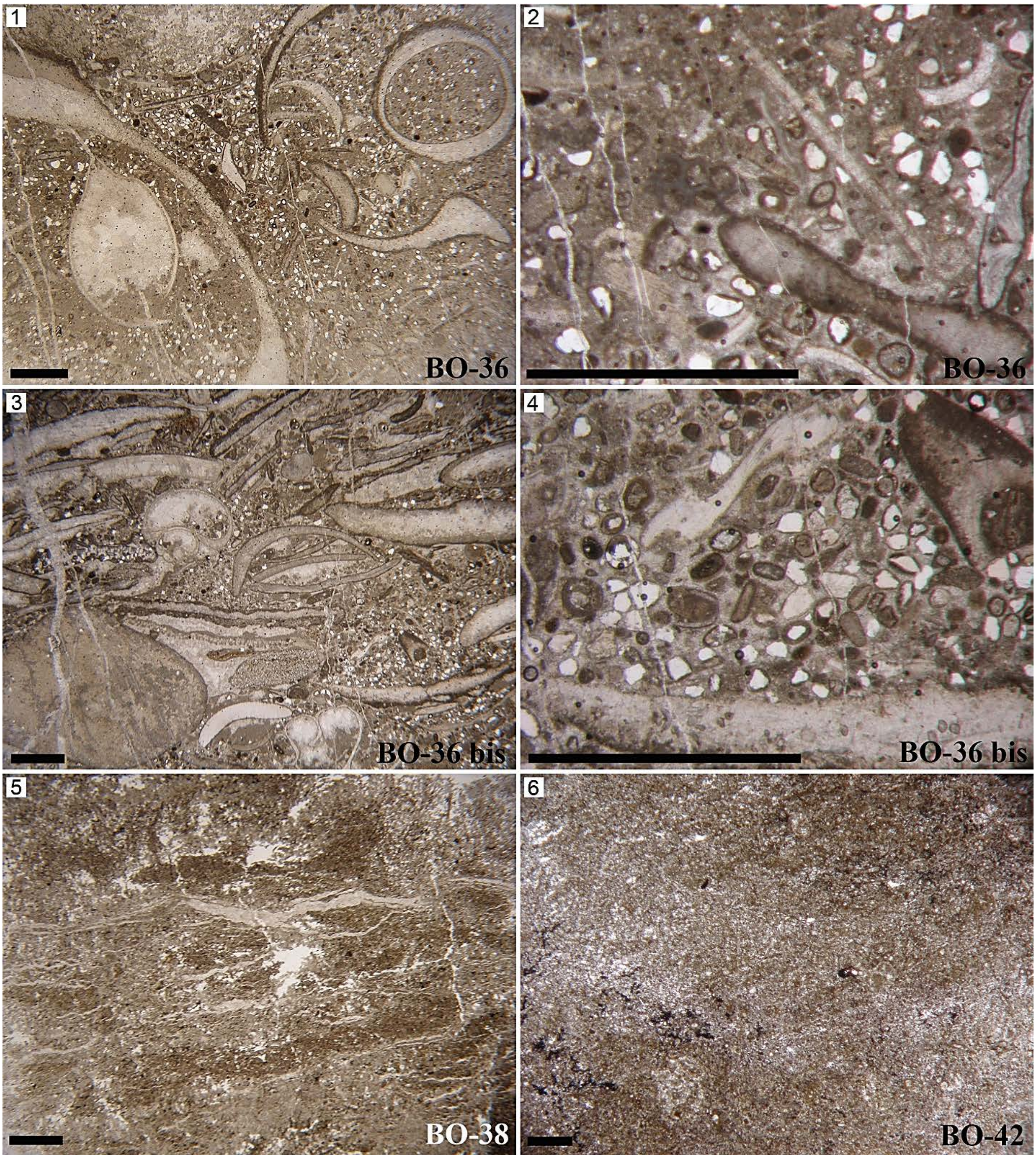

Fig. 13: Microfacies of Bioclastic Limestone Member, Oued Ayada Formation, at Boudouda, scale bar = 1 mm, part IV. **1.** Gastropod-brachiopod-extraclast floatstone with complete (bivalved) and incomplete shells; **2.** matrix of Bed 36, showing poor sorting of small bioclasts, some coated grains, abundant, fine, angular quartz sand, and dense micrite matrix that is partly washed out, Bed 36; **3-4.** Second thin-section of Bed 36, brachiopod-gastropod-extraclast rudstone with broken brachiopod shells and sandy matrix with well-sorted, angular quartz, coated grains, and washed out micrite; **5.** Strongly bioturbated, reddish weathering dolomicrite with numerous calcite veins, Bed 38; **6.** Bioturbated dolomicrite, with all fauna destroyed by diagenesis, Bed 42.

	BO-1	BO-3	BO-7b-ooidal	BO-7b-bioclastic	BO-8a	BO-8d	BO-12	BO-14	BO-15	BO-15 numb	BO-17c	BO-19a	BO-20	BO-25	BO-29	BO-30	BO-33	BO-36	BO-36 bis	BO-38	BO-42
ostracods	2	10	1					1		5		2	1				5	5	≤1		
foraminifers	5	5	2	1	1	1	1	1	≤1	10	4	2	2	1	1		5	3	≤1		
crinoids	3	15	10	25	20	5	1	5	30	5	20	5	5	5	15		5	10	1		
brachiopods	5	15	10	25	20	2		5	20	10	10	10	5	10	15		10	5	40		
molluscs							1												1		
gastropods												1									
fenestellid bryozoans	2							1							≤1						
encrusting bryozoans			1																		
green algae (koninckopora)	2	≤1	≤1	5	1		1	≤1	≤1	≤1	4	2	1	1	≤1		1	1	≤1		
aoujgaliids	1	≤1	1	≤1	≤1		≤1		≤1	≤1	2				≤1			≤1	≤1		
kamaeniids		30			≤1		≤1	≤1		40					≤1		1	≤1	≤1		
calcispheres		5								5											
Solenoporaceae																		≤1			
corals								1	≤1						≤1						
heterocorals										≤1											
ooids	30		40	5	10	5	60	40			30	40	60	50	40		10	5	≤1		
intraclasts	1				5			5	10			2			4		5				
quartz grains	2	≤1	5	1	25	50	5	30	15	≤1	5	5	5	15	5		30	25	25		
Felsparts						2															
sandstone, siltstone...																			5		
Sparry cement			30	25			30			≤5	25	30	20	10	20				5		
matrix	40	20		10	15	30		10	25	25				5			25	45	15		
Sorting	M	H	H	L	M to L	H	H to M	H to M	L	M to L	H to M	H	H	H	M to L	?	H	L	L	?	?
Orientation	cross	cross	flat	flat	flat	NO	cross	cross	flat	S flat	flat	cross	NO	flat	NO	?	NO	NO	flat	fla	?
packing	L to M	H	L	L	H	M	L	H	H	M	L	L	L	H	M	?	M	L	M	?	?
Fragmentation	M to H	H	H	M	H	H	H	H	H	M	H	H	H	H	H	?	H	M	H	?	?

