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View on the Silurian-Devonian cliff below the Taliouine (= Tiliwine) village

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Ralph Thomas Becker, Ahmed El Hassani and Zhor Sarah Aboussalam
(Guest Editors)

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Cover photo : View of the Silurian-Devonian cliff below the Taliouine Village (East of Ouarzazate), credit A. El Hassani.

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Prof. Dr. Driss OUAZAR
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FORWORD

On the occasion of the Solemn Plenary session of the Hassan II Academy of Science and Technology, on February 25th - 27th 2020, on the general theme "***Natural heritage and sustainable development***", The College of Science and Technology of Environment, Earth and Sea dedicates this volume of "*Frontiers in Science and Engineering*" to the scientific community in order to share the latest data on the Western Moroccan Meseta geology, particularly on an essential part of the Paleozoic era that is the Devonian and the Lower Carboniferous.

This document will focus on : « ***New data*** *on Devonian to Lower Carboniferous stratigraphy and facies of the Western Moroccan Meseta Implications for palaeogeography and structural interpretation* » and includes results and interpretations of research undertaken by a joint Moroccan-German team in the framework of a partnership between the Mohammed V University of Rabat (Morocco) and the Westphalian Wilhelms-University of Muenster (Germany), within the framework of an agreement between the CNRST (Morocco) and the DFG (Germany). This cooperation has been extended beyond the period allocated to it and now represents more than twenty years of cooperation. It brought together more than thirty specialists from around the world (Moroccans, Europeans and Americans) and constitutes a model of successful group work in in Earth Science.

Concerning the project itself, as the first and major step, it was planned to document, characterize and analyze with highest stratigraphic resolution the depositional and faunal history of so far poorly studied Middle Devonian (Eifelian) to Lower Carboniferous (Tournaisian) sections of the Western Moroccan Meseta and of a few Palaeozoic windows within the Atlas Mountains. These represent tectonically complex, different structural zones and sedimentary basins of Hercynian Morocco. It was not expected or required to cover all sections in this rather large region, but the concentration on representative and fossiliferous key sections for each block enabled a meaningful overview of the whole region. In several cases, revisions and more detailed re-sampling of previously published sections took place.

The given time (Devonian-Lower Carboniferous) interval was chosen since it includes sufficiently fossiliferous strata and since it allows to follow the Eovariscan developments from the time before reef complexes were established on specific blocks until the time when rather poorly fossiliferous, thick, flyschoid clastics started to prevail in the whole region, as sign of the beginning of the main phase of Variscan orogeny.

Cooperating specialists from Germany and France provided identifications of various fossil groups, such as brachiopods, trilobites, rugose and tabulate corals, stromatoporids, ostracods, bivalves, and palynomorphs. This continued long-term cooperations, for example in the frame of the IUGS International Subcommission on Devonian stratigraphy.

The biostratigraphic investigations required some taxonomic revisions, the first description of faunas, especially of new and rare forms, and an improved correlation of different biozone systems. Our high-resolution dating of sediments and Eovariscan tectonic movements as well as interbasinal correlations are based on conodonts, ammonoids, miospores, event (sedimentology/microfacies, stable isotopes) and sequence stratigraphy. In this context, several aspects were especially important:

- The development and correlation of regional zonal schemes with the established international zonations (for example, for the dating of facies changes, periods of condensation, and discontinuities).

- Reworking units, such as conglomerates, synsedimentary breccias and chaotic olistolites, their composition (lithological type, abundance, and sorting of components), texture, and the time range of reworked clasts and faunas needed to be elucidated with the best available precision.

- Biostromal and biohermal complexes of specific areas (their faunal composition, microfacies, palaeoecology, age, and cyclicity).

The tectonic setting of the studied sections is generally known but detailed structural features (macro- and microscopic; local style of folding and faulting, analyses of tectonic transport directions) were needed. Such expertise was important in order to evaluate the palinspastic configuration of outcrops and studied blocks, especially of allochthonous complexes embedded in Carboniferous flysch facies.

Another focus was on strata that correlate with the established fine global event succession, in order to provide data on their regional/local expression and characteristics. As known from pelagic successions of the Anti-Atlas, France, Carnic Alps, or Germany (e.g., BUGGISCH et al. 2006, KAISER et al. 2006, 2008), carbon isotope stratigraphy of carbonate matrix is now an important tool in Devonian event stratigraphy. New faunal data sets can be used for palaeobiogeographic comparison within Hercynian Morocco, and between the latter and the Tafilalt, Maider and Dra Valley regions of the Anti-Atlas.

A wealth of new biostratigraphic data provided an improved overview of the timing and regional extent of Eovariscan movements. Taking into consideration the post-sedimentary tectonic dislocations, the study aims at the production of a dynamic palaeogeographical model at substage or even biozonal time resolution. Comparisons with the Tafilalt, Maider, and Dra Valley areas, which regional history is now much better known, enabled to compare the structural history of the stable cratonic NW Gondwana and of the southern margin of the Hercynides at the time of craton margin disintegration (WENDT 1985). In this context, the Devonian facies development at the Anti-Atlas/Atlas boundary (e.g., Skoura and Tindjad-Tinerhir areas) deserves special attention.

The results of these studies will be presented in a series of three FSE documents (one per year) and it will concern the following areas:

Volume 10 - Number 1 (2020) : Oued Cherrat area (sections of Aïn Khira, Aïn Dakhla, Aïn-Al-Aliliga, and Aïn-as-Seffah); allochthonous Mrirt area (sections of Gara de Mrirt and Anajdam); and Imouzer du Kandar area (Middle Atlas Basement).

Volume 10 - Number 2 (2021) : Ben Ahmed area (sections of Boudouda, Oued Aricha, Zwair); Rehamna area (sections of Mechra Ben Abbou, and Foum El Mejez); Jebilet area (sections Jaidet East, and Mzoudia/Jebel Ardouz); Skoura/South Atlas area (sections of Taliouine, Tizi n'Ourthi, and Asserhmo).

Volume 10 – Number 3 (2022) : Rabat-Tiflet area (Chabet El Harcha, Oued Tiflet), Oulmes area (sections of Aïn Jemaa, Ta'araft, Moulay Hassane, and Bou Alzaz); Azrou area (sections of Jebel ben Arab, Bab El Ari, and Bou Ighial); Khenifra area (sections of Ziyyar and Jbel Tabainout).

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Introduction

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Palaeozoic units of the Moroccan Variscides (sensu-stricto) crop out in the Meseta and the "buttonholes" of the Highlands ("Hauts Plateaux") and of the High Atlas. Hercynian folds, of varying age and intensity, affected two structural domains (Fig. 1), a western (Western Meseta) and eastern domain (Eastern Meseta). The succession of tectonic events in these two areas is based on stratigraphic arguments. The Devonian and Carboniferous period that we present in this synopsis is significant for understanding the early phases of the Hercynian orogeny and particularly for dating the precise timing of syndepositional block faulting episodes, which fundamentally shaped the Palaeozoic massifs. Effectively, the improved stratigraphical knowledge allows us to distinguish and describe specific episodes of early orogenic processes and to separate successive events from the later main deformation.

The present study combines field observations (stratigraphy, macrofaunas, sedimentary and tectonic environment) and laboratory analyses (micropaleontological studies and microfacies analyses, in particular) in order to date the multifold Moroccan Meseta structural units with the highest available accuracy. It is the logical continuation of the first volume that we published in 2020 in this journal, which concerned the Oued Cherrat and the eastern part of the massif of central Morocco (Mrirt and Imouzzer-du-Kandar regions). For the general scope of the joint, interdisciplinary DFG-CNRST Maroc project, please see the introduction chapter of that volume.

Structural units of the Meseta Paleozoic

The Moroccan Meseta is constituted by the Paleozoic Plateau and its flat lying cover between the Atlas system and Rif mountains (Fig. 1). The Middle Atlas divides this domain into two areas:

The ***Western Meseta*** is located approximately between the cities of Rabat, Taza, Marrakesh, and Essaouira. There are three major Palaeozoic zones (massifs), the Massif Central, Rehamna, and Jébilet, and some outcrops in the small valleys of the Atlantic coastal rivers (e.g., at the Oued Oum Er Rbia). These massifs are separated by Mesozoic and Cenozoic areas, the Khouribga and Gantour Phosphate plateau, Doukkala, and Chaouïa. Despite this cover, it is possible to establish detailed stratigraphic and structural correlations and to reconstruct a common Palaeozoic history.

The ***Eastern Meseta*** consists also of Palaeozoic regions and a Mesozoic-Cenozoic cover, but outcrops are smaller than those of the western part. It is composed of the Midelt area, and the areas of Zekkara, Jorf Ouezzène, Jerada Debdou, and Mekkam. The small outcrop sizes make correlations more difficult.

The Palaeozoic basement of the ***Middle Atlas*** is poorly exposed in small tectonic windows, for example at Immouzer-du-Kandar S of Fez (e.g., CHARRIÈRE & RÉGNAULT 1989; ABOUSSALAM et al. 2020). Reworked Neoproterozoic and Lower

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Palaeozoic rocks, especially magmatic pebbles and the Devonian facies development, differ significantly from other Meseta regions, but there are some similarities with the nappes of the eastern Central Meseta.

The principle palaeogeographic configuration of the Meseta began in the upper Silurian, followed by the earliest Hercynian tectonic movements. Early Devonian sedimentation continued in most regions conformably from the Silurian (Pridoli). The transition is characterized by a strong increase of calcareous deposition related to a decreasing amount of terrigenous supply from the West African Craton in the South. This was accompanied by climatic warming due to the motion of northwest Gondwana into a warmer, southern subtropic position.

Three paleogeographic zones are distinguished in the Moroccan Meseta. A western carbonate platform zone (Western Meseta) was subdivided during the Lower and Middle Devonian into several calcareous ridges and adjacent, deeper-water troughs with shales and subordinate calcareous intercalations. Biostromes and bioherms grew along the borders of tectonically uplifted and emerged areas, and were often disturbed or even killed by ongoing tectonism. A second, transitional zone, corresponding to eastern parts of the Central Moroccan Massif, is characterized by differentiated facies in allochthonous and autochthonous series. Reef growth was rather localized. The third zone, the Eastern Meseta, shows turbiditic and pelagic sedimentation with siliciclastics derived both from distant African shields and from emerged areas (e.g., ACOTTO et al. 2019).

Content

In this volume, we will focus on the Silurian-Devonian and Carboniferous period of four regions (Fig. 1) that have not been dealt with in the first volume:

1. The south-western part of central Morocco, the southern continuation of the Oued Cherrat-Al Attamna-Mdakra regions: Ben Ahmed area (e.g., sections of Boudouda, Dar Cheikh el Mfaddel, Zwayir, and the Oued Aricha);
2. The Rehamna massif, mainly the northern part (sections near Mechra Ben Abbou, Koudiat ed Diab, Foum el Mejez, and Sakhrat et Taïcha);
3. The Jebilet massif, in particular its eastern part (Jaidet East sections),
4. The south-western part of the Jebilet (Mzoudia region, Jebel Ardouz);
5. The Skoura region at the southern foot of the High Atlas, (sections of Taliouine, Tizi-n-Ouourti, and Asserhmo).

Research concept and perspectives

We were pleased to cooperate in the field and in the later analyses of faunas with leading specialists of fossil groups and with highly experienced Moroccan experts on the Palaeozoic. This led to a high number of co-authors and other persons that all deserved our thanks for the good collaboration, which now extends for almost a decade (see acknowledgements). This cooperation enabled us to cover a wide range of fields, such as lithostratigraphy, event stratigraphy, clastic sedimentology, carbonate microfacies, palaeogeography, structural geology, and the taxonomy, biostratigraphy, and palaeobiogeography of numerous fossil groups, especially of conodonts, ammonoids, nautiloids, brachiopods, trilobites, foraminifers, corals, stromatoporids, and gastropods. Therefore, this volume addresses a wide readership. There are many new data that are relevant far beyond the scholars of the Meseta Palaeozoic, for the broad international community of Devonian and Carboniferous workers.

If you read the individual chapters, you will realize that we always took care of the research history of all treated regions. This does not only honor the past research efforts but we prefer to put old data into a modern perspective and to exploit their significance for revisions and refinements, in context – sometimes in contrast - with the new results. All chapters are work in progress. New results led to new questions and allowed us to clearly name the open problems, where more field work and analyses are required. Therefore, we are convinced that this work will initiate and stimulate further research on the fascinating Devonian and Lower Carboniferous of the Meseta.

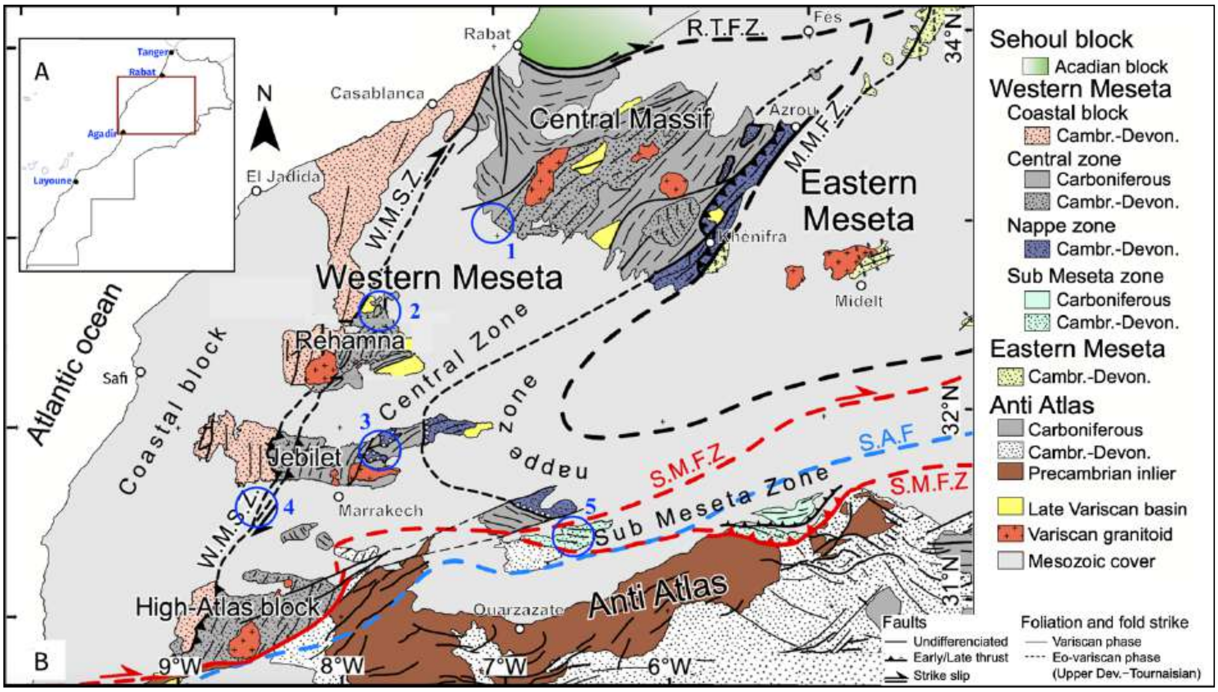

Fig. 1: A. General map of Morocco showing the Western Meseta position (red frame); B. The Meseta Domain and adjacent Anti-Atlas foreland; structural map of the Hercynian Meseta Domain, from MICHARD et al. (2008, fig. 3.16), modified after PIQUE & MICHARD (1989), OUANAIMI & PETIT (1992), HOEPFFNER et al. (2005), BAIDDER et al. (2008), SOULAIMANI & BURKHARD (2008), MICHARD et al. (2010), and TAHIRI et al. (2010). White: Mesozoic–Cenozoic cover, MMFZ: Middle Meseta Fault Zone, WMFZ: Western Meseta Shear Zone, SMFZ: South Meseta Fault Zone; SAF: South Atlas Fault, RTFZ: Rabat-Tiflet Fault Zone. Studied areas: 1. Ben Ahmed region; 2. Northern Rehamna; 3. Eastern Jebilet; 4. Mzoudia; 5. Skoura.

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Brachiopoda	SMF 102133-102136

If not stated otherwise, all thin-sections and additional non-figured (currently un-numbered) specimens will be deposited in the Geomuseum Münster.

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Devonian of the Benahmed region, western Moroccan Meseta

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Fig. 1: View on the Emsian-Givetian hill opposite of Dar Cheihk el Mfaddel with a large quarry in massive Lower Devonian limestones (right background) and a Middle Devonian succession exposed in minor limestone beds on the lower slope, from the white house in the middle to the small house on the left (photo from spring 2012).

Abstract. Based on new field work, sampling for conodonts, ammonoids, and microfacies analysis, the Lower to Upper Devonian stratigraphy of the Benahmed region is refined. Fossiliferous neritic limestones of the Pragian/lower Emsian represent a continuation of the shallow carbonate platform of the Al Attamna region to the north (Units A/B of Sidi Ahmed Lemdoun Formation). More argillaceous upper Emsian/Eifelian strata are regionally still poorly known. In the southern Chaouïa or Beni Sekten region NW of Benahmed, Givetian deep neritic to shallow pelagic mud-wackestones of the new Oulad Amar Formation were partly reworked and re-sedimented together with crinoidal grainstones in conglomeratic debris flow beds. Peaks of Eovariscan block faulting and reworking occurred high in the middle (*ansatus* Zone) and at the top of the Givetian (*norrisi* Zone). Lower/middle Frasnian strata are still unknown in outcrop but limestones with corals of possible Givetian/Frasnian age have been reported from E/SE of Benahmed. In the NW, the new upper Frasnian Boudouda Formation is characterized by transgressive hypoxic goniatite shales, which are unique for the Moroccan Meseta and which strongly resemble the contemporaneous Büdesheim Goniatite Shales of Germany. Unfortunately, the top-Frasnian and Frasnian-Famennian boundary are not exposed. Upper/uppermost ("Strunian") limestones and siliciclastics belong to a neritic succession that requires further research. In the southern Mdakra Massif E of Benahmed, there was a distinctive, middle/upper Famennian basin with richly fossiliferous, hypoxic ammonoid shales, the new Oued Aricha Formation. More than forty goniatite and clymeniid species are recorded, with up to 13 new forms that are currently left in open nomenclature. They fall in the UD III-C to V-A_2 interval of the international ammonoid zonation and include many common taxa with the contemporaneous Fezzou Formation (Lahfira to Jebel el Krabis Members) of the Maïder Basin of the eastern Anti-Atlas. The associated fauna is composed of

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rugose corals, including the revised *Hebukophyllum arichense*, nautiloids, bivalves, gastropods, brachiopods, and trilobites. As the Chabet el Baya Formation of the northern Mdakra Massif, the Oued Aricha Formation grades upwards into the poorly fossiliferous Mgarto Formation that straddles the Devonian-Carboniferous boundary.

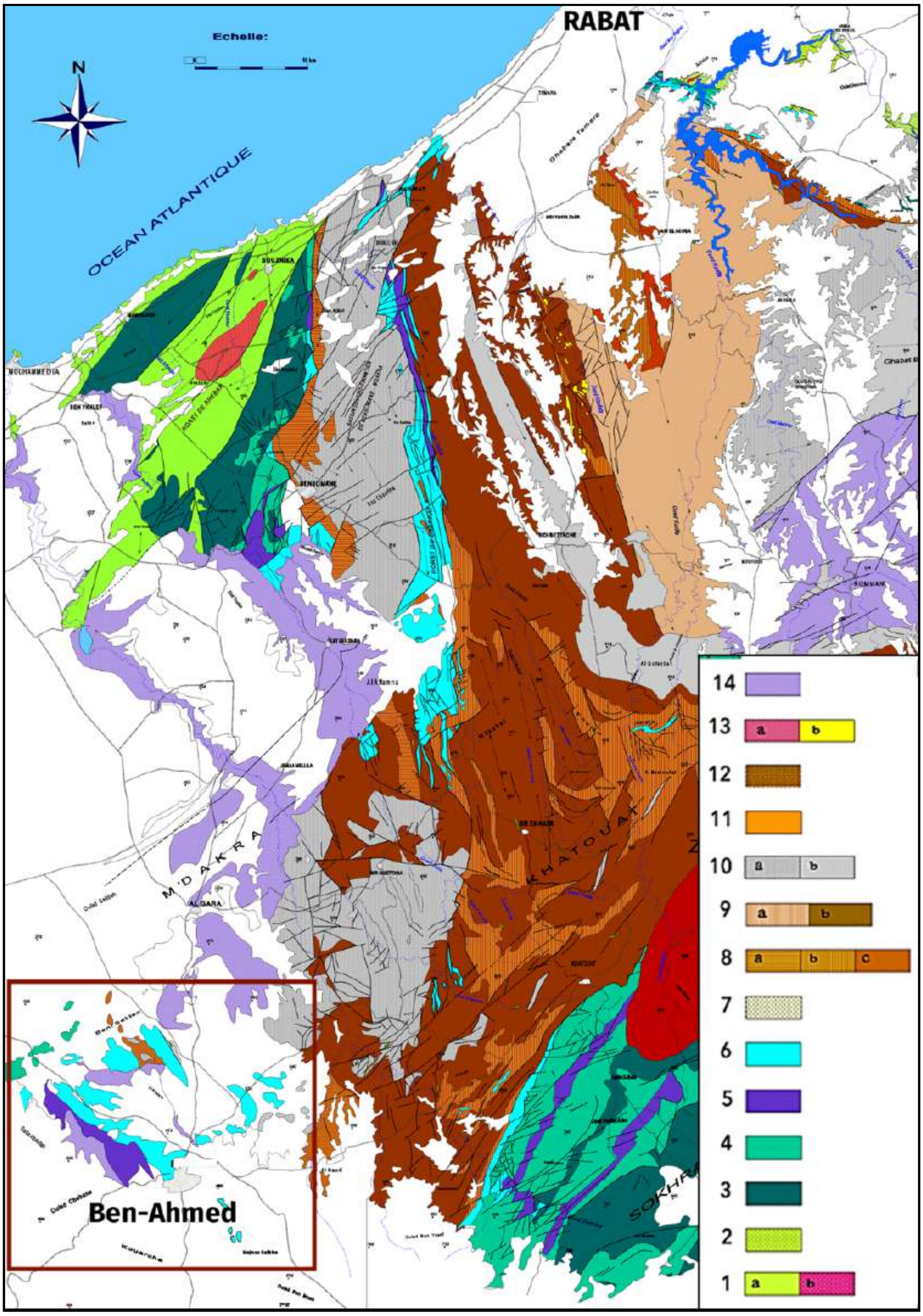

Fig. 2: Hercynian geological map of Western Central Morocco (FADLI et al. 2008) showing the regional geological position (square) of the Benahmed Palaeozoic. 1. Cambrian (a: greywackes, siltstones and quartzites; b: trachyandesites and rhyolites); 2. Cambrian-Ordovician (Zain quartzites and phyllites of the Sehoul Block); 3. Lower Ordovician; 4. Upper Ordovician; 5. Silurian; 6. Lower-Middle Devonian; 7. Undifferentiated Devonian; 8. Upper Devonian and Tournaisian; 9. Lower Visean ; 10. Middle/upper Visean and lower Namurian; 11. Upper Namurian to lower Westphalian; 12. upper Westphalian; 13. Stephanian/Permian; 14. Triassic.

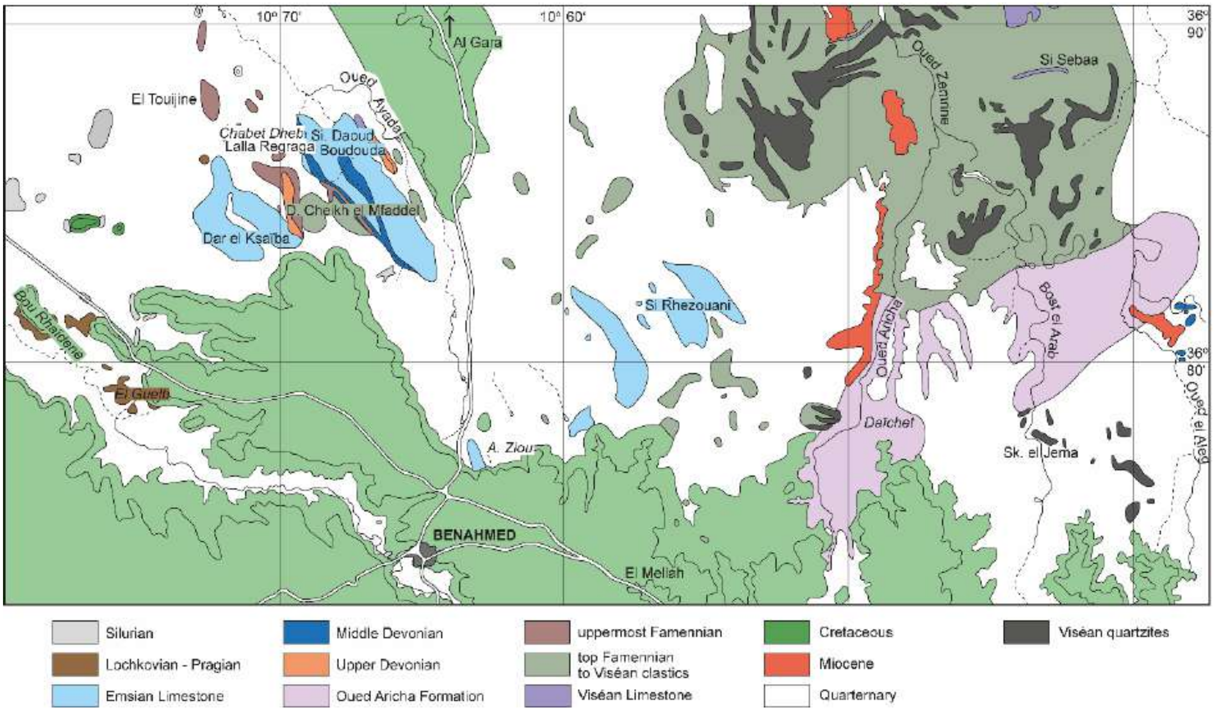

Fig. 3: Simplified geological map of the Benahmed region, based on TERMIER & TERMIER (1951a), showing the position of localities mentioned in the text (not showing the new motorway; see later Google Earth figures). The Beni Sekten region lies NW of Benahmed, the area to the NE belongs to the southern Mdakra Massif.

1. Introduction

Within the Western Meseta, the Devonian outcrops around Benahmed are positioned ca. in the middle (on a NE-SW transect) between the Oued Cherrat Zone south of Rabat and the Mechra-Ben-Abbou region of the northern Rehamna (HOLLARD 1967). Benahmed lies ca. 110 km SSW of Rabat (Fig. 2). In structural terms, its Palaeozoic belongs to the Central Meseta Zone sensu PIQUE & MICHARD (1981). Despite its intermediate position, almost nothing has been added on Devonian biostratigraphy and faunas since the pioneer monograph by TERMIER & TERMIER (1951a). The regional Devonian successions belong to two different palaeogeographic and structural units. The outcrops to the north and northwest of Benahmed (or between Benahmed and Al Gara,) are assigned to the southern part of the Chaouïa or Beni Sekten region, whilst a unique Famennian goniatite shale basin of the Oued Aricha-Bost el Arab-Oued el Aleg region, ca. 10-23 km to the east/northeast of Benahmed, forms the southern extension of the Mdakra Massif (Figs. 2-3). Isolated minor Emsian to ?Givetian outcrops are also known at ca. 6-8 km to the southeast of Benahmed, surrounded by Cretaceous strata (e.g., GENTIL 1909; outside the map of Fig. 3).

In 2012-2014 we logged and sampled sections for conodonts, ammonoids, other fauna, and microfacies. There was a focus on the Middle/Upper Devonian and on intervals with Eovariscan reworking. Therefore, only a summary of literature knowledge is provided for the highly fossiliferous Lower Devonian. Frasnian goniatite faunas and the Lower Carboniferous transgression, including rich foraminifer faunas and reworked Devonian conodonts, are dealt with in separate chapters.

2. Research history

GENTIL (1909): First report of a Lower Devonian ("Coblentzian") fauna with trilobites (*Cryphaeus laciniatus, Odontochile*) and brachiopods (e.g., "*Spirifer Pellicoi, Sp. Rousseaui, Sp. Bischofi, Uncinulus subwilsoni*") from the Chaouïa region.

JORDAN in DOUVILLE (1910): Report mentioning Lower Devonian strata with brachiopods in the area of the Cretaceous plateau (Mejmâa es Salihine = Majma Ac-Calihine region southeast of Benahmed, SW corner of topographic sheet Mgarto, NI-29-XI-2b, 1 : 50 000).

RUSSO (1924): Unpublished map showing the presence of the Devonian at Sidi Daoud.

BEAUGÉ (1924): Reference to supposed "Gothlandian" trilobites from Benahmed, including *Phacops fecundus*, which is the Devonian type-species of the genus.

TERMIER (1927a): Brief reference to the discovery of the Famennian at Oued Aouïja (= Oued Aricha).

TERMIER (1927b): New records of Devonian strata and faunas, including Emsian ("Coblentzian") neritic assemblages from Aïn Zian (= Aïn Ziou) and Sidi Rezouani in the north and northeast of Benahmed, Emsian phacopids (*Ph. potieri*) from Sidi Daoud to the northwest, and Famennian shales with sporadoceratids from the Oued Aricha.

TERMIER (1936): Lower Devonian brachiopod and trilobite faunas; illustration of some (originally) pyritized *Erfoudites* from the Oued Aricha as *Sporadoceras biferum,* of a probably squashed goniatite as *Tornoceras retrorsum* var. *acutum* SANDBERGER, and of a platyclymeniid as *Pl.* gr. *laevigata*; discovery of an isolated, supposed Frasnian reefal limestone with *Alveolites tenuissimus* east of the Oued Aricha and ca. 9 km SSE of Sidi Sebaa; discovery of an uppermost Famennian (Strunian) fauna with brachiopods and trilobites at Sidi-el-Haj-Tarhi northeast of Benahmed.

RICHTER & RICHTER (1943): Description of the rare trilobite *Malladaia*? sp. from Mejmâa es Salihine (= Mejma-Salihine), *Phacops* sp. indet. from Sidi Daoud, and of *Ph. (Ph.) accipitrinus accipitrinus* from the uppermost Famennian crystalline limestone discovered by TERMIER (1936).

TERMIER & TERMIER (1950a): Documentation of four Emsian species of tabulate corals, of two Emsian species of rugose corals, including the new *Hapsiphyllum maroccanum*, *"Loepophyllum" arichense* (correct spelling *Loiphyllum*) from the upper Famennian of Oued Aricha, and of the uppermost Famennian (see POTY et al. 2006) *Clisiophyllum omaliusii* from the Benahmed region

TERMIER & TERMIER (1950b): Documentation of four bryozoans and of more than 40 species of brachiopods from the Benahmed region (23 from the Lower Devonian, 18 from the Upper Devonian), including the new upper Famennian *Ambocoelia pentagonalis*, which was left out from later revisions of the genus, and related forms (e.g., GOLDMAN & MITCHELL 1990; ZAMBITO & SCHEMM-GREGORY 2013).

TERMIER & TERMIER (1950c): Documentation of Lower and Upper Devonian gastropods of the Benahmed region, of six species of Emsian bivalves, of eight species of Upper Devonian bivalves, including the new upper Famennian nuculoids *Ctenodonta maroccana* and *Nucula arichensis*, of two species of Frasnian manticoceratids, of 13 species of upper Famennian ammonoids and a bactritid from the Oued Aricha, and of five species of orthocones/nautiloids.

TERMIER & TERMIER (1950d): Documentation of a few Emsian ostracods, 14 species of Lower Devonian trilobites, including the new, later often ignored *Odontochile chaouiensis* (e.g., in BUDIL et al. 2009), of the new upper Famennian *Phacops arichensis* (which requires revision), and of the upper/uppermost Famennian blastoid *Pentremites touijinensis*.

ROCH (1950): Summary of Devonian localities in the Benahmed region, mentioning the fossiliferous Emsian of Sidi Rhezouani in the northeast, reefal limestones at Medjma es Salihine, the Famennian ammonoids of Oued Aricha, and strata with *Phacops accipitrinus* (= *Omegops*), spiriferids and *Productella*.

TERMIER & TERMIER (1951a): Compact monograph on the Benahmed Silurian to Carboniferous, with extensive faunal lists and locality information.

TERMIER & TERMIER (1951b): Discussion of Benahmed Upper Devonian pyritic faunas.

PETTER (1959): Re-illustration of *"Lobotornoceras" bicaniculatum*.

ALBERTI (1969, p. 27-28, 414): References to earlier Benahmed trilobite records.

HOLLARD (1967: fig. 4): Summary of the Devonian succession at Benahmed.

STRUVE (1976): Re-description of the Sidi-el-Haj-Tarhi phacopid as *Phacops (Omegops) accipitrinus insolatus* (*Omegops* is now a full genus).

LOBOZIAK et al. (1990): Palynostratigraphy of the Tournaisian-Viséan Sidi Sebaa Formation at Oued Zemrine, overlying the Mgarto Formation in the southern Mdakra Massif NE of Benahmed.

FADLI (1990): Unpublished Ph.D. Thesis including a new geological map and the sedimentology and structural geology of the southern Mdakra Massif.

RACHEBOEUF (1990a): Description of the chonetids *Plicaoplia alani, Loreleiella termierorum,* and *Plebejochonetes moniellensis* from Mejma Salihine.

ZAHRAOUI (1994): Brief reference to Pragian clastics, assumed Emsian limestones and overlying shale with goniatites at Sidi Daoud, and to Frasnian nodular limestones and shales of the Beni Sekten region.

FADLI (1994b): Summary of the Famennian to Tournaisian successions both in the Oued Aricha and Beni Sekten regions.

EL HASSANI (1994): Tectonic style of the Beni Sekten and Oued Aricha regions.

SARTENAER (1998, 2000): Comments on Oued Aricha "*Calvinaria undulata*".

EL HASSANI & BENFRIKA (1995, 2000): Review of the Devonian of the Mdakra Massif and Beni Sekten succession.

JANSEN (2001): Comments on previously reported Benahmed brachiopods.

SARTENAER & PLODOWSKI (2003): Description of *Araratella centralis* from the "Strunian" of El Touijine.

KAISER et al. (2007): Literature-based re-identification and stratigraphic re-evaluation of the Oued Aricha fauna and brief comments on the Strunian brachiopod fauna from Lalla Regraga.

BASSE (2012): Re-assignment of *Odontochile chaouiensis* to the genus *Spinodontochile*, which other authors regard as a subjective synonym of *Zlichovaspis*.

SCHWERMANN (2014): Description of an *Omalodus* shark tooth from the Givetian.

3. Regional and structural context

The Benahmed area is part of the south-western part of central Morocco, where the Devonian facies constitute the southern continuation of the Oued Cherrat, Al Attamna, and Mdakra regions (Fig. 2). Silurian-Devonian outcrops occur often only in small places, compared to those we know from further north. The region was part of a mapping program in 1956 (published in 1959). Fig. 3 is based on the map in TERMIER & TERMIER (1951a), which shows in detail the position of Silurian to Viséan outcrops. They lie east of the large "flexure de la Meseta", a NE-SW alpine normal fault, which is easily seen in the general morphology of this region.

The Benahmed Palaeozoic represents the SW end of the Khouribga-Oulmes Anticlinorium, a structure stretched over a distance of more than 100 kilometers in NE-

SW direction. This anticlinorium consists of a succession of anticlines and synclines in the same direction and involves Palaeozoic strata (TERMIER, 1936; VAN LECKWIJK et al. 1955; CAILLEUX 1975; TAHIRI 1991; ZAHRAOUI 1991). Ordovician deposits constitute the largest outcrop areas and contribute mainly to the structure's morphology, notably by small quartzitic massifs that often form high peaks.

A significant regional Eovariscan phase of the region corresponds to the opening of Lower Carboniferous basins at the edge of tilted block (generally Devonian), which provided polygenic conglomerates that are seen in several regions on the western edge of the Khouribga-Oulmes Anticlinorium, and which crop out in the Boudouda area (see Carboniferous chapter). The fundamental Hercynian fold is characterized by kilometric and decametric folds, straight, with a large curvature radius, trending NNW-SSE, with axes slightly dipping to the south, and without schistosity, even in the soft shale levels of the Silurian, Eifelian, and "Strunian".

The Oued Aricha-Souk Jemaa area constitutes the southern part of the Mdakra Massif, limited to the north by the Kef Tallal Fault, to the south by the phosphate plateau, and to the east by the southern extension of the Cherrat zone (referred to by FADLI 1990 as Setti Meryem area). The Mdakra Massif, again, was in sedimentary continuity with the Upper Devonian to Viséan of the Khataout Massif and Sidi Betache Basin to the northeast. From the Oued Aricha valley to the east of Viséan quartzites, there are NW-SE decametric and hectometric large synclines. But moving north, they take NE-SW directions with a SE vergence. This variation in the direction of the Hercynian major folding is the expression of the dextral clearance virgation of the Kef Tallal Fault.

As a general rule, the Hercynian fundamental folding shows increasing intensity towards the east. Their arrangement in the echelon, along the N-S Cherrat area, indicates that the zone acted as N-S dextral setback during the fundamental folding.

4. Devonian of the Beni Sekten region

4.1. Lower Devonian

As noted in the introduction, the Lower Devonian of the Benahmed region is very poorly studied despite its richness in fossils. So far, there are no data at all for conodont stratigraphy or microfacies/sedimentology.

4.1.1. "Lochkovian/?Pragian"

Possible Lochkovian-Pragian beds are thought to occur in the area northwest of Benahmed, e.g., around El Guelb (= El Goulib) and at the Bou Rheïdene (Fig. 3). TERMIER & TERMIER (1951a) noted in the first locality shales with limestones with crinoids and brachiopods of Silurian ("Gothlandien") age, followed at the top (SW flank) by beds with the tabulate coral *Cleistopora geometrica*. FREY et al. (2014) described cf. specimens of this species from the Pragian of the southern Tafilalt. But in the Ougarta region of Algeria, *Cl. geometrica* is abundant in the Lower Member of the Dkhissa Formation, which was dated by chitinozoans as middle Lochkovian *Fungochitina lata* Zone (BOUMENDJEL et al. 1996). *Cleistopora* had obviously a global Lochkovian/Pragian distribution, living even on the far distant shelf around the Jiamusi-Mongolian block of NE China (WANG et al. 2013). However, the precise taxonomy of cleistoporids is complex (e.g., PLUSQUELLEC 1973, 2007).

The facies setting of the supposed Lochkovian/Pragian west of Benahmed appears to have been a mixed siliciclastic-carbonatic shallow (neritic) shelf. In the facies model of OUALI MEHADJI et al. (2011) for the Saoura-Ougarta region (Algeria), *Cleistopora* was noted in an intermediate position of neritic shallowing upwards cycles.

Fig. 4: Geographic position of sampled Devonian localities in the Beni Sekten region NW of Benahmed, based on a satellite photo of Google Earth.

4.1.2. "Emsian limestone" (Pragian to lower Emsian)

Limestones of "Coblentzian" age are widespread in the northwest and northeast of Benahmed (Fig. 2), where they are partly exploited in large quarries, for example opposite Dar Sheik el Mfaddel (Figs. 1, 4). Small occurrences lie within the Cretaceous plateau southeast of Benahmed near Mejma Salihine, which yielded distinctive brachiopods (GENTIL 1909; DOUVILLE 1910; RACHEBEUF 1990a). TERMIER (1936) and TERMIER & TERMIER (1950a-d, 1951a) listed or illustrated six species of corals 23 species of brachiopods, 13 species of trilobites, six species of bivalves, bryozoans, and the crinoid-affine gastropod *Platyceras*. Their new *"Hapsiphyllum" maroccanum* is probably a species of *Adradosia* BIRENHEIDE & SOTO, 1977; the true *Hapsiphyllum* is based on Carboniferous forms. Unfortunately, the rich fauna has never been dealt with in sufficient detail and all previous identifications require revision.

Most common are solid, light-grey and bluish-grey, sometimes sandy or silicified, often dolomitized, then brownish or reddish weathering limestones. Decalcification led to an unusual application of the term "greywacke". TERMIER & TERMIER (1951a) mention from east of El Menzeh intercalated cross-bedded sandstones. Locally (e.g., at Dar el Kseiba, TERMIER & TERMIER 1951a), abundant tabulate and rugose corals mark transitions towards biostromes. A true reefal facies is not known from the Beni Sekten region. The setting was a neritic and storm-influenced carbonate platform. It can be seen as a southern continuation of the Dhar-es-Smene Formation of the Oued Cherrat (see BECKER et al. 2020b) and Units A/B of the Sidi Ahmed Lemdoun Formation of the Al Attamna (BENFRIKA & BULTYNCK 2003).

Until the brachiopod and trilobite faunas are revised, it is difficult to derive precise biostratigraphic ages from the published faunal lists. Among the brachiopods, the early (GENTIL 1909; DOUVILLE 1910) quoted *Spirifer Rousseaui* now belongs to *Torosospirifer* GOURVENNEC, 1989, which occurs low in the Pragian of the Oued Cherrat (BECKER et al. 2020b) and of the Ougarta region of Algeria (PARIS et al. 1996). In Spain, *Tor. rousseaui* is characteristic for the upper Nogueras Formation (also lower Pragian, VALENZUELA-RÍOS et al. 2019). *Spirifer Trigeri*, quoted by DOUVILLE (1910), is the type-species of *Vandercammenina* BOUCOT, 1975 and also a lower Pragian species, but the identification requires confirmation. For example, JANSEN (2001, p. 288) rejected the identification of a specimen from a different locality figured by TERMIER & TERMIER (1950b), as it has bifurcating costae on its flanks. *Schizophoria provulvaria* became the type-species of the subgenus *Rhenoschizophoria* JANSEN, 2001 (in the meantime used as a separate genus; see JANSEN 2016) and is a Pragian to lower Emsian species. Based on a restudy of the material housed in Rabat in 1996, JANSEN (2001, p. 123) excluded the Benahmed specimen figured by TERMIER & TERMIER (1950b, pl. 71, figs 10-11) and called it an early form which can be regarded as close to *Rhenoschizophoria torkozensis* from the Assa Formation (lower Pragian, Dra Valley). The restudy of the specimens recorded as "*Acrospirifer arduennensis*" (today genus *Arduspirifer*), that would actually indicate an upper Emsian age, has shown that these do not belong to that species. They may represent a very early *Arduspirifer* or even an advanced species of *Hysterolites*, both suggesting a Pragian age. *Stropheodonta gigas*, figured by TERMIER (1936, pl. 3, figs 6-7) and TERMIER & TERMIER (1951a, pl. 78, fig. 20), belongs to the genus *Gigastropheodonta* JANSEN, 2014, ranging from upper Pragian to upper Emsian beds; the Benahmed specimens are determined as *G.* cf. *gigas* and plea for a middle to late Siegenian (Pragian) age in the Rhenish sense. The other specimens figured as the same species (op. cit., pl. 78, figs 18-19) belong to *Crinistrophia* HAVLÍČEK, 1967, ranging from upper Pragian to lower Emsian beds. *Eodevonaria dilatata* (today genus *Loreleiella*) from the "region of Benahmed", (TERMIER & TERMIER 1951a, pl. 77, fig. 12) would, if correctly identified, suggest an Emsian age. *Chonetes tenuicosta* (today genus *Ctenochonetes*), figured by TERMIER (1936, pl. 3, fig. 11) and TERMIER & TERMIER (1951a, pl. 84, fig. 9), is redetermined as *Ct. aremoricensis*, an upper Pragian species common in the Dra Valley and Meseta (Morocco), the Iberian Chains (Spain), and the Armorican Massif (France) (e.g., RACHEBOEUF 1981, 1990a). The reported *Euryspirifer pellicoi* is an Emsian species but JANSEN (2001, p. 194) placed forms from the Meseta into undifferentiated *Euryspirifer* sp. and noted that these partly come probably from the Pragian (Siegenian). The true *Iridistrophia* (*Flabellistrophia*) *hipponyx*, listed in TERMIER & TERMIER (1951a) as *Hipparionyx hipponyx*, is in Germany an uppermost Emsian to basal Eifelian species.

But the ancestral species *Ir*. (*Flab*.) *musculosa* JANSEN, 2016 and possibly conspecific relatives from the Anti-Atlas (*Ir*. cf. *hipponyx* of JANSEN 2001) enter earlier, near the lower/upper Emsian boundary. The affiliation of the Benahmed representative is not clear. These are just a few examples and it is currently not conclusive to comment on the other brachiopod species that are only known from faunal lists and pencil drawings.

The situation is not easier for the recorded trilobites. *Malladia* (?) sp. described by RICHTER & RICHTER (1943) was later not recognized as a member of the genus, which proven geographic range did not list Morocco (e.g., STRUVE in BOUCOT et al. 1989, p. 562). Odontochilids range from the basal Pragian to the top of the lower Emsian (BUDIL et al. 2009), not higher. In modern taxonomy, specimens identified in the past as *Cryphaeus laciniatus* could belong to several genera of asteropygids (see BASSE 2004). *Kayserops kochi* is a species from the upper Emsian of Germany but the name has been used for other, partly even slight younger asteropygids that are not necessarily congeneric (see BASSE 2004). *Calymene curvicauda* and *Asteropyge lips* were first described by RICHTER & RICHTER (1943) from the Ezzhiliga region of the Meseta and could be of Pragian or lower Emsian age. The first was episodically placed with a query in *Gravicalymene* (ALBERTI 1969, p. 414), the second is a species of *Metacanthina* (see BASSE 2012). Previously it was placed by SMEENK (1983) in *Pilletina* but it has been omitted from the revision of Devonian asteropygid systematics and phylogeny by BIGNON & CRÔNIER (2013). The reported homalonotids *Digonus rhenanus* and *Dipleura simplex* are species described originally from the Rhenish Facies of Germany. The first is a synonym of *Digonus ornatus ornatus* (BASSE & MÜLLER 2004), which occurs in the lower Emsian of the Taunus region (southern Rhenish Massif, Germany). The second species is a possible junior synonym of *Dipl. laevicauda* and originally from the lower Emsian of the Eifel Mountains (see WENNDORF 1990; BASSE & MÜLLER 2004). It has also been recorded from the lower Emsian of Libya (MERGL & MASSA 2000). It needs to be proven whether the North Gondwana specimens are really conspecific with the Rhenish taxa.

In summary, the literature record suggests that the widespread Lower Devonian limestone unit of the Benahmed region begins rather early in the Pragian and that it ranges through the lower Emsian. An upper Emsian age for highest parts is less likely.

4.1.3. Lower Devonian of Sidi Daoud

We examined the Lower Devonian limestones at two localities in the Sidi Daoud (= Sidi Dawd) region NW of Benahmed (Fig. 4). At Aïn Lahjare (GPS N33°16,012´, W7°24,814´), blocks of light-grey micritic to slightly crinoidal limestones with 2-3 cm large brachiopods crop out. A conodont sample was unfortunately barren.

The second locality is the elongated hill above/behind the school and small sanctuary at Sidi Daoud itself (GPS N33°10´46.5´´, W7°16´18.4´´). In the lower part of the up to 150 m thick succession, there are fine-grained detrital limestones with rare brachiopods. A small conodont fauna with *Latericriodus bilatericrescens* was collected by M. RAJI & E. M. BENFRIKA (oral comm. 2012) in the ca. middle part. It confirms a lower Emsian age. The ca. upper third exposed along the top of the hill in a trench dug for a watering system is characterized by up to 30 cm thick, unfossiliferous dolomite beds alternating with deeply weathered shales. Because of the dull, altered lithology, no samples were taken. The top of the unit is not exposed.

TERMIER (1927a, 1936) and ROCH (1950) recorded *Cryphaeus laciniatus* (see comments above) and *Phacops potieri* from Sidi Daoud.

The latter is a species originally described from the Pragian or lower Emsian of France (see revision by MORZADEC 1969).

4.2. Upper Emsian/Eifelian

The regional knowledge of the upper Emsian and Eifelian is very poor. TERMIER & TERMIER (1951a, p. 66) assigned a shale unit excavated at Chat ed Dheb, west of Sidi Daoud, to the Eifelian. It yielded bivalves, brachiopods, phacopids, crinoid ossicles, orthocones, and a pyritic goniatite illustrated by TERMIER & TERMIER (1950c) as "*Mimagoniatites* cf. *evexus*". Based on the drawings, it is difficult to interpret. It could be either an upper Emsian mimagoniatitid or a lower Eifelian agoniatitid, such as *Fidelites bicanaliculatus* (see EBBIGHAUSEN et al. 2011). The associated "*Thysanopeltis* (?) *bifidum*" TERMIER & TERMIER, 1950d has been re-assigned to the genus *Tenuipeltis* LÜTKE, 1965 (see BASSE 2012, p. 118), which occurs elsewhere in the Meseta only in the pelagic upper Emsian of Dechra-Aït-Abdallah (RICHTER & RICHTER 1943: *Thys. maurus*). The type-species (*Thys. tenuicosta*) is also from upper Emsian pelagic facies (of the Harz Mountains) but the genus is thought to range higher.

As a research hypothesis, the deepening and onset of low-oxygen conditions above the neritic carbonate platform represents regionally the global Daleje Event at the base of the upper Emsian. It is well-developed in the Oued Cherrat area (BECKER et al. 2020b) but less distinctive in the Al Attamna (EICHHOLT & BECKER 2016; new data).

4.3. Givetian (new **Oulad Amar Formation)**

The Givetian of the Benahmed region yielded rich, new conodont faunas. There was considerable Eovariscan synsedimentary tectonic overprinting that caused reworking and re-sedimentation. In terms of facies and faunas, differences to contemporaneous units known to the north (Al Attamna) and south (Rehamna) are large. Therefore, a new Oulad Amar Formation is introduced, based on the name marked on the topographic map, Benahmed,1 : 50.000, NI-29-XI-2a, for the Palaeozoic region east of Beni Sekten and north of the Cretaceous lobe of Oulad Zahra. Type locality is the section near Dar Cheikh el Mfaddel (see below).

4.3.1. Givetian at Zwayir

Givetian crinoidal limestones and conglomerates are exposed in boulders along an agricultural track at Zwayir (= Zwaouir = Az Zwir on the topographic map). This is Section ZW of M. RAJI (Fig. 5). Most limestones are light to middle grey and grade macroscopically from fine or coarse-grained crinoidal limestone to conglomerates with variably small or large, fine-grained pebbles surrounded by crinoidal matrix (Fig. 6). Some beds provide evidence for double reworking: pebbles sitting in coarse crinoid matrix consist themselves of mixed smaller-sized pebbles and fine crinoidal matrix. A simplified overview of the exposed succession is shown in Fig. 7. In nature, the bedding is partly not well defined and crinoidal and conglomeratic parts intergrade within boulders exceeding a meter of thickness. Intercalated shales/marls are deeply weathered and poorly exposed.

In order to understand the local facies and age relationships, seven samples were taken (ZW S1-7), which all yielded conodonts, partly monospecific (ZW S1, S7), partly with up to nine species (ZW S3, S4; Tab. 1). There are two principle microfacies types that show some variation. Limestone pebbles are darker grey than the conglomerate matrix and consist of variably fossiliferous and bioturbated mud-wacke- to packstones with dense, micrite matrix, non-orientated styliolinids (ZW S1), very fine shell detritus, some ostracods, large trilobite remains (ZW S2, Fig. 8.2), rare gastropods (ZW S6), occasional idiomorphic pyrite (ZW S2, Fig. 8.3), and secondary dolomitization. Mudstones tend to be peloidal (ZW S4, Fig. 8.5) and occasionally the micrite has been washed out (ZW S7, Fig. 8.8). Subrounded to rounded but irregularly shaped pebbles range in size from a few mm to 2 cm (ZW S2, Fig. 8.3) and up to 10 cm (Fig. 6; ZW S4, S7). As an exception, small terebratuloid brachiopods, resembling in shape and ribbing style the genus *Ense* STRUVE, 1992 ("*pumilio* type"), occur as plasters (ZW-S1, Fig. 11.6). As these have a distinctly larger size and more costae than all known species of *Ense*, they are tentatively assigned to ?*Rhipidothyris* sp., possibly ex gr. *africana* BOUCOT, MASSA & PERRY, 1983, suggesting a Givetian age (see BOUCOT et al. 1983; HAVLÍČEK & RÖHLICH 1987; MERGL & MASSA 2004).

Fig. 5: The middle Givetian (Eovariscan) conglomerate unit exposed in the curve of an agricultural track at Zwayir (oldest bed in the lower foreground).

Fig. 6: Field photo of intergrading coarse conglomerate and crinoidal limestone at the base of the section at Zwayir.

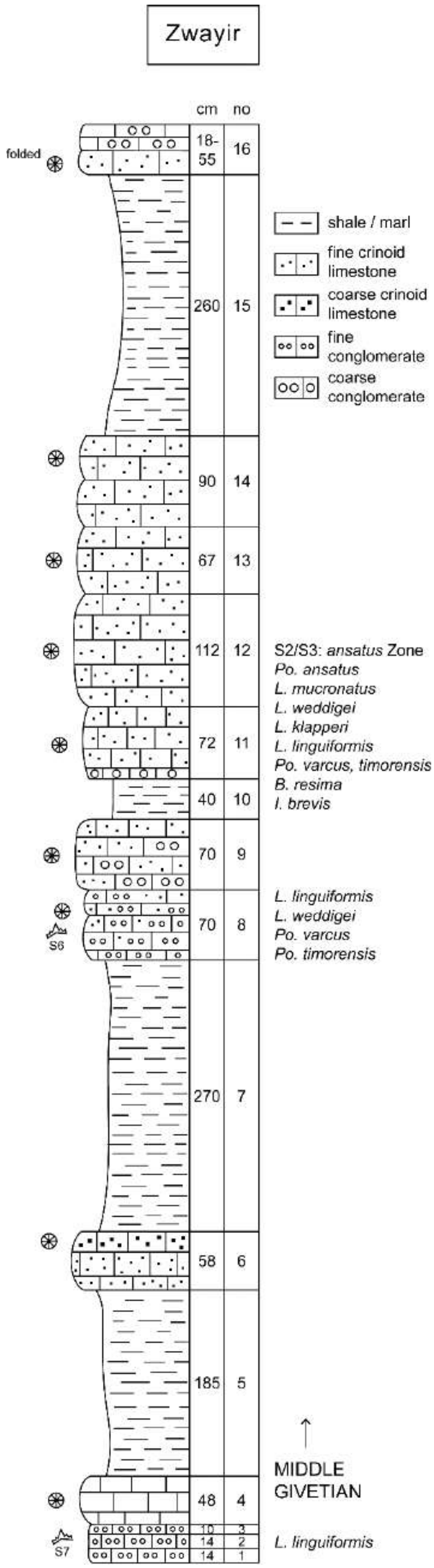

Fig. 7: Simplified lithological log and conodont data for the conglomerate section at Zwayir.

The original environmental setting of the mudstones was deep neritic to shallow pelagic, without or with only weak bottom currents. This is supported by an outer shelf polygnathid conodont biofacies. Skeletal remains of photic zone organisms are lacking.

The crinoidal limestone and matrix of the conglomerates (extraclast float-rudstones) consist of light-grey, more or less strongly recrystallized and partly dolomitized (then more brownish) grainstones without any sorting or grading (Figs. 8.3, 8.6), fine or coarse, angular crinoid debris, sometimes complete ossicles, and shell fragments. As noted above, Sample ZW S1 is very rich in brachiopods (Fig. 8.1), while there are peloids and styliolinids in the sparitic matrix of ZW S2 and ZW S6 (Fig. 8.6); the latter sample shows also trilobite fragments. Diagenetic compaction caused styliolithic pressure solution contacts with ferromanganese encrustation of angular pebbles in ZW S3 (Fig. 8.4) and ZW S6 (Fig. 8.7). In ZW S3, original micrite was only partly washed out, causing a gradual change from crinoidal grain- to packstone.

The irregular bedding, lack of any sorting or grading, both among the extraclasts and within the matrix, indicates deposition by debris flows that originated due to synsedimentary Eovariscan seismic activity near a former fault scarp. The hemipelagic mud-wackestones must have been uplifted by block faulting, were eroded and turned in a shallower setting into pebbles of variable size. The rather good rounding in some of the samples requires an extended period of high-energy conditions, adjacent to a setting, where currents and storms accumulated crinoid and brachiopod debris. However, the local lack of corals and other shallow neritic organisms and the presence of planktonic styliolinids in the grainstone matrix suggests that the complete reworking took place around an offshore crinoid shoal/ramp. Finally, seismic events at the persisting fault scarp caused imbalances of slope sediment sheets that moved as debris flows downslope.

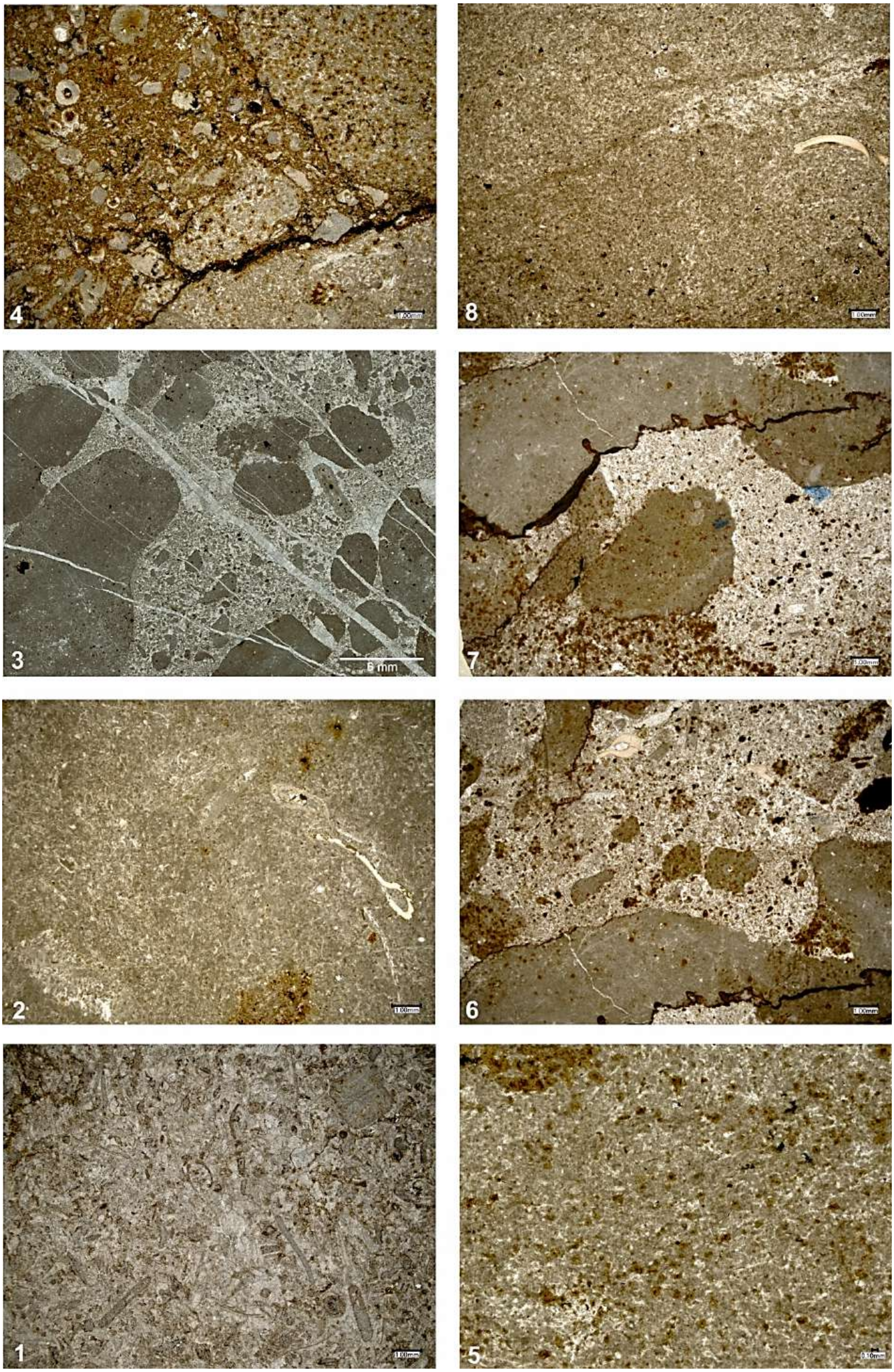
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Fig. 8: Microfacies of limestone samples from Zwayir. **1.** Recrystallized bioclastic grainstone with many fragmentary brachiopod shells, crinoid debris, and some styliolinids (ZW S1); **2.** Pebble of slightly peloidal mud-wackestone with dense micrite matrix and large trilobite piece (ZW S2); **3.** Large-scale picture of extraclast float-rudstone of ZW S2, showing the lack of sorting or grading, rounding of unsorted pebbles, and variable grain size of matrix; **4.** Stylolithic and Fe-M-impregnated contact of peloidal and bioturbated mud-wackestone clasts with unsorted, heterogeneous crinoidal packstone matrix (ZW S3); **5.** Detailed view of peloidal mudstone of pebble ZW S4, with very low amount of fine shell debris; **6.** Extraclast float-rudstone of ZW S6 with angular shape of very differently sized mud-wackestone pebbles and peloidal grainstone matrix with poorly preserved styliolinids and trilobite fragments; **7.** Larger view of ZW S6, showing the stylolithic contact of angular mudstone extraclasts; **8.** Pebble of peloidal mudstone with partly washed out micrite matrix and trilobite fragment (ZW S8).

The conodont data suggest that the complete interval of hemipelagic deposition, reworking, and re-deposition took place within the upper half of the middle Givetian. While mudstone pebble ZW S7 from the lower part of the succession yielded only a few *Linguipolygnathus linguiformis* (Figs. 10.14-15), the dolomitized mudstone pebble ZW S4 contained also *Polygnathus varcus* (Fig. 9.24), *Po. xylus* (Fig. 9.25), *L. klapperi, L. weddigei, L. mucronatus* (Fig. 9.20), and *Tortodus caelatus* (Fig. 9.26). The combination of the latter two species indicates the *ansatus* Zone (former Middle *varcus* Zone; Aboussalam 2003) in the upper part of the middle Givetian. In the top-middle Givetian facies model of Narkiewicz et al. (2016), a relative dominance of both *L. linguiformis* (Figs. 9.18-19, ca. 33 % of the assemblage) and *Belodella resima* (Fig. 9.17, ca. 39 %) is assigned to a "brackish lagoon or estuary". At Zwayir, such an interpretation is clearly contradicted by the microfacies and overall setting. It is long known that *Belodella*-rich faunas occur also in Lower Devonian pelagic limestones in offshore facies (Aboussalam et al. 2015). In the Givetian, a rarity of icriodids, as at Zwayir, indicates a deeper ramp deposition.

Conodonts from samples ZW S2, S3, and S6 can either come from the grainstone matrix or from reworked pebbles. The index species of the *ansatus* Zone was found both in ZW S2 (Fig. 9.5) and S3 (Figs. 9.14-15), in both cases jointly with *L. mucronatus* ((Figs. 9.3, 9.13), which has its main level in the *ansatus* Zone (see discussion in Brett et al. 2018). Sample ZW S3 yielded locally the only icriodid, *I. brevis* (Figs. 9.9-10; < 0.5 % of all specimens). *Polygnathus varcus* is moderately common (ca. 10-30 % of faunas). The bioclastic grainstone with large amounts of styliolinids and brachiopods (ZW S1) gave a monotypic *L. linguiformis* assemblage, which differs from the faunas from conglomerate samples. This suggests that the diverse conodont faunas derive mostly from the reworked mud-wackestones, in agreement with their original deeper-water deposition. Locally rare taxa are *Prioniodina* sp. (Sample ZW S4, Fig. 9.27), *"Ozarkodina" plana* (Sample ZW S5, Fig. 10.3), and *L. weddigei* (Sample ZW S2, Fig. 9.4).

The overall conodont fauna does not differ from middle Givetian pre-reefal assemblages of the southern Oued Cherrat (flaserlimestone of Aïn-as-Seffah, Becker et al. 2020a) or from the Anti-Atlas (Aboussalam 2003). The local carbonate ramp was open. This suggests that the reef platforms to the north (At Attamna) and south (northern Rehamna) were separated by wide deeper shelf areas. As suspected by previous authors, the spatial distributions of Givetian biostromes and bioherms in the Western Meseta was probably constrained by the mosaic of synsedimentary block movements that later caused the uplift and reworking.

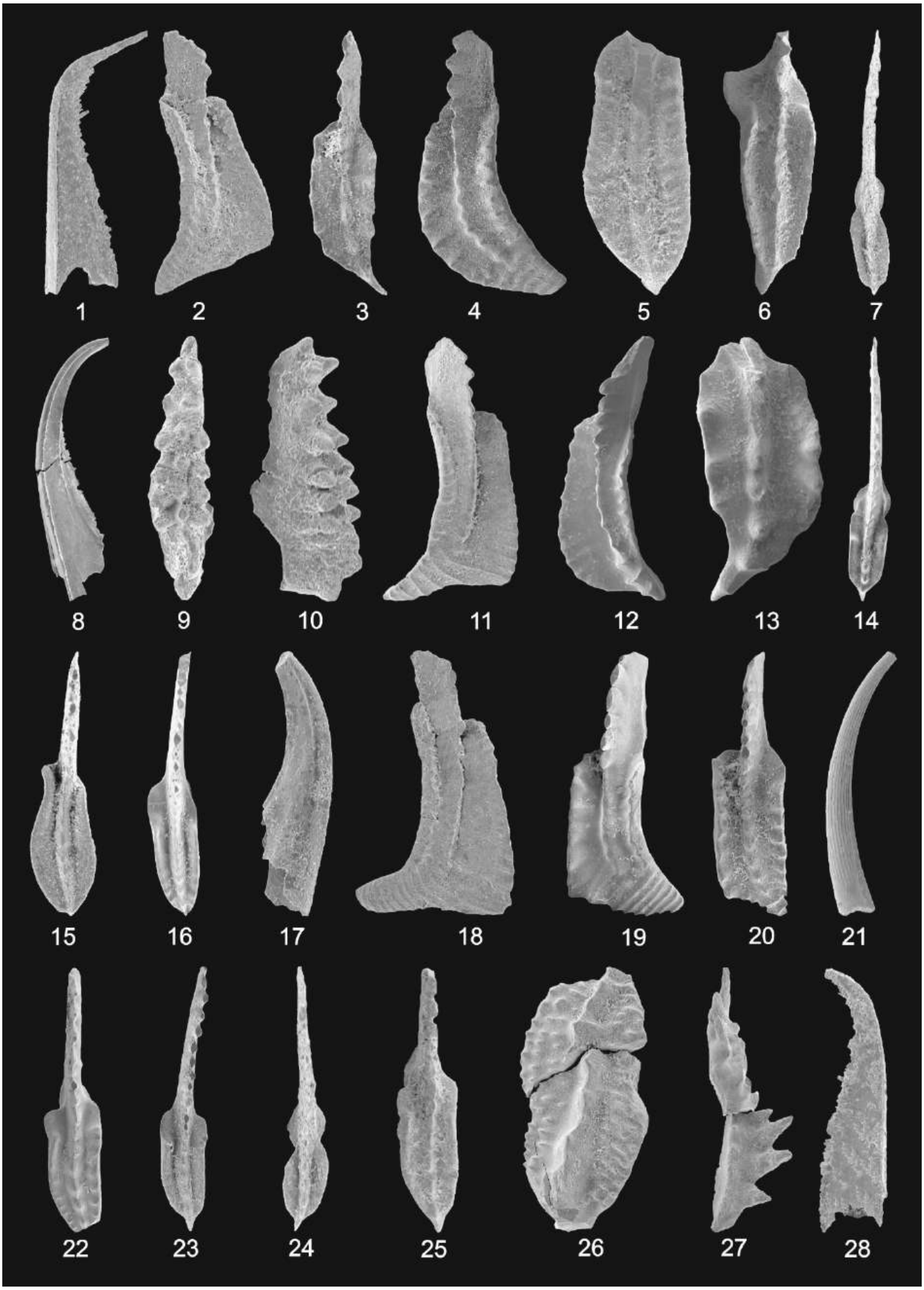

Fig. 9: Givetian conodonts from Zwayir (1-7 = ZW S2, 8-16 = ZW S3, 17-27 = ZW S4, 28 = ZW S5), GMM B4C.2.1-28. **1, 8, 17, 28.** *Belodella resima* (x 60, 40, 55, 55); **2, 11-12, 18-19.** *Linguipolygnathus linguiformis* (x 30, 40, 70, 30, 30); **3, 13, 20.** *L. mucronatus* (x 65, 95, 35); **4.** *L. weddigei* (x 35); **5, 14-15.** *Polygnathus ansatus* (x 60, 45, 60); **6, 16, 22-23.** *Po. timorensis* (x 60, 60, 45, 65); **7, 24.** *Po. varcus* (x 55, 85); **9-10.** *Icriodus brevis* (x 65); **21.** *Neop. perlineatus* (x 65); **25.** *Po. xylus* (x 80); **26.** *Tortodus caelatus* (x 40); **27.** *Prioniodina* sp. (x 40).

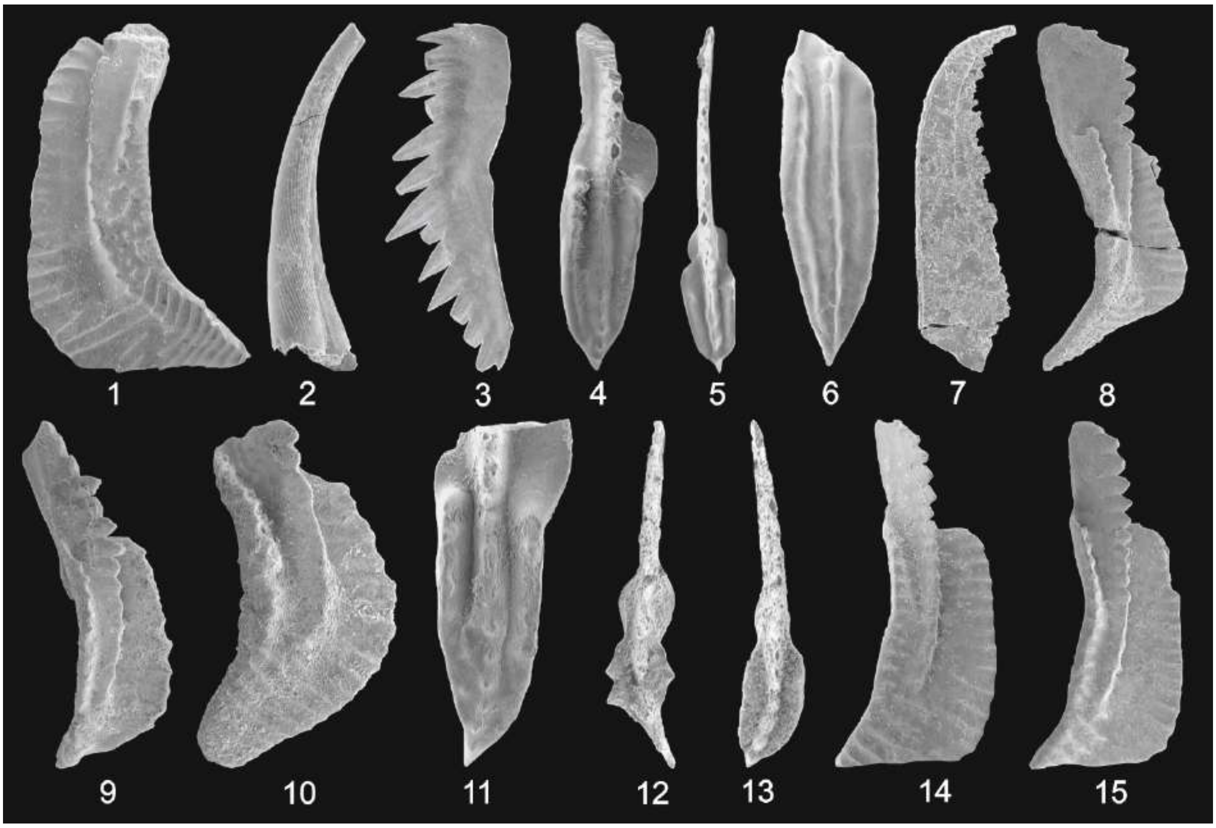

Fig. 10: Givetian conodonts from Zwayir, part II (1-6 = ZW S5, 7-13 = ZW S6, 14-15 = ZW S7), GMM B4C.2.29-43. **1, 8, 10, 14-15.** *Linguipolygnathus linguiformis* (X 40, x 30, x 40, x 50, x 55); **2.** *Neopanderodus perlineatus* (x 60); **3.** *"Ozarkodina" plana* (x 65); **4, 11.** *Polygnathus timorensis* (x 45, x 75); **5, 12-13.** *Po. varcus* (x 60, x 65, X 65), including an unusual morphotype with spinose side nodes (12.); **6.** *Po. xylus* (x 80); **7.** *Belodella resima* (x 60); **9.** *L. mucronatus* (x 65).

Zwayir							
Conodont zones	***rhenanus-varcus - ansatus***						
Sample no.	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
L. linguiformis	**20**	**16**	**12**	**22**	**5**	**7**	**2**
L. klapperi		**1**	**2**	**3**		**3**	
L. weddigei		**1**		**1**			
L. mucronatus		**1**	**1**				
Po. timorensis		**1**	**4**	**2**	**2**	**5**	
Po. ansatus		**1**	**7**				
Po. varcus		**10**	**5**	**9**	**3**	**3**	
Bel. resima		**5**	**11**	**26**	**6**	**1**	
I. brevis			**1**				
T. caelatus				**1**			
Prioniodina sp.				**1**			
Po. xylus				**2**	**1**		
Neop. perlineatus			**1**		**3**		
"Oz." plana					**1**		
total conodonts	**20**	**36**	**44**	**67**	**21**	**19**	**2**

Tab. 1: Conodont abundance and diversity in the seven samples from Zwayir.

Fig. 11: Middle Devonian brachiopods from the brachiopod bed at Dar Cheikh el Mfaddel (1-5, Bed 1, SMF 102134.1-5) and from Zwayir (6, Sample ZW S1, SMF 102135). **1.** ?*Devonochonetes* sp., external and internal moulds; **2.** Chonetid, ventral valve, internal mould (left specimen) and orthotetide brachiopod, dorsal valve, internal mould (large specimen); **3. ?***Strophodonta* sp., dorsal valve, external mould; **4.** *Tropidoleptus* sp., ventral internal mould; **5.** Chonetid, ventral internal mould; **6.** *Pumilio*-like terebratulide, tentatively assigned to ?*Rhipidothyris* sp. ex gr. *africana* Boucot, Massa & Perry, 1983, decorticated ventral valve exterior.

Fig. 12: Overview of the middle/upper Givetian succession opposite of Dar Cheikh el Mfaddel, showing the position of sampled beds.

4.3.2. Givetian at Dar Cheikh el Mfaddel

The Middle Devonian succession exposed along the hill opposite of Dar Cheikh el Mfaddel (Figs. 1, 12) is the type locality of the new **Oulad Amar Formation**. GPS coordinates for the top of the section (Bed 12b) are N33°9´57.2´´, W7°16´39.4´´. In total, the formation includes a range of lithologies: deeply weathered shale/marl, peloidal mudstones, bioclastic wackestones with abundant styliolinids, bioclastic wackestones with dominant shell debris and brachiopods, grainstones with variable amounts of crinoid, brachiopod or trilobite debris, styliolinids and peloids, styliolinid pack-grainstones, and coarse, unsorted conglomerates (extraclast float-rudstones). In the Beni Sekten area, corals are rare.

At Dar Cheikh el Mfaddel, the calculated thickness SW of the Lower Devonian quarry (Fig. 1) is in the range of 80-90 m but the precise formation base has not been established. The bedding changes laterally, with more solid units cropping out or disappearing on strike (Fig. 12). Figure 13 is, therefore, a representative but simplified section log for the ca. upper half of the formation. It begins close to the house visible in the middle of Fig. 1, at GPS N33°9´56.5´´, W7°16´34.6´´ (on the right in Fig. 12). Stratigraphically below, towards the quarry, more limestones crop out for a distance of ca. 75 m.

The resistant Bed 1 contains abundant univalved brachiopods that partly cover the bed. A larger block contained ?*Devonochonetes* sp. (Fig. 11.1), a large orthotetide (Fig. 11.2), ?*Strophodonta* sp. (Fig. 11.3), and *Tropidoleptus* sp. (Fig. 11.4). *Devonochonetes* is a Middle Devonian genus; the specimens resemble *D.*? cf. *scitulites* sensu RACHEBOEUF, 1981 from the Givetian of Palencia (Spain) or *D. salami* MERGL & MASSA, 1992 from the Givetian-Frasnian transition of Libya. The genus *Strophodonta* has been reported from the uppermost Silurian to Frasnian, the only external mould is a coarsely ribbed form. *Tropidoleptus* is widely known in North Africa (from Mauritania to Niger), from the Pragian (JANSEN et al. 2007) to the Givetian (e.g., ARDEN & RHERIG 1964; BOUCOT et al. 1983; MERGL & MASSA 1992, 2004; RACHEBOEUF et al. 2001), with the main occurrences in the Pragian-Emsian and Givetian. In summary, the brachiopods suggest a Middle Devonian and possibly a Givetian age for the base of our logged section. The unit yielded no conodonts. The microfacies is a dull, strongly recrystallized microsparite. Laterally to the west (Fig. 12), the beds dip more or less in parallel with but slightly steeper than the slope. Thickness calculations of covered intervals are arbitrary; partly distances on the slope between limestones are given. Bed 6b on the upper slope is an irregularly-bedded, up to 2 m thick conglomeratic interval. Pebbles consist of light-grey, bioturbated mud-wackestone with dense micrite matrix, fine shell and trilobite debris, abundant, and poorly preserved crinoid fragments (Fig. 14.1). Conodonts (Tab. 2) of this deep neritic facies belong mostly to single cone genera, such as *Belodella* (Figs. 16.1, 4) and *Neopanderodus* (Fig. 16.3). A single *Icriodus brevis* (Fig. 16.2) gives a position no older than the late lower Givetian *brevis* Zone, correlating ca. with the *timorensis* Zone of the polygnathid succession (BULTYNCK 1987).

The next conglomerate (Bed 7b) contains 1-4 cm large, subrounded pebbles, partly in stylolithic contact, of a slightly deeper (shallow pelagic) facies: bioclastic wacke-floatstones with abundant, poorly preserved styliolinids, some ostracods, and orthocones (Fig. 14.2). A second pebble is rich in fine filaments and sparite fenestrae. The rudstone matrix is a peloidal, bioclastic grainstone with poorly preserved styliolinids (Fig. 14.3). Rests of a micrite matrix are partly preserved and there is some dolomitization. The unit produced a much more diverse conodont fauna (eight species, Tab. 2). The mixed polygnathid-belodellid facies is in accord with the neritic microfacies. It includes the index species of the *difficilis* Zone of the icriodid zonation (BULTYNCK 1987; Fig. 16.5) and *Po. varcus* (Fig. 16.9), one of the index species of the middle Givetian *rhenanus-varcus* Zone. *Polygnathus* is slightly more common than linguipolygnathids (*L. linguiformis*, Fig. 16.6, *L. weddigei*, Fig. 16.7). There are two rather distinctive prioniodinids with high anterior blade (e.g., Fig. 16.10); their dense denticulation resembles *Tortodus sardinia* (see ABOUSSALAM 2003, pl. 26, fig. 12) but there is no incipient platform along the blade.

After an outcrop gap of 43 m distance, a sequence of solid limestones crops out close to a smaller house on the lower slope (Figs. 1, 12). A conodont fauna from the almost 1 m thick Unit 10b, which consists of subunits, is rather poor and dominated by *L. linguiformis* (Fig. 16.11). The microfacies is a recrystallized bioclastic grainstone with styliolinids, ostracods, pyrite, and shell debris, but without peloids and with only subordinate crinoid debris (Fig. 14.4). Above, the conglomeratic Bed 11b yielded with *L. mucronatus* (Fig. 16.12) an indicator that the top of the *rhenanus-varcus* or (more likely) *ansatus* Zone has been reached (BULTYNCK 1987; BRETT et al. 2018). There is also a poorly preserved, incomplete shark tooth belonging to *Omalodus grabaui* (see SCHWERMANN 2014). In Morocco, *Omalodus* has previously been described from contemporaneous limestones of the southern Tafilalt (HAMPE et al. 2004). Reworked pebbles of Bed 11b are ca. 1-3 cm large, are surrounded by sparitic dissolution seams, and consist of peloidal mudstone. Within one pebble, there is a mixed amalgamated micrite-fenestral fabric, which may represent a small sponge (Fig. 14.5; see discussion in KERSHAW et al. 2021). The rudstone matrix differs from that in Bed 10b; it is a very shell-rich grainstone (calcarenite) with ostracods, trilobite, some fragmentary corals and crinoid debris (Fig. 14.6). This indicates deposition at shallower depth than before.

At the foot of the hill, just above a small gully, Bed 12b is an irregularly-bedded, massive boulder unit (Fig. 12). A thin-section shows peloidal grainstone with fine shell debris and some retained micrite (Fig. 14.7), followed above a pyrite enrichment by recrystallized styliolinid packstone with partly washed out micrite matrix, ostracods, brachiopod and crinoid debris (Fig. 14.8). This upper part may represent a contourite deposit, as it is known from the Tafilalt Platform (HÜNEKE et al. 2021 submitted). The rich and diverse (23 species) conodont fauna includes some top-Givetian species that are new for the western parts of the Meseta. This applies to some species of *Schmidtognathus* (9.6 % of the total assemblage; *Schm.* aff. *hermanni*, Fig. 15.7, *Schm. wittekindti*, Fig. 15.12, *Schm. pietzneri*, Fig. 15.11, *Schm. latifossatus*, Fig. 15.8, *Schm.* aff. *latifossatus*, Fig. 15.9, *Schmidtognathus* n. sp. DCM, Figs. 15.10), *"Ozarkodina"* aff. *adventa* (Fig. 16.23), and *Klapperina* (*Kl. vysotzkii*, Fig. 16.20, < 0.4 %). Unusually dominant for the stratigraphic position is a flood of *Po. xylus* (Figs. 15.5-6, 36 % of the assemblage), followed in terms of abundance by *Po. dubius* (Fig. 16.25, ca. 18 %), *Po. paradecorosus* (Fig. 15.1, 15.4 %), and belodellids (*B. resima*, Fig. 16.15, *B. triangularis*, Fig. 16.16; both = 12.2 %). This polygnathid facies, with close to 80 % of the total fauna, is indicative for an offshore setting. It includes some *"Oz." semialternans* (Figs. 16.21-22, 1.3 %) and *Po. cristatus ectypus* (Fig. 16.26, 1.5 %) and only a very minor contents of icriodids (*I. expansus*, Fig. 16.19, < 0.2 %), *Elsonella* (Figs. 16.17-18, 0.6 %), and *Tortodus* (*caelatus* Group, Fig. 15.13, < 0.2 %). Associated are rare shark teeth (Fig. 15.14) and phosphatic brachiopod remains (Fig. 15.15). It is likely that the fauna represents by condensation several upper Givetian zones; otherwise there is a considerable gap between Beds 11b and 12b. The common *Po. paradecorosus* and single specimens of *Po. alatus* (Fig. 16.24) and *Po.* aff. *pennatus* (Fig. 15.4; pathological) give a topmost Givetian age for the final deposition (*norrisi* Zone); an absence of *Skeletognathus norrisi* is also known from top-Givetian samples of the Tafilalt (see ABOUSSALAM & BECKER 2007). Two somewhat pathological polygnathids belong probably to *Po. tafilaltensis* (Figs. 15.2-3), which enters in its type-region in the *dengleri dengleri* Subzone (ABOUSSALAM & BECKER 2007). Two features of the assemblage are noteworthy: 1. The occurrence of pathological specimens of several polygnathid species, and 2. The extreme rarity of *Klapperina*, which suggests that sediment of the *disparilis* Zone was poorly represented by our sample, perhaps due to a gap or strong condensation.