H= hight
M= Moderate
L= Low
cross= oblique oriented
flat= parallel oriented
NO= no apparent orientation
S= slightly

Tab. 1: Distribution of litho- and bioclasts, matrix, and general carbonate fabric in the Oued Ayada Formation at Boudouda (same numbering as for thin-sections of Figs. 10-13).

							sandy										dol.			dol.	dol.	
Bed number	BO 1a	BO 1b	BO 3	BO 7b	BO 7c	BO 8a	BO 8d	BO 12	BO 14	BO 15	BO 15-2	BO 17c	BO 19a	BO 20	BO 25	BO 29	BO 30	BO 33	BO 36	BO 38	BO 42	Kgl 1
FORAMINIFERS																						
Archaediscus at *angulatus* stage	1	1	2	2	1	1	1	2	3	2	2	1	2	3	3	3		2	2			3
Archaediscus krestovnikovi	1	1			1				1				1		1							
Endothyra bowmani	1		1		1																	
Mediocris mediocris	1		1								2											
Nodosarchaediscus spp.	1				1			1														
Eostaffella spp.	1				1									1	1	1		1	1			1
Pseudotaxis eominima	1										1							1	1			
Cepekia buskensis	1												2	1				1	1			
Endothyra aff *phrissa*	1																					
Endothyra spp.	2	2	2	2	1	1	1	1	1			1		1				1				2
Archaediscus at *concavus* stage	2	2	4	3	2	2	1	2	2	2	4	1	1	2	2	2		3	2			1
Globoendothrya spp.	2	2			2	1	1		1	1	2					1		1	1			
Globoendothyra globulus	3	3	2	2	1	1			1		2		1			1		1	1			
Koskinotextularia sp.		1	1			1										1						
Pseudoendothyra struvei		1	1			1							2									
Mikhailovella aff. *enormis*		1	1																			
Endothyra similis		1		2	1	1				1	3		1	1		1		2	1			
Endothyranopsis compressa		1				1					2	1				1			1			
Consobrinella spp.		1																				
Nodasperodiscus spp.		1										2	3	2		2		1	2			3
Cepekia regularis		2								1	1	1										
Plectogyranopsis ampla			1			1					1											
Pseudoammodiscus priscus			1			1					1											
Archaediscus moelleri			1			1										1						
Archaediscus karreri grandis			1					1			af				1	1		1				
Eblanaia michotti			1								1							1				
Forschia mikhailovi			1								1											
Forschiella prisca			1								1											
Lituotubella magna			1								1											
Archaediscus koktjubensis			1																			
Archaediscus stilus			1																			
Cepekia sp.			1																			
Mediocris breviscula			1											1								
Pirletidiscus sp.			1															1				
Pojarkovella sp.			1																			
Pseudoammodiscus volgensis			2	2				1			1					1		1				
Pseudoendothyra aff. *sublimis*				1	1							1	1		1							
Nodasperodiscus saleii				1		1			1	1					1							
Pseudoendothyra spp.				2	1			1							1	1		1				
Omphalotis minima					1	1					1					1						
Nodasperodiscus aff. *demaneti*					1		1		1		1	1			1							
Eostaffella parastruvei					1				1						2			1	1			
Eostaffella mosquensis					1								2		2				2			
Uralodiscus sp.					?																	
Nodasperodiscus aff. *saleii*						1																

Tab. 2: Distribution of foraminifers in the Oued Ayada Formation at Boudouda, Part I (dol. = dolomitized).

	BO 1a	BO 1b	BO 3	BO 7b	BO 7c	BO 8a	BO 8d	BO 12	BO 14	BO 15	BO 15-2	BO 17c	BO 19a	BO 20	BO 25	BO 29	BO 30	BO 33	BO 36	BO 38	BO 42	Kgl 1
FORAMINIFERS																						
Pseudoendothyra bona						1							1			1						
Eostaffella radiata										1	2					2						
Archaediscus velguriensis										1						1						
Omphalotis frequentata										1												
Palaeotextularia sp.										?												
Consobrinella consobrina											1											
Endostaffella delicata											1											
Endostaffella fucoides											1							1				
Endothyranopsis compressa/crassa											1											
Planoarchaediscus spirillinoides											1		1					1				
Plectogyranopsis pechorica											1											
Earlandia minor											2											
Eoendothyranopsis? sp.											2											
Euxinita efremovi											?		?	?								
Earlandia moderata												2										
Eostaffella aff. *ikensis*													1		1	1		1				
Endostaffellopsis? sp.													2									
Endostaffella sp.														1					1			
Archaediscus trans. *tenuis*														1								
Tetrataxis spp.															1	1						
Archaediscus at *involutus* stage																1						
Conilidiscus sp.																1						
Omphalotis omphalota																1						
Pseudoendothyra illustria																?		?				
Ademassa inuncta																			1			
Glomodiscus rigens																						1
Praeostaffellina sp.																						1
Neoarchaediscus? sp.																						1
AOUJGALIIDS																						
Epistacheoides spp.	2																					
Roquesselsia radians	1	1	1	2							1								1			
Aoujgalia sp.		1																				
Aoujgalia variabilis			1			1																
Stacheoides tenuis					1					1	1					1						
Efluegelia johnsoni								1														
Aphralysia carbonica																			1			
PALAEOBERESELLIDS																						
Kamaenella denbighi			4								3											
Kamaena delicata						1										1						
Palaeoberesella lahoseni								1	1		1					1			1			
Kamaenella tenuis																		1				
DASYCLADALES																						
Koninckopora inflata	2	2	1			1				1	2		1			1		1				
Koninckopora sahariensis	2	1		3	2	1		1			2	2	3	2	1			1	1			
Nanopora anglica	2	2														1		2	1			
Koninckopora tenuiramosa			1	1				2	1			3				1			3			1
Koninckopora mortelmansis											1							1				
Solenoporaceae																			1			

Tab. 3: Distribution of foraminifers (Part II), algae, and Algospongia in the Oued Ayada Formation at Boudouda.