The reworking at Dar Sheik el Mfaddel was probably related to the same fault scarp as at Zwayir. Early consolidated lime mud and sand (calcarenite) of both deep neritic and shallow pelagic origin was uplifted and transformed into pebbles.

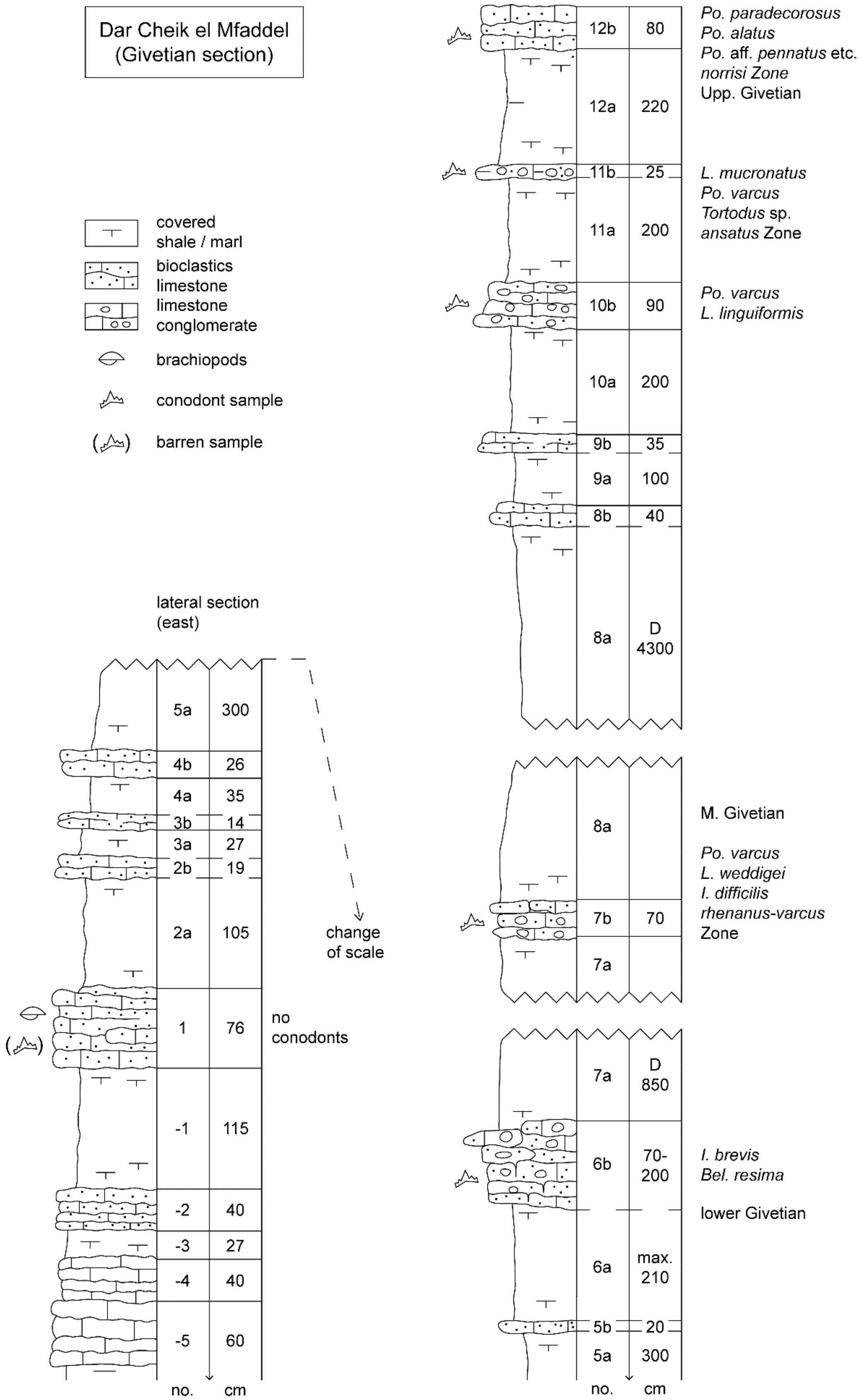

Fig. 13: Simplified section log for the Givetian at Dar Cheikh el Mfaddel, showing the position of conodont faunas and their age.

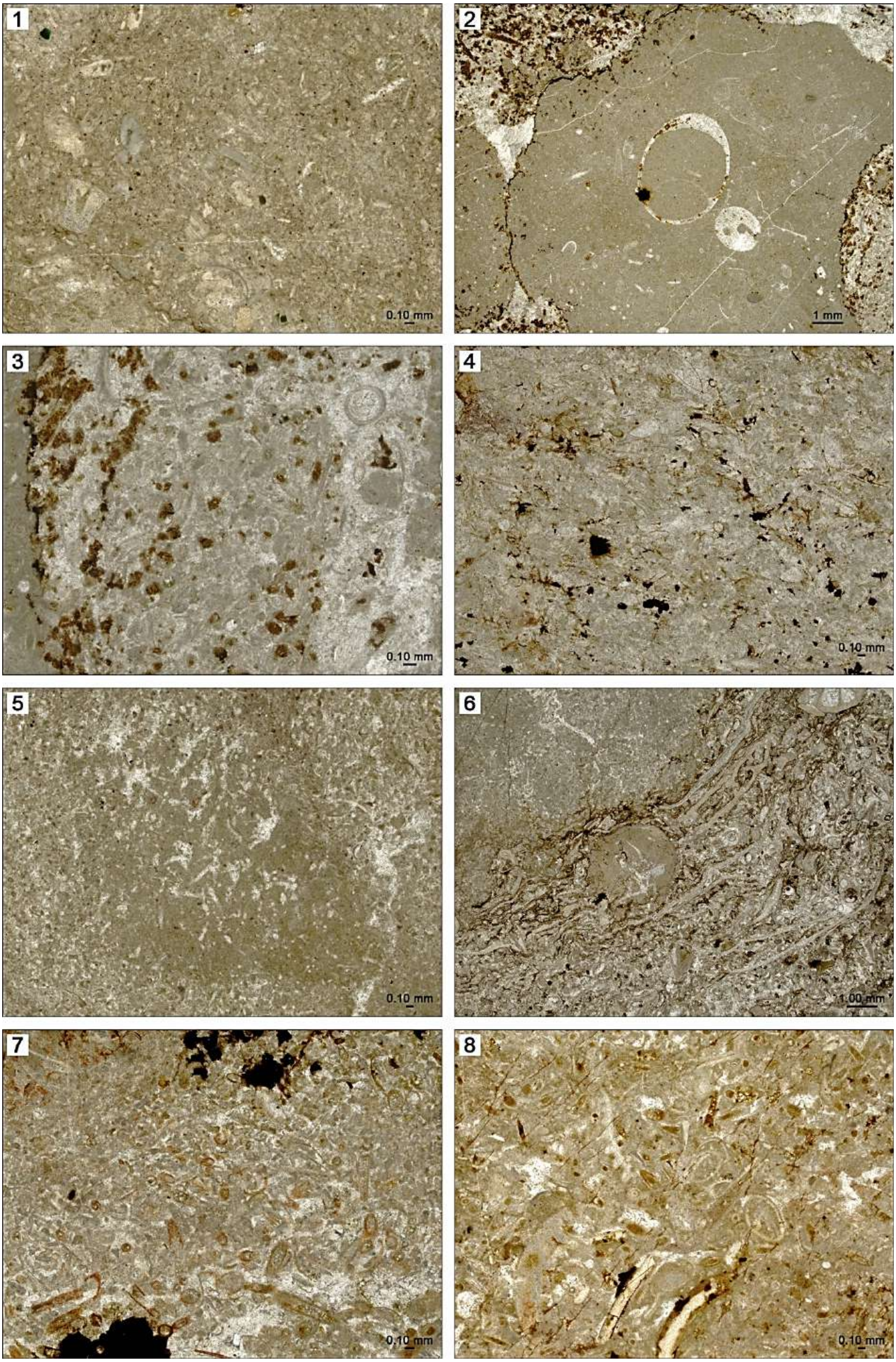
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Fig. 14: Microfacies of limestones from the upper part of the Oulad Amar Formation at Dar Cheik el Mfaddel. **1.** Pebble consisting of bioturbated mud-wackestone with fine shell debris, poorly preserved crinoid fragments, and dense micritic matrix, Bed 6b; **2.** Pebble of bioturbated, bioclastic wacke-floatstone with a few poorly preserved styliolinids, some ostracods, a crinoid ossicle, an orthoconic cephalopod, and dense micrite matrix Bed 7b; **3.** Matrix of conglomerate of Bed 7b, partly dolomitized peloidal and bioclastic grainstone with poorly preserved styliolinids and remnants of original micrite matrix; **4.** Recrystallized, partly micritic, partly sparitic bioclastic wacke-grainstone with abundant shells, Bed 10b; **5.** Possible sponge remain within a peloidal mudstone matrix of a pebble within Bed 11b; **6.** Bioclastic grain-packstone matrix of the conglomerate of Bed 11b, rich in fragmented brachiopod shells, with a coral fragment (upper right corner), and crinoid fragments; **7.** Recrystallized styliolinid pack-grainstone, partly enriched in pyrite, Bed 12b, lower part; **8.** Peloidal grain-packstone with abundant shell debris and partly washed out micrite matrix, Bed 12b, upper part.

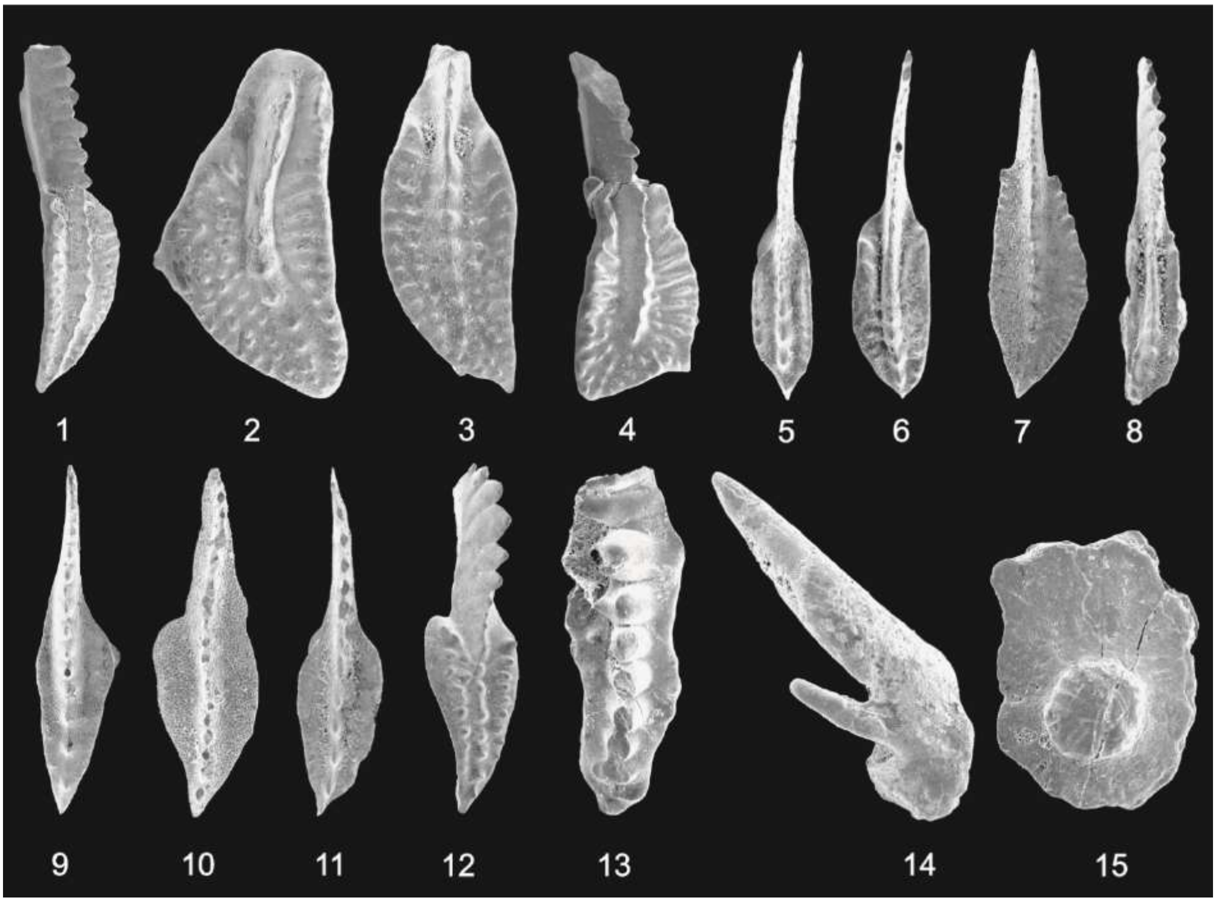

Fig. 15: Conodonts from the upper Givetian (top Oulad Amar Formation) at Dar Cheikh el Mfaddel, all from Bed 12b, GMM B4C.2.44-56. **1.** *Polygnathus paradecorosus*, x 40; **2-3.** *Po. tafilaltensis*, pathological, both x 55; **4.** *Po.* aff. *pennatus*, pathological, x 40; **5-6.** *Po. xylus*, x 75, x 50; **7.** *Schmidtognathus* aff. *hermanni*, x 35; **8.** *Schm. latifossatus* with rather irregular, narrow platform. x 40; **9.** *Schm.* aff. *latifossatus*, x 60; **10.** *Schmidtognathus* n. sp. DCM with chagrin platform surface, x 60; **11.** *Schm. pietzneri*, x 50; **12.** *Schm. wittekindti*, x 35; **13.** *Tortodus* sp. (*caelatus* Group), x 45; **14.** Skark tooth (?symmoriid), lateral view, x 45, GMM A1C.5.1; **15.** phosphatic brachiopod piece (?acrotetrid valve), GMM B5B.16.2, x 65.

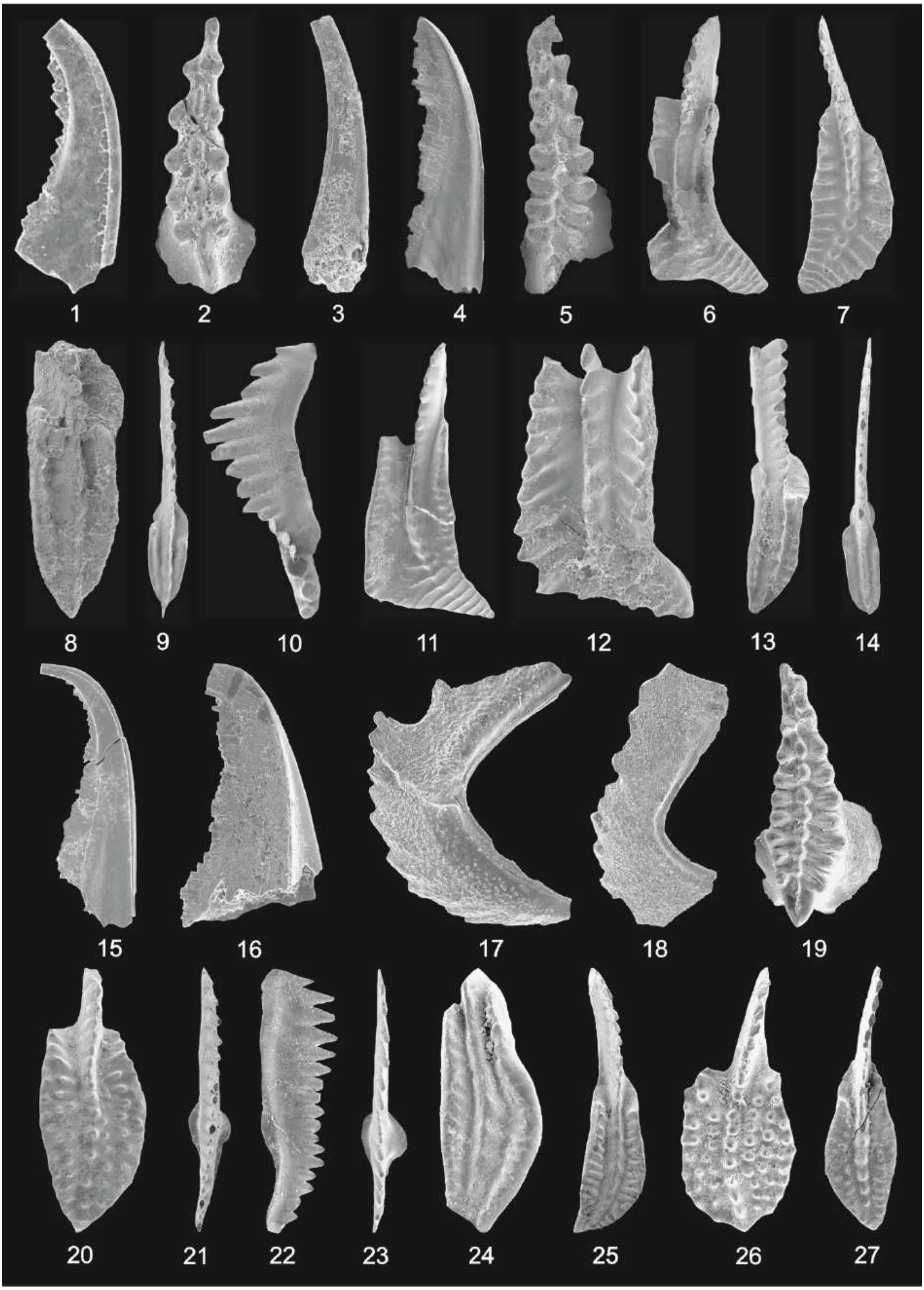

Fig. 16: Conodonts from the Givetian Oulad Amar Formation at Dar Cheikh el Mfaddel (1-4 = Bed 6b, 5-10 = Bed 7b, 11 = Bed 10b, 12-14 = Bed 11b; 15-27 = Bed 12b), GMM B4C.2.57-82. **1.** *Belodella resima*, x 140; **2.** *Icriodus brevis*, x 90; **3.** *Neopanderodus perlineatus*, x 55; **4.** *Bel. resima*, x 55; **5.** *I. difficilis*, x 50; **6.** *Linguipolygnathus linguiformis*, x 35; **7.** *L. weddigei*, x 45; **8.** *Polygnathus timorensis*, x 80; **9.** *Po. varcus*, x 55; **10.** *Prioniodina* sp., x 35; **11.** *L. linguiformis*, x 35; **12.** *L. mucronatus*, x 60; **13.** *Po. timorensis*, x 40; **14.** *Po.*

varcus, x 50; **15.** *Bel. resima*, x 60; **16.** *Bel. triangularis*, x 95; **17-18.** *Elsonella rhenana*, x 90, x 60; **19.** *I. expansus*, x 60; **20.** *Klapperina vysotzkii*, x 40; **21-22.** *"Ozarkodina" semilalternans*, x 45; **23.** *"Oz."* aff. *adventa*, x 60; **24.** *Po. alatus*, x 55; **25.** *Po. dubius*, x 35; **26.** *Po. cristatus ectypus*, x 50; **27.** *Po. ovatinodosus*, x 45.

Dar Cheik el Mfaddel					
Conodont zones	***timorensis***	***rhenanus-varcus***		***ansatus***	***norrisi***
Bed no.	**6b**	**7b**	**10b**	**11b**	**12b**
Neop. perlineatus	6	5			
Bel. resima	1	25	*	20	61
I. brevis	1				
L. linguiformis		6	10	62	
L. weddigei		10	*	1	
Prioniodina sp.		2			
Po. varcus		13	4	6	26
Po. timorensis		5	*	5	
I. difficilis		2	*	1	
Tortodus sp.				1	
L. mucronatus				**8**	
I. expansus					2
Bel. triangularis					5
Elsonella rhenana					3
Tortodus sp.					1
Po. dubius					96
Po. xylus					194
Po. alatus					**1**
Po. aff. *pennatus* (path.)					1
Po. paradecorosus					**83**
Po. ovatinodosus					13
Po. tafilensis (path.)					2
Po. cristatus ectypus					8
"Oz." semialternans					7
"Oz." aff. *adventa*					1
Schm. wittekindti					18
Schm. hermanni					9
Schm. aff. *hermanni*					1
Schm. planus n. sp.					2
Schm. pietzneri					3
Schm. latifossatus					1
Klapperina vysotzkii					2
total conodonts	**8**	**68**	**14**	**104**	**539**

Tab. 2: Conodont abundances at Dar Cheik el Mfaddel.

Re-deposition occurred by debris flows that mixed pebbles and shell or crinoid-rich debris. The most conodont- and dacryoconarid-rich bed at the top (Bed 12b) shows that the succession ended in a moderately deep outer shelf environment.

4.3.3. Possible Givetian E/SE of Benahmed

TERMIER (1936) reported from a locality named as Tantana, 9 km SSE of Sidi Sebaa (see Fig. 2), a limestone lense with alveolitids that he compared with the Frasnian of the Ardennes. Alveolitids are typical for the initial stadium of biostromes, both in Europe and in Morocco (e.g., MAY 1992, 1994; BOULVAIN et al. 1995; MÉNDEZ-BEDIA et al. 1994; FRÖHLICH 2003 for an Anti-Atlas example; compare facies diagram of EICHHOLT & BECKER 2016, fig. 6). The isolated occurrence of Givetian or Frasnian reefal facies far away from the Oulad Amar Formation outcrops has not been re-studied. The same applies to the assumed Givetian limestone with various tabulate corals (three genera) from Sidi Cadi Hajja SE of Benahmed (TERMIER & TERMIER 1951a, pp. 66-67). Both occurrences leave the possibility that biostrome facies stretched from the Al Attamna (Sidi Mohammed Smaine Formation) and Khatouat Massif (Jennabia Formation) areas far southwards. New data on age and microfacies are needed.

4. Frasnian at Boudouda

TERMIER & TERMIER (1951a, 1951b) noted that thin limestones and shales with pyritic fauna, including two species of *Buchiola* and two species of *Manticoceras*, were found NNW of Sidi bou Chatah, with the most fossiliferous occurrence at Boudouda (Fig. 3). A piste leading from Benahmed to the NW exposes in the low slope of a roadcut on its NE side (Fig. 17, coordinates x = 100, y = 200) a fine upper Frasnian succession that we sampled in October 2012 bed-by-bed for ammonoids, conodonts, and other fauna.

Fig. 17: Exposure of the new Boudouda Formation in a roadcut (NE slope) at its type locality at Boudouda, NW of Benahmed.

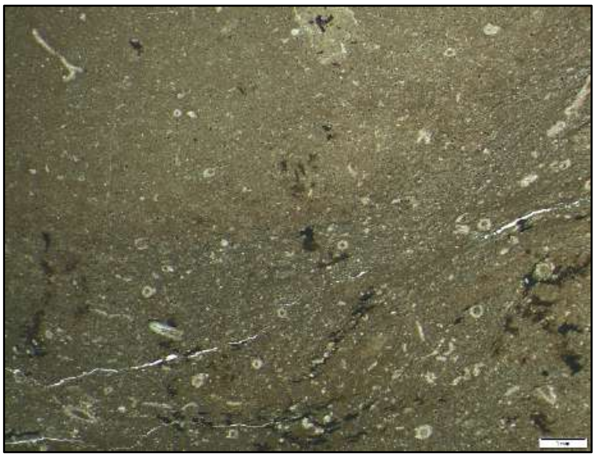

Fig. 18: Microfacies of Frasnian Bed 6b, a dark-grey, pyrite-rich mud-wackestone with recrystallized dacryoconarids.

Fig. 19: Surface of Frasnian marker Bed 9, with randomly distributed, partly fragmentary styliolinids.

The section log is illustrated, with local ammonoid ranges, in the following taxonomic chapter. All beds dip steeply to the SE, with the oldest strata commencing ca. 30 m to the SE of an electricity pole that can be used as a landmark. The succession is unique for all of the Meseta and assigned to the **new Boudouda Formation**, which is defined as an alternation of thin nodular limestones and pyritic, hypoxic goniatite shale. The exposed thickness on the NE side is ca. 13 m but there are several more meters of outcrop on the SW side of the roadcut, where logging is difficult due to the Quarternary cover.

The section commences with red limestone nodules, followed by alternating gray shales and slightly more solid marls (Beds 1-4). These yielded both gephuroceratids and tornoceratids (see following chapter), bactritids, other orthocones, two species of rhynchonellids (smooth and ribbed), *Buchiola* and other bivalves, and ribbed gastropods representing a new genus. This is a typical faunal assemblage of Frasnian goniatite shales, as long-known and famous for the Eifel Mountains of Germany (Büdesheim Goniatite Shale = Büdesheim Formation; e.g., CLAUSEN 1968, 1969). A similar contemporaneous litho- and biofacies is not known from the Anti-Atlas, where goniatite shales with different faunal compositions occur in the top-Frasnian of the Tafilalt Basin (undescribed UD I-K faunas) and in the Middle/Upper Frasnian of the eastern Dra Valley (e.g., at Oued Mzerreb, BECKER et al. 2004a).

Bed 5a is a distinctive red shale with restricted fauna and yellowish nodules at the top. Bed 6a is richer in goniatites and rhynchonellids and yielded a crinoid stem piece. The top, a reddish-weathering nodular limestone, contains a relatively diverse conodont fauna. In contrast to the dominance of pelagic macrofauna, its conodont facies is of shallow-water type (mixed polygnathid-icriodid). There are only two juvenile palmatolepids that cannot be identified at species level. The common icriodid, *I. symmetricus* (Fig. 20.8; 31.5 % of the assemblage) occurs both in neritic and pelagic settings. All the polygnathids are long-ranging within the Frasnian and provide no zonal age: *Po. alatus* (Figs. 20.3 and 9), *Po. webbi, Po. aequalis*, *Po. varcus* (Fig. 20.2), *Po.* "aff. *angustidiscus*" sensu HUDDLE (1981) (Fig. 20.1, a widely distributed un-named species; compare ABOUSSALAM et al. 2020, figs. 33.10 and 21), and *Ctenopolygnathus angustidiscus* (Fig. 20.10). The microfacies of Bed 6b is an argillaceous mud-wackestone with recrystallized dacryoconarids and abundant, fine, regularly distributed pyrite, as typical for offshore shelf basin facies. However, the contrast between litho-, micro-, macrobio- and conodont biofacies suggests that the local basin was not very deep.

Beds 7 and 8 are two further cycles of shale, with only a few goniatites, and argillaceous limestone nodules at the top. Bed 9 stands out because laminated shales grade upwards into a very fossiliferous, fissile, dark-grey, laminated shale with masses of squashed goniatites, orthocones, manticoceratid anaptychi, styliolinids (Fig. 19), homoctenids, and entomozoid ostracods. This faunal bloom level has been sampled by C. HARTKOPF-FRÖDER (Krefeld) for palynomorphs but results are not yet available.

Bed 11 is another shale-nodule couplet, followed by the unfossiliferous Bed 12. The subsequent interval of Beds 13-17 has the richest goniatite faunas, with a maximum of twelve species found in Bed 15. Bed 13a contains pyritic microspheres, perhaps the internal moulds of tasmanitid algae. From Bed 14a, a distinctive, possibly new lunulacardiid bivalve was collected; the group occurs regurlarly in pelagic facies (e.g., NAGEL-MYERS & AMLER 2007), but mostly in cephalopod limestones.

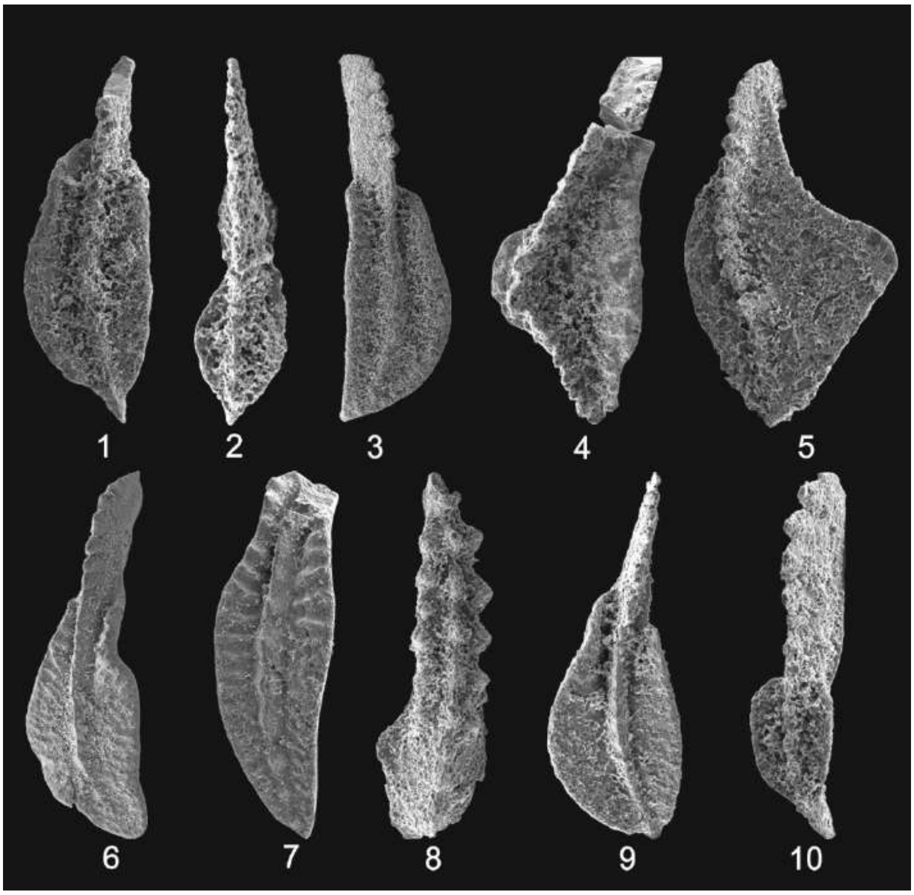

Fig. 20: Frasnian conodonts from Boudouda (1-3 and 8-10= Bed 6, 4-5 = Bed 21, 6-7 = sample from last limestone of the SW side of the roadcut, GMM B4C.2.83-92. **1.** *Polygnathus* "aff. *angustidiscus"* sensu HUDDLE (1981), x 90; **2.** *Po. varcus*, x 140; **3.** *Po. alatus*, x 50; **4.** *Nothognathella* sp., x 100; **5.** *Palmatolepis* sp. juv., x 85; **6.** *Po.* aff. *reitlingerae*, form with pronounced anterior platform rostra, higher on the right side, x 35; **7.** *Po. paradecorosus*, x 70; **8.** *Icriodus symmetricus*, x 70; **9.** *Po. alatus*, x 80; **10.** *Ctenopolygnathus angustidiscus*, x 90.

In Bed 15a, smooth rhynchonellids are accompanied by small-sized *Ambocoelia*- or *Crurithyris*-type brachiopods. Their range into hypoxic facies is widely known (BECKER et al. 2004a; ZAMBITO & SCHEMM-GREGORY 2013). The ribbed gastropod re-appears in Bed 16a. Buchiolids occur in most beds, associated in Bed 17a by a different bivalve.

The fossiliferous Bed 21a ends with variably thick limestone concretions (Bed 21b), which was sampled for conodonts. Apart from a broken *Ancyrognathus triangularis*, a typical species for the lower half of the upper Frasnian (KLAPPER 1990), we found *I. symmetricus*, a juvenile *Palmatolepis* (Fig. 20.6), and a *Nothognathella* sp. (Fig. 20.5), the supposed Pb element of *Palmatolepis*. The previously dominant polygnathids have vanished, indicating a deepening trend. The microfacies, a poorly fossiliferous mudstone with a single, sparite filled juvenile goniatite (Fig. 21) provides full support for this interpretation. Above follow more goniatite shales but the local biodiversity becomes reduced. The number of ammonoid species declines to four or five.

On the other (SW) side of the roadcut, younger strata are partly exposed. There is an alternation of red shales and of a few, up to 10 cm thick, micritic, reddish-grey limestones. Loose fauna included rare orthocones and poorly preserved brachiopods, no goniatites. The highest limestone found in a corner within the Quaternary cover, a mud-wackestone with abundant dacryoconarids (Fig. 22), continues the monotonous pelagic facies. It yielded three specimens of *Po. paradecorosus* (Fig. 20.7), a questionable *Ancyrodella lobata*, and the first North African relative of the Russian *Po. reitlingerae* (Fig. 20.6; see taxonomy paragraph). The assemblage is not zonally diagnostic but indicates that the highest Frasnian has not been reached. Unfortunately, Boudouda provides no outcrop to study regionally the Frasnian-Famennian boundary.

Fig. 21: Almost unfossiliferous pelagic mudstone of Frasnian Bed 21 at Boudouda.

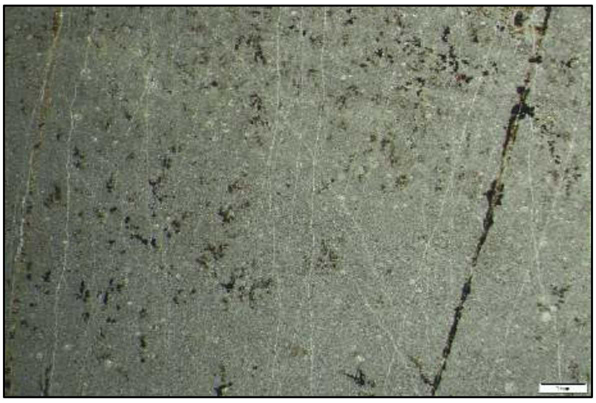

Fig. 22: Argillaceous mud-wackestone with abundant, recrystallized dacryoconarids, last Frasnian limestone exposed on the SW side of the roadcut at Boudouda.

4.5. Famennian of the Beni Sekten area

There is currently no outcrop with Famennian pelagic limestones around Boudouda or in the wider Beni Sekten area. However, conodonts of this interval were originally deposited, as evidenced by reworked material in Viséan limestones (see Carboniferous Boudouda chapter).

Termier & Termier (1951a) described briefly several localities in the Beni Sekten area, where mixed silt- and sandstones and limestones yielded neritic "Strunian" faunas, notably with brachiopods (15 genera and species), bivalves (four taxa), rugose corals ("*Clisiophyllum omaliusi*"), trilobites (*Omegops accipitrinus*, see Richter & Richter 1943), and echinoderms. The latter includes the blastoid *Pentremitidea toujinensis*, which in modern taxonomy should belong to the genus *Hyperoblastus* (wr. comm. J. Waters, February 2021).

The types of the reported productid *Mesoplica praelonga* come from the uppermost Famennian (LE spore zone) Lower Pilton Formation of North Devon. But the species is wide-spread in the upper/uppermost Famennian, including Algeria and the Dra Valley (e.g., Kaiser et al. 2004; Nicollin & Brice 2004; Brice et al. 2007). Caution is required since there are related species of the genus, which can be confused; these enter also in the upper Famennian (Brice et al. 2005). The reported *"Mucrospirifer" strunianus* now belongs to the genus *Prospira*. The types are from the uppermost Famennian of the Avesnois (northern France) but the species appears to have a lower, upper Famennian range in the Dra Valley (Lower Fauna, Brice et al. 2005: jointly with *Mes. praelonga*). *Punctospirifer laminosus* is now a species of *Tylothyris*, and normally a widespread Lower Carboniferous taxon (Brunton 1984; Brice et al. 2005). But the genus commences in the uppermost Famennian of the Dra Valley (Kaiser et al. 2004; Brice et al. 2007). Again, there are several related taxa, which underline the importance of taxonomic stringency. Rhynchonellids from El Touijine identified originally as "*Camarotoechia moresnetensis*" (det. F. Demanet) were described as *Araratella centralis* by Sartenaer & Plodowski (2003). The genus is a globally widespread marker for the "Strunian".

Omegops is a typical "Strunian" genus in the Rhenish Massif; the Benahmed specimen was re-assigned to *Om. accipitrinus insolatus* STRUVE, 1976. The genus has an upper Famennian (UD V) range in Iran (FEIST et al. 2003; GHOBADI POUR et al. 2018). In summary, the brachiopod/trilobite records support an uppermost Famennian (UD VI) age for "Strunian" deposits described by TERMIER & TERMIER (1951a) but it cannot be ruled out that some beds are older (UD V). After a revision of sections and sedimentology, a new lithostratigraphic term will be required.

5. The Famennian Oued Aricha Basin

5.1. Overview

The Famennian goniatite shales of the badlands in the upper (southern) reaches of the Oued Aricha (Figs. 23-24) were discovered by TERMIER (1927a, 1927b), who later (TERMIER 1936) figured the locally most common sporadoceratids and a platyclymeniid, which indicated a UD IV (early upper Famennian) age. The later fossil monograph by TERMIER & TERMIER (1950a-d) included many drawings of other taxa and a long faunal list was provided by TERMIER & TERMIER (1951a). TERMIER & TERMIER (1951b, p. 21) compared the pyritic fauna with the Fezzou region of the eastern Anti-Atlas. PETTER (1959) re-illustrated the type-specimen of *Gundolficeras bicaniculatum*, which subsequent loss resulted in a neotype designation (using a Maïder specimen) by BECKER (1995). The records of TERMIER & TERMIER (1950c, 1951a) were re-interpreted based on the subsequent taxonomic advances by BECKER in KAISER et al. (2007). This suggested that most of the fauna comes from the Upper Hembergian (UD IV, *Platyclymenia* Stufe) of German terminology. However, there also a few records that indicated the subordinate presence of Lower Hembergian (UD III, late middle Famennian, *Prolobites* Stufe) and lower Dasbergian (UD V, *Clymenia* Stufe) taxa. We sampled in 2012 and 2014 four localities within different parts of the Oued Aricha, here named as Oued Aricha A-C and Oued Aricha Z (Fig. 25). At Oued Aricha Z, we logged a detailed section (Figs. 24, 26-27) and tried, without success, to retrieve conodonts from thin calcareous levels.

The dominating lithologies are alternating grey and reddish, hematite-rich shales with originally pyritic, secondarily goethitic to hematitic mollusk faunas and thin, fine, sometimes calcareous siltstone beds (Fig. 26). Brachiopods, rugose corals, and crinoid stems retained their light-grey calcitic skeletons; only aragonite shells were dissolved and filled with pyrite during diagenesis. In the northern badlands, faunas disappear and siltstones become more abundant. Lithofacies and faunas are unique for all of the Meseta. Comparable and contemporaneous beds occur only in the Maïder Basin of the eastern Anti-Atlas (e.g., BECKER et al. 2018d).

Fig. 23: Southern entry to the badlands of Oued Aricha east of Benahmed (middle/upper Famennian Oued Aricha Formation), with Locality A to the right of the central gully and Locality/Section B on the slope in the background to the right (east). Section Z lies behind the hill in the central background.

FADLI (1994) placed the distinctive Oued Aricha goniatite shales in the lower part of his Chabet-el-Baya Formation, which occurs in the northern Mdakra Massif. However, the differences are too large. The typical Chabet-el-Baya Formation consists of practically unfossiliferous grey shales and siltstones

(Lower Member), followed by an increasing content of quartzites in the Upper Member. Locally there are boulders (olistolites) of older Devonian rocks, as in the Al Brijat Formation of the Oued Cherrat region (e.g., BECKER et al. 2020b) or in the middle part (Biar Setla Member) of the Fouizir Formation of the Khatouat Massif to the east (FADLI 1994). We propose to assign the Oued Aricha shales, which represents a much more distal and hypoxic setting undisturbed by synsedimentary tectonism, to a **new Oued Aricha Formation**. Upwards, it grades, as the Chabet-el-Baya Formation, into the siltstones and greenish shales alternating with thin sandstones of the Mgarto Formation (FADLI 1994), which straddles the Devonian-Carboniferous boundary.

The preliminary faunal list of the Oued Aricha Formation comprises the following ammonoids (*type locality):

Famennian III

Planitornoceras aff. *euryomphalum* (with ventral varices; **B, Z**; Figs. 28.5-6)

Sporadoceras angustisellatum (poorly preserved; **A**; Figs. 28.7-8).

Fig. 24: Overview of the upper Famennian Section Z at Oued Aricha (for section log see Fig. 26).