Within the succession, Beds 12, 19, 20 represent a mixed carbonate-sand intertidal bar. The shoal around the "Devonian Island" obviously included exposed sandstone, as the abundant quartz grain source. Their angularity shows transport without a long period of reworking. It is less likely that the fine siliciclastic material derived from a distant source, such as the Mdakra Basin. There was no Viséan (pro)deltaic system in the area. All outcrops from the Beni Sekten area (Groups III/IV) represent neritic carbonates (Termier & Termier 1951a; Fadli 1990, 1994b).

Bed 3 (Figs. 10.3-4) represents a different tempestite facies, a kamaeniid packstone. Kamaeniids belong to the Palaeoberesellidae, possible algae assigned to the class Algospongia by Vachard & Cózar (2010). In the Viséan carbonate platform of the Bechar Basin, southern Algeria, they characterize a distinctive oolithic benthic assemblage (H1) in the upper ramp position and on the euphotic shore side from coral mounds and productid colonies.

Bed 36 (Figs. 6.5, 13.1-4) is a peculiar gastropod-brachiopod-extraclast float-rudstone with large, partly complete gastropods, fragmented, thick-shelled brachiopods, moderately large, micritic and partly internally bedded extraclasts, and a micritic to grainstone matrix with abundant silt/fine quartz sand, and coated grains. Gastropods are variably filled with cement or micrite/wackestone. Some dolomitization occurred and there is weak normal grading (Fig. 6.5).

Beds 3 and 36 show that there was an ecological zonation of the platform prior to erosion and lateral storm transport. The bioturbated and strongly dolomitized upper part of the member (especially Beds 30, 38, 42) probably represent the lower ramp below the storm wave base. Therefore, a deepening trend is reconstructed.

5. Microfossil Stratigraphy

The Oued Ayada Formation yielded more than 70 foraminifer taxa (Tab. 2; Figs. 14-16), partly only identified at generic level. There are also ten different Aoujgaliidae and Palaeoberesellidae and five species of dasycladacean green algae (Tab. 3), which little biostratigraphical value for the studied interval. For example, several *Koninckopora* occur in most beds at Boudouda, including bi-layered species, which are recorded from the base of the Viséan (Riley 1993). In addition, *Stacheoides tenuis* was considered by Vachard & Tahiri (1991) as a marker in Morocco of the Cfm6 foraminiferal zone (uppermost Cf6β to lowermost Cf6γ = uppermost V3bβ to lowermost V3bγ). Other Algospongia have much wider stratigraphic ranges (Vachard & Cózar 2010)

Boulders analyzed from the Conglomerate Member contain scarce foraminifers and the assemblages do not seem to be representative enough for a precise biostratigraphy. Within these assemblages, the occurrence of *Archaediscus* at *angulatus* stage and primitive *Neoarchaediscus*, such as *N. chantonae* (Figs. 16.10-12), are noteworthy. The former taxon first occurs in the uppermost part of the middle Viseán (e.g., Strank 1981), but it is more widely represented from the base of the upper Viséan (Cf6α = V3bα; Conil et al. 1980; Cózar et al. 2005). The first occurrence of *Neoarchaediscus* is somewhat questionable because for some authors it occurs from the base of the upper Viséan (Conil et al. 1980; Poty et al. 2006), whereas for other authors, the primitive species of the genus are recorded from the upper Asbian and the evolved forms from the Brigantian (e.g., Cózar & Somerville 2020). In addition, successions from the Oued Cherrat, Jerada and Azrou-Khenifra basins contain primitive *Neoarchaediscus* only from the Brigantian (Cózar et al., in press), a fact which suggests

a late occurrence of the genus for the Moroccan Meseta, similar to other anomalous foraminiferal stratigraphic ranges observed in the region (CÓZAR et al. 2020b). Thus, a plausible age for the Conglomerate Member would be upper Asbian to lowest Brigantian.

The lower levels of the Bioclastic Limestone Member contain richer foraminiferal assemblages although limestones are affected by dolomitization. In these assemblages, taxa recorded from the Conglomerate Member occur too. Furthermore, these lower levels also contain common *Pseudoendothyra* species, of which the first occurrence of *P. struvei* (Fig. 14.10) was considered as a marker for the Cf6β foraminiferal subzone (CONIL et al. 1980; VACHARD & TAHIRI 1991) and *P. sublimis* (Fig. 15.9) as first occurring from the Cf6γ subzone (GALLAGHER & SOMERVILLE 1997). *Cepekia regularis* (Fig. 14.7) was proposed by IZART et al. (2017) as a marker for the Brigantian in Morocco, although this species has been recorded from the base of the Asbian in El Goulib section (CÓZAR et al. 2020a). *Archaediscus karreri* s.l. is a long ranging group, with smaller species with well-developed microgranular layer from the base of the upper Viséan (VACHARD & TAHIRI 1991), whereas the larger species with reduced microgranular layer (e.g., *A. karreri grandis*) are more typically recorded in the uppermost Asbian and Brigantian in Western Europe (CÓZAR & SOMERVILLE 2004), as well as in Morocco (CÓZAR et al. in press). In between, there are some intermediate forms (Fig. 14.9). Another marker of the upper Asbian to lower Brigantian is *Eostaffella ikensis*, although the scarce specimens recorded in Boudouda show the final whorl broken (Fig. 15.3), and do not allow to observe the complete periphery of the test.

Ademassa inuncta is recorded from Sample 36 (Fig. 16.8), a species which in Morocco is known from the Asbian/Brigantian transitional beds (CÓZAR et al. in press). Owing to dolomitization and recrystallization problems, only questionable specimens of *Euxinita* occur in the upper part of the succession (Fig. 15.8), which is confirmed in Sample 36 (Fig. 16.4). *Euxinita* is first recorded at similar levels than *Ademassa* in Morocco. Questionable specimens of *Endostaffellopsis* were found (Figs. 15.11-12), although this genus was previously recorded in younger levels, at the base of the Serpukhovian (CÓZAR et al. 2016). Similarly, *Mikhailovella enormis* (Fig. 14.6) was described from the lower Serpukhovian of the Montagne Noire (Southern France), although some questionable specimens from the upper Viséan were also included by VACHARD et al. (2016).