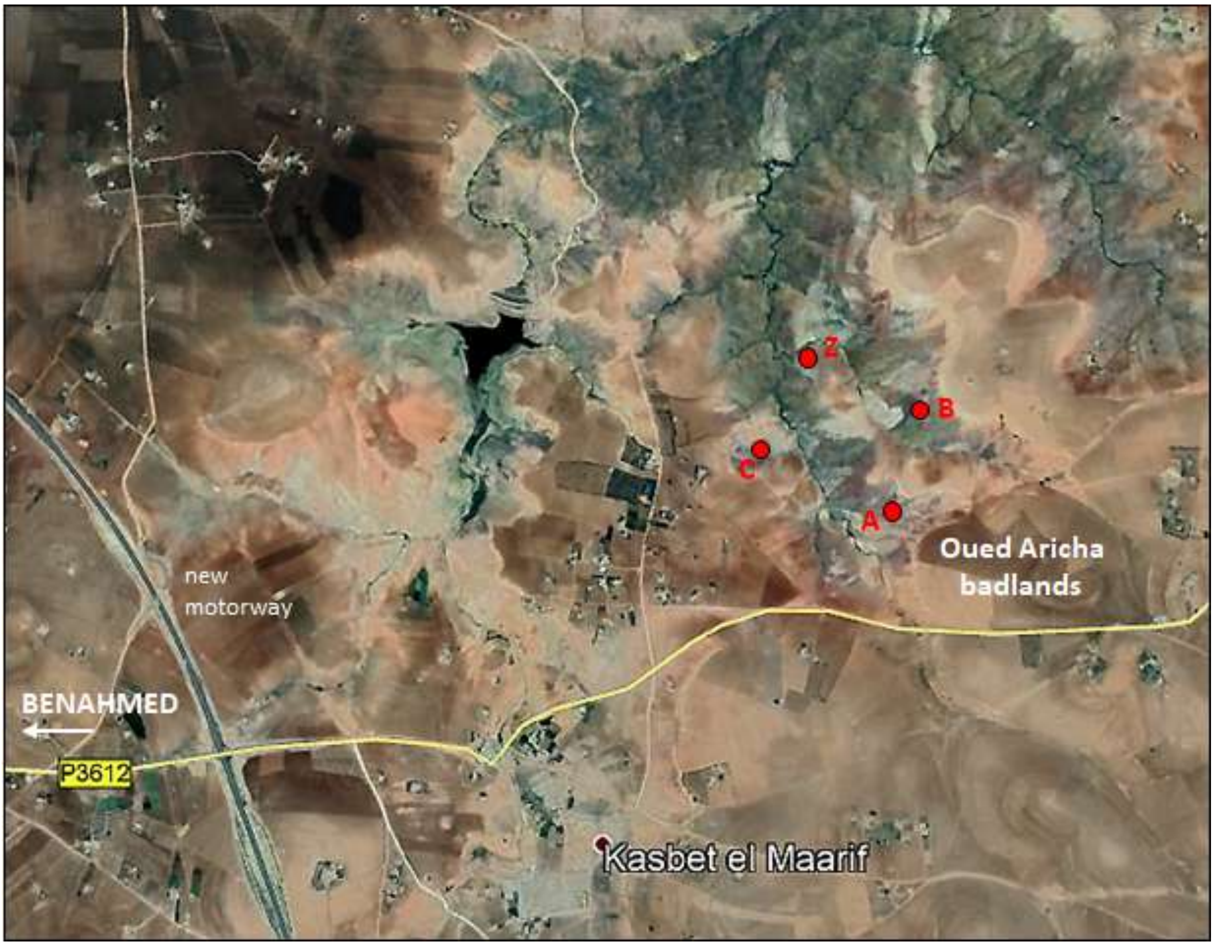

Fig. 25: Position of the Oued Aricha badlands and sampled localities east of Benahmed on a satellite photo of Google Earth.

Enkebergoceras cf. *varicatum* (= *Sp. muensteri* in Termier & Termier 1951a; rare; **A**; Figs. 28-3-4)
"*Prolobites*" n. sp. aff. *korni* (micromorphic form with prolobitid constrictions and very shallow lobes; very rare; **A;** Figs. 28.1-2)
?Praeglyphioceras sp. (= *Sp. biferum* in Termier & Termier 1950c: small specimen with open umbilicus and *Lagowites*-type secondary E-lobes)
Protactoclymenia implana Group (with ventral varices, single fragment; **B**)

Famennian IV

Gundolficeras bicaniculatum (= *Lobotornoceras Sandbergeri* in Termier & Termier 1950c, 1951a)
Gundolficeras reisdorfi (rare; **Z**; Figs. 29.11-12)
Pr. (Prionoceras) divisum lamellosum (= *Imitoceras intermedium* in Termier & Termier 1950c; **A, B, C2, C4, Z**; Figs. 28.3-4)
Pr. (Prionoceras) aff. *divisum* (extremely thick, ww/wh > 2; **Z**)
Pr. (Prionoceras) n. sp. (compressed, with unique shape of A-lobe; **Z**)
Pr. ("Prionoceras") lentis (thinly discoidal, with trilobate varices, **A, Z**; Figs. 29.1-2)
Pr. ("Prionoceras") sp. 2 (moderately thick, with only two varices at small size; **Z**)
Pr. ("Prionoceras") sulcatum Group (thickly discoidal and tegoid; **A**; Figs. 29.5-6)
Pr. ("Prionoceras") vetum (rare, with quadripartite varices at small size; **A**)
Erfoudites rherisensis (with high whorls, very common, = *Sporadoceras rotundolobatum* in Termier & Termier 1950c, 1951a; **A, B, C2, Z**; Figs. 29.9-10)
Erfoudites zizensis (with lower whorls, locally rare; **A, Z**)
Sporadoceras muensteri orbiculare (rare, = *Sporadoceras* sp. and possibly *Sp.* cf. *Ungeri* in Termier & Termier 1950c; **A**)
Ungusporadoceras unguiferum (rare, **A, Z**; Figs. 29.7-8)
Protactoclymenia stenomphala (smooth, subinvolute, compressed; = *Cyrtoclymenia angustiseptata* in Termier & Termier 1950c, 1951a; **A, B, C2, C4, Z**; Figs. 29.17-18)
Protactoclymenia aff. *subcostata* (with umbilical ribs, subevolute, high whorls, see Hartenfels & Becker 2016a; **Z**)
Protactoclymenia "crassa" (sensu Petter 1960, (which is an invalid junior homonym; depressed until middle stages, and with nodose ribbing of early whorls; **A, B**)
Procymaclymenia pudica (with ventral varices; **A,** cf. **C1, Z**; Figs. 30.6-7)
Carinoclymenia beuelensis (very rare; **A**; Figs. 29.15-16)
Platyclymenia (Pl.) levata (ww/wh = 0.76-0.79 around ca. 20 mm dm, partly with weak, undulating ribbing; **A, B**; Figs. 29.13-14)
Platyclymenia (Pl.) annulata richteri (rare; **Z**)
Pl. (Trigonoclymenia) protacta (rare, = *Platyclymenia Barrandei* in Termier & Termier 1950c, fragments only; **A**)
Protoxyclymenia cf. *dunkeri* (only fragments with oval whorls, moderately evolute, A-lobe subangular; = *Oxyclymenia* in Termier & Termier 1950c; **A, B, Z**; Figs. 30.1-3)
Protoxyclymenia ?n. sp. (rather evolute, uw/dm > 0.50 at ca. 20 mm dm, compressed fragment with tegoid cross-section, rare; **A, B**; Figs. 30.4-5)
Protoxyclymenia sp. 2 (small, compressed fragment with well-developed E-lobe; **Z**)

Famennian V

?Gundolficeras n. sp. (= *Lobotornoceras* sp. in Termier & Termier 1950c; strongly compressed at small size, with strong ventrolateral furrows, subinvolute, and suboxyconic; if the suture drawing is correct, then the A-lobe is not of *Gundolficeras*-type and this unique specimen could represent a new genus)
Ebbighausenites weyeri (only whorl fragments, = *Discoclymenia cucullata* in Termier & Termier 1950c, 1951a; **A**; Figs. 30.14-15)
Pr. (Rectimitoceras) jeranense (subglobular; **top B**; Figs. 30.8-9)
Pr. ("Prionoceras") aff. *mrakibense* (only 2 varices/whorl until 10 mm dm, **top B**; Figs. 30.10-11)
Erfoudites cf. *ungeri* (fragment with narrow and pointed A_1-lobe; **top B**)
Erfoudites rherisensis (**top B**)
Ungusporadoceras n. sp. (rare, with strongly biconvex varices and low ventral saddle; **top B**)

Sporadoceras muensteri orbiculare (**top B**, Figs. 30.12-13)
?Nanoclymenia sp. (evolute fragments with very shallow, simple flank lobe; **top B**)
Protoxyclymenia sp. (fragments, probably cf. *dunkeri*; **top B**)
Protoxyclymenia ?wendti (compressed fragment, venter tabulate; **top B**)
Kosmoclymenia sp. (= *Oxyclymenia undulata* in TERMIER & TERMIER 1950c; **B, top B**; Figs. 30.20-21)
Kosmoclymenia n. sp. (extremely evolute; **C2**; Fig. 30.22)
Protactoclymenia sp. OA (fragment, whorls smooth and depressed; **top B, C2**)
Cymaclymenia striata formosa (strongly compressed at early stages and subevolute, smooth; **top B, C2**; Figs. 30.18-19)
Cymaclymenia n. sp. (fragment with rib-like lirae crossing the venter; **top B**; Figs. 30.16-17)

Specimens assigned to "*Platyclymenia gr. laevigata"* in TERMIER (1936) and "*Clymenia laevigata*" in TERMIER & TERMIER (1950c) are difficult to interpret; they may belong to *Platyclymenia*. A supposed "*Tornoceras retrorsum* var. *acutum*" figured by TERMIER (1936) is probably a squashed goniatite, not an oxyconic form. The ammonoid taxonomy used here is preliminary. Only studies of ontogenetic morphometry will enable a better comparison with the contemporaneous species of the Anti-Atlas. This is especially relevant for the prionoceratids, sporadoceratids, and protactoclymeniids. Among the first, *Pr. ("Prionoceras")* refers to species with subevolute (uw/dm > 0.30) early whorls. Species which are not known to have strictly dorsolateral shell constrictions in early to middle stages are assigned to *Pr. (Rectimitoceras)* BECKER, 1996.

As an oddity, there is a small, incomplete goniatite with low whorls, strong varices and a suture with v-shaped A_1-lobe and very incipient A_2-lobe resembling *Maeneceras subvaricatum nuntio* BECKER, 1993, which is a marker for the base of the middle Famennian (UD II-G). No other UD II ammonoid has been found and differences to *M. subvaricatum nuntio* are strong enough to suspect that the specimen belongs to a new, younger sporadoceratid (not *Erfoudites*).

Associated Oued Aricha fauna (including literature records):
*Hebukophyllum arichense** (see taxonomic paragraph)
Bactrites cf. *declivis* (slightly oval cross-section, sutures rectiradiate, rare; **A**)
Lobobactrites sp. indet. (rare; **A**)
"*Troedssonoceras* sp."
"Dawsonoceras annulatum" (type-species of the genus, wrongly placed by TERMIER & TERMIER 1950c, 1951a in *Neocycloceras*; however, the true *D. annulatum* is an Ordovician to Silurian species; see KRÖGER & ISAKAR 2006; new fragments with reticulate ornament; **Z**)
"*Orthoceras Murchisoni"* (type-species of the Silurian genus *Murchisoniceras* BABIN, 1966, which ranges in the Anti-Atlas into the lower Emsian, e.g., KLUG et al. 2008; a Famennian range is rather unlikely)
"*Orthoceras amaltheum*"
"*Orthoceras* sp. (cf. *captor*)"
Bogoslovskiya sp. (with subcircular cross-section and subventral siphuncle; **A, B, top B, C2**)
brevicone indet. (**C2**)
*Orthonychia heterogena** (platyceratid)
"*Loxonema*" sp.
"*Worthenia*" sp.
Bellerophontid
"Planitrochus" sp. (new record, rare; **top B, C2**)
Ctenodonta maroccana TERMIER & TERMIER, 1951a nom. nud. (= *Ctenodonta* sp. in TERMIER & TERMIER 1950c; deposition of figured specimen unknown, see COLO & PETITOT 1956, p. 69)
*"Nucula" arichensis** (new topotype, holotype deposited under no. ds 601 in the collection of the Service géologique du Maroc, see COLO & PETITOT 1956, p. 39; re-assigned questionably to *Nuculoma (Palaeonucula)* in FRENEIX 1957, p. 32; however, *Palaeonucula*, now a full genus, is based on a Jurassic type-species and not known from the Devonian; **top B, Z**)
other nuculid **(top B)**
Guerichia venusta

Loxopteria gibbosa (= *Kochia laevis* in TERMIER & TERMIER 1950c, see NAGEL-MYERS et al. 2009; new specimen; **A**)
Vetupraeca venusta (see revision in NAGEL-MYERS et al. 2008).
?Hadyrhyncha meridionalis (= two of the rhynchonellids placed by TERMIER & TERMIER 1950b in *Calvinaria undulata*; see SARTENAER 1998, 2000; excluding the Anti-Atlas type of that species; collection of new material from **A** and **Z**)
*Ambocoelia pentagonalis**
Aulacella sp. (rare; **Z**)
chonetid
crinoid stem pieces
*"Phacops" arichensis**
"Phacops" erfoudensis

All nautiloids require revision; genus and species names of the literature merely can give some orientation concerning superficial morphological similarities. Both phacopids are inadequately known but may belong to the *Ph. granulatus* Group, for which the name *Rabienops* is available. BASSE (2008, p. 179) was misgiven to assume for *Ph. arichensis* possible relationships with *Prokops* and a Lower Devonian age; there are no Lower Devonian outcrops near Oued Aricha.

5.2. Oued Aricha A

Trekking from the road northwards, the first exposed red shales of the Oued Aricha Formation yielded only rare fauna. Exceptional is a large-sized *Gundolficeras reisdorfi*. From there to the northeast, the area around a small, ca. west-east running valley is Locality A. It yielded from the slopes and base a rich loose fauna, marked in the faunal lists by an A.

5.3. Oued Aricha B

Section B ranges from the base of the badlands upwards the eastern slope, which is capped by flat lying Cretaceous strata (Fig. 24). At the base, a grey shale package yielded *Pr. (Prionoceras) divisum lamellosum* and *Erfoudites rherisensis*, indicative of UD IV-A. It is followed by ca. 28 m red shale with poor fauna in the lower part (*Prionoceras* sp. indet.). At the top, *Pr. (Pr.) divisum lamellosum, Erf. rherisensis*, and *Protacto. stenomphala* are abundant (UD IV-A fauna).

Laterally, a minor plateau yielded a mixed fauna collected mostly by Lea Amira BECKER. It combines species of UD III B/C (*Planitornoceras* aff. *euryomphalum*), UD IV, and rare *Kosmoclymenia* sp. from the basal UD V. The complete record is indicated in the fossil lists by a B. The local rarity of prionoceratids is remarkable.

A ca. 12 m thick second grey shale interval includes a steep minor gully. Just above, S. EICHHOLT collected a small but important fauna of the lower Dasberg Stufe (UD V-A_1), with *Kosmoclymenia* sp. (Figs. 30.20-21), *Cymaclymenia striata formosa* (Figs. 30.18-19), and *Sp. muensteri orbiculare* (Figs. 30.12-13). The fragmentary kosmoclymeniid may belong to the same early species as the oldest members of the genus from the thick Dasberg Crisis Interval of the Maïder (see BECKER et al. 2018d). In the continuously anoxic shelf basin setting of Oued Aricha, the Dasberg Events (see HARTENFELS & BECKER 2009) left no specific sedimentary signature. A second faunule from the top of the grey unit included *Pr.* (*Rectimitoceras) jeranense*, an index species for the Upper Dasberg Event level in the southern Tafilalt (KORN et al. 2014; HARTENFELS & BECKER 2018). Associated is a squashed *Erfoudites* with narrow and v-shaped A_1-lobe.

The main slope below the Cretaceous comprises an up to 50 m thick upper red shale with fauna collected at 20-22 m (only *Erf. rherisensis*) and 14-16 m below the top. In the latter position, ammonoids were mostly small-sized and fragmentary, but there are taxa not known from other Oued Aricha spots (marked as "top B" in the faunal lists). Especially remarkable is a new species of *Ungusporadoceras*, a genus that was previously only known from UD IV-A of the northern Tafilalt and Maïder (KORN et al. 2015; HARTENFELS & BECKER 2016a). The presence of *Cymaclymenia* (Figs. 30.16-17) and *Kosmoclymenia* proves a lower Dasbergian (UD V-A_1) age. A prionoceratid is similar to the slightly older Tafilalt *Pr. ("Pr.") mrakibense* but differs in its lower number of varices. The so far youngest Oued Aricha ammonoid, a second *Pr. ("Pr.")* aff. *mrakibense* (Figs. 30.10-11), is from 5-6 m below the top of the upper red shale.

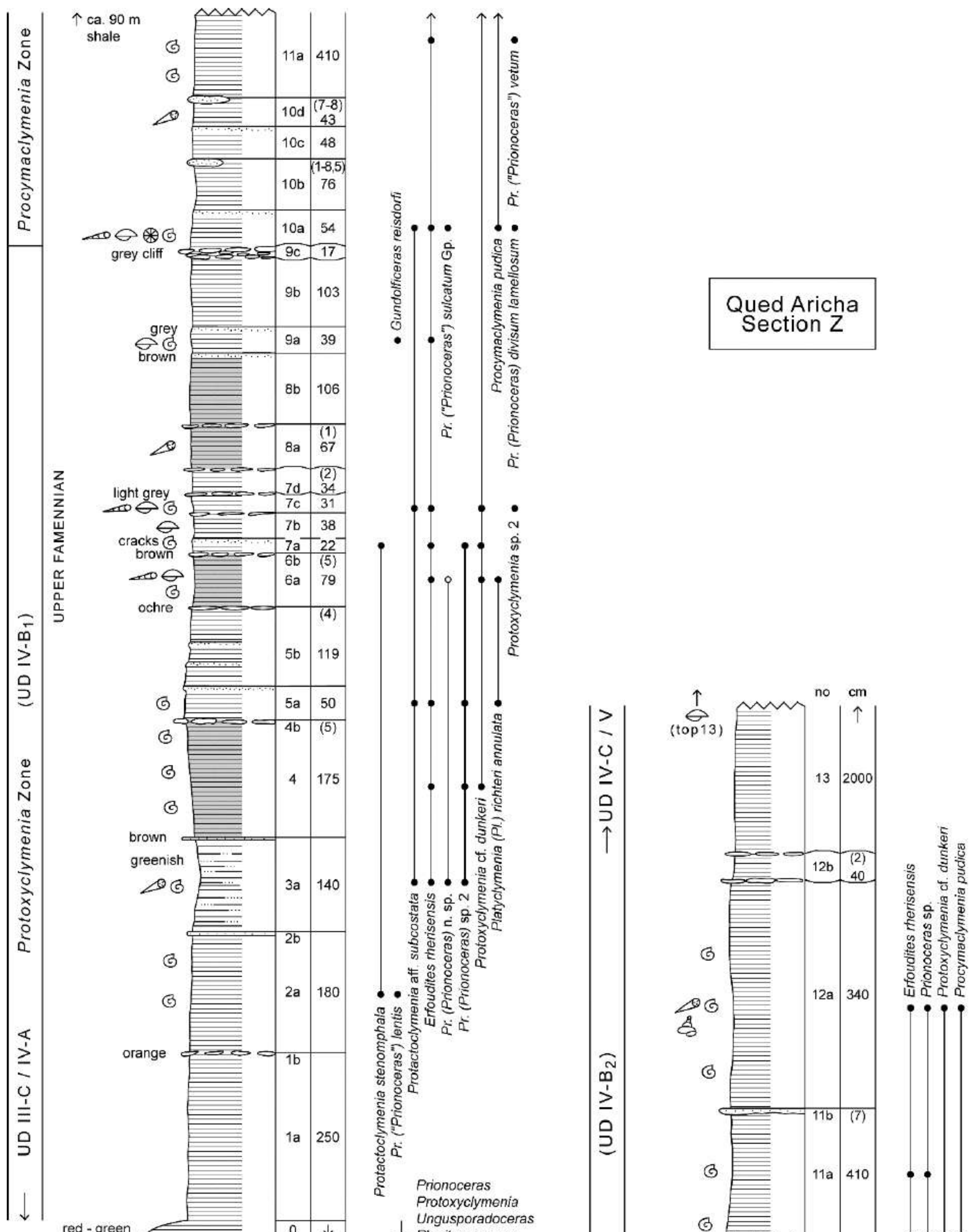

Fig. 27: Lithological log and ammonoid ranges in section Oued Aricha Z.

Fig. 28: Representative ammonoids from the upper middle Famennian (UD III-B/C) of Oued Aricha, loose from Locality A if not stated otherwise; GMM B6C.54.157-160. **1-2.** "*Prolobites*" n. sp. aff. *korni*, lateral and adoral views, with characteristic prolobitid inner flank constriction, x 5; **3-4.** *Enkebergoceras* cf. *varicatum*, lateral and septal views, x 3; **5-6.** *Planitornoceras* aff. *euryomphalum*, lateral and ventral views, tabulate venter with varices, Locality Z, from below measured section, x 4; **7-8.** *Sporadoceras angustisellatum*, lateral and ventral views, poorly preserved but showing the typical sutures with A_2-lobe > A_1-lobe, x 2.5.

1 **2**

Fig. 26: 1. Beds 4-7 of Oued Aricha Z showing regular bedding of thick, dark-grey to slightly reddish shale and thin siltstone intercalations; **2.** Detailed view showing the grading of siltstone layers into thicker, irregular concretions; scale lies on the top of Bed 4b.

5.4. Oued Aricha Z (Figs. 25-26)

A suitable succession for bed-by-bed measurements and collecting was encountered in more northern parts of the badlands. Unfortunately, only some of the fauna is well-preserved. A thick lower succession of dominantly red, partly yellowish weathering shales (to the right in Fig. 26.1) is poorly exposed on a hill to the south. A loose sample of S. HARTENFELS yielded a nice *Planitornoceras* aff. *euryomphalum*, the barrel-shaped *Pr. (Pr.)* aff. *divisum*, juvenile *Pr. (Pr.) divisum lamellosum*, *Pr. ("Pr.") lentis, Erf. rherisensis*, a single, incomplete *Ungusporadoceras unguiferum*, fragments of *Protoxy*. cf. *dunkeri*, rhynchonellids and a minute *Aulacella*. This is a mixture of UD III-C to IV-B_1 species.

Different faunal elements commence in Beds 2a and 3a: *Protacto. stenomphala*, *Protacto.* aff. *subcostata* sensu HARTENFELS & BECKER (2016a), *Pr.* (*Prionoceras)* n. sp., and *Pr. (Prionoceras)* sp. 2. with only two varices per whorl at small size. The complete ammonoid ranges of Section Z are illustrated in Fig. 27. Shales are dark-grey (especially Beds 6a, 8a, 8b) to greenish-grey (Fig. 26) while the thin siltstones weather orange-brown (Bed 1b), brown (Bed 3b, 4b, 6b, top of 8b), ochre (Bed 5c), or light-grey (top of Bed 7c, top of 9a, 9c, marly Bed 11b). Solitary rugose corals were found in several beds but are rare. The rather irregular, often platy, up to 8 cm thick and unfossiliferous siltstone concretions (Fig. 26.1) are a diagenetic feature.

Since *Protoxyclymenia* is known from below, all beds of Section Z fall in the middle part of UD IV (IV-B). The entry of *Procymaclymenia* in Bed 10a marks the base of UD IV-B_2 (compare HARTENFELS & BECKER 2016a; BECKER et al. 2018a, 2018d) and this zone continues to Bed 12a (Fig. 27). Remarkable is the local rarity of platyclymeniids (only in Beds 5a and 6a), a major difference to the Anti-Atlas, and the differentiated prionoceratid sequence, with only early *Pr. ("Pr.") lentis* and rather late and sporadic occurrences of *Pr. (Pr.) divisum lamellosum* (Bed 10a) and *Pr. ("Pr.") vetum* (Bed 11a).

5.5. Section C

A rather fossiliferous stretch of steeply bedded Oued Aricha Formation was found in the western part of the badlands and named as Locality C. Locally, the shales are partly more deeply weathered and softer but due to strong fracturing and incrustations, many specimens are not well preserved and distorted. During a brief stay, faunas were collected at four spots (SP1-4). SP1 yielded fragmentary *Procymaclymenia* and *Prionoceras*. It falls in UD IV-B_2 (*Procymaclymenia* Zone). SP2 was richer but not in species; its faunal content is marked in the fossil lists as C2. By far dominant is *Pr. (Pr.) divisum lamellosum*, followed in terms of abundance by *Protactoclymenia stenomphala*, as typical for UD IV. Most peculiar is a single, fragmentary *Kosmoclymenia* with a rather advanced suture that is more evolute (uw/dm > 0.60) than any described species (e.g., PRICE 1982; KORN & PRICE 1987; NIKOLAEVA & BOGOSLOVSKIY 2005). It is even more evolute than *K. linearis* (MÜNSTER, 1832), which unjustifiably has been neglected in the recent clymeniid literature. However, to some extent the evolute coiling may have been exaggerated by deformation. A mixture of UD IV/V species in Sample SP2 is further indicated by several *Cyma. striata formosa*.

5.6. Palaeobiogeographic relationships of Oued Aricha ammonoid faunas

TERMIER & TERMIER (1951b) compared the overall similar Oued Aricha and Fezzou region (Maïder Basin. eastern Anti-Atlas) faunas. A large number of the Oued Aricha ammonoids occurs also in the Ibaouane Formation (BECKER et al. 2018d). *Enkebergoceras varicatum,* rare prolobitids, and *Planitornoceras* with ventral varices are typical for the Lahfira Member. However, *Sulcoclymenia*, which is abundant in its upper part, also on the Tafilalt Platform (BECKER et al. 2002; HARTENFELS & BECKER 2016a), is not yet known from the Meseta. The new prolobitid is closest to *"Prol." korni* DZIK, 2006 from the Holy Cross Mountains of Poland but, based on the suture, there are also relationships with the endemic *Afrolobites mrakibensis* BECKER & BOCKWINKEL in BECKER et al., 2002 from the Maïder.

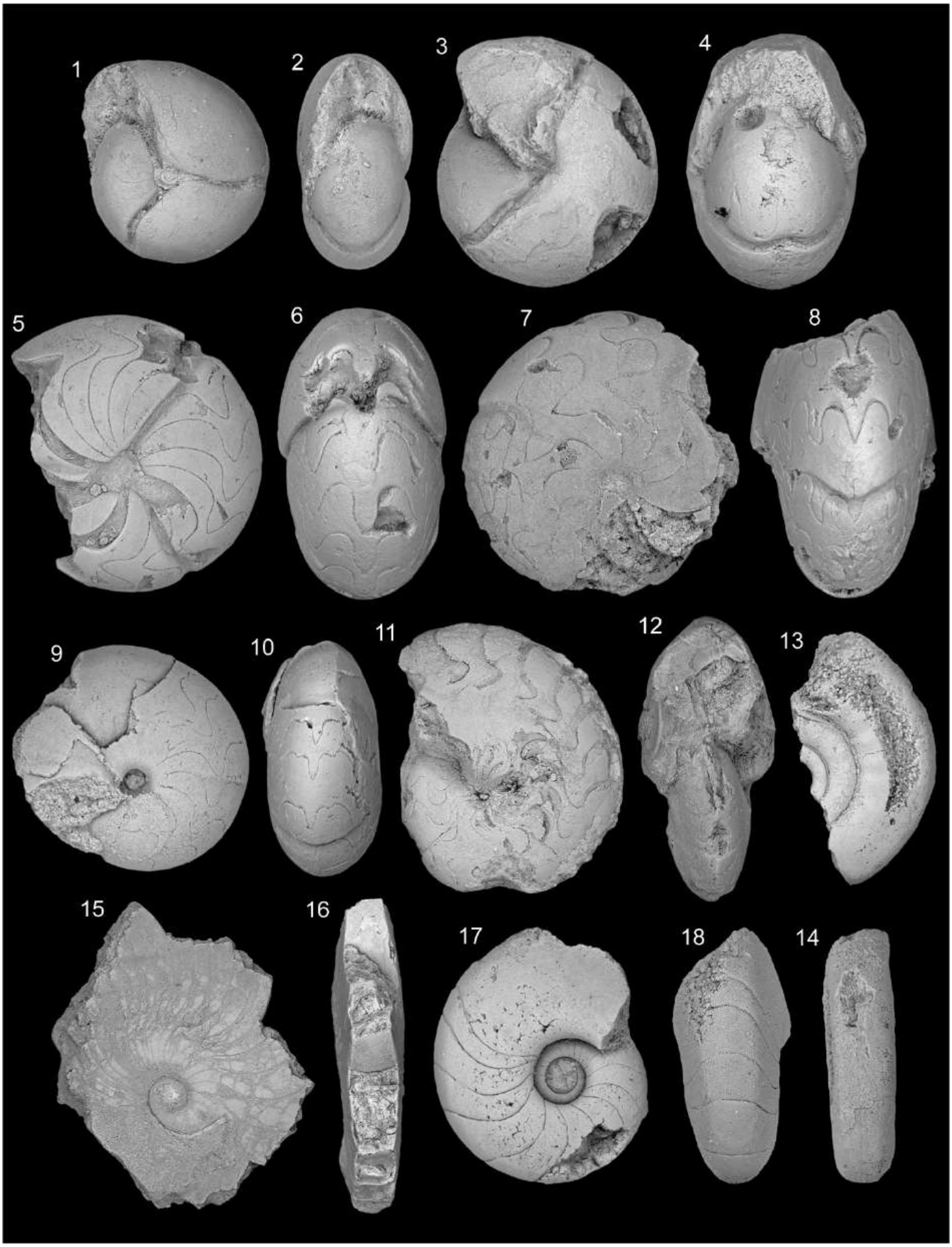

Fig. 29: Representative ammonoids from the lower upper Famennian (UD IV) of Oued Aricha, all loose from Locality A, if not stated otherwise; GMM B6C.54.161-169. **1-2.** *Pr. ("Prionoceras") lentis*, x 4; **3-4.** *Prionoceras (Pr.) divisum lamellosum*, x 4; **5-6.** *Pr. ("Prionoceras") sulcatum* Group, x 3.5; **7-8.** *Ungusporadoceras unguiforme*, , Locality Z, Bed 9a, x 3; **9-10.** *Erfoudites rherisensis*, x 4; **11-12.** *Gundolficeras reisdorfi*, x 2.5; **13-14.** *Platyclymenia (Pl.) levata*, x 3; **15-16.** *Carinoclymenia beuelensis*, oxyconic outer flanks broken off, x 2; **17-18.** *Protactoclymenia stenomphala*, x 4.

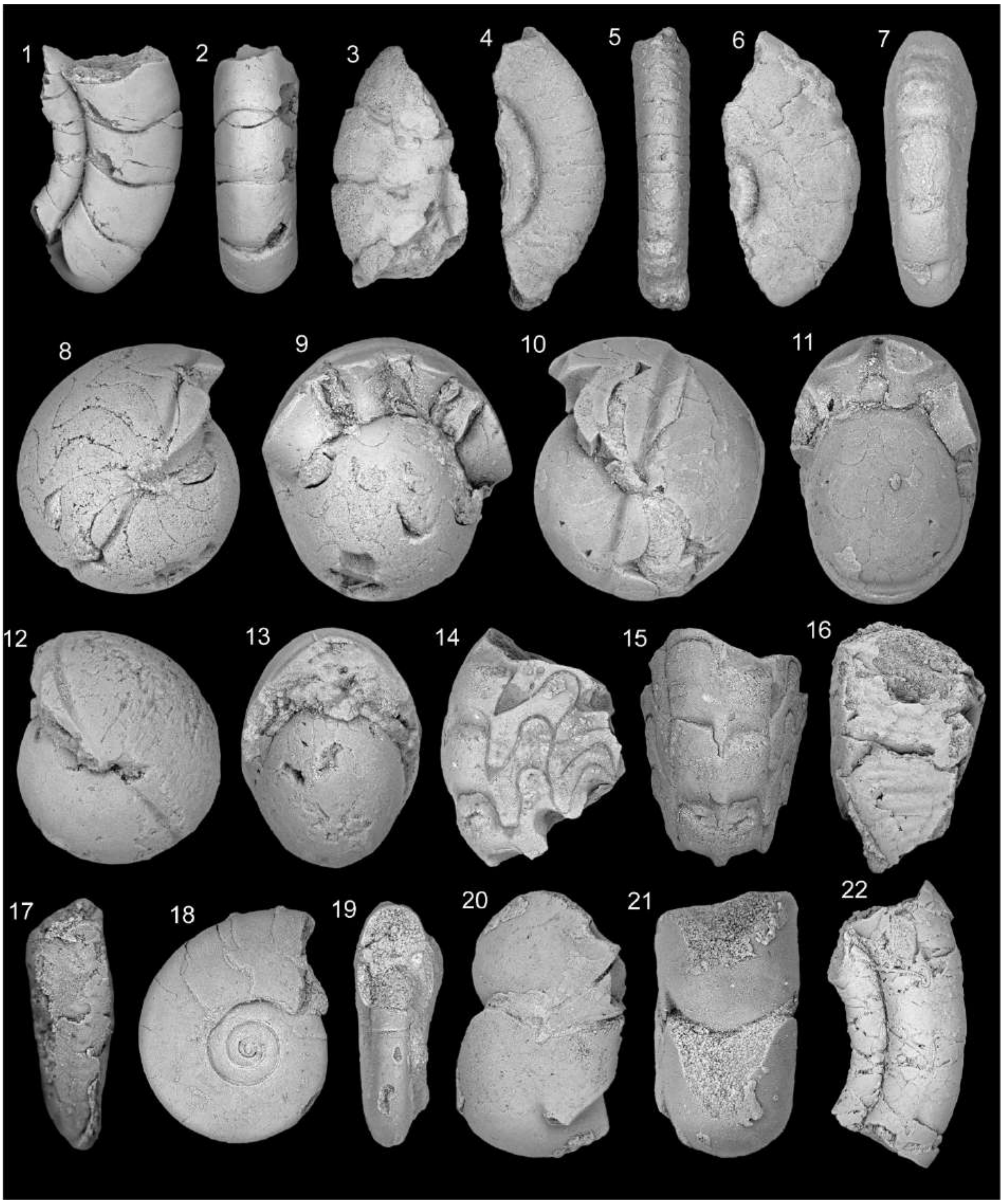

Fig. 30: Representative ammonoids from the upper Famennian (UD IV-B = 1-7 to $V-A_1$ = 8-22) of Oued Aricha; GMM B6C.54.170-181. **1-3.** *Protoxyclymenia* cf. *dunkeri*, whorl fragments, Locality A, loose, x 3 and x 2.5; **4-5.** *Protoxyclymenia* ?n. sp., widely evolute, Locality A, loose, x 2.5; **6-7.** *Procymaclymenia pudica*, juvenile with ventral varices, Locality Z, Bed 10a; x 5, **8-9.** *Prionoceras (Rectimitoceras) jeranense*, Locality B, second grey interval, x 5; **10-11.** *Pr. ("Prionoceras")* aff. *mrakibense*, with only two varices per whorl, Locality B, second red interval, 5-6 m below top, x 4; **12-13.** *Sporadoceras muensteri orbiculare*, Locality B, second grey interval, x 4; **14-15.** *Ebbighausenites weyeri*, whorl fragment, Locality A, loose, x 4; **16-17.** *Cymaclymenia* n. sp., fragment with lirate flanks and venter, Locality B, second red interval, 14-16 m below top, x 3.5; **18-19.** *Cymaclymenia striata formosa*, juvenile, Locality B, second grey interval, x 4; **20-21.** *Kosmoclymenia* sp., two septa only, Locality B, second grey interval, x 5; **22.** *Kosmoclymenia* n. sp., widely evolute fragment, Locality C.

Joint species occurrences of Oued Aricha and the Anti-Atlas Mrakib Member (UD IV) are *Pr. (Pr.) divisum lamellosum, Pr. ("Pr.") vetum, Pr. ("Pr.") lentis, Erfoudites rherisensis, Erf. zizensis, Platyclymenia (Pl.) levata, Pl. (Trigonoclymenia) protacta, Protoxyclymenia* cf. *dunkeri, Carinoclymenia beuelensis*, *Sporadoceras muensteri orbiculare*, *Ungusporadoceras unguiferum*, and some of the protacto- and protoxyclymeniids. However, it is interesting that *Procymaclymenia* is represented at Oued Aricha not by *Pro. ebbighauseni*, but by *Pro. pudica* with ventral varices, known from Poland (Czarnocki 1989) and the Rhenish Massif (Becker 1992). At the genus-level, similarities with European UD III/IV faunas are not as strong as in the Boudouda Formation (see chapter by Söte & Becker).

For the basal UD V, the new Oued Aricha records of *Ebbighausenites weyeri, Prionoceras (Rectimitoceras) jeranense*, abundance of *Erf. rherisensis*, early *Kosmoclymenia*, possible *Nanoclymenia*, and *Cymaclymenia striata formosa* suggest close links with the lower part of the Jebel el Krabis Member of the Maïder (Becker et al. 2018d). This is supported by joint occurrences of the nuculoid *"Palaeonucula" arichensis* (see Freneix 1957). However, there are some rare endemic forms at Oued Aricha, such as the new *Ungusporadoceras, Cymaclymenia*, and *Kosmoclymenia*, which show that there was no complete faunal continuity. Rather unusual is the lack of *Costaclymenia* at Oued Aricha, which is the zonal index genus of UD V-A_1 and very common in the eastern Anti-Atlas.

6. Palaeogeographic trends and regional comparisons of the Benahmed Devonian

Unlike as in most regions of the Moroccan Meseta, there is no evidence for hypoxic, dark, organic-rich graptolite, "orthoceratid", or scyphocrinitid facies around the Silurian/Devonian boundary in the Benahmed region. Supposed Lochkovian shales and limestones may correspond to poorly studied, similar strata of the northern Oued Cherrat Zone (Zahraoui 1991, 1994). In the northern (Hollard et al. 1982) and northeastern Rehamna (El Kamel et al. 1992), there is also mixed shale, siltstone and limestone facies in the Lochkovian (Fig. 31). This suggests a general pattern, a shallow basal Devonian shelf occupying all of the western part of the Central Meseta.

The Pragian and lower Emsian thick limestones of the Benahmed region represent a southern continuation of the non-reefal Al Attamna carbonate platform (Sidi Ahmed Lemdoun Formation, Units A/B; Bultynck & Benfrika 2003). Future work has to clarify whether the Al Attamna formation name can be simply extended to the Benahmed "Emsian Limestone". Macrofaunas and microfacies of the Sidi Ahmed Lemdoun Formation are also largely unstudied. The neritic platform extended further to the Rehamna, from Mechra Ben Abbou to Foum el Mejez (e.g., Hollard et al. 1982; El Kamel 2004).

The currently poor data for the Benahmed upper Emsian and Eifelian indicate a deepening, perhaps as a consequence of the global Daleje Transgression. The same trend is recognizable at the base of Unit C of the Sidi Ahmed Lemdoun Formation in Al Attamna (Benfrika & Bultynck 2003). Further northwards, in the Oued Cherrat Zone, it introduced the lateral shaly Mohammed-Ben Brahim (Lower Member) and shaly-turbiditic Ain-Kheneg-en-Nmer formations (Eichholt & Becker 2016; Becker et al. 2020b). By contrast, the Eifelian of the Rehamna represents a deep neritic platform setting with biogenic chert content (e.g., Ben Bouziane 1995; El Kamel 2004; lower member of Mechra Ben Abbou Formation).

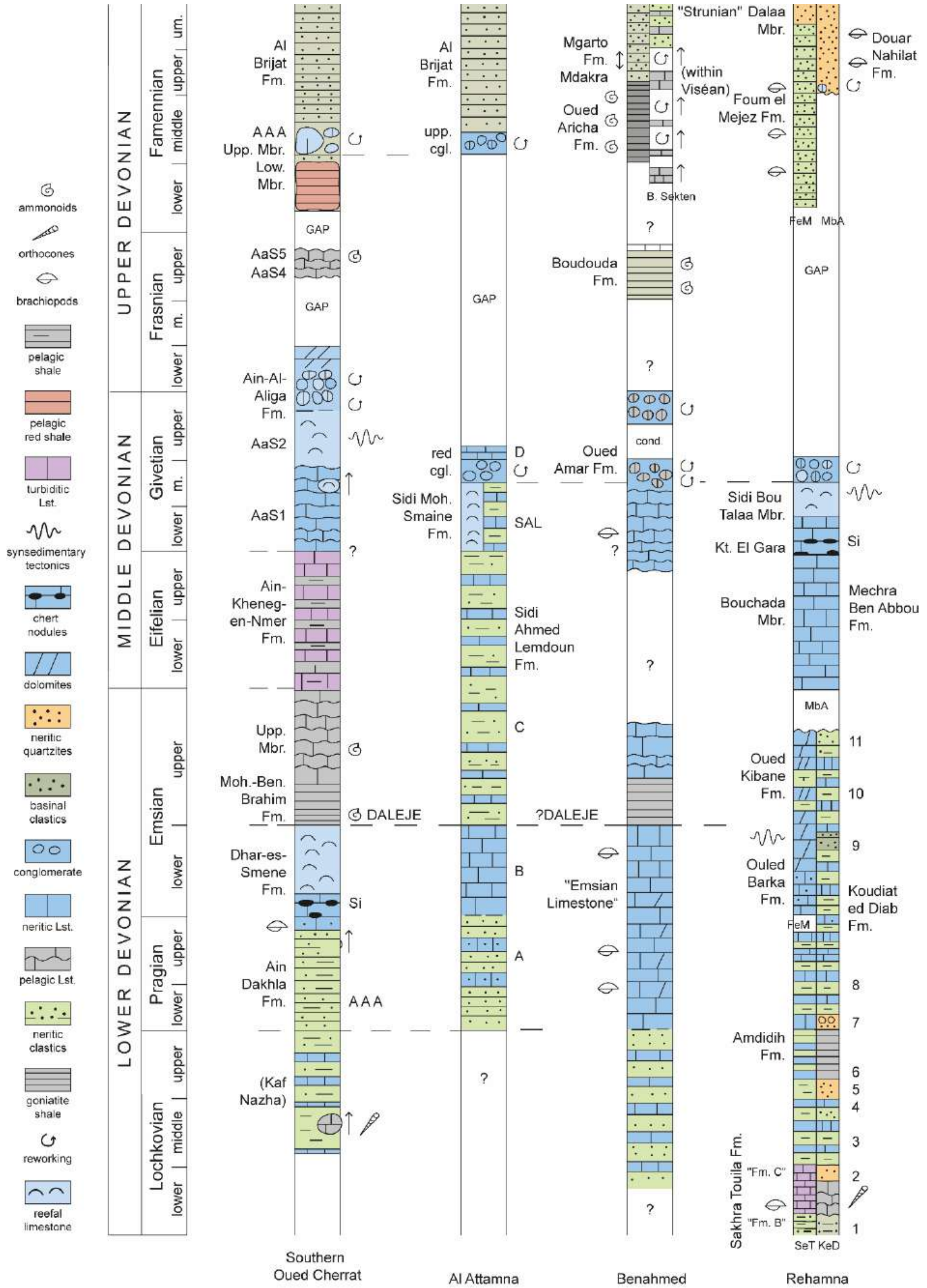

Fig. 31: Correlation of Devonian successions of the Oued Cherrat (BECKER et al. 2020a; AaS1-5 = members of Aïn-as-Seffah Formation), Al Attamna (EICHHOLT & BECKER 2016, SAL = Sidi Ahmed Lemdoun succession), Benahmed, and northern Rehamna (see Rehamna chapter) regions.