On the other hand, there are also some rather primitive foraminifers that are more frequently represented in lower and middle Viséan limestones (e.g., *Archaediscus* at *involutus* stage, *Conilidiscus*, *Pirletidiscus*, *Eblanaia*), although, as demonstrated by CÓZAR et al. (2020a), they occur in the upper Viséan of Morocco. Thus, a plausible reworking of the foraminifers does not seem to be feasible, nor do assemblages at Boudouda contain typical Tournaisian species.

Taking into consideration the above discussed taxa, the lower part of the Bioclastic Limestone Member (approximately up to Bed 15) might represent the upper Asbian, whereas the upper part of the section can be assigned to the upper Asbian-lowest Brigantian. These data suggest that there is no significant biostratigraphic difference between the Conglomerate Member and the lower part of the Bioclastic Limestone Member. It is well possible that the conglomerate eroded a channel into the Bioclastic Limestone Member and further down into the Devonian.

6. Regional comparisons

The lost Famennian to middle Tournaisian pelagic carbonates of Boudouda correlate in the southern Mdakra Basin with the much thicker, hypoxic goniatite shales of the Oued Aricha Formation and the overlying siltstones of the Mgarto Formation (FADLI 1994a; main Benahmed chapter). There, the subsequent upper Tournaisian is represented by quartzites of the Sidi Sebaa Formation (Member E1, FADLI 1990, 1994b; LOBOZIAK et al. 1990). The closest Carboniferous goniatite shale has been mentioned, but not yet been described, from Sidi Mohamed Ben Abdallah, ca. 16 km NE of Boudouda (TERMIER & TERMIER 1951a; ca. 8.5 km E of Al Gara, topographic sheet 1 : 50 000, Al Gara, NI-29-XI-2d). However, it is top-Viséan in age (see DELEPINE 1941). Beyond, the supposed upper Tournaisian goniatite fauna of Aïn Aouda in the western Sidi Betache Basin (BOLELLI et al. 1953) is in fact mostly middle Tournaisian in age and preserved in siderite nodules (BECKER et al. 2006), not in pyrite/goethite.

At Boudouda, the older alternation of black shales and bioclastic limestones described laterally by FADLI (1990, 1994b) has not been observed and is missing, at least at the conglomeratic channel. Since there is no outcrop below the main section, we cannot judge whether it is possibly present laterally to the NE. Based on foraminifer stratigraphy, the Oued Ayada Formation is a time equivalent of Units 2 and 3 of FADLI (1990, 1994b) recognized in the near-by Dar Cheik el Mfaddel Syncline of the Beni Sekten area (see CÓZAR et al. 2020a). Notable are the presence there of coral limestone, a volcanic level, and of a conglomerate at the top. This suggest a small-scale palaeotopography in the upper Viséan in the region.

In the southern Mdakra Basin, the Oued Ayada Formation correlates with the transgressive basal Mellila Formation, which is partly reefal and conglomeratic (FADLI 1990, 1994b). Its foraminifer and algal fauna (including the Algospongia) is different than at Boudouda (see VACHARD & FADLI 1991) and the formation ranges higher, into the lower Serpukhovian. Further to the south, in the NE Rehamna (Mechra Ben Abbou region), the Asbian transgression introduced the bioclastic limestones and conglomerates of the Bled Mekrach Formation (EL KAMEL & EL HASSANI 2006; KHOLAIQ et al. 2015), ranging to the upper Asbian "calcaire à *Productus*" of GIGOUT (1951; = Member c; compare CÓZAR et al. 2020a).

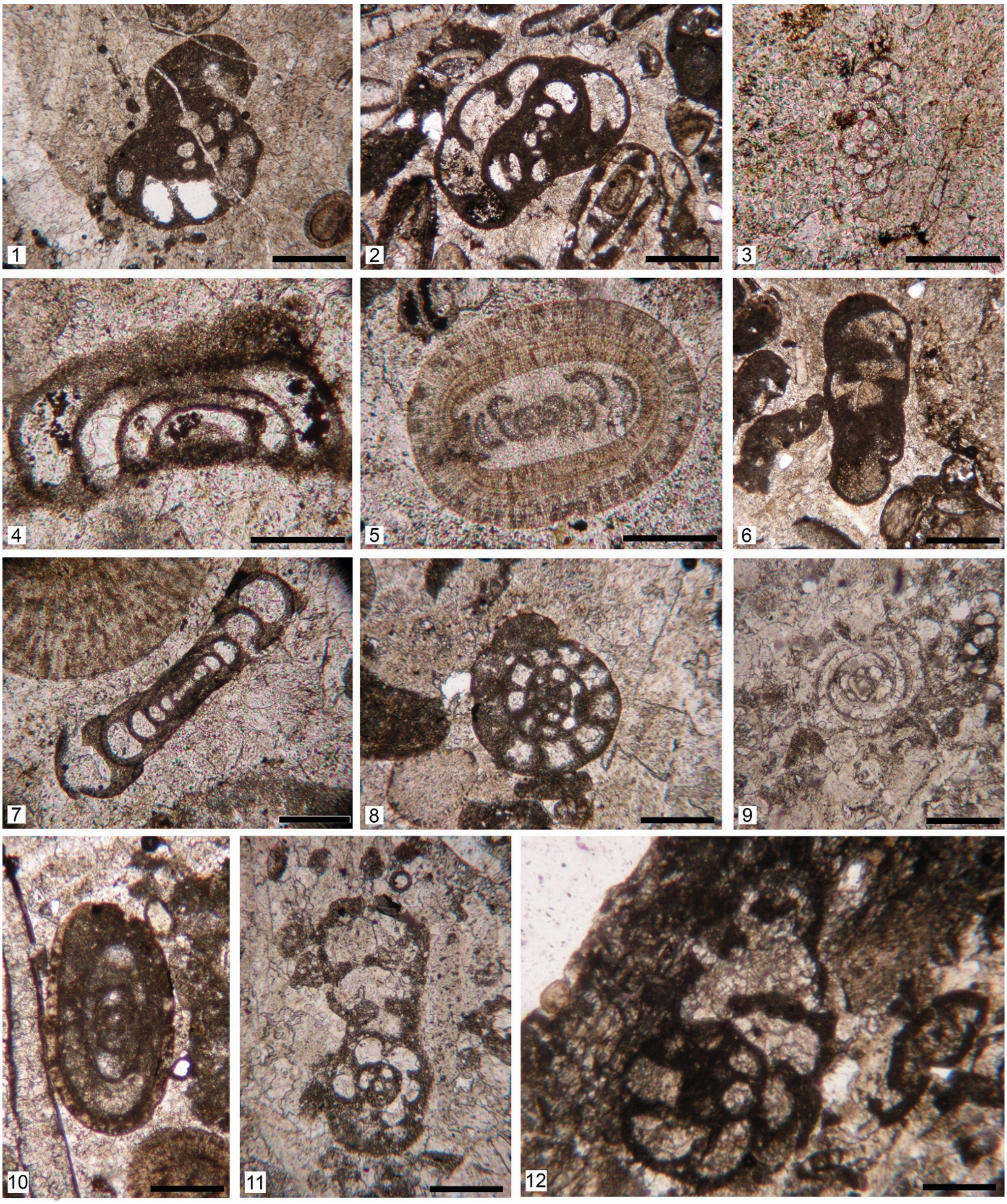

Fig. 14: Selected foraminifers from Beds 1 (1−8) to 3 (9−12) of the Bioclastic Limestone Member (Oued Ayada Formation) at Boudouda; scale bar for figures 1, 2, 6 = 400 microns, for figures 3, 4, 5, 7 = 100 microns, and for figures 8 to 12 = 200 microns. **1**. *Endothyranopsis compressa* transitional to *E. crassa*; **2**. *Globoendothyra globulus*; **3**. *Archaediscus krestovnikovi*; **4**. *Cepekia* cf. *buskensis*; **5**. *Neoarchaediscus chantonae*; **6**. *Mikhailovella* aff. *enormis*; **7**. *Cepekia regularis*; **8**. *Endothyranopsis compressa*; **9**. *Archaediscus* aff. *karreri grandis*; **10**. *Pseudoendothyra struvei*; **11-12**. Endothyranopsinae new genus.

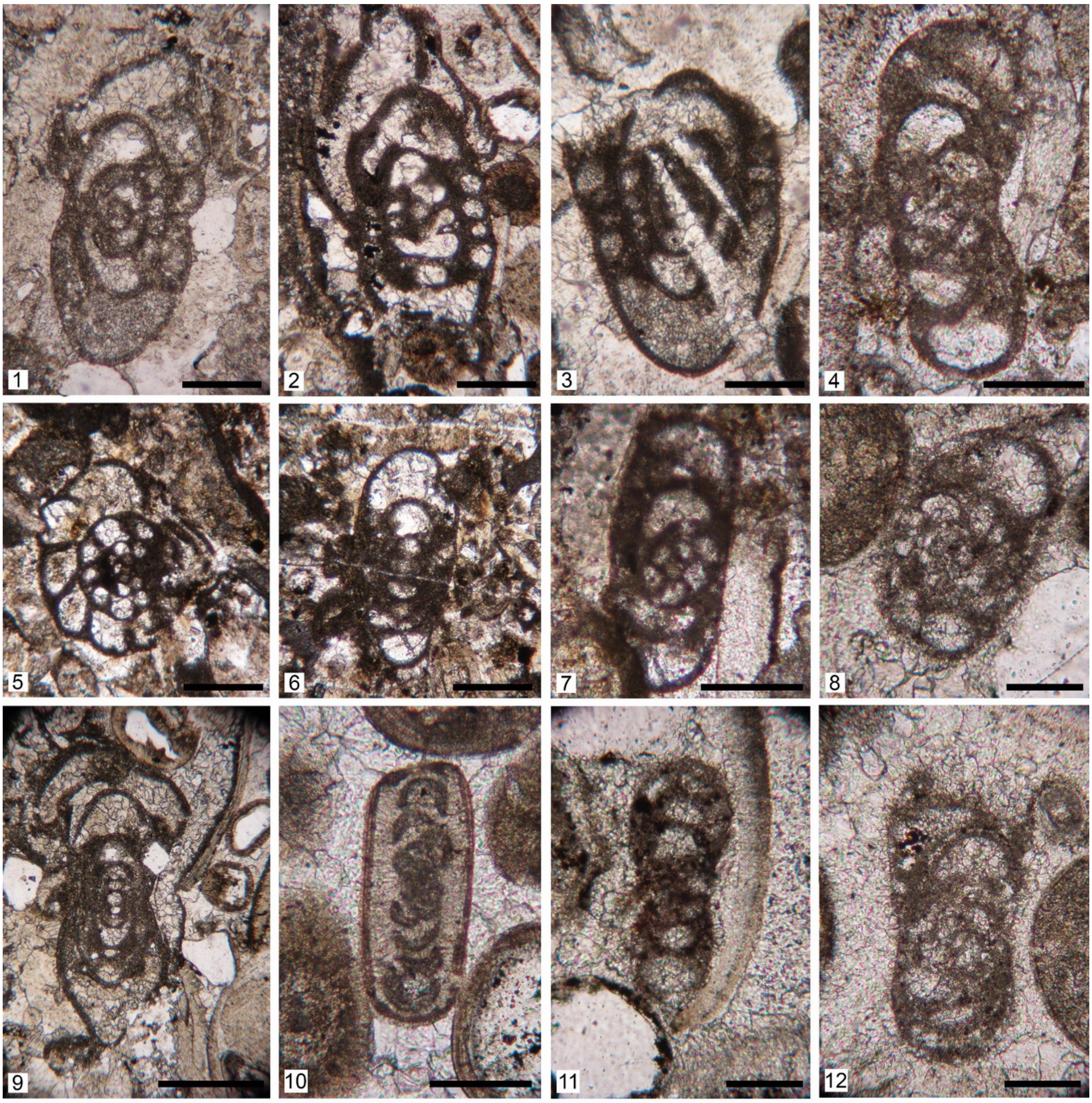

Fig. 15: Selected foraminifers from the Bioclastic Limestone Member (Oued Ayada Formation) at Boudouda; scale bar for figures 1−3, 5−6, 9 = 200 microns, and for figures 4, 7−8, 10−12 = 100 microns. **1**. *Pseudoendothyra* aff. *sublimis*, Bed 7; **2**. *Eostaffella parastruvei*, Bed 7; **3**. *Eostaffella* aff. *ikensis*, Bed 19; **4**. *Endostaffella delicata*, Bed 15; **5−6**. *Eoendothyranopsis*? sp., Bed 15; **7**. *Endostaffella fucoides*, Bed 15; **8.** *Euxinita*? sp., Bed 19; **9**. *Pseudoendothyra sublimis*, Bed 17; **10**. *Neoarchaediscus mirabilis*, Bed 17; **11−12**. *Endostaffellopsis*? sp., Bed 19.