The Givetian of the Benahmed region differs from the partly thick reefs of the Oued Cherrat Zone and El Attamna (EICHHOLT & BECKER 2016). The environment was a deep neritic carbonate platform or ramp receiving distal, fine carbonate and clastic detritus of a shallower platform, perhaps from the north. The two Givetian episodes of synsedimentary faulting, reworking and re-deposition recognized at Zwayir and Dar Cheik el Mfaddel underline that this first major interval of Eovariscan block movements (BECKER et al. 2015) shook the whole belt from the Oued Cherrat (BECKER et al. 2020b) to the Rehamna (see EL HASSANI & EL KAMEL 2000; Rehamna chapter), and beyond (see Jebel Ardouz and Skoura chapters). In the Al Attamna, only the "red conglomerate" is an equivalent, which terminated the Givetian reef growth (EICHHOLT & BECKER 2016).

Facies similarities and palaeogeographic relationships ended after the top-Givetian tectonism. The hypoxic, pelagic goniatite shales of Boudouda may have formed on the subsiding side of a tilted block in combination with the overall trend of Frasnian eustatic rise, and specifically with the *semichatovae* Transgression. Frasnian strata are unknown from the uplifted blocks of the Al Attamna and northern Rehamna. This facies difference increased further in the Famennian: the thick basinal siliciclastics with conglomerates, breccias and olistolites of the Al Brijat (Oued Cherrat, Al Attamna) and Chabet el Baya formations (northern Mdakra) contrast with the calm, hypoxic goniatite shales of Oued Aricha. In the Beni Sekten area, there was a subsequently eroded, small deep-water carbonate platform, which is only known by reworked pelagic conodonts (see Carboniferous Boudouda chapter). The topmost Devonian is represented by the mixed sand-limestone "Strunian" facies of the Beni Sekten region. None of these facies extend to the Rehamna, where upper Famennian quartzites with brachiopods transgressed the Givetian reef platform (Mechra Ben Abbou region: Douar Nahilar Formation, HOLLARD et al. 1982; BEN BOUZIANE 1995), grading into first prodeltaic brachiopod-rich siltstones and then quartzites of the thicker Foum el Mejez Formation (HOLLARD et al. 1982; EL KAMEL 2004; see Rehamna chapter).

7. Taxonomic notes

7.1. Conodonts

***Schmidtognathus* aff. *hermanni* ZIEGLER, 1965**

Fig. 15.7

Description: A single specimen (GMM B7A.12.50) from Bed 12b of Dar Sheikh el Mfaddel (upper Givetian) is characterized by a slightly asymmetric platform with an almost straight free blade and a carina that does not reach the posterior end. The moderately wide and flat platforms bear fine ribs and nodes restricted to the margin, turning on the outer anterior side into a series of more pronounced margin denticles. The anterior platform ends abruptly on both sides, with the last nodes forming a narrow, sharply defined shoulder.

Discussion: A similar form with wider platforms and almost straight anterior platform shoulders has been described by ABOUSSALAM (2003) from the *hermanni* Zone (basal upper Givetian) of the Tafilalt as *Schm*. aff. *hermanni*. *Schmidtognathus hermanni* is a rather variable species but irregular platform shapes and ornamentation are typical (e.g., ZIEGLER 1965; ABOUSSALAM 2003; ABOUSSALAM & BECKER 2007). We are confident that the two Moroccan specimens fall outside the variability spectrum of *Schm. hermanni*, especially with respect to the anterior platform end and regular, fine ribbing. It is not yet clear whether both specimens represent the same new species. Therefore, we apply open nomenclature until more material becomes available.

Schmidtognathus n. sp. A of MAWSON & TALENT (1989) differs in asymmetrically leaf-shaped platforms with rounded anterior margins and regular, fine transverse ribs that almost reach the carina.

***Schmidtognathus* aff. *latifossatus* WITTEKINDT, 1965**

Fig. 15.9

Discussion: Within the genus *Schmidtognathus*, there are currently two distinctive species groups, which may be separated in future taxonomically. In the *Schm. latifossatus* Group, platforms are small and narrow and the basal pit is wide and extends posteriorly almost to the end. This is true for a specimen from Dar Cheik el Mfaddel, Bed 12b (GMM B7A.12.51), identified as *Schm*. aff. *latifossatus*. It differs from typical representatives of the species, including local aberrant forms (Fig. 15.8), by its small, asymmetric, triangular platform that is smooth apart from minor marginal folds and nodes. Both the blade and carina are very gently bent (convex), with low and small denticles of the free blade that is much shorter than the platform. Since we have so far only one specimen, we apply open nomenclature.

***Schmidtognathus* n. sp. DCM**

Figs. 15.10

Description: Blade and carina slightly sinuous, with a cockscomb-type, very high free blade (defined by platform end on the left side) consisting of five merged denticles, and a few isolated denticles near the posterior end of the carina. The platform is convexly bent but in general flat, asymmetric, slightly wider on one side, smooth, with chagrin surface, and reaches on the right side almost the anterior end. The basal cavity is median-sized, in a central position, as in the typical *Schm. hermanni* Group.

Discussion: None of the named *Schmidtognathus* species shows a similar platform shape and smooth ornament. The specimen (GMM B7A.12.12.52) lies clearly outside the well-established variability of common species, such as *Schm. hermanni, Schm. peracutus, Schm. wittekindti*, and *Schm. pietzneri.* However, since we have so far only one specimen, open nomenclature is currently applied.

The only known similar form was described by TIAN (in HOU 1988) as *Schmidtognathus* n. sp. A from the Longmenshan section of Sichuan, South China. It differs in narrower platforms and a more elongated basal pit and may not be conspecific.

***"Ozarkodina"* aff. *adventa* POLLOCK, 1968**

Fig. 16.23

Discussion: A single ozarkodinid from Bed 12b of Dar Cheik el Mfaddel (upper Givetian; GMM B7A.12.79) differs from other upper Givetian forms by its small, asymmetric basal cavity platform, which lies ca. one third from the posterior end of the almost straight blade, below teeth no. 8-12 (counting from the anterior end). There is a strong, irregular alternation of long and minor teeth. At the anterior margin, there is a very small first tooth, followed by three larger ones that are inclined backwards and higher than all the posterior teeth.

In the slightly older *"Oz." maroccanica* ABOUSSALAM & BECKER, 2007, the blade is curved and the cavity platform smaller, without an asymmetric extension. In *"Oz." adventa*, which also has some larger anterior teeth, the smooth incipient platforms are even larger. In the much older (upper Eifelian) *"Oz." bidentata* BISCHOFF & ZIEGLER, 1957, the somewhat larger cavity platforms sit in a more anterior position and the blade denticulation is denser. Until more specimens become available, we apply open nomenclature.

The Middle Devonian ozarkodinids are not related to the type *Ozarkodina* from around the Silurian/Devonian boundary. While the *Oz. brevis* Group now falls in *Nicollidina* DZIK, 2002, all other species (e.g., *maroccanica, plana, semialternans, sannemanni, proxima*) are currently not assigned to a valid genus. Until the required revision has proceeded, they are placed in "*Ozarkodina*".

***Polygnathus* aff. *reitlingerae* OVNATANOVA & KONONOVA, 2008**

Fig. 20.6

Description: A single polygnathid (GMM B7A.12.88) from Bed 6b at Boudouda is characterized by a wide, flat lappet-like platform with delicate ornament consisting of fine ridges and nodes and a marked anterior rostrum, which steep sides are slightly higher on the right side. The free blade is short and consist of equally high, merged teeth. The carina is fine, not bordered by marked adcarinal groves after the rostrum, and does not reach the rounded posterior platform end.

Discussion: A somewhat similar species is *Po. reitlingerae* described from the top middle and early upper Frasnian of the southern Timan. Previously, it has not been recorded from outside of Russia. Most characteristic is its class 3b asymmetry of platform shape with weakly developed anterior rostra, and with a higher right platform margin. Only right-curved specimens (as ours) may have wide platforms (see OVNATANOVA & KONONOVA 2008: pl. 24, fig. 5). Apart from the weaker rostrum, further differences to our specimen are a different denticulation of the free blade and a fine, curved carina that reaches the posterior end of the platform. Therefore, we assign the Benahmed specimen, which has the same age as the Russian types, preliminarily with an aff. to *Po. reitlingerae*.

The only other similar Frasnian polygnathid is *Po. frons* HUDDLE, 1981, which has been ignored by later authors. It occurs in older strata (upper Givetian Leicester Pyrite to lower Frasnian Genundewa Limestone) of New York State. In comparison to our specimen, the species is characterized by a somewhat longer anterior rostrum and a wider outer than inner platform with rather dense and somewhat coarser nodes.

7.2. Ammonoids

***Gundolficeras bicaniculatum* (PETTER, 1959)**

Discussion: We found two new *Gundolficeras* specimens in the UD IV of Oued Aricha but both are much larger and more compressed than known *G. bicaniculatum* and lack ventrolateral furrows. The cross-section is tegoid, the umbilicus is narrow, with very steep walls. The preservation is not suitable to produce a cross-section in order to observe the shell ontogeny.

After the juvenile Oued Aricha type specimen of *G. bicaniculatum* could not be traced in the Paris collection, BECKER (1995) selected a neotype from the Fezzou region of the Anti-Atlas, which became the new type region. The two new specimens agree largely with the slightly younger (UD V-A_1) *Gund. reisdorfi* KORN, BOCKWINKEL & EBBIGHAUSEN, 2016a from the southern Tafilalt. In the absence of specimens of intermediate size, it is difficult to judge whether the thick-whorled juvenile *G. bicaniculatum* changes perhaps during ontogeny into *reisdorfi*-type adults. Juvenile *G. reisdorfi* from the Anti-Atlas are clearly more compressed than the *bicaniculatum* original of TERMIER & TERMIER (1950c) and PETTER (1959), or the neotype of Becker (1995).

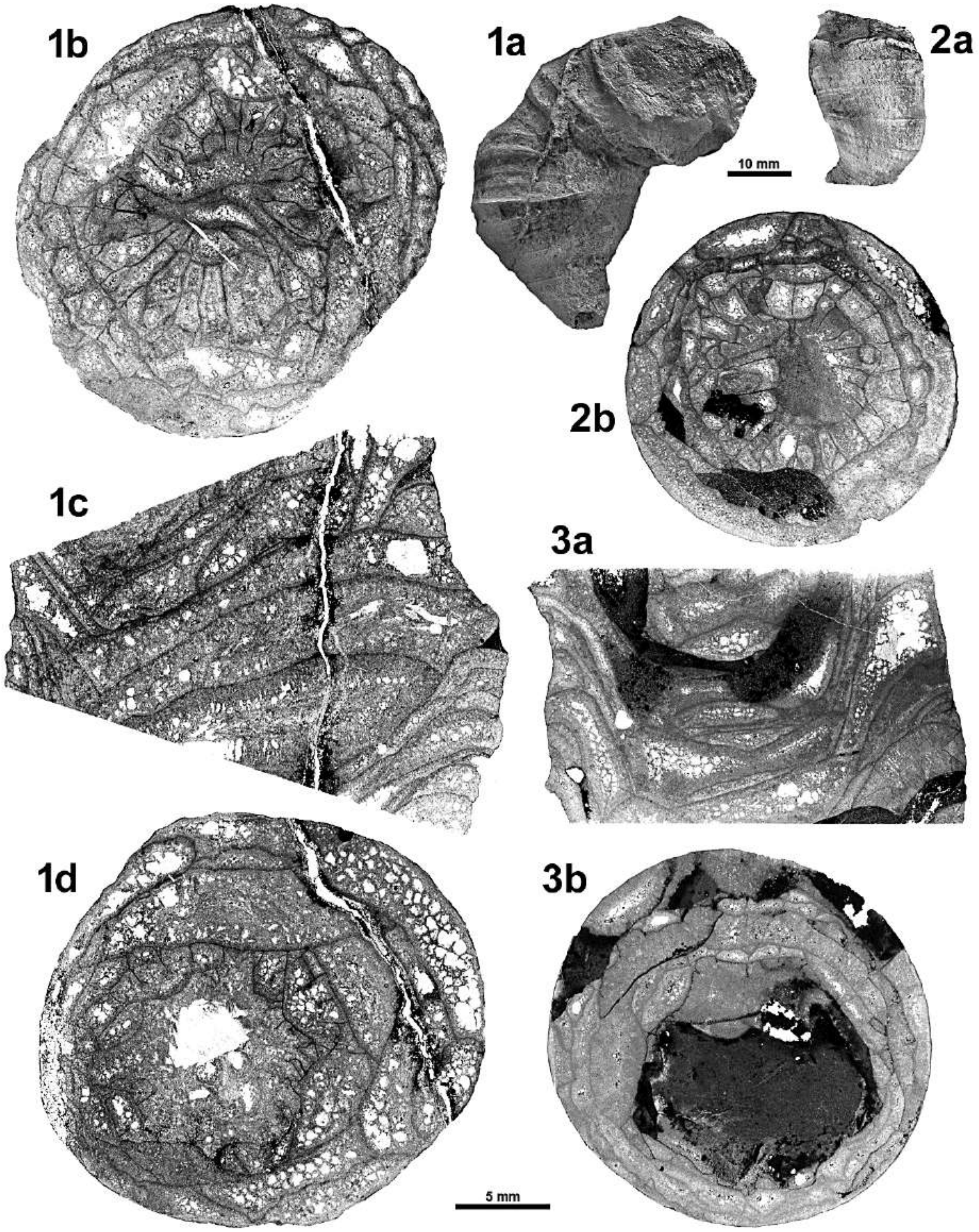

Fig. 32: *Hebukophyllum arichense* (TERMIER & TERMIER, 1950a), new topotypes from Oued Aricha, Section Z, upper Famennian. **1.** MB.K.8071a., Bed 12a, a. Side view of coral, x 1, b, d. Late subtabular transverse sections, x 3, c. Median longitudinal section, x 3; **2.** MB.K.8071c., Bed 8a, a. Side view of coral, x 1, b. Subtabular transverse section, x 3; **3.** MB.K.8071b., Bed 8a, a. Median longitudinal section, x 3, b. Adult transverse section, x 3 [6 protosepta not identifiable; perhaps? correct orientation, with cardinal septum above, only in Fig. 2b, according to possible cardinal fossula indicated by tabulae].

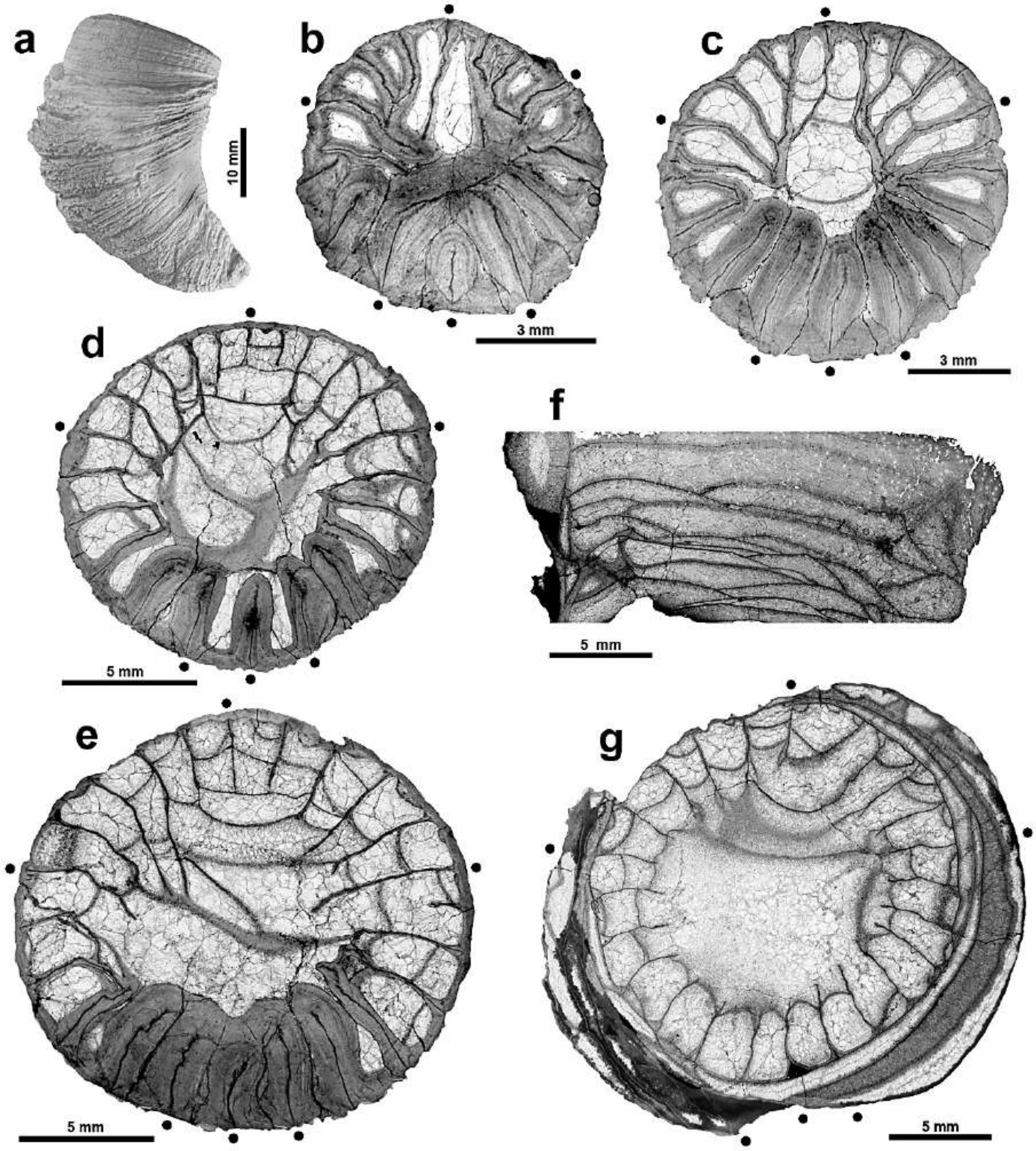

Fig. 33: *Hebukophyllum* sp. M, upper Famennian (upper *Platyclymenia* "Stage"), *orbiculare* Bed (Bed R1b, see Korn et al. 2014: fig. 3, Becker et al. 2018d), *Sporadoceras muensteri orbiculare* Zone (UD IV-C, Becker et al. 2002) or *Prionoceras subtum*-Zone sensu Korn et al. (2014), Madène el Mrakib 27 km SE Fezzou, Maïder Basin, eastern Anti-Atlas. Specimen MB.K.8072. (collection R. T. Becker 1996) = 8cs, 1ls, 2R. **a.** Coral in side view, x 1; **b-e.** Series of transverse sections (early and middle growth stages), x 6 (b), x 5 (c), and x 4 (d, e); **f.** Median longitudinal section, x 3; **g.** Adult transverse section, x 3.

septal formulae:		3 3 / 5 5	4 4 / 5 5	4 4 / 6 6	5 5 / 6 6	5 5 / 6 7	5 5 / 7 7
	n	20	22	24	26	27	28
	N	32	36	40	44	46	48
	D mm	7,7	10,5	12	14	17	24
	Figs.	b	c	–	d	e	g

(abbreviations: n = number of protosepta + metasepta, N = number of all septa, D = diameter)

The latter was re-illustrated by KORN et al. (2016b) but their supposed adult *bicaniculatum* specimen (MB.C.27032) is a *"G". fezzouense* (BECKER, 1995), which is characterized by an additional L-lobe right at the umbilical seam.

KORN et al. (2016b) correctly noted that there is a small difference of whorl form between the Oued Aricha original and neotype of *G. bicaniculatum*. Both may represent closely related but different species. Since we did not retrieve a potential Oued Aricha *bicaniculatum* neotype, the matter cannot be resolved at present. However, the Oued Aricha badlands have not been fully exploited by us, leaving options for future collecting.

7.3. Rugose corals (by DW)

Suborder Cyathaxoniina SPASSKIY, 1977

Family Petraiidae DE KONINCK, 1872

Subfamily Guerichiphyllinae RÓŻKOWSKA, 1969

Genus *Hebukophyllum* LIAO & CAI, 1987

*1987 *Hebukophyllum* gen. nov. - LIAO & CAI: 698, 704

1988 *Hebukephyllum* CAI: 45 [nomen vanum]

Type species: *Hebukophyllum xinjiangense* LIAO & CAI, 1987.

Further species:

Cyathophyllum priscum MÜNSTER, 1840

Loepophyllum arichense TERMIER & TERMIER, 1950a (Fig. 32)

Siphonophyllia cf. *caninoides* (SIBLY, 1906) in WU (1964: p. 66), see YU (1988: p. 189)

Guerichiphyllum parvum RÓŻKOWSKA, 1969

Guerichiphyllum concavum RÓŻKOWSKA, 1969

Siphonophyllia minor ZUO in JIA et al. 1977 (according to YU 1988: p. 189)

Guerichiphyllum sp. in SANDO & BAMBER (1985: p. 22, pl. 2, figs. 6-7)

Circellia guangxiensis YU, 1988

Guerichiphyllum sp. in SEMENOFF-TIAN-CHANSKY (1988: p. 130, fig. 12)

Guerichiphyllum hebukeense SOTO & LIAO, 2002

Guerichiphyllum mirabile WEYER, 2002

Hebukophyllum sp. M (Fig. 33)

Problematical Famennian-Tournaisian species:

Caninia rudis HILL, 1954 (assigned to *Guerichiphyllum* by WEYER 1978: p. 495, and by SORAUF & PEDDER 1986: p. 1284; including HILL & JELL 1971: pl. 2, fig. 18)

Catactotoechus sp. aff. *irregularis* HILL, 1954 (sensu HILL & JELL 1971; assigned to *Guerichiphyllum* by WEYER 1978: p. 495, and by SORAUF & PEDDER 1986: p. 1284)

Guerichiphyllum kazakhstanicum ULITINA, 1975

Caninia tregaensis POTY, 1982

Tabulophyllum normale platetabulatum CAI in ZENG & CAI, 1983

Guerichiphyllum sinense LIAO & CAI, 1987 (see SOTO & LIN 2000 and SOTO & LIAO 2002)

Tabulophyllum postnormale LIAO & CAI, 1987

Siphonophyllia hobokensis WANG & ZHAO, 1987

Siphonophyllia karamayensis WANG & ZHAO, 1987

Circellia xinjiangensis WANG & ZHAO, 1987

Circellia minor WANG & ZHAO, 1987

Guerichiphyllum gansuense CAO in CAO & OUYANG, 1987

Guerichiphyllum crassiseptatum CAO in CAO & OUYANG, 1987

Guerichiphyllum minor CAO in CAO & OUYANG, 1987

Guerichiphyllum angustivesiculosum CAO in CAO & OUYANG, 1987

Hebukephyllum equitabulatum CAI, 1988

Hebukephyllum curvuse CAI, 1988

Hebukephyllum elegantum CAI, 1988

Kielcephyllum guangxiense WU & LIAO, 1988

Guerichiphyllum elegantum FAN in HE & FAN, 1988

Guerichiphyllum jirongi FAN in HE & FAN, 1988

Guerichiphyllum convexitabulatum SOTO & LIN, 2000

Guerichiphyllum sp. A, SOTO & LIN, 2000

Discussion: TERMIER & TERMIER (1950) described an upper Famennian solitary rugose coral from Oued Aricha as *Loepophyllum arichense* nov. sp. (Rugosa). This taxon was never revised on the base of additionally collected specimens, which are now available.

Loepophyllum is a nomen vanum introduced by LANG, SMITH & THOMAS (1940: p. 79) for *Loipophyllum* WEDEKIND, 1925. Type species is *Loipophyllum kerpense* WEDEKIND, 1925 from the upper Eifelian, originally introduced as a subgenus of *Neospongophyllum* WEDEKIND, 1922. BIRENHEIDE (1962b: pp. 119-120) revised *Loipophyllum kerpense* as identical with *Neospongophyllum rotundum* WEDEKIND, 1925, and as a junior synonym of the Givetian *Stringophyllum* (*Neospongophyllum*) *primordiale* WEDEKIND, 1922. *Neospongophyllum* is classified either as a separate genus (ENGEL & SCHOUPPÉ 1958: pp. 88, 93, LIN et al. 1995: p. 291) or as a subgenus of *Stringophyllum* WEDEKIND, 1922 (BIRENHEIDE 1962a: p. 52, 1962b: p. 118; HILL 1981: p. F248). These corals are taxa of the Ptenophyllina WEDEKIND, 1927 (family Stringophyllidae WEDEKIND, 1922), a suborder, which had disappeared before the end-Frasnian Kellwasser Event. There are no relationships with the Oued Aricha species.

In the times around 1950, the Rugosa of the Famennian Stage were extremely poorly known globally. This changed with the outstanding monograph of RÓŻKOWSKA (1969), who described corals from the lower and upper Famennian of the Holy Cross Mountains (Poland) as the new genus *Guerichiphyllum.* Hereafter, further Famennian species of that genus were described (mainly from China): *Guerichiphyllum kazakhstanicum* ULITINA, 1975, *Guerichiphyllum sinense* LIAO & CAI, 1987, *Guerichiphyllum jirongi* FAN in HE & FAN, 1988, *Guerichiphyllum elegantum* FAN in HE & FAN, 1988, *Guerichiphyllum convexitabulatum* SOTO & LIN, 2000, and *Guerichiphyllum hebukeense* SOTO & LIAO, 2002. The Moroccan *Loipophyllum arichense* was now included into *Guerichiphyllum*: WEYER (1978: p. 495), SORAUF & PEDDER (1986: p. 1284). In addition, also a lower Tournaisian species, *Cyathophyllum priscum* MÜNSTER, 1840, was transferred to *Guerichiphyllum*: WEYER (1979: p. 100, pl. 5, fig. 8), BARTZSCH & WEYER (1982: p. 31, pl. 7/1-3, pl. 10, figs. 1-4). This taxon is now an excellent index fossil of the lower Hastarian (lower Tournaisian) *Gattendorfia* "Stage" (in cephalopod facies), recorded mainly from Germany and sporadically from Poland, France, and southern Morocco.

Then it became more and more evident that the widely defined genus *Guerichiphyllum* RÓŻKOWSKA, 1969 represents a polyphyletic classification of homoeomorphic taxa. LIAO & CAI (1987) separated in a first step their new genus *Hebukophyllum*, characterized by developing only lonsdaleioid dissepiments. This was accepted in WEYER (1994: p. 186). *Circellia* YE & WANG, 1983 (also used by WANG & ZHAO 1987: p. 480, and BERKOWSKI 2002: p. 22) was preferred by YU (1988: p. 188) as senior synonym of *Hebukophyllum* LIAO & CAI, 1987. This was refused by LIAO & SOTO (2001), after the restudy of the *Circellia* type collections, which came from upper (not lower) Tournaisian beds. The longitudinal sections of *Circellia irregularis* YE & WANG, 1983 (with a concave tabularium: their pl. 9, figs. 1c, 2b, 3b, refigured in LIAO & SOTO 2001: pl. 2, figs. 4c, 5e, 6b) even suggest relationships to the Uraliniidae DOBROLYUBOVA, 1962, which are typical at this younger stratigraphical level. WEYER (2002: p. 17) also doubted the generic identity of several Famennian "*Guerichiphyllum*" with the basal Givetian type species, *Guerichiphyllum skalense* (GÜRICH, 1896), as restudied by FEDOROWSKI (1965).

Currently, *Hebukophyllum* LIAO & CAI, 1987 seems to be the best choice among available genus names for the group of Famennian – lower Tournaisian so-called *Guerichiphyllum* species that bear only lonsdaleioid dissepiments. In Europe, these are mainly *Hebukophyllum parvum* (RÓŻKOWSKA, 1969), *Hebukophyllum concavum* (RÓŻKOWSKA, 1969), *Hebukophyllum priscum* (MÜNSTER, 1840), and *Hebukophyllum mirabile* (WEYER, 2002). In Morocco, there are *Hebukophyllum arichense* (TERMIER & TERMIER, 1950a) in the upper Famennian, and *Hebukophyllum priscum* (MÜNSTER, 1840) in the basal Tournaisian (Tafilalt, Ouidane Chebbi region, locality Mkarig, see KAISER et al. 2011, figs. 2, 6, Beds 37-38a = level with *Acutimitoceras* (*Stockumites*) *intermedium* sensu BECKER et al. 2002: p. 173, collections of R. T. BECKER 2001, 2003: six specimens in hematite preservation). Other so-called *Guerichiphyllum*-like Rugosa with regular dissepiments between major septa are also found in the upper Famennian of Morocco (Fig. 34); this new species, preliminarily named as *Guerichiphyllum*? sp. EA, resembles *Guerichiphyllum*? *kowalense* RÓŻKOWSKA, 1969.

Caninia tregaensis POTY, 1982 (lower Tournaisian, lower and basal upper Hastarian, Belgium) was transferred into their new genus *Hebukophyllum* by LIAO &CAI (1987). This was not accepted by POTY & BOLAND (1996: pp. 203, 205), when they proposed a new genus *Conilophyllum* (type species *Conilophyllum streeli* POTY & BOLAND, 1996, lower Tournaisian), with a second species, *Conilophyllum priscum* (MÜNSTER, 1840), which included *Caninia tregaensis* as junior synonym (see also BOLAND 1997: p. 78, and DENAYER et al. 2011: p. 159). Any synonymy between the warm and shallow water (photic zone) coral *Conilophyllum tregaense* (POTY, 1982) and the cold/deep water (dysphotic/aphotic zone, cephalopod facies) coral *Hebukophyllum priscum* (MÜNSTER, 1840) was refused by KORN & WEYER (2001: p. 111) This is based on unpublished studies of rich *tregaensis* collections from the northern margin of the Eastern Rhenish Mountains (debris of former HEINRICH mine, near Lintorf N of Ratingen) and from boreholes on the Baltic Sea island of Rügen. These well-preserved materials allowed intensive early ontogenetic studies, necessary to verify phylogenetic relationships. Also, LIAO & SOTO (2001: p. 47) argued for a classification of *Hebukophyllum* and *Conilophyllum* in different families.

Distribution in time and space: The genus *Hebukophyllum* had a cosmopolitic geographic distribution. There are records from middle Famennian to lower Tournaisian strata (dysphotic-aphotic *Cyathaxonia* facies sensu HILL 1938) on five continents, mainly Europe, Asia, and North Africa. Also, the Famennian of western Australia yields such corals in the ammonoid facies of the Canning Basin, described as *Catactotoechus* HILL, 1954 and *Caninia* MICHELIN in GERVAIS, 1840 (HILL 1954; HILL & JELL 1971). The only North American record was *Guerichiphyllum* sp. of SANDO & BAMBER (1985: p. 22, pl. 2, figs. 6-7) from the lower Tournaisian (Kinderhookian) of Montana, Idaho, and Utah. The only published adult transverse section is very similar to *Hebukophyllum priscum* (MÜNSTER, 1840).

Hebukophyllum arichense (TERMIER & TERMIER, 1950a)

Fig. 32

*1950a *Loepophyllum arichense* nov. sp., TERMIER & TERMIER: 46, pl. 46, figs. 15-18

Material: Three topotype specimens (collection R. T. BECKER 2012), Oued Aricha Formation, upper *Platyclymenia* “Stage” (UD IV-B_2), *Procymaclymenia pudica* Zone, southern Mdakra Massif E of Benahmed (western Moroccan Meseta), Oued Aricha section Z (see coral signatures in Fig. 27). The specimens are stored in the Museum für Naturkunde, Berlin, under the following numbers:

MB.K.8071a (Bed 12a) = 10cs, 2ls, 3R, Figs. 32.1a-d.

MB.K.8071b (Bed 8a) = 7cs, 2ls, 2R, Figs. 32.3a-b.

MB.K.8071c. (bed 8a) = 6cs, 2R, Figs. 32.2a-b.

(cs = transverse section, ls = longitudinal section, R = remaining piece)

Description: The three available specimens are conical and cornute (juvenile) to subcylindrical and straight (adult), in Fig. 32.2a with basal talon. Their preservation is not the best: slightly silicified, destroyed juvenile part. Calicular diameters are 18, 21 and 23 mm; the maximal length is 53 mm (Fig. 32.1a, with previous even larger calices of 27 and 25 mm diameter before rejuvenations). The archaeotheca bears fine and coarse transverse growth rings and very weak narrow longitudinal septal furrows of major and minor septa (no hyposepta). The position of the cardinal septum cannot yet be determined by external wall furrows or by ontogenetic analysis, but there seems to be a somewhat shortened septum surrounded by a fossular depression on the convex side (calice, Fig. 32.2), as mostly in *Hebukophyllum priscum* (MÜNSTER, 1840). Visible upper septal margins in the calice show no trabicular spines.

The transverse sections offer in middle and late growth phases thin filiform major septa, longer and still slightly thicker in the youth (but not reaching the center), later more and more shortening (and amplexoid), but never totally reduced as in *Hebukophyllum mirabile* (WEYER, 2002). Minor septa are not visible; they exist as active protuberances only at the upper calicular margin, as in *Hebukophyllum priscum* (MÜNSTER, 1840) (see WEYER 1994, figs. 5.3d, f). Deeper in the calice, these catasepta are reduced and disappear within the thickening wall. Dissepiments of small and large, even extremely extended lonsdaleioid vesicles in 2 or 3 rows, characterize middle and late growth stages. These start at diameters of 9-15 mm. Simple horizontal tabulae and rare similar tabellae cross the interior lumen and fall down peripherally, thus presenting a weakly domed appearance.

Discussion: The taxon seems to be the second-oldest valid species of *Hebukophyllum* (after *Cyathophyllum priscum* MÜNSTER, 1840); all other (and especially the many Chinese) members were introduced with and after RÓŻKOWSKA (1969). Comparisons are difficult in this not yet intensively (using greater populations) studied genus, and the present revision is incomplete due to the still missing, but indispensable early ontogenetic stages. Even a new, nearly synchronous record from Morocco (Fig. 33) seems to present a separate species, not developing lonsdaleioid dissepiments up to a diameter of 17 mm, and during this youth with extremely thickened major septa in the counter quadrants. It is provisionally named as *Hebukephyllum* sp. M and comes from the upper Famennian *orbiculare* Bed (UD IV-C) of the Maïder.

Two middle Famennian species from the Holy Cross Mountains (Poland) differ in size - *Hebukophyllum parvum* (RÓŻKOWSKA, 1969) - and in the dominating normal, not lonsdaleioid dissepiments – *Hebukophyllum concavum* (RÓŻKOWSKA, 1969: her holotype, figs. $23A_{1-2}$, $24A_{1-5}$). The latter species was also cited by BERKOWSKI (2002: p. 22, assigned to *Circellia* YE & WANG, 1983) from Kowala, but this record might be not conspecific because of the solely lonsdaleioid dissepiments, and could be a new taxon.

For comparison, another new form, named as *Guerichiphyllum?* sp. EA, is illustrated from the upper Famennian *Gonioclymenia* Limestone of the southern Tafilalt (Amessoui Syncline, Fig. 34). It underlines that the diversity of the Guerichiphyllinae was much higher in the Famennian cephalopod facies of Morocco than previously known. The two forms of the subfamily left in open nomenclature require further studies based on additional material.

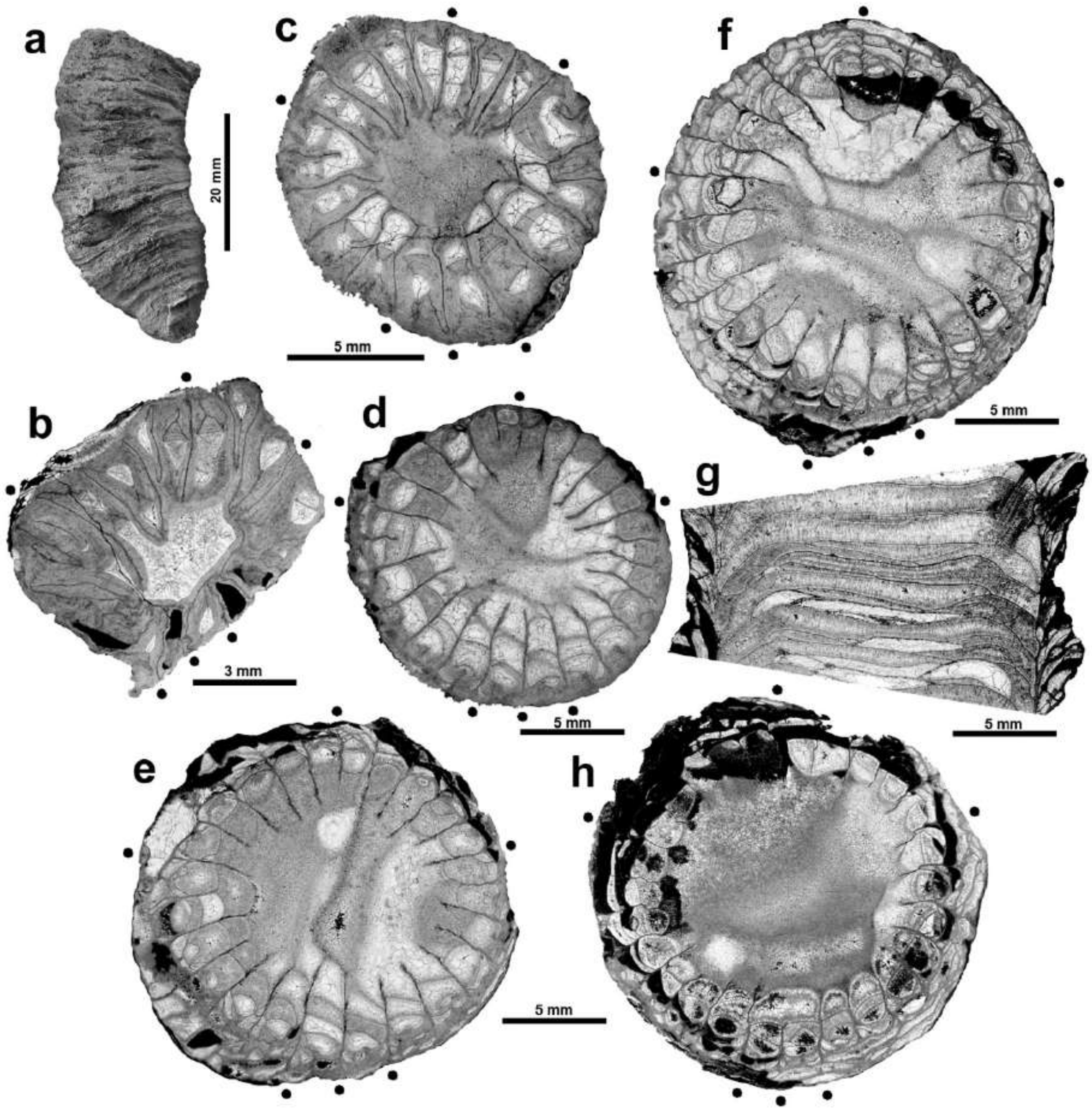

Fig. 34: *Guerichiphyllum*? sp. EA, upper Famennian (*Clymenia* "Stage"), *Gonioclymenia* Limestone (UD V-B, *Bi. costatus* Zone), trenches W of abandoned village El Atrous (Amessoui Syncline, 15 km NW Taouz), Tafilalt, eastern Anti-Atlas (see section description in HARTENFELS 2011). Specimen MB.K.8073. (= 8cs, 4ls, 4R; collection D. WEYER 1995); **a.** Side view of coral, x 1; **b-f.** Transverse sections of early and middle growth stages, x 5 (b), x 4 (c) and x 3 (d-f); **g.** Median longitudinal section, x 3; **h.** Adult transverse section, x 3.

septal formulae:		3 2	4 3	5 5	5 5	5 5
		5 5	6 6	7 7	8 7	8 8
	n	19	23	28	29	30
	N	30	38	48	50	52
	D mm	9	12,2	16/18,6	19,7	19,8
	Fig.	b	c	d, e	f	h

(abbreviations: n = number of protosepta + metasepta, N = number of all septa, D = diameter)

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Upper Frasnian ammonoids and gastropods from Boudouda (Benahmed region, Moroccan Meseta)

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Fig. 1: Limonitized and squashed *Serramanticoceras* on the upper surface of the dark-grey, laminated paper shale of Bed 9 at Boudouda, photographed in lifetime orientation.