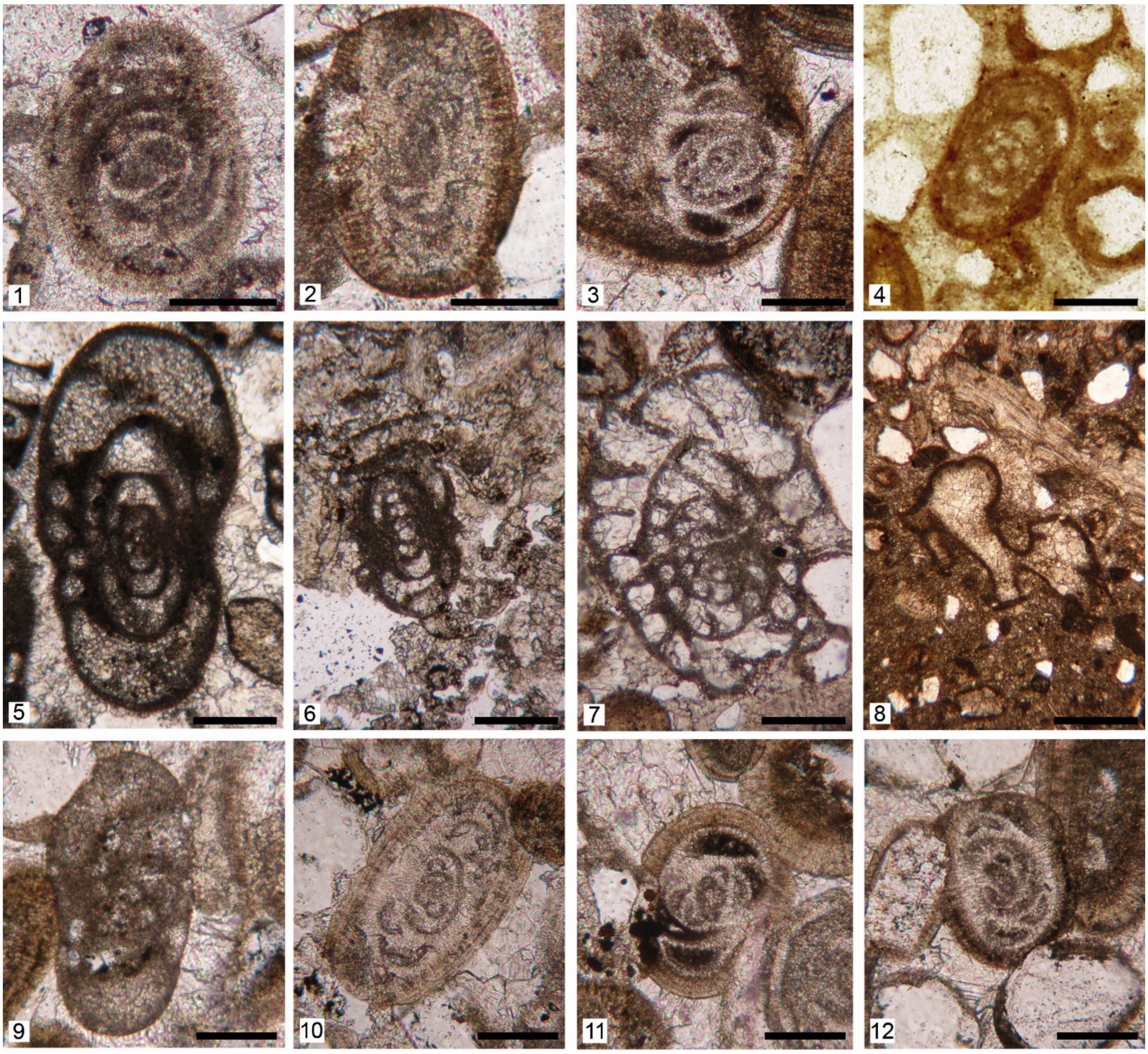

Fig. 16: Selected foraminifers from the Bioclastic Limestone Member (1-8) and Conglomerate Member (9-12) of the Oued Ayada Formation at Boudouda; scale bar for figures 1−2, 4, 9−12 = 100 microns, for figures 3, 5−7 = 200 microns and for figure 8 = 400 microns. **1**. *Archaediscus* sp. at *angulatus* transitional to *tenuis* stage, Bed 20; **2**. *Neoarchaediscus* sp. (evolved form), Bed 25; **3**. *Archaediscus velguriensis*, Bed 29; **4**. *Euxinita efremovi*, Bed 36; **5**. *Eostaffella mosquensis*, Bed 19; **6**. *Pseudoendothyra illustria*, Bed 33; **7**. *Pseudoendothyra bona*, Bed 29; **8**. *Ademassa inuncta*, Bed 36; **9**. *Praeostaffellina*? sp., Conglomerate Boulder 1; **10**. *Neoarchaediscus chantonae*, Conglomerate Boulder 1; **11**. *Nodasperodiscus* sp., Conglomerate Boulder 1; **12**. *Neoarchaediscus* sp. (primitive form), Conglomerate Boulder 1.
(Figs. 14-16: thin-sections kept in the collection of P. Cózar)

References

Aboussalam, Z. S. & Becker, R. T. (2007): New upper Givetian to basal Frasnian conodont faunas from the Tafilalt (Anti-Atlas, Southern Morocco). – Geological Quarterly, **51** (4): 345-374.