Abstract. The upper Frasnian of the Boudouda Formation of the Benahmed region yielded a diverse, originally pyritized (secondarily limonitized) ammonoid fauna that resembles assemblages from contemporaneous goniatite shales of the Rhenish Massif (Germany: Büdesheim Formation). There are nine species each of the Tornoceratidae and Gephuroceratoidea (Gephuroceratidae and Ponticeratidae). New endemic taxa are *Crassotornoceras boudoudense* n. sp., *Costornoceras multiseptatum* n. gen. n. sp., which both fall in the Crassotornoceratinae n. subfam., and *Costamanticoceras hybris* n. sp. *Tornoceras* aff. *contractum* and *Trimanticoceras* n. sp. (based on fragments) are left in open nomenclature. Eight more species are recorded for the first time from North Africa, *Aulatornoceras auris* and *Lobotornoceras ausavense* are illustrated for the first time from Morocco. Associated are three bactritid species, bivalves, brachiopods, and the small gastropod *Goniphilus delicatulus* n. gen. n. sp. Based on *Aulatornoceras auris, Lobotornoceras ausavensis*, *"Ponticeras" prumiense*, and *Manticoceras carinatum*, the ammonoid succession falls in the lower (pre-Kellwasser) part of the upper Frasnian (UD I-I and I-J). The local absence of Beloceratidae was controlled by the hypoxic facies. At species level, the fauna includes 2/3 common taxa with the distant Büdesheim region, while the similarity with the closer and contemporaneous Anti-Atlas faunas (Tafilalt, Maïder, and Dra Valley) is only 1/3. The insufficiently known upper Frasnian goniatite faunas of other Meseta regions are also different. This unusual pattern can be explained to a large extent by biofacies differences but the lack of Frasnian outcrops in the southern Meseta is also well-known. There may have been a palaeobiogeographic barrier caused by strong Eovariscan block faulting and uplift that started in the middle/upper Givetian. It was obviously biogeographically more relevant than the wide, structurally complex western Prototethys (Variscan Sea) between the Meseta and Rhenohercynian Zone.

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1. Introduction

TERMIER & TERMIER (1951a, 1951b) noted the presence of Frasnian shales with manticoceratids at Boudouda NW of Benahmed. This initiated a thorough field survey, section logging and bed-by-bed collecting of ammonoids and associated fauna, such as bactritids, bivalves, gastropods, and brachiopods. The original preservation was pyritic; deep humid weathering led to oxidation and limonitization (Fig. 1).

For the locality position, section description, conodont faunas and microfacies proving a calm environment see the general Benahmed chapter. The upper Frasnian goniatite shale facies is unique for the Moroccan Meseta and for all of North Africa. In terms of sediment and overall faunal composition, the famous Büdesheim Goniatite Shale (Büdesheim Formation) of the Eifel Mountains of Germany (e.g., CLAUSEN 1968, 1969) is most similar. Distinctive is the richness and diversity of tornoceratids, as it is also known from the slightly younger Sand Formation of the Rhenish Massif (SÖTE et al. 2021). In the Moroccan Meseta, upper Frasnian ammonoids, mostly manticoceratids, occur in condensed cephalopod limestones of the Oued Cherrat (BECKER et al. 2020a) and in the Mrirt-Azrou Nappe (BECKER et al. 2020b). Very few limonitic gephuroceratids were collected from an extremely condensed shale unit of the Middle Atlas basement at Immouzer-du-Kandar (ABOUSSALAM et al. 2020). In the eastern Anti-Atlas, Kellwasser-type, organic-rich limestones commence with the basal upper Frasnian *semichatovae* Transgression (e.g., WENDT & BELKA 1991; BECKER et al. 2018b). Undescribed, originally pyritic faunas occur in intercalated marls of the Tafilalt Basin but are younger than the Boudouda fauna (see below). This is also true for the hematitic fauna of the *Carinoceras* Beds of Oued Mzerreb in the eastern Dra Valley (BECKER et al. 2004a), which is dominated by oxyconic gephuroceratids.

This contribution aims to document the Frasnian goniatite faunas from Boudouda, their age, and palaeobiogeography. There is a focus on the Tornoceratidae, which are currently subject to vigorous revision (e.g., SÖTE et al. 2021). Identifications of the Gephuroceratidae and Ponticeratidae have to remain somewhat arbitrary until the type material of long-established taxa is revised, too. The local bed-by-bed record of all species is given in Tab. 1, with their ranges plotted against the lithological log in Fig. 2. The complete ammonoid fauna is as follows:

Tornoceras aequilobum SÖTE, BECKER, HERD & BOCKWINKEL, 2021 (Figs. 3a-b)
Tornoceras aff. *contractum* GLENISTER, 1958 (Figs. 3c-d)
Lobotornoceras ausavense (STEININGER, 1849) (Figs. 3i-j)
Lobotornoceras hassoni HOUSE, 1978 (Figs. 3k-l)
Crassotornoceras hetzeneggeri SÖTE, BECKER, HERD & BOCKWINKEL, 2021 (Figs. 3g-h)
Crassotornoceras boudoudense n. sp. (Figs. 3e-f)
Costornoceras multiseptatum n. gen. n. sp. (Figs. 3m-p)
Aulatornoceras auris (QUENSTEDT, 1846) (Figs. 4a-b)
Aulatornoceras constrictum (STEININGER, 1849) (Figs. 4c-d)
Manticoceras carinatum (BEYRICH, 1837) (Figs. 4e-f)
Manticoceras cordatum (SANDBERGER & SANDBERGER, 1851) (Figs. 4g-h) (?= *M. intumescens* of TERMIER & TERMIER 1951b)
Sphaeromanticoceras orbiculum (BEYRICH, 1837) (Figs. 4i-j)
Sphaeromanticoceras affine (STEININGER, 1849) (Figs. 4k-l)
Serramanticoceras serratum (STEININGER, 1849) (Figs. 5c-d)
Trimanticoceras n. sp. (Figs. 5a-b)
Costamanticoceras hybris n. sp. (Figs. 4m-n)
"Ponticeras" prumiense (STEININGER, 1853) (Figs. 5e-f) and *Ponticeras* sp.

Family Tornoceratidae	**2a**	**3a**	**4a**	**5a**	**6a**	**8a**	**9a**	**13a**	**14a**	**15a**	**16a**	**17a**	**18a**	**19a**	**20a**	**21a**	**23a**	**25**	**+**
Aulatornoceras auris	1	-	-	-	-	-	-	1	-	1	-	3	-	-	-	-	-	-	2
Aulatornoceras constrictum	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	2	-	1	2
Aulatornoceras sp.	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Costornoceras multiseptatum n. gen. n. sp.	-	-	1	-	-	-	-	1	-	1	-	2	-	-	1	1	-	-	-
Crassotornoceras hetzeneggeri	-	-	-	-	-	-	1	-	-	2	-	-	-	-	-	-	-	-	1
Crassotornoceras boudoudense n. sp.	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Crassotornoceras sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Lobotornoceras ausavense	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lobotornoceras hassoni	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	1	2
Tornoceras aequilobum	-	1	-	-	-	-	-	3	1	2	1	1	-	1	-	-	1	-	3
Tornoceras aff. *contractum*	-	-	-	-	-	-	1	-	2	4	1	-	-	-	1	-	-	-	3
Tornoceras sp.	-	-	-	-	1	-	-	4	-	2	1	-	-	-	-	-	-	-	-
Family Gephuroceratidae																			
Costamanticoceras n. sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Manticoceras cordatum	-	-	2	-	-	-	-	4	-	1	-	2	-	-	1	-	-	2	-
Manticoceras carinatum	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	3	-	2
Manticoceras sp.	-	-	-	2	-	-	-	-	-	-	-	-	1	-	-	-	-	1	1
Serramanticoceras serratum	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Sphaeromanticoceras affine	-	1	1	1	1	2	-	-	-	3	-	1	-	-	1	-	1	-	1
Sphaeromanticoceras orbiculum	3	-	-	-	-	-	-	-	-	1	1	3	-	-	3	-	-	-	1
Trimanticoceras n. sp.	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-
Family Ponticeratidae																			
"*Ponticeras*" *prumiense*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-
Ponticeras sp.	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-

Tab. 1: Local Frasnian ammonoid occurrences at Boudouda.

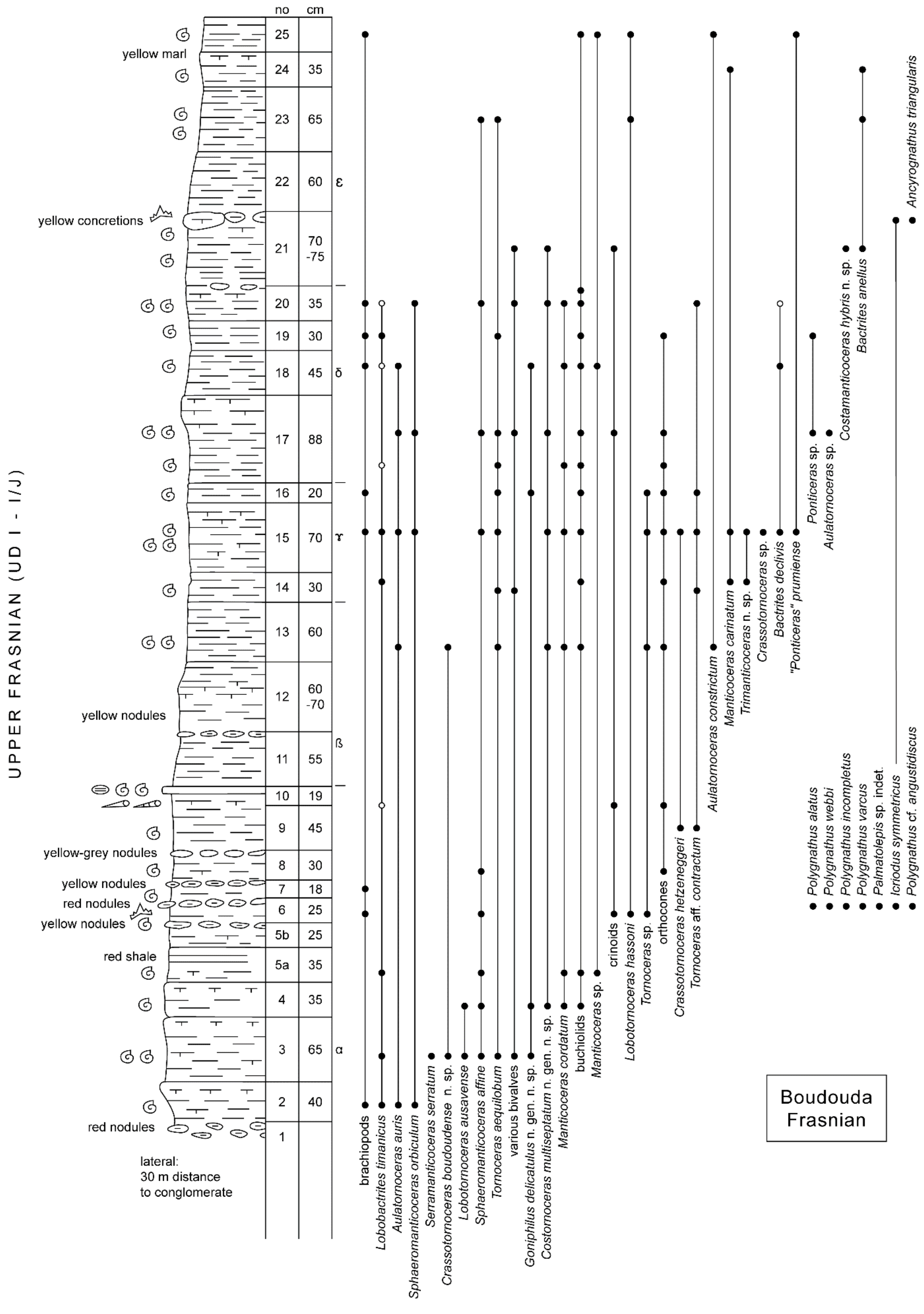

Fig. 2: Stratigraphic ranges of ammonoids, conodonts, and associated fauna in the upper Frasnian of Boudouda.

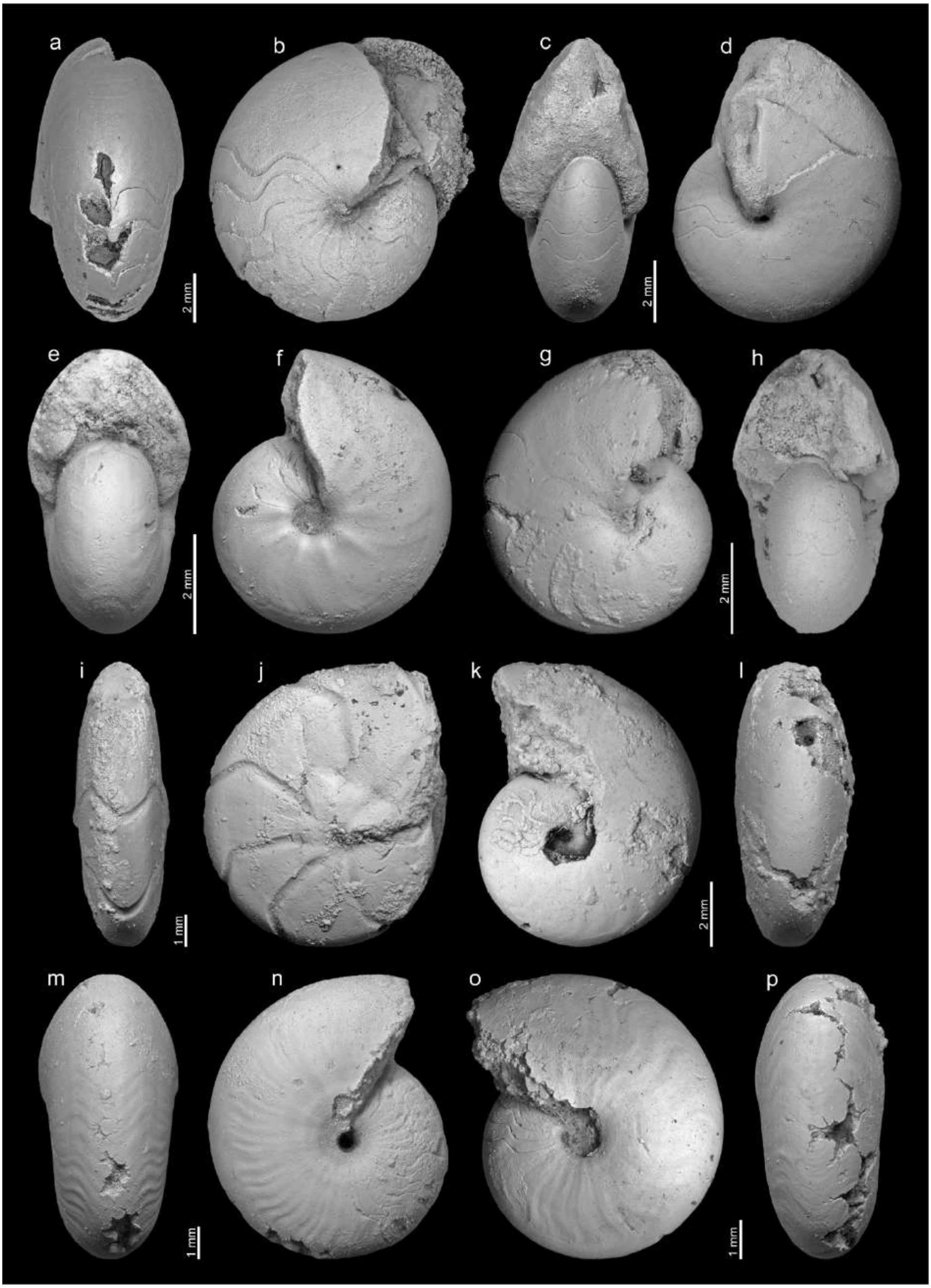

Fig. 3: Upper Frasnian ammonoids from Boudouda. **a-b.** *Tornoceras aequilobum*, GMM B6C.54-122, Bed 16a; **c-d.** *T.* aff. *contractum,* GMM B6C.54-132, Bed 15a; **e-f.** *Crassotornoceras boudoudense* n. sp., holotype GMM B6C.54-46, Bed 3a; **g-h**. *Crasso. hetzeneggeri*, GMM B6C.54-49, Bed 9a; **i-j.** *Lobotornoceras ausavense*, GMM B6C.54-60, loose; **k-l.** *Lobo. hassoni*, GMM B6C.54-61, Bed 6a; **m-p.** *Costornoceras multiseptatum* n. gen. n. sp., m-n. holotype GMM B6C.54-35, Bed 4a, o-p. paratype GMM B6C.54-42, loose.

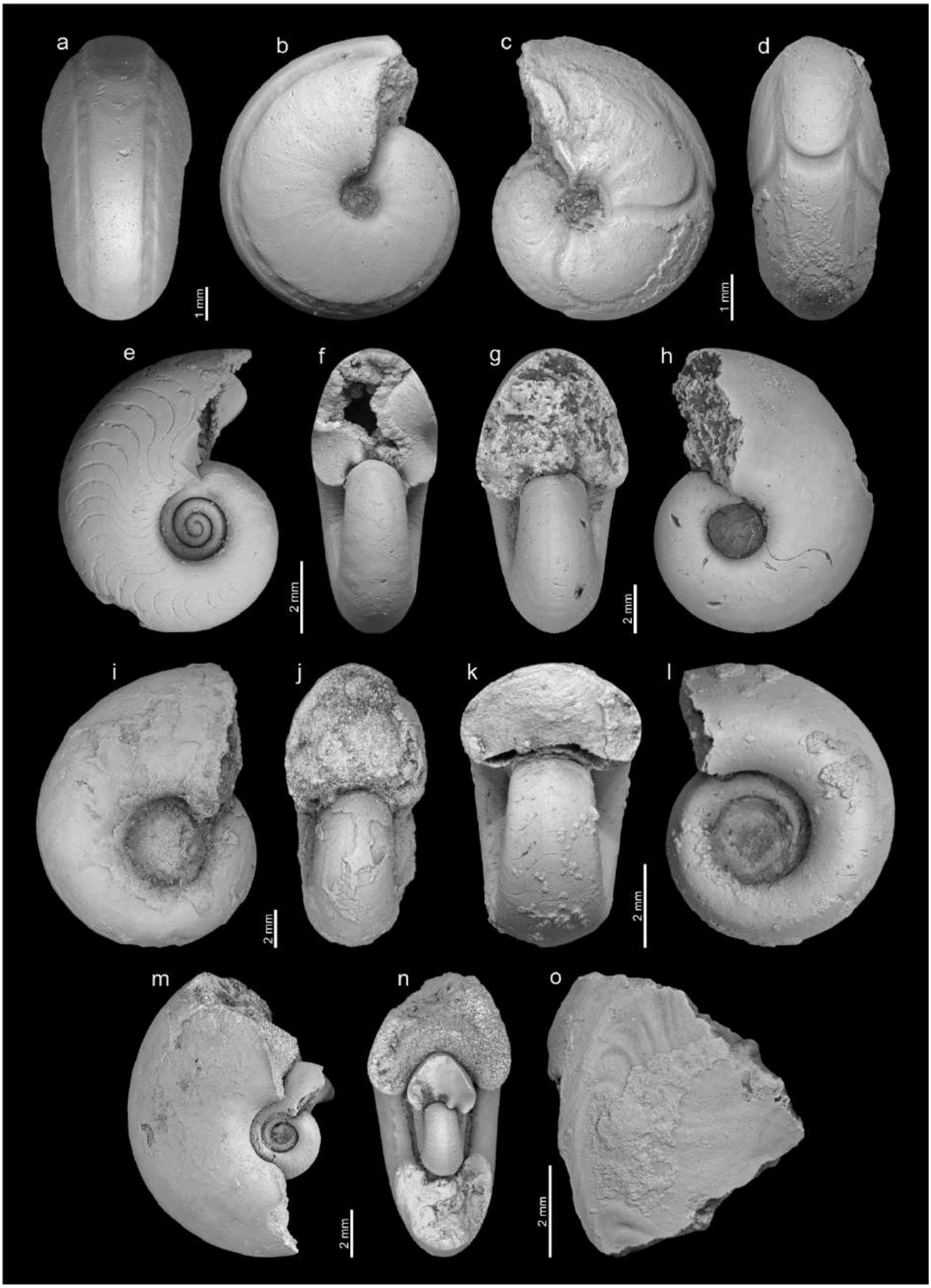

Fig. 4: Upper Frasnian ammonoids from Boudouda. **a-b.** *Aulatornoceras auris*, GMM B6C.54-7, Bed 17a; **c-d.** *Aul. constrictum*, GMM B6C.54-13, Bed 21a; **e-f.** *Manticoceras carinatum*, GMM B6C.54-68, Bed 23a; **g-h.** *M. cordatum*, GMM B6C.54-76, Bed 25; **i-j.** *Sphaeromanticoceras orbiculum*, GMM B6C.54-110, Bed 16a; **k-l.** *Sph. affine*, GMM B6C.54-104, Bed 23a; **m-n.** *Costamanticoceras hybris* n. sp., holotype GMM B6C.54-34, Bed 21a; **o.** *Aulatornoceras* sp., GMM B6C.54-3, Bed 17a.

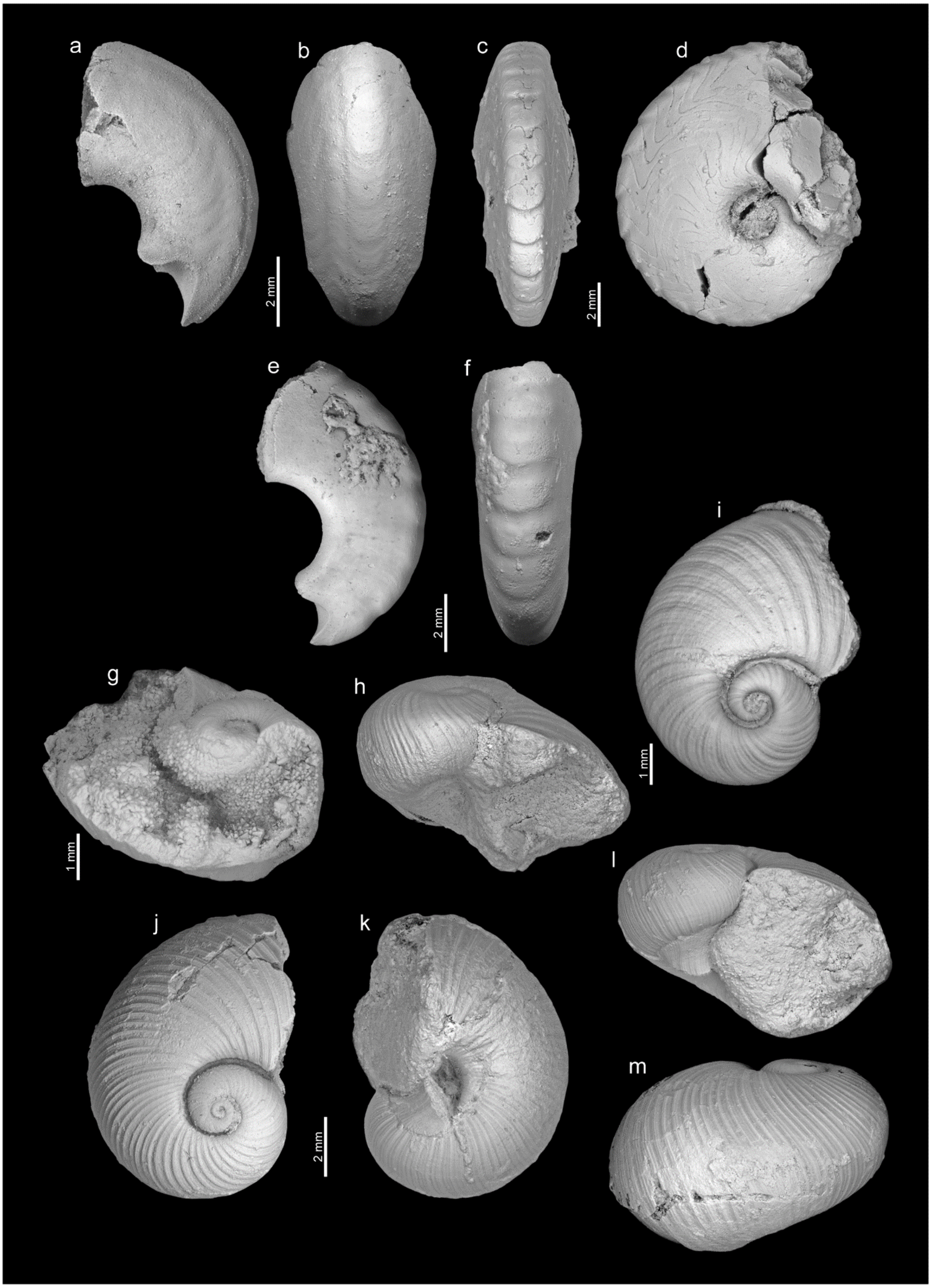

Fig. 5: Upper Frasnian ammonoids and gastropod from Boudouda and gastropods from Büdesheim. **a-b.** *Trimanticoceras* n. sp., GMM B6C.54-152, Bed 14a; **c-d.** *Serramanticoceras serratum*, GMM B6C.54-92, loose; **e-f.** "*Ponticeras*" *prumiense*, GMM B6C.54-2, Bed 25; **g-i.** *Goniphilus ausavensis* n. gen., Büdesheim, g. topotype GMM B6B.11-7, h-i. topotype and potential neotype GMM B6B.11-6, showing the inserted first whorl; **j-m.** *G. delicatulus* n. gen. n. sp., showing the typical inner whorl form, holotype GMM B6B.11-1, Bed 18a.

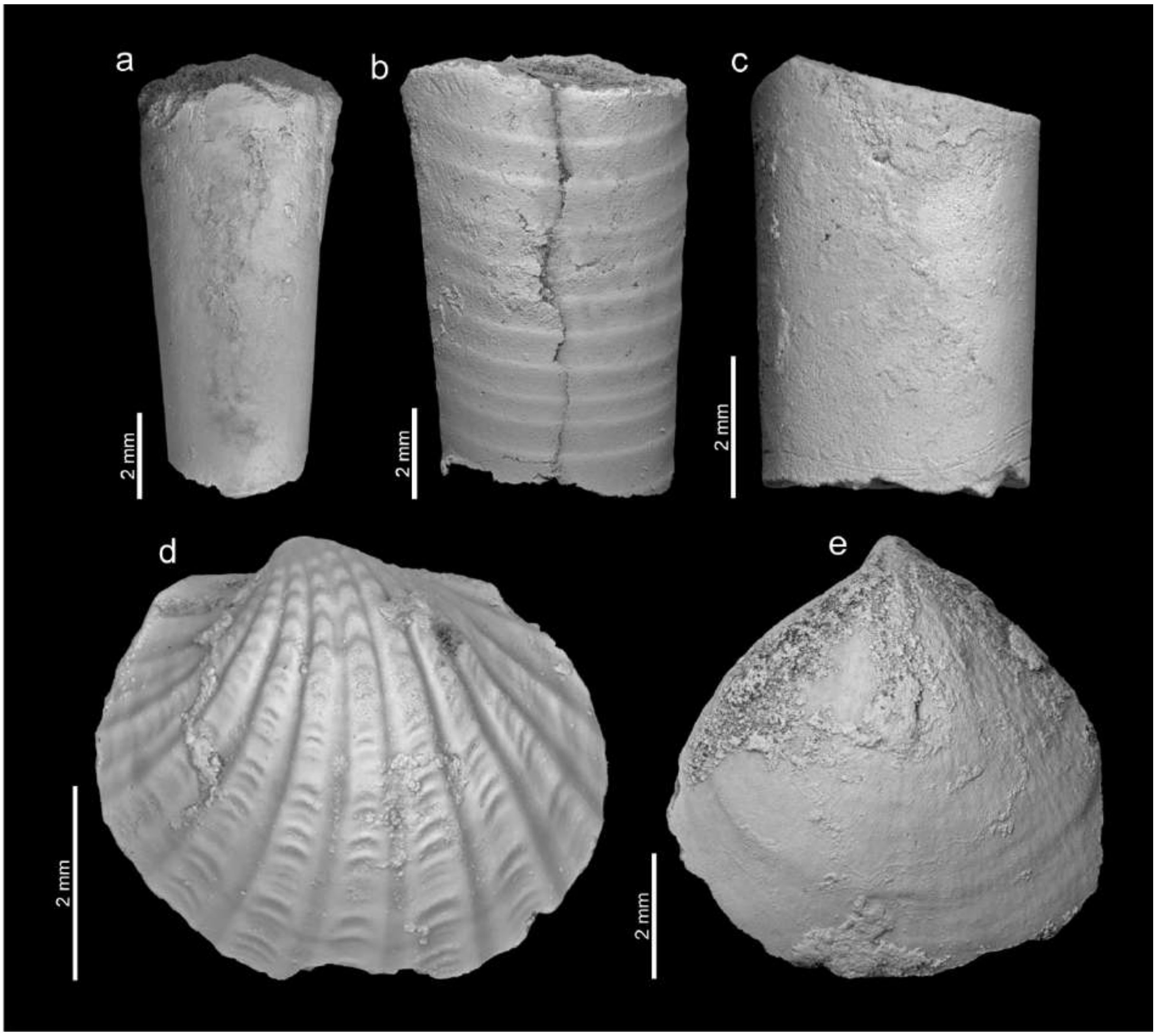

Fig. 6: Associated fauna from the Bououda Formation. **a.** *Bactrites declivis*, GMM B6C.54-27, Bed 18a; **b.** *Bac. annellus*, GMM B6C.54-21, loose; **c.** *Lobobactrites timanicus*, GMM B6C.54-56, Bed 19a; **d.** *Glyptohallicardia palmata*, GMM B6A.37-1, Bed 5a; **e.** ?athyridid, GMM B5B.16-1, Bed 2a.

Among the orthoconic cephalopods, there are three species of bactritids, which also closely resemble species known from Büdesheim (see CLAUSEN 1968):

Bactrites anellus CLAUSEN, 1968 (Fig. 6b)
Bactrites declivis CLAUSEN, 1968 (Fig. 6a)
Lobobactrites timanicus SCHINDEWOLF, 1933 (Fig. 6c)

A typical faunal element of hypoxic (pyritic) goniatite shales are buchiolid bivalves, which were monographed by GRIMM (1998). At least some of our Boudouda specimens (Fig. 6d) belong to *Glyptohallicardia palmata* (GOLDFUSS, 1837), one of the most widespread Frasnian buchiolids, which occurs also at Büdesheim. A small-sized gastropod closely resembles the poorly known *Natica ausavensis* STEININGER, 1853 from Büdesheim (Figs. 5g-i) but is not conspecific. Due to the constant association of similar forms with goniatites, it is here described as *Goniphilus delicatulus* n. gen. n. sp. (Figs. 5j-m).

2. Biostratigraphic age

The Frasnian ammonoid zonation was refined by BECKER et al. (1993), who introduced a subdivision of the Upper Devonian I (UD I) into twelve zones (I-A to I-L), with regionally different subzones. Following the proposed substage definition by ZIEGLER & SANDBERG (1997: *semichatovae* Transgression), the upper Frasnian begins with UD I-I, not with the Lower Kellwasser faunas, as in the traditional definition of the Upper Adorf-Stufe sensu WEDEKIND (1913a). The *semichatovae* Transgression is characterized by a significant ammonoid radiation and migrations. Typical is a proliferation in genera, such as *Serramanticoceras, Playfordites, Trimanticoceras, Costamanticoceras*, *Stilleoceras* (an objective senior synonym of *Maternoceras* HOUSE & ZIEGLER, 1977; see BECKER 2018), *Ponticeras*, and the *Manticoceras latisellatum* Group, characterized by species with widely rounded flank saddles. Since BECKER & HOUSE (2009, p. 420) mentioned undescribed new *Playfordites* and *Costamanticoceras* from the middle Frasnian *Mesobeloceras* Zone of Australia, it seems that *Serramanticoceras* is internationally the most suitable genus to define UD I-I, which revives the original concept of BECKER et al. (1993).

Apart from *Stilleoceras* and *Playfordites*, the mentioned upper Frasnian genera are present at Boudouda. An important index species for UD I-I is *Aulatornoceras auris*, which occurs in Bed 2, and which enters also in the basal upper Frasnian of Germany (UD I/J, type-level at Büdesheim, Eifel Mountains; Martenberg, eastern Rhenish Massif), in southern France (BECKER & HOUSE 1994a), Western Australia (BECKER & HOUSE 2009) and in the Timan of northern Russia (BECKER et al. 2000). At Boudouda, Beds 2a to top 13a are assigned to a local *Aul. auris-Serr. serratum* Zone representing division UD I-I. *Lobotornoceras ausavense*, which begins in Bed 3a, is also a typical UD I-I/J species at Büdesheim and in the Dra Valley of southern Morocco (BECKER et al. 2004a). However, closely related forms appear already in the middle Frasnian of the Timan and Dra Valley (BECKER et al. 2000, 2004a). Lobotornoceratids without varices were previously only known from the upper Givetian to middle Frasnian of North America and the Anti-Atlas (HOUSE 1978; HOUSE & KIRCHGASSER 2008; BECKER et al. 2004a; BOCKWINKEL et al. 2013). The Boudouda specimens, which cannot be distinguished from the lower Frasnian *Lobo. hassoni* of West Virginia, mean a considerable upper range extension. *Sphaeromanticoceras* enters high in the middle Frasnian of Australia (BECKER et al. 1993; BECKER & HOUSE 1993) but is very common in the UD I-I/J of Büdesheim.

The international separation of zones UD I-I and I-J is hampered by strong regional differences (see BECKER & HOUSE 1994a, fig. 17). Characteristic for I-J are advanced oxyconic gephuroceratids, such as *Virginoceras* (Australia, Timan) and *Neomanticoceras* (Büdesheim), as well as *Clauseniceras*, a relative of *Manticoceras* with (sub)convex growth ornament (BECKER & HOUSE 1993). Both in the Rhenish Massif (WEDEKIND 1913a: classical do Iγ fauna) and in the Anti-Atlas (BECKER & HOUSE 2000a; BECKER et al. 2018a), the compressed *Mant. carinatum* enters abundantly as an index fossil in limestones of UD I-J. The species is characterized by a wide and subsymmetric flank saddle and a late ontogenetic sharpening of the lateral lobe (see BECKER & HOUSE 1994a, fig. 15C). The ventral carina of the types (see HOUSE & ZIEGLER 1977) is not regarded as a meaningful character, which was already noted in the first revision by WEDEKIND (1913a). Consequently, we assign the Boudouda succession from Bed 14a on to UD I-J, a regional *M. carinatum* Zone.

In Germany (WEDEKIND 1913a; MATERN 1931b, HOUSE & ZIEGLER 1977), SW England (HOUSE 1963; GAUSS & HOUSE 1972) and in Australia (GLENISTER 1958; BECKER & HOUSE 2009), regionally different species of *Ponticeras* bloomed in UD I-J. The fragmentary *Ponticeras* found in Beds 17a and 19a agree with this distribution patterns. BECKER & HOUSE (1993, p. 122) emphasized that *"Ponticeras" prumiense*, another Büdesheim species, found at Boudouda in Beds 15a and 25 (Tab. 1, Fig. 2), belongs to a distinctive side-branch of ponticeratid evolution. Closely related forms occur in SW England (GAUSS & HOUSE 1972) and NW Australia in the upper part of UD I-I (BECKER & HOUSE 2009) but the species may range throughout I-I/J in Germany.

3. Palaeobiogeography (Tab. 2)

As noted in the introduction, upper Frasnian goniatite faunas are sparse in the Moroccan Meseta and come mostly from extremely condensed cephalopod limestone facies, which is dominated by manticoceratids and beloceratids. *Beloceras* is generally very rare in hypoxic, organic-rich facies, with single exceptions from the *"Archoceras"* Zone (UD I-K) of Büdesheim (KORN et al. 2013), the Dra Valley (UD I-I, BECKER et al. 2004a), and from Kellwasser facies of the southern Tafilalt (specimen overgrown by *Prosochasma bickense* from El Atrous = Takhat ou Heyene, see section of BECKER et al. 1989a). The absence of *Beloceras* from the Boudouda fauna has biofacies, not palaeobiogeographic reasons.

A moderately diverse, only partly described upper Frasnian manticoceratid fauna occurs in the Mrirt region (BECKER et al. 2020b, UD I-I to I-L), which represents an allochthonous nappe derived from the east. Its fauna consists mostly of *Manticoceras* groups; other genera of the Gephuroceratidae are not known with certainty (one questionable "*Maternoceras*"). Again, this is thought to reflect a strong biofacies difference to Boudouda. The restricted number of sufficiently preserved specimens has to be taken into consideration, too, but genera, such as *Costamanticoceras, Trimanticoceras, Ponticeras,* and *Aulatornoceras*, are well-known from German cephalopod limestone facies. Interestingly, *M. cordatum* (s.str.) and *M. carinatum* have not yet been recorded from the Mrirt region. The poorly preserved *Aulatornoceras* and *Tornoceras* of Bou Ounebdou are from younger (Kellwasser) levels than the Boudouda faunas and cannot be compared until further investigation. In summary, the differences between upper Frasnian goniatite faunas of the Benahmed region and Mrirt-Azrou Nappe may reflect a combination of dominant biofacies and subordinate palaeogeographic patterns.

The goniatite faunule from UD I-J goniatite shale of Immouzer-du-Kandar (Middle Atlas basement, ABOUSSALAM et al. 2020) is too small for detailed comparisons. But the presence there of *M. cordatum* and *Sph. orbiculum* give biogeographically relevant similarities.

At Boudouda, three of 18 species are endemic according to current knowledge: *Costornoceras multiseptatum* n. gen. n. sp., *Crassotornoceras boudoudense* n. sp., and *Costamanticoceras hybris* n. sp. The spatial range of *Trimanticoceras* n. sp. is not yet known since similar forms occur in other regions but have not yet been described; all other taxa are more or less cosmopolitic (Tab. 2). The local genus-level endemism is especially significant.

From the Tafilalt and Maïder of the eastern Anti-Atlas, which was not separated from the Meseta by a plate tectonic suture (BAIDDER et al. 2008; FERONI et al. 2010; RYTINA et al.

2013), only ca. a third of the Boudouda species are known, and not necessarily from faunas of the same zones. There are occurrences of *Aul. auris*, *Aul. constrictum, Lobo. ausavense*, *M. cordatum*, *M. carinatum*, and close relatives of the Australian *T. contractum* (e.g., BECKER & HOUSE 2000a; BECKER et al. 2018b, 2018c; Tab. 2). A poorly preserved, not yet illustrated *Costamanticoceras* from Jebel Amelane (BECKER & HOUSE 2000b) could be added. As in the case of the Mrirt area, biofacies differences can account for a good deal of the distinction. All UD I-I/J goniatites of the eastern Anti-Atlas are from condensed, dark-grey Kellwasser-type facies. Originally pyritic faunas are only known (but not yet described) from the *"Archoceras"* Zone (UD I-K, Tafilalt Basin: Ouidane Chebbi and Hassi Nebech regions).

In the eastern Dra Valley, goniatite shales of UD I-I occur at Oued Mzerreb SE of Tata (BECKER et al. 2004a). The fauna of the "*Carinoceras* Beds" shares with Boudouda three or four species: *Trimanticoceras* n. sp., close relatives of *T. contractum, Aul. auris*, and *Lobo. ausavense*. In this case, the large difference of the associated gephuroceratids is interesting; at Oued Mzerreb an oxyconic species of *Gephyroceras* (= *M. rhynchostomum* Group) dominates. Different compositions apply also to Oued Mzerreb faunas from the middle Frasnian (UD I-G) and top upper Frasnian (UD I-K/L), with the exception that *M. carinatum* enters abundantly with the Lower Kellwasser level. Since the northern margin of the Tindouf Basin was palaeogeographically not more remote from the central Meseta than the eastern Anti-Atlas, it must be concluded that the Dra Valley "*Carinoceras* Beds" represent a different goniatite shale ecosystem than the Boudouda Formation. This view is supported by the unusual grading upwards into a crinoid shale (WEBSTER & BECKER 2009). Few upper Frasnian sediments are known from the southern Meseta regions, such as the Rehamna, Jebilet, High Atlas, and Skoura. A major phase of Eovariscan block faulting started in the middle/upper Givetian (BECKER et al. 2015) and may have created a barrier. However, a questionable *Ponticeras* from Taliouine (see Skoura chapter) indicates that upper Frasnian goniatite shale facies did exist locally.

Going northwards from the Meseta, the next crustal block with described upper Frasnian ammonoid faunas is the Montagne Noire of southern France (e.g., FRECH 1887; HOUSE et al. 1985; BECKER & HOUSE 1994a). While faunas from condensed cephalopod limestones, e.g., of the Frasnian-Famennian GSSP at Coumiac and other sections of the Mt. Peyroux Nappe (BECKER et al. 1989b), differ strongly, with only *M. cordatum, Aul. auris,* and perhaps *T. contractum* Gp. in common, the goniatite shale assemblages of the Cabrières region have not been revised. They share with Boudouda occurrences of *Sphaeromanticoceras* (probably both species) and *Serramanticoceras*.