Angiolini, L., Long, S. & Davies, L. (2011): Revision of Sowerby´s species "*Spirifer bisulcatus, Spirifer pinguis* and *Spirifer rotundatus*" from the late Tournaisian-Visean of Great Britain. – Memoirs of the Association of Australasian Palaeontologists, **41**: 71-85.

Becker, R. T., Kaiser, S. I. & Aboussalam, Z. S. (2006): The Lower Alum Shale Event (Middle Tournaisian) in Morocco – facies and faunal changes. – Kölner Forum für Geologie und Paläontologie, **15**: 7-8.

Boardman, D. R., Thompson, T. L., Godwin, C., Mazzullo, S. J., Wilhite, B. W. & Morris, B. T. (2013): High-Resolution Conodont Zonation for Kinderhookian (Middle Tournaisian) and Osagean (Upper Tournaisian-Lower Visean) Strata of the

Western Edge of the Ozark Plateau, North America. – Shale Shaker, **2013**: 98-151.

BOLLELI, E, DESTOMBES, J. & KARPOFF, R. (1953): Découverte du Tournaisian à goniatites dans le Meseta côtière marocaine. – Comptes Rendus de l'Académie des Sciences, Paris, **236**: 1906-1908.

BRANSON, E. B. & MEHL, M. G. (1934): Conodonts from the Bushberg Sandstone and equivalent formations of Missouri. – The University of Missouri Studies, **8** (4): 265-299, pls. 22-24.

CLAUSEN, C.-D., LEUTERITZ, K., ZIEGLER, W. & KORN, D. (1989): Ausgewählte Profile an der Devon/Karbon-Grenze im Sauerland (Rheinisches Schiefergebirge). – Fortschritte in der Geologie von Rheinland und Westfalen, **35**: 161-226, 1 pl.

CONIL, R., LONGERSTAEY, P. J. & RAMSBOTTOM, W. H. C. (1980): Matériaux pour l'étude micropaléontologique du Dinantien de Grande-Bretagne. – Mémoires de l´Institute Géologique de l´Université de Louvain, **30**: 1-187 [imprint 1979].

CÓZAR, P. & SOMERVILLE, I. D. (2004): New algal and foraminiferal assemblages and evidence for the recognition of the Asbian-Brigantian boundary in northern England. Proceedings of the Yorkshire Geological Society, **55**: 43-65.

CÓZAR, P. & SOMERVILLE, I. D. (2020 online): Foraminifers in upper Viséan-lower Serpukhovian limestones (Mississppian) from South Wales: regional correlation and implications for British foreaminiferal zonal schemes. – Proceedings of the Yorkshire Geological Society, **63**, doi.org/10.1144/pygs2020-009.

CÓZAR, P., SOMERVILLE, I. D., ARETRZ, M. & HERBIG, H.-G. (2005): Biostratigraphical dating of Upper Viséan limestones (NW Ireland) using foraminiferans, calcareous algae and rugose corals. – Irish Journal of Earth Sciences, **23**: 1-23.

CÓZAR, P., SOMERVILLE, I. D., VACHARD, D., CORONADO, I., GARCÍA-FRANK, A., MEDIA-VAREA, P., SAID, I., DEL MORAL, B. & RODRÍGUEZ, S. (2016): Upper Mississippian to lower Pensylvanian biostratigraphic correlation of the Sahara Platform successions on the northern margins of Gondwana (Morocco, Algeria, Libya). – Gondwana Research, **36**: 459-472.

CÓZAR, P., VACHARD, D., IZART, A., SAID, I., SOMERVILLE, I., RODRÍGUEZ, S., CORONADO, I., EL HOUICHA, M. & OUARHACHE, D. (2020a): Lower-middle Viséan transgressive carbonates in Morocco: Palaeobiogeographic insights. – Journal of African Earth Sciences, **168** (103850): 27 pp., doi.org/10.1016/j.jafrearsci.2020.103850.

COZAR, P., VACHARD, D., IZART, A. & CORONADO, I. (2020b): Survival of early Viséan foraminifers in the Western Meseta of Morocco. – Palaeoworld, **29**: 75-87.

CÓZAR, P., IZART, A., SOMERVILLE, I. D., ARETZ, M., CORONADO, I. & VACHARD, D. (2021 in press): Environmental controls on the development of Mississippian microbial carbonate mounds and platform limestones in southern Montagne Noire. - Doi: 10.1111/sed.12594.

DELEPINE, G. (1933): Fossiles carbonifères de la région de Tiflet. – Notes et Mémoires, Service des Mines et de la Carte Géologique du Maroc, **28**: 55-77.

DELEPINE, G. (1941): Les Goniatites du Carbonifère du Maroc et des confins algéro-marocains du Sud (Dinantien-Westphalien). – Notes et Mémoires du Service géologique du Maroc, **56**: 1-111.

EBBIGHAUSEN, V., KORN, D. & BOCKWINKEL, J. (2010): The ammonoids from the Dalle à *Merocanites* of Timimoun (Late Tournaisian-Early Viséan; Gourara, Algeria). – Fossil Record, **13** (1): 153-202.

EL KAMEL, F. & EL HASSANI, A. (2006): Étapes de la structuration et de la sedimentation du bassin viséen de Mechra ben Abbou (Meseta occidentale marocaine). – Geodiversitas, **28** (4): 529-542.

FADLI, D. (1990): Évolution sédimentaire et structural des massifs de Mdakra et du Khatouat; deux segments hercyniens de la Meseta marocaine nord-occidentale. - Unpublishhed Ph.D. Thesis, University Rabat, 272 pp.

FADLI, D. (1994a): Le Fameno-Tournaisian. – Bulletin de l'Institut Scientifique, Rabat, **18**: 57-70.

FADLI, D. (1994b): Le Viséen. - Bulletin de l´Institut Scientifique, Rabat, **18**: 71-83.

GIGOUT, M. (1951): Études géologiques sur la Meseta marocaine occidentale (arrière-pays de Casablanca, Mazagan et Safi). – Notes et Mémoires du Service géologique Maroc, **86**: 507 pp. + atlas with 9 pls.

GALLAGHER, S. J. & SOMERVILLE, I. D. (1997): Late Dinantian (Lower Carboniferous) platform carbonate stratigraphy of the Buttevant area, North Co. Cork, Ireland. – Geological Journal, **32**: 313-335.