The largest congruence of the Boudouda succession are with contemporaneous faunas from the Rhenish Massif. From the 18 species at Boudouda, at least 12 (2/3) are known from the Rhenish Massif. These are all abundant at Büdesheim, Germany (e.g., CLAUSEN 1969). Further similarity comes from the associated bactritids and bivalves. This points to very similar ecosystems developed contemporaneously despite a considerable palaeolatitudinal distance and despite a complex of intervening terrains (chain of South European blocks and the Armorican Terrain Assemblage) and oceanic passages. The only significant difference requiring an explanation is the lack of *Linguatornoceras* at Boudouda. Despite the extinctions associated with the Lower Kellwasser Event (e.g., of most Ponticeratidae and *Costamanticoceras*), similarity continued upwards, with the presence of nine common species still found in UD I-K at Bergisch Gladbach-Sand (Söte et al. 2021). In Rhenish cephalopod limestone facies (e.g., Wedekind 1913a; Matern 1931b; House & Ziegler 1977), the similarity decreases to ca. 40 % (Tab. 2), a similar value as for Anti-Atlas limestones. However, one has to acknowledge the limited knowledge of tornoceratids in the latter facies.

Matern (1931a), Maillieux (1936), and Gatley (1983) documented faunas from the Ardennes, where goniatite shales dominate the upper Frasnian. Termier & Termier (1951b, p. 20) compared the pyritic "Sidi Bou Chatah" fauna with the Matagne Shale. Again, the Belgian tornoceratid knowledge is much more restricted than that of gephuroceratids. At species-level, ca. 50 % of the Boudouda taxa may be present. A significant distinction, which does not occur at Büdesheim, are the various carinoceratids (s.l.) of the Ardennes Shelf basin. This gives an interesting parallel to the hypoxic Dra Valley fauna. Westwards, the goniatite shales of UD I-I/J of North Cornwall (Lower Merope Island Shale) have been compared by House (1963) and Gauss & House (1972) with the Büdesheim Goniatite Shale. At least more than a third of the Boudouda taxa are present but the fauna, especially the tornoceratids, has been poorly documented so far. The biogeographic trend continues in the younger (UD I-K/L) goniatite shale fauna of Waterside Cove, South Devon (House 2002), resembling the Rhenish trend.

Much further away, rich upper Frasnian ammonoid faunas are known from eastern North America (revised by House & Kirchgasser 2008), the Timan of northern Russia (revised by Becker et al. 2000), southern Siberia (Bogoslovskiy 1969), and the Canning Basin of NW Australia (Glenister 1958; Becker et al. 1993; Becker & House 2009). The Appalachian Basin shares only two taxa (*Aul. auris* and *Lobo. hassoni*; compare House & Kirchgasser 2008). Interestingly, *Lobo. hassoni* is currently only known from the Appalachian Mountains and Morocco, suggesting a limited breakdown of faunal isolation with the basal upper Frasnian *semichatovae* Transgression. Sporadic occurrences of upper Frasnian goniatites in the west (Missouri, Iowa), in the Great Basin (Utah), and in the Canadian Rocky Mountains do not include any Boudouda forms.

In the Timan, on the eastern tropical shelf of Laurussia, four Boudouda species occur in the calcareous, upper Franian Lyaiol Formation: *Aul. auris*, *Aul. constrictum* (= *Aul. bickense* in Becker et al. 2000), *M. cordatum,* and *M. carinatum.* In the middle Frasnian Domanik Formation, *T. contractum* is widespread and *Lobo. strangulatum* is a close relative of *Lobo. ausavense*. This gives a similarity with Boudouda in the range of Anti-Atlas and Rhenish cephalopod limestones. A single biogeographic province (biochore) stretched from NW Gondwana to the shelf belt around the southern and eastern margin of Laurussia.

Upper Frasnian ammonoids from Novaya Zemlya, other regions of Arctic Russia, Iran, and South China are very poorly known. With respect to the enormous spatial distance between the western and eastern Protethys, there are surprisingly intensive links between the ammonoid faunas of Boudouda and those of the Canning Basin (8-9 common species, Tab. 2). This is even more remarkable considering that the latter region does not include upper Frasnian goniatite shales.

In conclusion, the composition of upper Frasnian ammonoid faunas is generally controlled more strongly by biofacies than by biogeographic barriers. The total Boudouda assemblage is dominated by taxa with wide to even cosmopolitic distribution, for example across the Variscan Sea towards the Rhenish Massif and beyond, and along the Prototethys towards Western Australia. With *Costornoceras* n. gen., there is one endemic genus distinctive for Boudouda. The rather strong difference to Anti-Atlas faunas may reflect a barrier caused by the top-Givetian Eovariscan block tectonics and uplift characteristic for the southern Meseta. The Boudouda record of *Lobo. hassoni* suggests an episodic and partial viability of the Afro-Appalachian Seaway during times of transgression.

4. Taxonomic Notes

4.1. Ammonoidea

Abbreviations: Dm = diameter, wh = whorl height, ah = apertural height, ww = whorl width, uw = umbilical width, WER = whorl expansion rate, E = external or ventral lobe, A = adventitious flank lobe, L = lateral lobe at the umbilical seam (in the Tornoceratidae), I = inner or dorsal lobe.

Suborder Tornoceratina WEDEKIND in POMPECKJ, 1912

Discussion: In many publications, the authorship of the suborder Tornoceratina is given rather variably to WEDEKIND (1914a) or WEDEKIND (1918). However, the correct suborder term appeared for the first time in the systematics of POMPECKJ (1912, p. 291), who gave credits to an unpublished paper by R. WEDEKIND. As a consequence, there was also no first correction ("nom. transl.") of the suborder term in RUZHENCEV (1957), as quoted sometimes.

Superfamily Tornoceratoidea WEDEKIND, 1910
Family Tornoceratidae WEDEKIND, 1910
Subfamily Tornoceratinae WEDEKIND, 1910
Genus *Tornoceras* HYATT, 1884

***Tornoceras aequilobum* SÖTE, BECKER, HERD & BOCKWINKEL, 2021**

Figs. 3a-b, Tabs. 1-3

Discussion: There are 14 more or less well-preserved specimens with the typical, symmetrically rounded A-lobe and rounded, tegoid whorl form. The umbilicus of the moulds is so narrow that is was closed by the shell. The figured specimen GMM B6C.54-122 from Bed 16a is larger than the slightly younger (UD I-K) types from Bergisch Gladbach-Sand, but the cross-section and shell parameters agree well.

***Tornoceras* aff. *contractum* GLENISTER, 1958**

Figs. 3c-d, 7a-b, Tabs. 1-3

Description: Twelve specimens from Beds 9a to 20a are characterized by strongly tegoid cross-section with high (wh/dm ca. 0.58) and and compressed whorls (ww/wh = 0.80 at ca. 12 mm dm). Impressed traces of the ornament (Fig. 3d) suggest a well-developed ocular sinus and moderately high and wide ventrolateral salient. Sutures are characterized by a moderately wide, asymmetric, relatively low dorsolateral saddle, a wide and asymmetric A-lobe, and a wide and low (< 50 % dorsolateral saddle), asymmetrically ascending ventrolateral saddle.

Discussion: There are many similarities with *T. contractum*, which types are from the much older *Timanites* Zone (UD I-C, high lower Frasnian) of the Canning Basin. The main difference, which leads to an aff. identification, are the narrower A-lobes and ventrolateral saddles of the *contractum* holotype. We currently apply open nomenclature for the younger Boudouda form since the intraspecific variability of the Australian species is not yet established. This is especially relevant for stratigraphically intermediate specimens from middle Frasnian goniatite shales of the Bugle Gap region (sections 365, 367, McWhae Ridge Graben; BECKER & HOUSE 2009). BOGOSLOVSKIY (1971) illustrated typical *T. contractum* from the middle Frasnian of the Timan as "*T. simplex*" (see the *T. contractum* illustrated by BECKER et al. 2000, pl. 2, figs. 5-6).

REGION	Bou	Mr	IdK	Taf	Dra	MN	Büd	RhM	Ard	Eng	App	Tim	RA	CB
T. aequilobum	x						x							
T. contractum Gp.	x	?		x	x	?		x	?	?		x		x
Lobo. hassoni	x				cf.						x			
Lobo. ausavense	x			x	x		x					(str.)		
Crasso. boudoudense n. sp.	x													
Crasso. hetzeneggeri	x						x							
Cost. multiseptatum n. sp.	x													
Aul. auris	x	x		x	x	x	x	x	x	x	x	x		x
Aul. constrictum	x			x			x	x	?	cf.		x		
M. cordatum	x	aff.	x	x		x	x	x	x	x		x		x
M. carinatum	x			x	x		x	x	x			x	x	
Sph. orbiculum	x		x			x	x		x					
Sph. affine	x					x	x	?	x	cf.			?	x
Serr. serratum	x					aff.	x	x	x					x
Trimanticoceras n. sp.	x				cf.			cf.		cf.				cf.
Costam. hybris n. sp.	x			?										?
Ponticeras sp.	x						x	x	x	x				x
"Pont." prumiense	x						x		x	x				x
common species [%]		< 10	?	33	cf. 33	22-33	67	ca. 40	ca. 50	?44	11	ca. 33	<10	40-50

Tab. 2: Distribution of Boudouda ammonoids in other regions. Bou = Boudouda, Mr = Mrirt region, Meseta, IdK = Immouzer-du-Kandar, Middle Atlas basement, Taf = Tafilalt/Maïder, eastern Anti-Atlas, Dra = Tata region, eastern Dra Valley, MN = Montagne Noire, southern France, Büd = Büdesheim, Eifel Mts., Germany, RhM = cephalopod limestone facies of Rhenish Massif, Ard = Ardennes, Eng = Devon/Cornwall, SW England, App = Appalachian Foreland (New York State to West Virginia), Tim = Timan, northern Russia, RA = Rudnyi Altai, southern Siberia, CB = Canning Basin, Western Australia, (str.) = *Lobo. strangulatum*.

species	GMM B6C.54	bed no.	dm	wh	ah	ww	uw	wh/ dm	ww/ wh	uw/ dm	ww/ dm	WER	IZR
T. aequilobum	54-122	16a	12.40	7.84	-	6.49	0.05	0.63	0.83	0.00	0.52	-	-
T. aff. *contractum*	54-132	15a	9.37	5.33	-	-	0.60	0.57	-	0.06	-	-	-
T. aff. *contractum*	54-133	15a	11.83	6.82	-	5.45	0.62	0.58	0.80	0.05	0.46	-	-
Lobo. hassoni	54-61	6a	9.10	5.75	3.37	3.80	0.10	0.63	0.66	0.01	0.42	2.52	0.41
Lobo. hassoni	54-64	-	11.27	6.57	3.90	4.25	0.05	0.58	0.65	0.00	0.38	2.34	0.41
Crasso. boudoudense n. sp. *	54-46	3a	5.80	3.14	1.75	3.15	0.76	0.54	1.00	0.13	0.54	2.05	0.44
Cost. multiseptatum n. sp. *	54-35	4a	9.52	4.75	2.70	4.43	1.10	0.50	0.93	0.12	0.47	1.95	0.43
Cost. multiseptatum n. sp.	54-42	-	8.02	4.01	2.45	3.70	1.20	0.50	0.92	0.15	0.46	2.07	0.39
Cost. multiseptatum n. sp.	54-43	-	5.35	2.66	1.62	2.79	0.96	0.50	1.05	0.18	0.52	2.06	0.39
Aul. auris	54-7	17/18	8.65	4.16	2.60	4.54	1.58	0.48	1.09	0.18	0.52	2.04	0.38
Costam. hybris n. sp. *	54-34	21a	12.5	6.10	5.90	5.93	2.50	0.49	0.97	0.20	0.47	2.47	-
Costam. hybris n. sp. *	54-34	21a	8.63	4.07	3.15	4.17	2.22	0.47	1.02	0.26	0.48	2.48	-
Costam. hybris n. sp. *	54-34	21a	5.35	2.50	2.00	2.81	1.91	0.47	1.12	0.36	0.53	2.55	0.20

Tab. 3: Shell parameters of some Boudouda ammonoids (* = holotype).

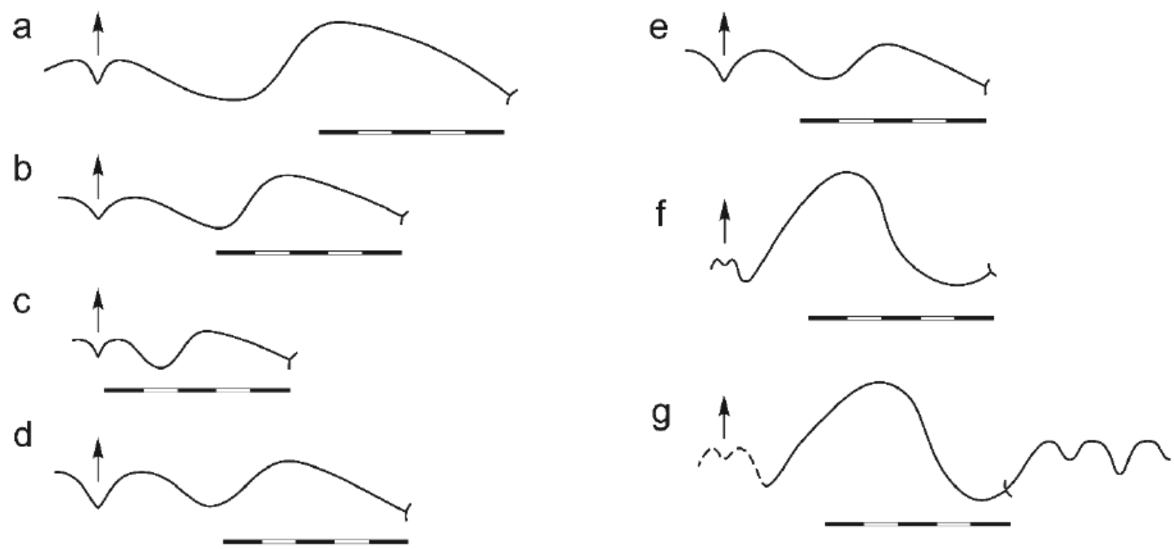

Fig. 7: Sutures of upper Frasnian ammonoids from Boudouda. Scale bar = 2 mm. **a.** *Tornoceras* aff. *contractum*, GMM B6C.54-133, Bed 15a; **b.** *T.* aff. *contractum*, GMM B6C.54-132, Bed 15a; **c.** *Crassotornoceras boudoudense* n. sp., holotype GMM B6C.54-46, Bed 3a; **d.** *Costornoceras multiseptatum* n. gen. n. sp., holotype GMM B6C.54-35, Bed 4a; **e.** *Cost. multiseptatum* n. gen. n. sp., paratype GMM B6C.54-41, Bed 21a; **f.** *Costamanticoceras hybris* n. sp., holotype GMM B6C.54-34, Bed 21a; **g.** *Trimanticoceras* n. sp., GMM B6C.54-152, Bed 14a.

BECKER et al. (2004a) noted previously that close relatives of *T. contractum* range in Morocco into the upper Frasnian.

Genus *Lobotornoceras* SCHINDEWOLF, 1936

***Lobotornoceras ausavense* (STEININGER, 1849)**

Figs. 3i-j, Tabs. 1-2

Discussion: The four available specimens from Boudouda strongly resemble the type material from the Rhenish Massif. As common in the species, varices have variably a slightly biconvex to convex course. The figured specimen displays at the aperture a seventh varix on the last whorl, which is one more than previously known for the taxon. Their spacing is not regular.

***Lobotornoceras hassoni* (HOUSE, 1978)**

Figs. 3k-l, Tabs. 1-3

Discussion: Three ammonoids from Boudouda are assigned to *Lobo. hassoni*, which was so far only known from the lower Frasnian Harrel Shale of the Appalachian Mountains (UD I-C, West Virginia, HOUSE, 1978). Our specimens are identical with the types in terms of suture, strongly compressed conch form, and ornament. The shell parameters (Tab. 3), which are somewhat variable in the holotype (USNM 239891) and best preserved in paratype (USNM 239893), e.g., wh/dm = 0.54 to 0.63, and ww/wh = 0.54 to 0.68, provide no reason for distinction. *Lobotornoceras* aff. *hassoni* described by HOUSE & KIRCHGASSER (2008) from the lower Frasnian West River Shale (UD I-C) of New York State differs in a slight flattening of the venter and subangular ventrolateral shoulders.

The Boudouda record increases significantly the geographical range of *Lobo. hassoni* and expands its stratigraphical range to the upper Frasnian.

Crassotornoceratinae n. subfam.

Diagnosis: Small-sized (micromorphic), shell thinly pachyconic, with rounded flanks and venter, umbilicus narrow but open throughout ontogeny, with or without varices, growth ornament biconvex, with low or high ventrolateral salient, mostly without, rarely with faint ventrolateral furrows. Sutures with moderately wide to narrow, rounded A-lobe and low ventrolateral saddle. Suture formula: EALI or ELI.

Included genera:

Crassotornoceras HOUSE & PRICE, 1985

Retrotornoceras HOUSE, 2002

Costornoceras n. gen.

Discussion: BECKER (1993) subdivided the Tornoceratinae into three tribes, which were elevated by KORN & KLUG (2002) to full subfamilies of the Tornoceratidae. The Tornoceratinae comprise all genera, which are involute after the 2nd whorl and which lack juvenile ventrolateral furrows. The ventrolateral growth line salient, if developed (not in *Domanikoceras*), is normally broad, the venter may be oxyconic, and the L-lobe is subdivided in *Lobotornoceras*. The Falcitornoceratinae are characterized by involute early stages with ventrolateral furrows. A phylogenetic subdivision into genera with undivided (*Phoenixites, Nebechoceras*) and divided L-lobe (*Falcitornoceras, Kourazoceras, Gundolficeras, "G." fezzouense* Group, *Exotornoceras*) is possible. The Aulatornoceratinae include mostly small-sized, open umbilicate genera. Again, there are two groups, the Frasnian and lower Famennian typical forms with projecting, very high ventrolateral salients lying in narrow furrows (*Aulatornoceras, Truyolsoceras, Polonoceras, Immenites*), and mostly middle Famennian genera without prominent salient furrows (*Armatites, Protornoceras, Tornia, Pernoceras, Planitornoceras*).

In this scheme, there is no clear place for the micro- and paedomorphic *Crassotornoceras* and its two related genera, which possess an open but narrow umbilicus and which normally lack a projecting ventrolateral apertural margin stiffened by furrows. Therefore, we introduce for this independent and long-lived side-branch of tornoceratid evolution a new subfamily. It is likely that the Crassotornoceratinae and Aulatornoceratinae have a common paedomorphic ancestor in the lower/middle Frasnian, which Tornoceratidae have hardly been studied.

Stratigraphical range: Middle Frasnian (UD I-E) to high in the lower Famennian (UD II-D).

Geographical distribution: Eastern North America (New York State), North Africa (Moroccan Meseta), Europe (Montagne Noire, Rhenish Massif, Ardennes, South Devon), Western Australia (Canning Basin). Specimens from the Holy Cross Mountains (Poland) identified by DZIK (2002) as "*Aulatornoceras belgicum*" are aulatornoceratids, not *Crasso. belgicum*.

Genus *Crassotornoceras* HOUSE & PRICE, 1985

***Crassotornoceras boudoudense* n. sp.**

Figs. 3e-f, 7c, Tab. 3

Types: Holotype GMM B6C.54-46 (Figs. 3e-f, 7c) is an internal mould displaying well the conch morphology as well as suture and ornament. There are two additional paratypes (GMM B6C.54-47 and 48).

Type level and locality: Type locality of Boudouda Formation, Benahmed region, Bed 3a, UD I-I, local *Aul. auris-Serr. serratum* Zone.

Derivation of Name: After the locality Boudouda.

Diagnosis: Very small-sized, with weakly depressed (ww/wh 1.00 at 5.80 mm dm) and thickly discoidal (ww/dm 0.54 at 5.80 mm dm) whorls, high WER (2.05 at 5.80 mm dm), and narrow umbilicus (uw/dm 0.13 at 5.80 mm dm). Ornament with characteristic, straight ribbing on the lower flanks (7-10 per whorl), broad ocular sinus of growth lines and moderately high, subtriangular ventrolateral salient, which apex lies in incipient furrows. No varices. Sutures with low ventrolateral saddle, shallow, wide A-lobe, and asymmetrically arched, relatively low dorsolateral saddle.

Description: All three specimen share the characteristic ribbing, which are not following the course of the bundled growth lines (Fig. 3f). The broadly rounded venter is smooth, lacking a ventral band (Fig. 3e). Faint, very narrow ventrolateral furrows are best visible in the holotype and connect spirally the apexes of the ventrolateral growth line bundles. They are lacking in paratype GMM B6C.54-48, which also displays a wide subsymmetrical A-lobe. Paratype GMM B6C.54-48 is roughly the same size as the holotype but rather poorly preserved. Nonetheless, it shows an open umbilicus, rounded venter, and lateral ribbing.

Suture differs from that in typical *Crassotornoceras* by a relatively wide A-lobe (Fig. 7c). The ventrolateral saddle is slightly lower than the inner flank saddle:

Discussion: The new species differs from the also ribbed *Crasso. belgicum* MATERN, 1931a by the lack of prominent varices, the incipient ventrolateral furrows, and much wider A-lobe. *Crassotornoceras nudum* lacks any ornament (ribbing and furrows), while *Crasso. hetzeneggeri* differs by its thicker conch (ww/wh ca. 1.30 at 5.80 mm dm) and lack of ventrolateral furrows (see below). *Crassotornoceras* aff. *belgicum* sensu SÖTE et al. (2021) resembles *Crasso. boudoudense* n. sp. in the combination of weak furrows and dorsolateral folds but has a markedly different suture, with higher suture relief, a low but rounded ventrolateral saddle, and smaller A-lobe. Furthermore, it possesses a higher whorl expansion rate at the same size (2.38 versus 2.05) and ventral varices. The ribbed lower Famennian *Crasso. isolatum* BECKER, 1993 has rursiradiate inner flank folds, a narrower venter, and sutures with higher relief.

Species, such as *Crasso. boudoudense* n. sp. and *Crasso*. aff. *belgicum*, lack the ventral band of *Aulatornoceras* but their faint ventrolateral furrows support the idea that both paedomorphic genera had a common origin.

Geographic and stratigraphic range: Restricted to lower parts of the upper Frasnian (UD I-I) of the west-central Moroccan Meseta.

Crassotornoceras hetzeneggeri **SÖTE, BECKER, HERD & BOCKWINKEL, 2021**

Figs. 3g-h, Tabs. 1-2

Discussion: Four Boudouda goniatites assigned to *Crasso. hetzeneggeri* show the faint, undulose ribbing on the inner flanks (Fig. 3g), the rounded, thick conch, a lack of varices, and a punctiform umbilicus, as in the type material from the Rhenish Massif. The typical crassotornoceratid suture with a low ventrolateral saddle and small A-lobe is present. *Crassotornoceras boudoudense* n. sp. is easy to distinguish by its incipient ventrolateral furrows and different, straight dorsolateral ribs. All other Frasnian *Crassotornoceras* species either possess prominent varices (e.g., *Crasso. crassum*, *Crasso. belgicum*, *Crasso. anissi*) or differ in terms of conch morphology and ornament (*Crasso. nudum*).

Costornoceras **n. gen.**

Derivation of name: After the characteristic ribbing.

Type species: *Costornoceras multiseptatum* n. sp.

Diagnosis: Small-sized (micromorphic), with compressed (from ca. 5 mm dm on), moderately high whorls, small open umbilicus, and towards maturity with increasingly regular, dense, biconvex flank ribbing characterized by a low ventrolateral salient. Suture with small, v-shaped ventral lobe, low ventrolateral saddle, wide, rounded A-lobe, and asymmetric, low ventrolateral saddle. Suture formula: EALI.

Discussion: The ontogenetically increasing prominent ribbing of the outer flanks separates the new genus from most other genera of the Tornoceratinae. Similar ribbing characterizes in the lower Famennian the two genera *Falcitornoceras* House & Price, 1985 and *Kourazoceras* Becker in Becker et al. (2002). The first has marked juvenile falcate ribs with high, narrowly triangular ventrolateral projection, lying often in spiral furrows. The second is strongly paedomorphic (as *Costornoceras* n. gen.) and develops regular ribs with low ventrolateral salient at maturity (at only ca. 10 mm dm). Both genera have closed umbilici and divided L-lobes, as typical for advanced Falcitornoceratinae.

Costornoceras n. gen. is closely related to *Crassotornoceras* but differs by its biconvex ribbing combined with a low ventrolateral salient and early ontogenetic shell compression.

Geographic and stratigraphic range: Restricted to lower parts of the upper Frasnian (UD I-I) of the west-central Moroccan Meseta.

***Costornoceras multiseptatum* n. gen. n. sp.**

Figs. 3m-p, 7d-e, Tab. 3

Types: Holotype GMM B6C.54-35 (Figs. 3m-n), a well-preserved internal mould showing all features. There are eleven paratypes (GMM B6C.54-36–45; see Appendix).

Type locality and level: Type locality of Boudouda Formation, Benahmed region, Bed 4a, UD I-I, local *Aul. auris-Serr. serratum* Zone.

Derivation of name: After the dense septal spacing.

Diagnosis: Very small-sized, whorls weakly depressed before 5-6 mm dm, afterwards weakly compressed, thickly discoidal (ww/dm slightly decreasing from 0.55 at 5 mm dm to 0.47 at 9.50 mm dm), moderately to fast expanding (WER = 1.90-2.10), in early ontogeny subinvolute (uw/dm = ca. 0.20 at 5 mm dm), later involute (uw/dm ca. 0.10 at 10 mm dm); with characteristic, densely spaced ribs on the outer flank half, following the biconvex growth lines, and with a low ventrolateral salient. Sutures with dense spacing, broad and moderately high, asymmetrically rounded dorsolateral saddle, widely rounded A-lobe, small, rounded and low ventrolateral saddle, and v-shaped E-lobe.

Description: The species is paedomorphic. The maximum known diameter is seen in the holotype at ca. 9.5 mm dm (Tab. 3). It features the most prominent ribs (ca. 25) on the last half whorl. Smaller specimens, such as paratype GMM B6C.54-42 (Figs. 3o-p), have visible but more undulose ribs. The ontogenetic change to prominent ribs starts around 5 mm dm. One specimen displays weak spiral depressions on the outer flank, outside the ventrolateral salient. Every specimen features dense sutural-spacing ranging between 30 to 40 sutures per whorl (compare Figs. 3n-o). At very small size, the ventrolateral saddle is almost flat. The uw/dm ratio decreases during ontogeny while the whorl expansion fluctuates around 2.0.

Discussion: The ribbing type is very different in some *Crassotornoceras* species. They display widely spaced minor folds restricted to the subumbilical area (*Crasso. boudoudense* n. sp., *Crasso. isolatum*), not on the outer flanks, often not in parallel with the growth ornament, or in conjunction with varices (*Crasso. belgicum*). All Frasnian *Crassotornoceras* species with marked dorsolateral folds display high, projecting ventrolateral salients of the ornament.

Geographic and stratigraphic range: As for the genus.

Subfamily Aulatornoceratinae KORN & KLUG, 2002

Genus *Aulatornoceras* SCHINDEWOLF, 1922

***Aulatornoceras auris* (QUENSTEDT, 1849)**

Figs. 4a-b, Tabs. 1-2

Discussion: The eight specimens assigned to *Aul. auris* belong to a morphotype with only weakly developed growth line bundles on the flank (Fig. 4b) and ventral festoons (Fig. 4a). In the Rhenish Massif, at Büdesheim, morphotypes with both weak or strong bundles and ventral band are abundant. Apart from this feature, the suture, ornament and conch morphology of the Boudouda specimens are identical. Previously, no Moroccan *Aul. auris* has been illustrated.

***Aulatornoceras constrictum* (STEININGER, 1849)**

Figs. 4c-d, Tabs. 1-2

Discussion: Characteristic are the regularly-spaced strong varices, narrow and strong ventrolateral furrows (Fig. 4c), and the weak ventral band (Fig. 4d). All six specimens from Boudouda are identical to material from the German type region (see SÖTE et al. 2021).

***Aulatornoceras* sp.**

Fig. 4o, Tab. 1

Discussion: There is one fragment, which resembles *Aul. auris*, especially in its strongly bundled flank ornament, but it seems to lack a ventral band. This feature is typical for the lower Famennian genus *Truyolsoceras* MONTESINOS, 1988, which, however, is also characterized by regular ventral ribbing (see revision by BECKER, 1993). Since there is only one small fragment, since the ventral part is not preserved well enough, and since all Boudouda aulatornoceratids have weak ventral bands, we allocate the specimen to *Aulatornoceras* in open nomenclature.

Suborder Gephuroceratina RUZHENCEV, 1957

Superfamily Gephuroceratoidea FRECH, 1897

Family Gephuroceratidae FRECH, 1897

Subfamily Trimanticoceratinae KORN in KORN & KLUG, 2002

Genus *Costamanticoceras* BECKER & HOUSE, 1993

***Costamanticoceras hybris* n. sp.**

Figs. 4m-n, 7f, Tabs. 1-3

Derivation of name: After the hybrid morphology of early and median ontogenetic stages.

Types: Only holotype GMM B6C.54-34.

Type level and locality: Type locality of Boudouda Formation, Benahmed region, Bed 21a, UD I-J, *M. carinatum* Zone.

Diagnosis: Early whorls between ca. 2.5 and 3.5 mm dm depressed, subevolute, and with dense, biconvex ribbing on the flanks and venter, apart from a smooth mid-ventral zone, subsequently without ribbing, whorls very high (WER = ca. 2.5), increasingly subinvolute and weakly compressed (uw/dm = 0.20 and ww/wh = 0.97 at 12.5 mm dm), tegoid, with narrowly rounded venter. Sutures with a relatively wide, subsymmetric ventrolateral saddle, rounded L-lobe and well-developed U-lobe of early stages.

Description: The only available specimen shows the early ontogeny and different median stage. The exposed inner whorl between ca. 2.5 and 3.5 mm dm bears ca. 15 dense, rounded, biconvex flank ribs (per half whorl) with a broad ventrolateral salient. Ribs and interspaces are equally wide; the ribs do not cross the mid-ventral field (Fig. 3n). They disappear rapidly until 5 mm dm, where the conch is still subevolute (uw/dm = ca. 0.35, Tab. 3) and depressed (ww/wh = 1.12). Later whorls become subinvolute, weakly compressed, with well-rounded, tegoid cross-section. The whorl expansion is very high (WER = ca. 2.5) from early on. The septal face at ca. 5.5 mm dm shows a rather deep and rounded, internal U-lobe and broad flank saddle (Figs. 4n, 6f). On the last preserved whorl, the latter become subsymmetric and moderately high (Fig. 4n).

Discussion: The regular ribbing at small size suggests that the new species belongs to *Costamanticoceras*. Typical species of the genus, however, retain ribbed and subevolute stages much longer during ontogeny. Since the ribs are rounded, not thin and sharp, the Boudouda form does not belong to *Gephyroceras* (compare the revision of North American typical species by HOUSE & KIRCHGASSER 2008).

Our new Boudouda form is isolated in terms of morphology and palaeogeography, which justifies to name it. It is not close to the *Costamanticoceras* illustrated from Immouzer-du-Kandar in ABOUSSALAM et al. (2020); this form is a more typical *Costamanticoceras*. A single *Costam*. cf. *nodulosum* from the Tafilalt mentioned by BECKER & HOUSE (2000b, p. 54) also refers to the typical group around the type-species.

Geographic and stratigraphic range: Restricted to type level and locality.

Genus *Trimanticoceras* HOUSE in HOUSE & ZIEGLER, 1977

***Trimanticoceras* n. sp.**

Figs. 5a-b, 7h, Tabs. 1-2

Description: Three small whorl fragments from Beds 14a and 15a are characterized by subinvolute, moderately high, very weakly depressed (ww/wh = 1.03), well-rounded, tegoid whorls. Most distinctive are strongly biconvex, undulose growth lines with a projecting ventrolateral salient delimited by spiral double furrows. The outer furrow is narrow and more distinctive. On the broadly rounded venter, a weak ventral band is developed. The adapical septal face of GMM B6C.54-152 shows a rounded L-Lobe, asymmetric, moderately wide and high ventrolateral saddle, a deep, asymmetrically pointed E-lobe, and low median saddle (Fig. 7h).

Discussion: So far, there are only two valid species in *Trimanticoceras*, the rather evolute *Tri. cinctum* (GLENISTER, 1958), the generotype from the Canning Basin and Germany (BECKER & HOUSE 1993), and the very poorly known, more compressed *Tri. retrorsum* (von BUCH, 1832) from Martenberg, Germany, which type (selected by WEDEKIND 1913a, p. 54) has never been illustrated and probably been lost. Based on very early juvenile furrows documented by CLAUSEN (1969) in Büdesheim specimens (not in type material), BECKER & HOUSE (2009) re-assigned *M. bullatum* WEDEKIND, 1913a to *Trimanticoceras*. However, it is now known that juvenile *Sphaeromanticoceras* s.str. are characterized by this feature (see BECKER & HOUSE 1994a; SÖTE et al. 2021).

The Boudouda specimens do not belong to either of the two named species, due to the double furrows and ventral band alone. BECKER et al. (1993) and BECKER & HOUSE (2009) listed several new trimanticoceratids from Western Australia. Since we only have fragments from Boudouda, it is better to leave them in open nomenclature until the general knowledge of the genus is improved.

Geographic and stratigraphic range: Restricted to lower parts of the upper Frasnian (UD I-J, *M. carinatum* Zone) of the west-central Moroccan Meseta.

4.2. Gastropoda

Family uncertain

***Goniphilus* n. gen.**

Derivation of name: After the regular co-occurrence with goniatites in hypoxic goniatite shale facies.

Type-species: *G. delicatulus* n. sp.

Other species: *Natica ausavensis* STEININGER, 1953, other un-named species, such as the lower Famennian "*Platyostoma* aff. *lineata*" sensu JUX & KRATH (1974), possibly also *Diaphorostoma (Naticopsis) rotundata* CLARKE, 1904 from the Angola Shale (lower part of upper Frasnian) of New York State.

Diagnosis: Small-sized, thin-shelled, with three whorls at maturity; whorls very fast expanding, low- to slightly inverse-spired, laterally inflated, apex region plain or slightly inserted (heterostrophic), umbilicus very deep and narrow, peristome subcircular to oval. First whorl gyroconic (open), with protoconch not overlapping the second whorl. Delicate ornament consisting of arched, biconvex growth lirae and non-bifurcating ribs are always impressed on internal moulds.

Discussion: The new genus forms a well-defined group of morphologically similar species that are restricted to pelagic ammonoid facies. *Goniphilus* n. gen. differs from the platyceratid *Platyostoma* in smaller size, with a lower number of even lower spired whorls. In *Platystoma*, the apex and first whorls are standing out in apertural view. In *Goniphilus* n. gen., the first whorl may be even "inserted" into the later ones, giving a slight heterostrophic coiling (Figs. 5g-h). The protoconch and perforate first whorl are not cyrtoneritimorph as in various Palaeozoic platyceratids (FRÝDA et al. 2009) but resemble that in some euomphalids (see BANDEL & FRÝDA 1998). PAECKELMANN (1913) had placed STEININGER´s species in *Platyceras*, which we do not agree with based on the early ontogeny alone.

The much younger (Triassic) genus *Planospirina* KITTL, 1899 shows a somewhat similar shell whorl form but is thick-shelled, larger, lacks ribbing or sharp growth lirae, and also the well-developed lateral sinus of the ornament.

Stratigraphic and geographical range: Upper Frasnian (UD I-I) to lower Famennian (ca. UD II-D) of Germany, the Montagne Noire (juveniles, BECKER 1993), eastern North America, and the Moroccan Meseta.

***Goniphilus delicatulus* n. sp.**

Figs. 5j-m, 8

Types: Holotype GMM B6B.11-1, paratypes GMM B6B.11-2 and 3.

Derivation of name: After the delicate ribbing.

Type level and locality: Type locality of Boudouda Formation, Benahmed region, Bed 18a, UD I-J, *M. carinatum* Zone.

Diagnosis: Small-sized, low, fast expanding whorls (WER in apical view = ca. 4.2) with short, steep-sided, subangular sutures, ovoid aperture, and fine, rursiradiate, biconvex, non-bifurcating ribs (ca. 45 on last whorl) consisting of bundled growth lirae.

Description: The holotype is the largest specimen with a diameter of near 10 mm and three completed whorls. The paratypes are slightly smaller or incomplete, and several other fragments do not suggest that the species reached larger size. The whorls increase apically measured (Fig. 5j) fast in width but remain low. At the fully rounded aperture, whorl height and width are similar. The "umbilical width" of the apical view is 25-27 % of the dm. On the underside, the umbilicus is very deep and narrow (ca. 15 % dm in paratype GMM B6B.11-3). The early whorls and apex are hardly visible in lateral or apertural view (Figs. 5l-m). The first whorl leaves a minor apical opening but the minute protoconch does not touch or overlap the second whorl (Fig. 8).

The delicate and regular ribs consist of bundled, fine growth lirae that are partly also recognizable in the rib interspaces. They run undivided all around the whorl and consist typically of one strong lira bordered by two smaller lirae. They begin ca. after the first half whorl and increase in strength with growth. On the upper whorl they are strongly convex (Fig. 5j), form a broad sinus on the flanks (Fig.

5m), followed by a wide salient that runs into the umbilicus (Fig. 5k). Since all specimens are internal moulds, it is remarkable that finest ornament details are preserved. Based on the width of the whorl sutures interspace (Fig. 8), the probably aragonitic adult shell was not more than 0.2 mm thick.

Fig. 8: Apical view of the holotype of *Goniphilus delicatulus* n. gen. n. sp. (GMM B6B.11-1), showing the perforate coiling and onset of ornament of the first whorl. Whorl sutures were originally filled by shell but leave an open apex in the center.

Fig. 9: Apical view of the topotype (potential neotype) of *Goniphilus ausavensis* n. gen. (STEININGER, 1853) from Büdesheim (GMM B6B.11-6), showing the perforate coiling and onset of ornament of the first whorl. Whorl sutures were originally filled by shell but leave an open apex in the center.

Discussion: Based on the examination of several topotypes (Figs. 5g-i, 9), *G. ausavensis* n. gen. from Büdesheim is similar but differs in more undulose, less sharply defined ribs, and convexly rounded, not flattened upper whorl sides. Consequently, the whorl sutures lie beneath rounded whorl shoulders (Fig. 5h). In addition, the first whorl sits in a lower position than the second one (in a minor depression), causing incipient heterostrophy (Fig. 5g). The first whorl seems to be slightly larger (Fig. 9) than in *G. delicatulus* n. gen. n. sp. (Fig. 8) but the open coiling is very similar. The still un-named lower Famennian species of the Knoppenbissen Formation ("*Platyostoma* aff. *lineata* sensu JUX & KRATH, 1974) and Nehden Goniatite Shale (Nehden Formation, BECKER et al. 2016) is characterized by fine reticulate ornament, featuring numerous longitudinal lirae. *Diarophostoma (Naticopsis) rotundatum* CLARKE, 1904 comes from upper Frasnians shales with goniatites (Angola Shale) of New York State. It differs from both *G. delicatulus* n. gen. n. sp. and *G. ausavensis* n. gen. in more globose, evenly rounded whorls, only very weak ribbing restricted to the outer whorl margin, and an apex of the first whorls that slightly stands out.

Stratigraphical and geographical range: Restricted to the lower part of upper Frasnian (UD I-I/J) of the west-central Meseta.