HARTENFELS, S. (2011): Die globalen *Annulata*-Events und die Dasberg-Krise (Famennium, Oberdevon) in Europa und Norda-Afrika – hochauflösende Conodonten-Stratigraphie, Karbonat-Mikrofazies, Paläoökologie und Paläodiversität. – Münstersche Forschungen zur Geologie und Paläontologie, **105**: 17-527.

IZART, A. & VIESLET, J. L. (1988): Stratigraphie, Sédimentologie et Micropaléontologie des sédiments du bassin de Sidi Bettache et ses bordures (Meseta marocaine nord-occidentale) du Famennien au Viséen supérieur. – Notes et

Mémoires du Service géologique du Maroc, **334**: 7-41.

IZART, A., VACHARD, D. & BERKHLI, M. (2017): The Carboniferous Culm Basins of Moroccan Meseta. – 51 pp.; LAP Lambert Academic Publishing (Saarbrücken).

JI, Q. (1985): Study on the phylogeny, taxonomy, zonation and biofacies of *Siphonodella* (Conodonta). – Bulletin of the Institute of Geology, Chinese Academy of Geological Sciences, **11**: 51-75, pl. 1-3 [in Chinese with English summary].

KAISER, S. I., BECKER, R. T., STEUBER, T. & ABOUSSALAM, Z. S. (2011): Climate-controlled mass extinctions, facies, and sea-level changes around the Devonian-Carboniferous boundary in the eastern Anti-Atlas (SE Morocco). – Palaeogeography, Palaeoclimatology, Palaeoecology, **310**: 340-364.

KAISER, S. I., KUMPAN, T. & CÍGLER, V. (2017): New unornamented siphonodellids (Conodonta) of the lower Tournaisian from the Rhenish Massif and Moravian Karst (Germany and Czech Republic). – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **286** (1): 1-33.

KHOLAIQ, M., SABER, N. & ZAHOUR, G. (2015): Le bassin dévono-dinantien de Mechraa ben Abbou: bassin pull apart sur décrochement dextre (rehamna septentrionaux, Maroc). – European Scientific Journal, **11** (21): 361-376.

KLAPPER, G. (1997): Graphic correlation of Frasnian (Upper Devonian) sequences in Montagne Noire, France, and western Canada. – In: KLAPPER, G., MURPHY, M. A. & TALENT, J. A. (Eds.), Paleozoic Sequence Stratigraphy, Biostratigraphy, and Biogeography: Studies in Honor of J. Granville ("Jess") JOHNSON. Geological Society of America, Special Paper, **321**: 113-129.

LANE, R. H., SANDBERG, C. A. & ZIEGLER, W. (1980): Taxonomy and phylogeny of some Lower Carboniferous conodonts and preliminary standard post-*Siphonodella* zonation. – Geologica et Palaeontologica, **14**: 117-164.

LEGRAND-BLAIN, M. (1985): A new genus of Carboniferous spiriferid brachiopod from Scotland. – Palaeontology, **28**: 567-575.

LOBOZIAK, S., VACHARD, D., FADLI, D. & STREEL, M. (1990): Datation par miospores et foraminifères du tournaisien et du Viséen de l'Oued Zemrine (Massif des Mdakra, Maroc). – Journal of African Earth Sciences, **11** (1/2): 113-118.

LÜDDECKE, F., HARTENFELS, S. & BECKER, R. T. (2017): Conodont biofacies of a monotonous middle Famennian pelagic carbonate succession (Upper Ballberg Quarry, northern Rhenish Massif). – Palaeodiversity and Palaeoenvironments, **97**: 591-613.

SANDBERG, C. A., ZIEGLER, W., LEUTERITZ, K. & BRILL, S. M. (1978): Phylogeny, speciation, and zonation of *Siphonodella* (Conodonta, Upper Devonian and Lower Carboniferous). – Newsletters on Stratigraphy, **7** (2): 102-120.

SPALLETTA, C., PERRI, M. C., OVER, D. J. & CORRADINI, C. (2017): Famennian (Upper Devonian) conodont zonation: revised global standard. – Bulletin of Geosciences, **92** (1): 31-57.

SPALLETTA, C., PERRI, M. C., OVER, D. J. & CORRADINI, C. (2017): Famennian (Upper Devonian) conodont zonation: revised global standard. – Bulletin of Geosciences, **92** (1): 31-57.

TERMIER, H. & TERMIER, G. (1951a): Stratigraphie et Paléontologie des Terrains Primaires de Benhamed (Chaouia sud, Maroc). – Notes et Mémoires du Service géologique Maroc, **85**: 47-104.

VACHARD, D. & CÓZAR, P. (2010): An attempt of classification of the Palaeozoic incerta sedis Algospongia. – Revista Española de Micropaleontologica, **42**: 129-241.

VACHARD, D. & FADLI, D. (1991): Foraminifères, Algues et Pseudo-algues du Viséen du massif des Mdakra (Maroc). – Annales de la Société Géologique du Nord, **109**: 185-191.

VACHARD, D. & TAHIRI, A. (1991): Foraminifères, algues et pseudoalgues du Viséen de la région d´Oulmès (Maroc). – Géologie Méditerranéenne, **43**: 21-41.

VACHARD, D., CÓZAR, P., ARETZ, M. & IZART, A. (2016): Late Viséan-Serpukhovian foraminifers in the Montagne Noire (France): Biostratigraphic revision and correlation with the Russian substages. – Geobios, **49**: 469-498.

WANG, Z.-H., BECKER, R. T., ABOUSSALAM, Z. S., HARTENFELS, S., JOACHIMSKI, M. M. & GONG, Y.-M. (2016): Conodont and carbon isotope stratigraphy near the Frasnian/Famennian (Devonian) boundary at Wulankeshun, Junggar Basin, NW China. – Palaeogeography, Palaeoclimatology, Palaeopecology, **448**: 279-297.

WEBSTER, G. D. & GROESSENS, E. (1990): Conodont subdivision of the Lower Carboniferous. – Courier Forschungsinstitut Senckenberg, **130**: 31-40.

YOUNGQUIST, W. & PATTERSON, S. H. (1949): Conodonts from the Lower Mississippian Prospect Hill Sandstone of Iowa. – Journal of Palaeontology, **23** (1): 57-73, pls. 15-17.