Appendix:

Boudouda Frasnian fossil specimen list (* = holotypes)

„Pont.“ prumiense	Fr-15a	B6C.54-1
„Pont.“ prumiense	Fr-25	B6C.54-2
Aulatornoceras sp.	Fr-17a	B6C.54-3
Aul. auris	Fr-02a	B6C.54-4
Aul. auris	Fr-13a	B6C.54-5
Aul. auris	Fr-15a	B6C.54-6
Aul. auris	Fr-17a	B6C.54-7
Aul. auris	Fr-17a	B6C.54-8
Aul. auris	Fr-17a	B6C.54-9
Aul. auris	loose	B6C.54-10
Aul. auris	loose	B6C.54-11
Aul. constrictum	Fr-13a	B6C.54-12
Aul. constrictum	Fr-21a	B6C.54-13

Aul. constrictum	Fr-21a	B6C.54-14	*M. carinatum*	Fr-23a	B6C.54-70
Aul. constrictum	Fr-25	B6C.54-15	*M. carinatum*	Fr-15a	B6C.54-71
Aul. constrictum	loose	B6C.54-16	*M. carinatum*	loose	B6C.54-72
Aul. constrictum	loose	B6C.54-17	*M. carinatum*	loose	B6C.54-73
Bac. anellus	Fr-21a	B6C.54-18	*M. cordatum*	Fr-17a	B6C.54-74
Bac. anellus	Fr-21a	B6C.54-19	*M. cordatum*	Fr-20a	B6C.54-75
Bac. anellus	Fr-23a	B6C.54-20	*M. cordatum*	Fr-25	B6C.54-76
Bac. anellus	loose	B6C.54-21	*M. cordatum*	Fr-25	B6C.54-77
Bac. anellus	loose	B6C.54-22	*M. cordatum*	Fr-13a	B6C.54-78
Bac. declivis	Fr-15a	B6C.54-23	*M. cordatum*	Fr-13a	B6C.54-79
Bac. declivis	Fr-15a	B6C.54-24	*M. cordatum*	Fr-13a	B6C.54-80
Bac. declivis	Fr-15a	B6C.54-25	*M. cordatum*	Fr-13a	B6C.54-81
Bac. declivis	Fr-15a	B6C.54-26	*M. cordatum*	Fr-15a	B6C.54-82
Bac. declivis	Fr-18a	B6C.54-27	*M. cordatum*	Fr-17a	B6C.54-83
Bac. declivis	Fr-18a	B6C.54-28	*Manticoceras* sp.	Fr-05a	B6C.54-84
Bac. declivis	Fr-18a	B6C.54-29	*Manticoceras* sp.	Fr-05a	B6C.54-85
Bac. declivis	Fr-18a	B6C.54-30	*Manticoceras* sp.	Fr-18a	B6C.54-86
Bac. declivis	Fr-18a	B6C.54-31	*Manticoceras* sp.	Fr-25	B6C.54-87
Bactrites sp.	Fr-20a	B6C.54-32	*Manticoceras* sp.	loose	B6C.54-88
Bactrites sp.	Fr-20a	B6C.54-33	*Ponticeras* sp.	Fr-17a	B6C.54-89
Costam. hybris n. sp. *	Fr-21a	B6C.54-34	*Ponticeras* sp.	Fr-19a	B6C.54-90
Cost. multiseptatum n. sp. *	Fr-04a	B6C.54-35	*Serr. serratum*	Fr-03a	B6C.54-91
Cost. multiseptatum n. sp.	Fr-13a	B6C.54-36	*Serr. serratum*	loose	B6C.54-92
Cost. multiseptatum n. sp.	Fr-15a	B6C.54-37	*Sph. affine*	Fr-03a	B6C.54-93
Cost. multiseptatum n. sp.	Fr-17a	B6C.54-38	*Sph. affine*	Fr-04a	B6C.54-94
Cost. multiseptatum n. sp.	Fr-17a	B6C.54-39	*Sph. affine*	Fr-05a	B6C.54-95
Cost. multiseptatum n. sp.	Fr-20a	B6C.54-40	*Sph. affine*	Fr-06a	B6C.54-96
Cost. multiseptatum n. sp.	Fr-21a	B6C.54-41	*Sph. affine*	Fr-08a	B6C.54-97
Cost. multiseptatum n. sp.	loose	B6C.54-42	*Sph. affine*	Fr-08a	B6C.54-98
Cost. multiseptatum n. sp.	loose	B6C.54-43	*Sph. affine*	Fr-15a	B6C.54-99
Cost. multiseptatum n. sp.	loose	B6C.54-44	*Sph. affine*	Fr-15a	B6C.54-100
Cost. multiseptatum n. sp.	loose	B6C.54-45	*Sph. affine*	Fr-15a	B6C.54-101
Crasso. boudoudense n. sp. *	Fr-03a	B6C.54-46	*Sph. affine*	Fr-17a	B6C.54-102
Crasso. boudoudense n. sp.	Fr-13a	B6C.54-47	*Sph. affine*	Fr-20a	B6C.54-103
Crasso. boudoudense n. sp.	loose	B6C.54-48	*Sph. affine*	Fr-23a	B6C.54-104
Crasso. hetzeneggeri	Fr-09a	B6C.54-49	*Sph. affine*	loose	B6C.54-105
Crasso. hetzeneggeri	Fr-15a	B6C.54-50	*Sph. orbiculum*	Fr-02a	B6C.54-106
Crasso. hetzeneggeri	Fr-15a	B6C.54-51	*Sph. orbiculum*	Fr-02a	B6C.54-107
Crassotornoceras sp.	Fr-15a	B6C.54-52	*Sph. orbiculum*	Fr-02a	B6C.54-108
Lobobactrites sp.	Fr-15a	B6C.54-53	*Sph. orbiculum*	Fr-15a	B6C.54-109
Lobobactrites sp.	Fr-15a	B6C.54-54	*Sph. orbiculum*	Fr-16a	B6C.54-110
Lobobactrites sp.	Fr-15a	B6C.54-55	*Sph. orbiculum*	Fr-17a	B6C.54-111
Lobobac. timanicus	Fr-19a	B6C.54-56	*Sph. orbiculum*	Fr-17a	B6C.54-112
Lobo. ausavense	Fr-03a	B6C.54-57	*Sph. orbiculum*	Fr-17a	B6C.54-113
Lobo. ausavense	Fr-04a	B6C.54-58	*Sph. orbiculum*	Fr-20a	B6C.54-114
Lobo. ausavense	Fr-04a	B6C.54-59	*Sph. orbiculum*	Fr-20a	B6C.54-115
Lobo. ausavense	loose	B6C.54-60	*Sph. orbiculum*	Fr-20a	B6C.54-116
Lobo. hassoni	Fr-06a	B6C.54-61	*Sph. orbiculum*	loose	B6C.54-117
Lobo. hassoni	Fr-23a	B6C.54-62	*T. aequilobum*	Fr-03a	B6C.54-118
Lobo. hassoni	Fr-25	B6C.54-63	*T. aequilobum*	Fr-14a	B6C.54-119
Lobo. hassoni	loose	B6C.54-64	*T. aequilobum*	Fr-15a	B6C.54-120
Lobo. hassoni	loose	B6C.54-65	*T. aequilobum*	Fr-15a	B6C.54-121
M. carinatum	Fr-14a	B6C.54-66	*T. aequilobum*	Fr-16a	B6C.54-122
M. carinatum	Fr-15a	B6C.54-67	*T. aequilobum*	Fr-17a	B6C.54-123
M. carinatum	Fr-23a	B6C.54-68	*T. aequilobum*	Fr-19a	B6C.54-124
M. carinatum	Fr-23a	B6C.54-69	*T. aequilobum*	Fr-23a	B6C.54-125

T. aequilobum	loose	B6C.54-126	*Tornoceras* sp.	Fr-06a	B6C.54-145
T. aequilobum	loose	B6C.54-127	*Tornoceras* sp.	Fr-13a	B6C.54-146
T. aequilobum	loose	B6C.54-128	*Tornoceras* sp.	Fr-15a	B6C.54-147
T. aequilobum	Fr-13a	B6C.54-129	*Tornoceras* sp.	Fr-16a	B6C.54-148
T. aequilobum	Fr-13a	B6C.54-130	*Tornoceras* sp.	Fr-13a	B6C.54-149
T. aequilobum	Fr-13a	B6C.54-131	*Tornoceras* sp.	Fr-13a	B6C.54-150
T. aff. *contractum*	Fr-15a	B6C.54-132	*Tornoceras* sp.	Fr-13a	B6C.54-151
T. aff. *contractum*	Fr-15a	B6C.54-133	*Trimanticoceras* n. sp.	Fr-14a	B6C.54-152
T. aff. *contractum*	Fr-15a	B6C.54-134	*Trimanticoceras* n. sp.	Fr-15a	B6C.54-153
T. aff. *contractum*	Fr-15a	B6C.54-135	*Trimanticoceras* n. sp.	Fr-15a	B6C.54-154
T. aff. *contractum*	Fr-16a	B6C.54-136	athyridid sp.	Fr-2a	B5B.16-1
T. aff. *contractum*	Fr-20a	B6C.54-137	*Glyptohallicardia palmata*	Fr-5a	B6A.37-1
T. aff. *contractum*	loose	B6C.54-138	*Goniphilus delicatulus* n. sp. *	Fr-18a	B6B.11-1
T. aff. *contractum*	loose	B6C.54-139	*Goniphilus delicatulus* n. sp.	Fr-3a	B6B.11-2
T. aff. *contractum*	loose	B6C.54-140	*Goniphilus delicatulus* n. sp.	loose	B6B.11-3
T. aff. *contractum*	Fr-09a	B6C.54-141	*Goniphilus delicatulus* n. sp.	Fr-4a	B6B.11-4
T. aff. *contractum*	Fr-14a	B6C.54-142	*Goniphilus delicatulus* n. sp.	Fr-16a	B6B.11-5
T. aff. *contractum*	Fr-14a	B6C.54-143	*Goniphilus ausavensis* (topotype)	Büd	B6B.11-6
Tornoceras sp.	Fr-15a	B6C.54-144	*Goniphilus ausavensis* (topotype)	Büd	B6B.11-7

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

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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 Palaeobereselliidae). 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.

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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 = N33º10'43.7", W7º15'46.4"). 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.

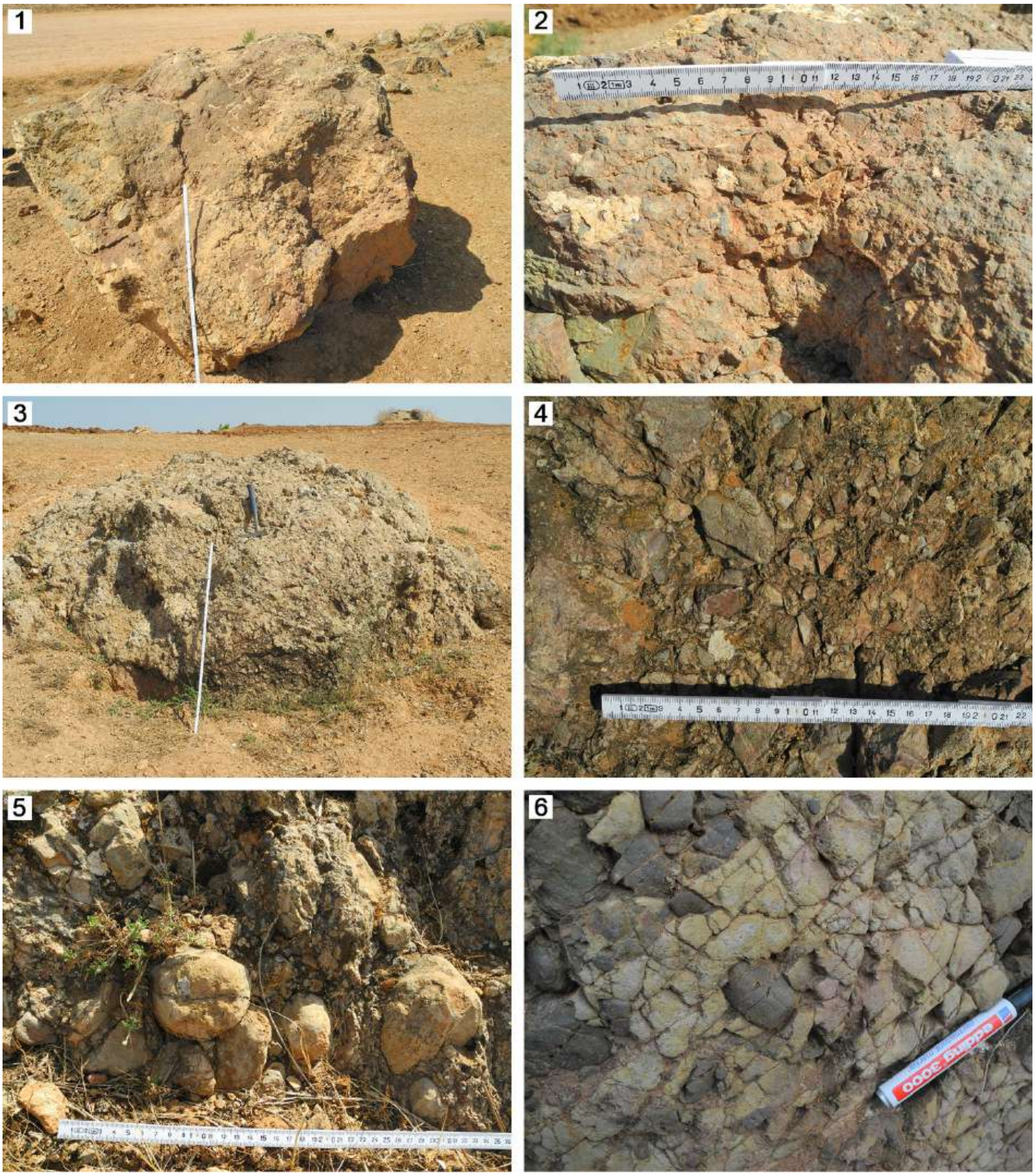

Fig. 3: Field photos of the Conglomerate Member of the new Oued Ayada Formation at Boudouda. **1.** Strongly dolomitized Block 1; **2.** Nodular, yellowish to orange weathering Block 2 with cm-sized subangular pebbles; **3.** Overview of massive Block 2, composed of mostly small-sized pebbles; **4.** 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.

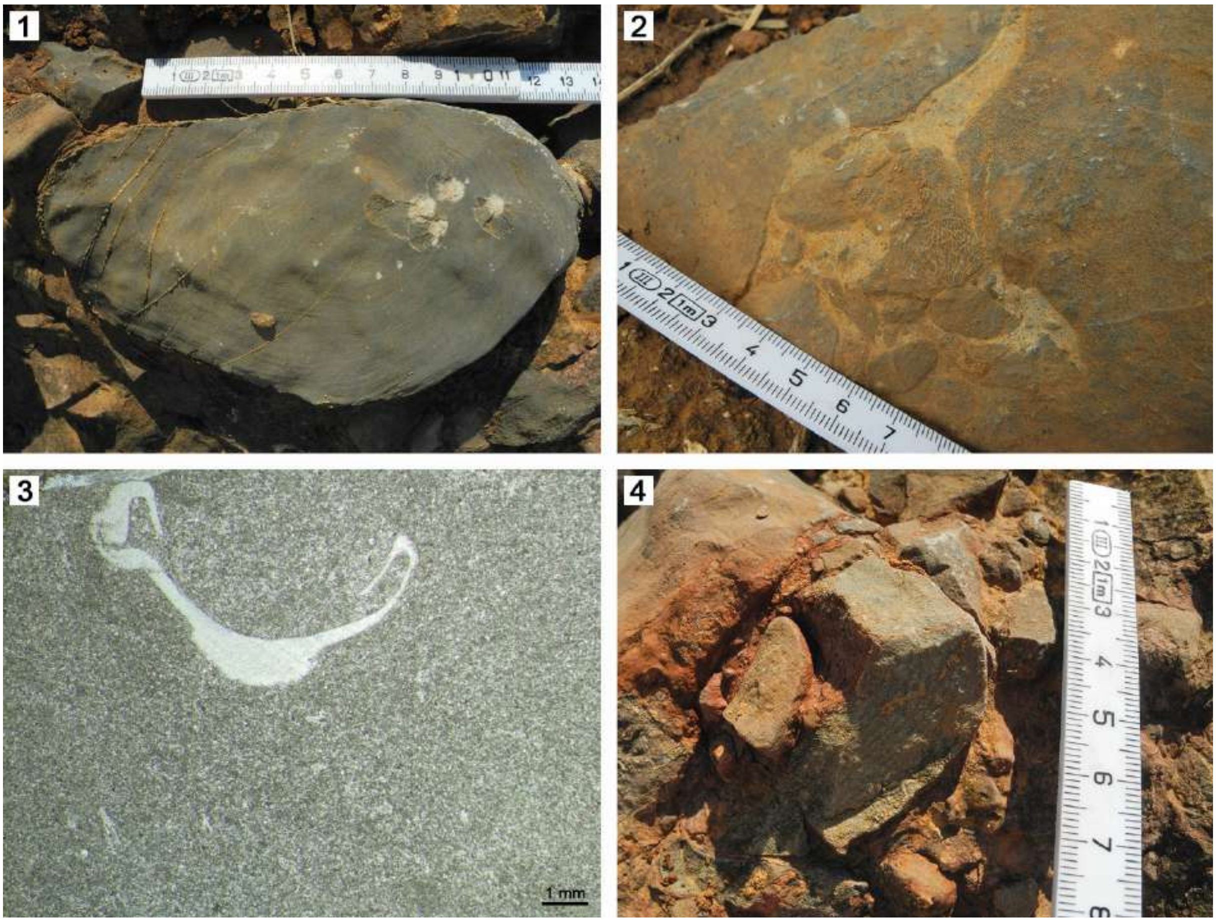

Fig. 4: Shallow-water Devonian fauna observed in the Viséan conglomerate boulders at Boudouda. **1.** Large, complete stromatopore; **2.** Favositid coral (center) lying adjacent to a large stromatopore (right); **3.** Thin-section of a mudstone pebble with the complete cross-section of a trilobite;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

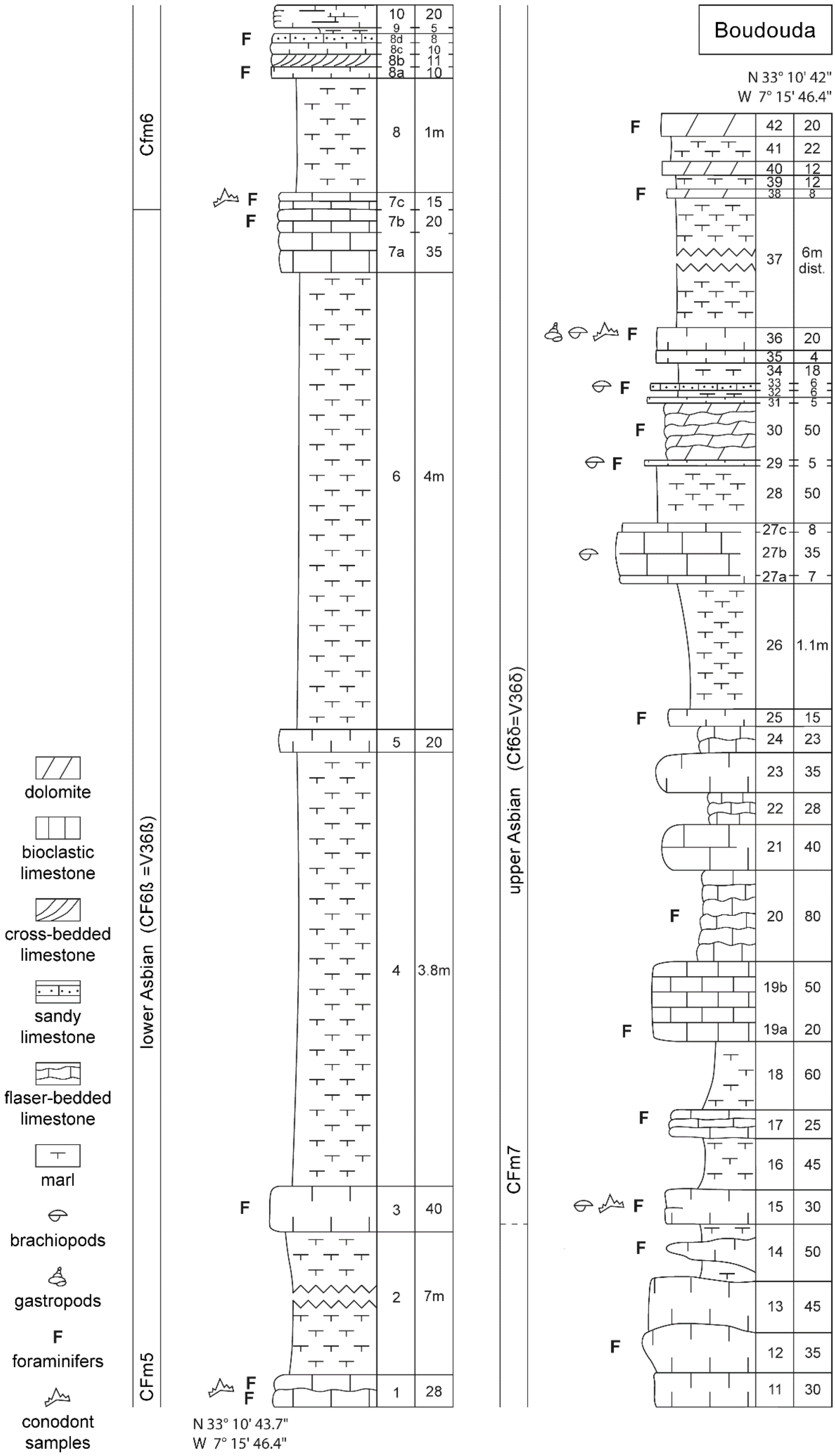

Fig. 5: Section log for the Bioclastic Limestone Member of the new Oued Ayada Formation at Boudouda, showing the position of conodont samples and foraminifer beds (thicknesses in cm if not stated otherwise).

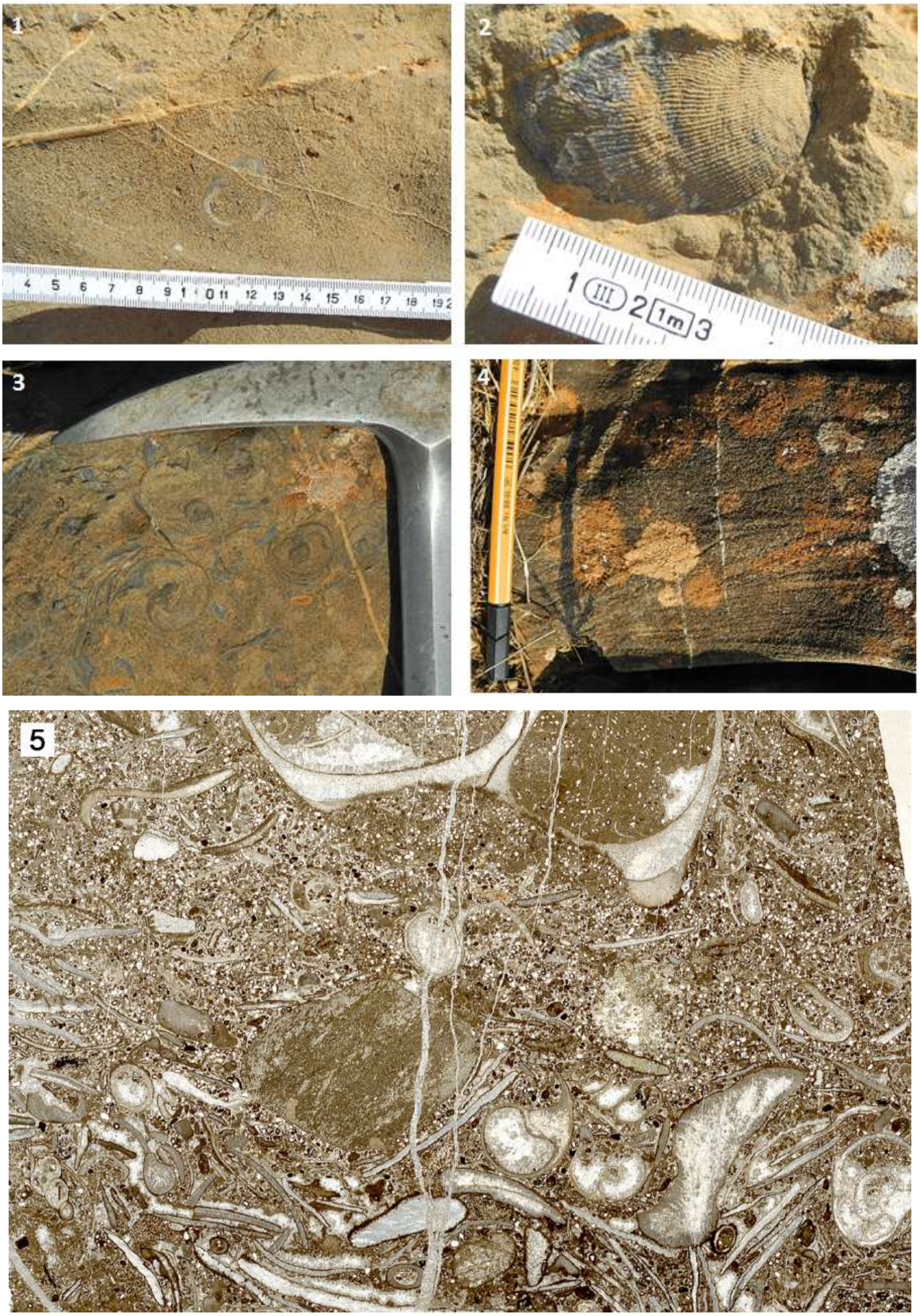

Fig. 6: Sedimentary and faunal characteristic of the Bioclastic Limestone Member (Oued Ayada Formation) at Boudouda. **1.** Fine-grained crinoidal limestone with brachiopod cross-section, Bed 27b; **2.** Detail of near-complete productid brachiopod, Bed 27b; **3.** Gastropod-rich limestone with fragmentary 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).

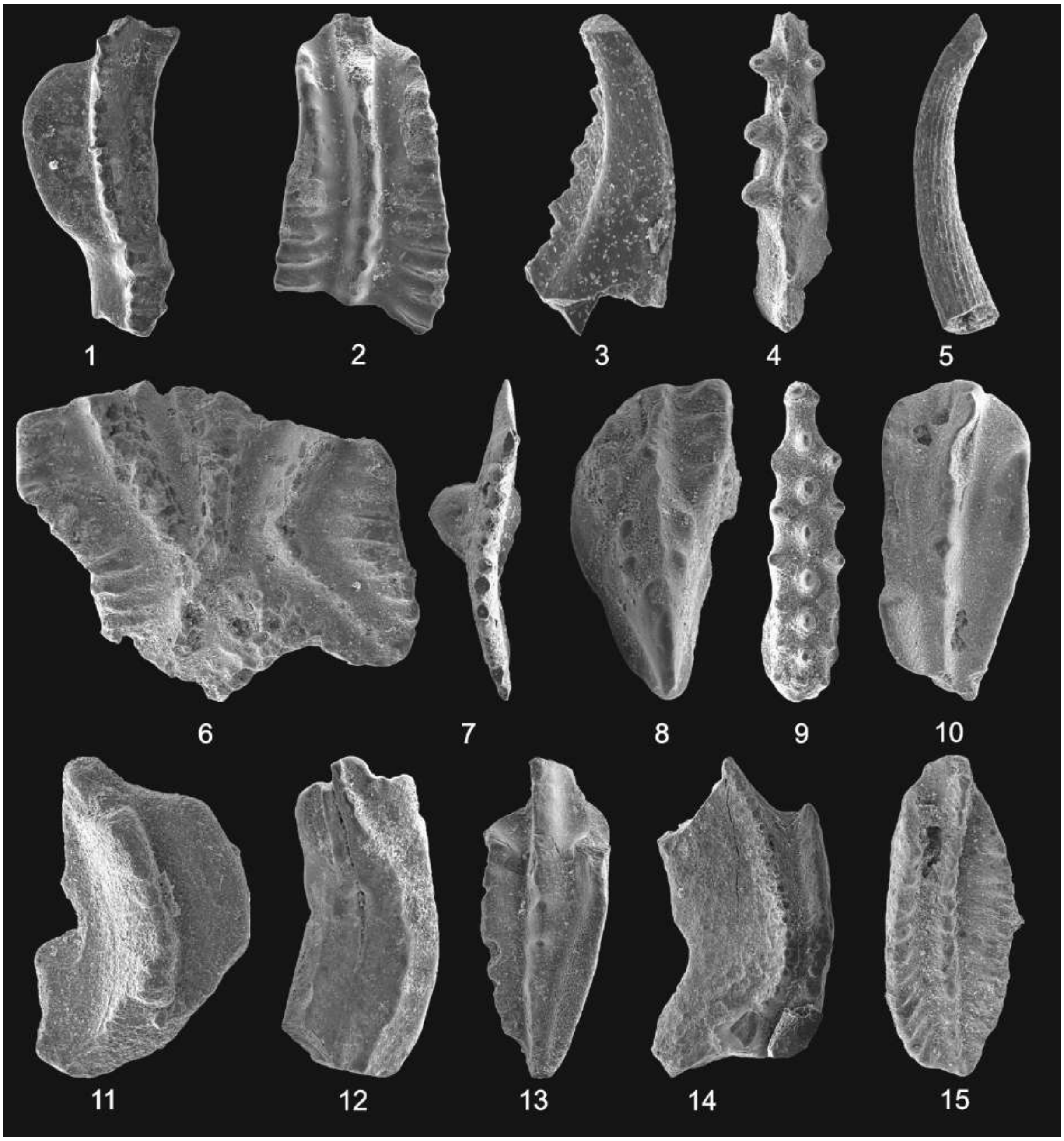

Fig. 7: Reworked Frasnian to Tournaisian conodonts from the Viséan Oued Ayada Formation at Boudouda (1-2 from conglomerate Block 1, 3-5 from conglomerate Block 2, 6 from Bed 1, 7-12 from Bed 7c, 13-15 from Bed 15, 16-18 from Bed 36), GMM B4C.2.93-107. **1.** *Palmatolepis glabra prima*, incomplete specimen 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.

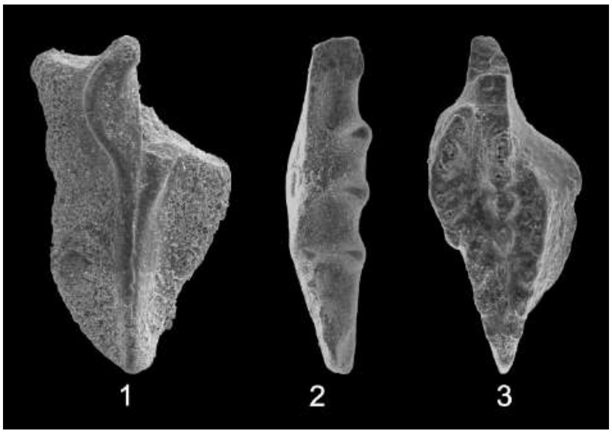

Fig. 8: Reworked conodonts from Boudouda, Bed 36, GMM B7A.12.108-110. **1.** *Pseudopolygnathus* sp., aboral view showing the wide basal pit, x 90; **2.** *Bispathodus aculeatus aculeatus*, x 80; **3.** *Gnathodus delicatus*, x 85.

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.

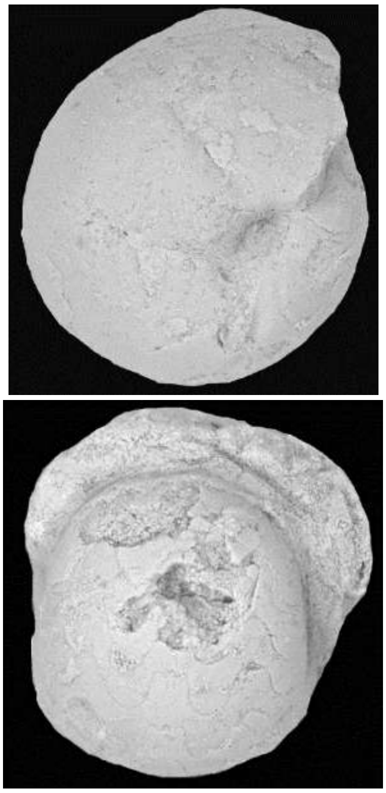

Fig. 9: Involute and globular, slightly deformed juvenile (4.8 mm diameter) goniatite (*?Eurites* sp.) with sutures as in upper Tournaisian/lower Viséan forms, found loose in scree of the upper Frasnian Boudouda Formation, lateral and adoral views, showing the subdivided E-lobe, GMM B6C.54.182.

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)

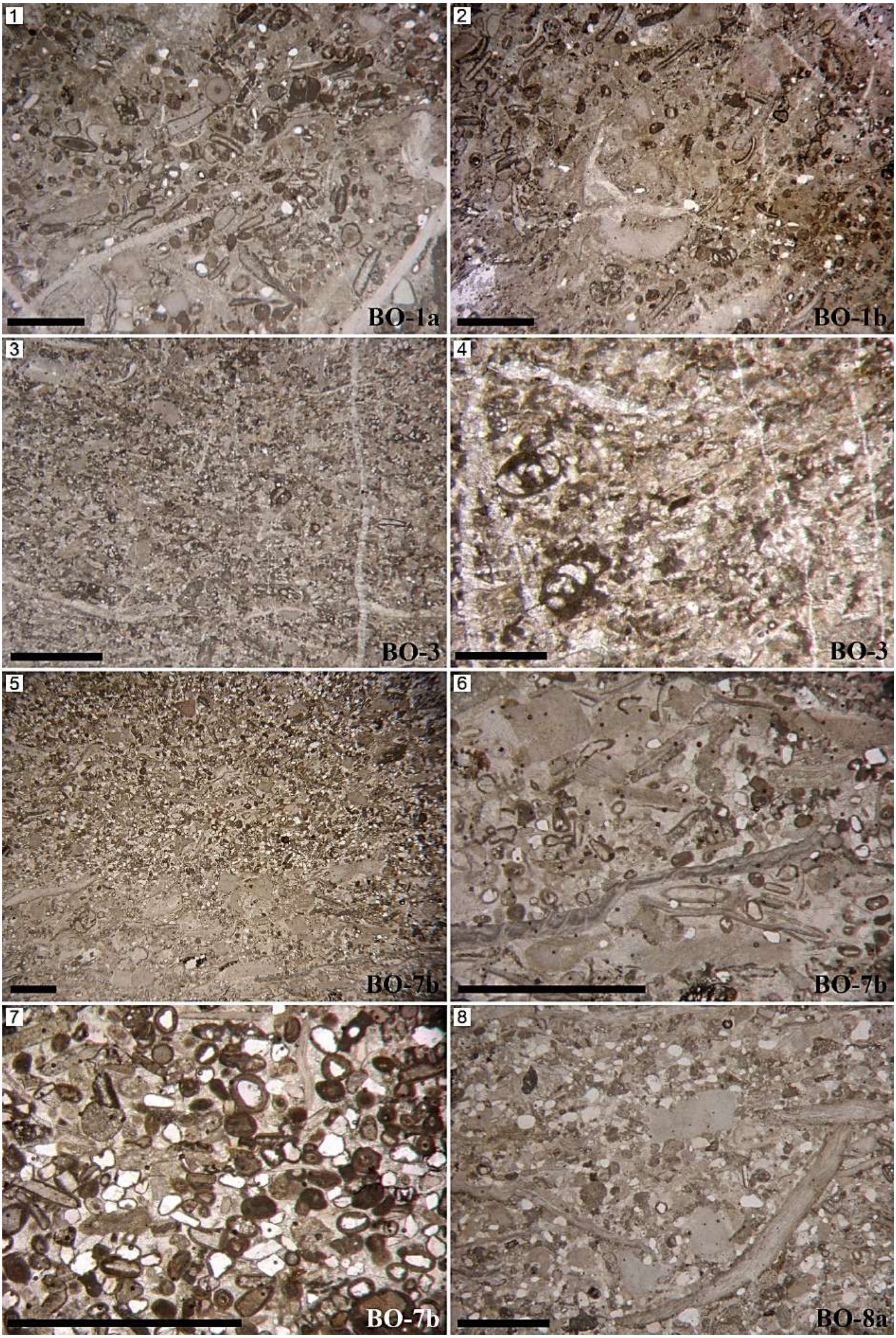

Fig. 10

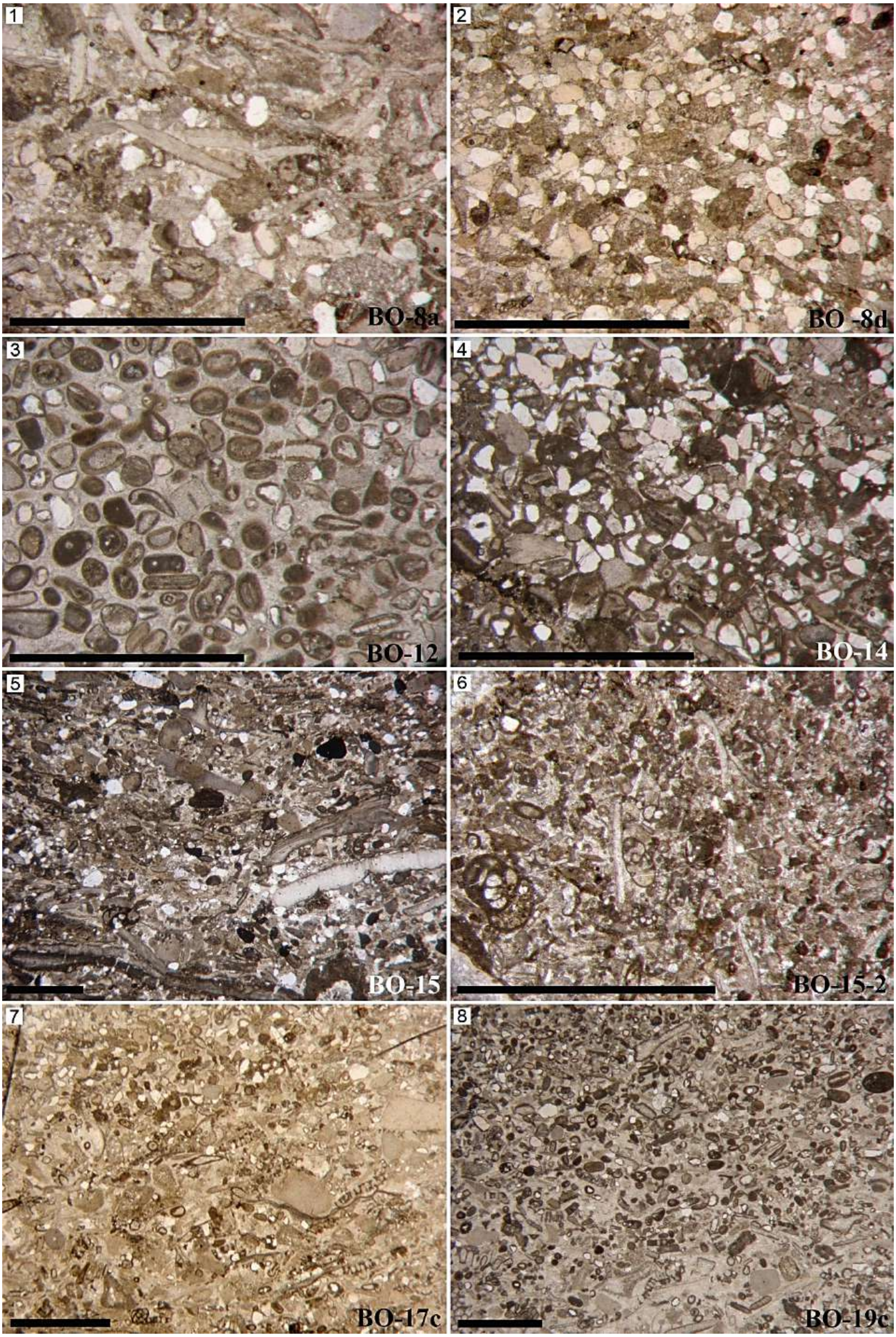

Fig. 11

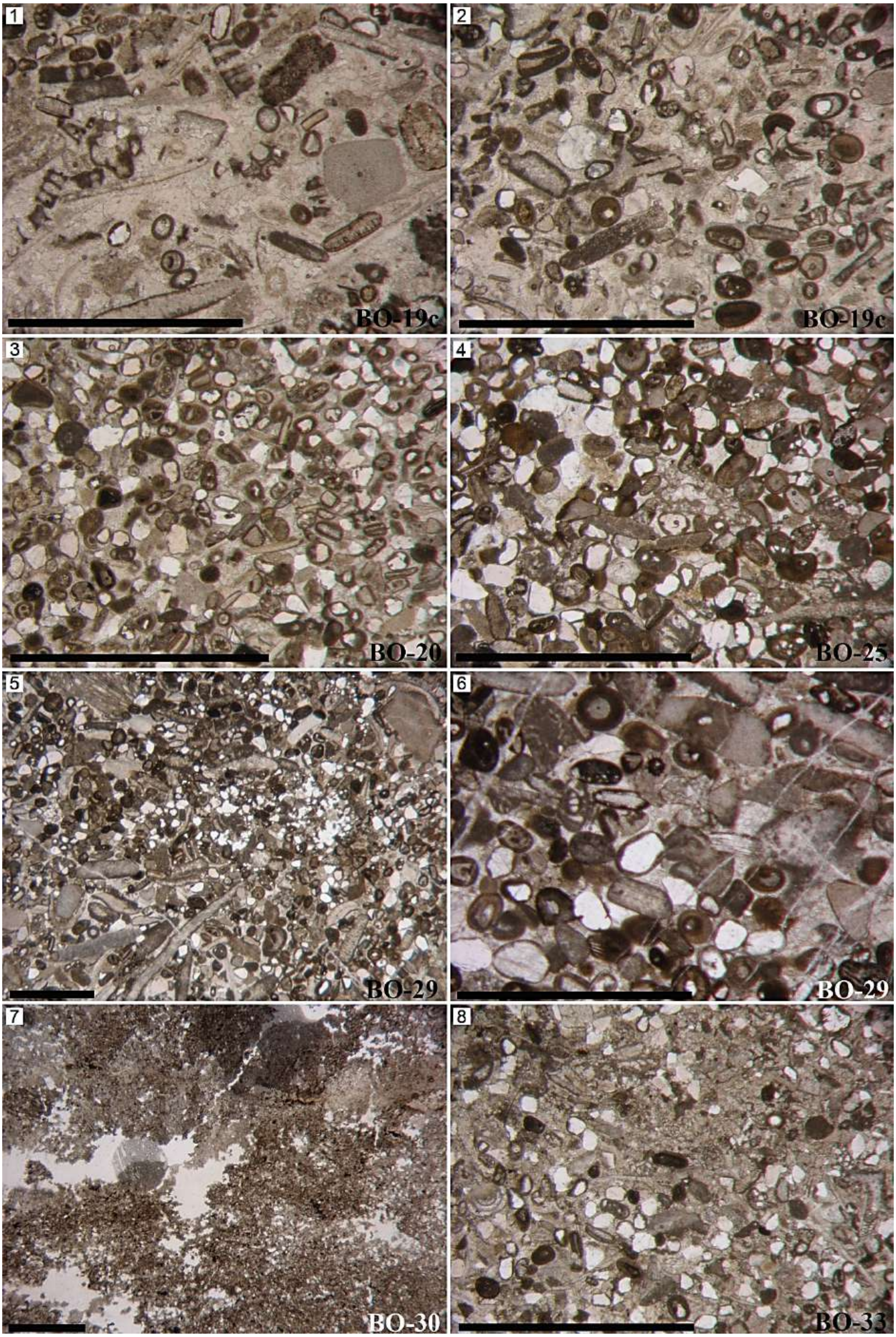

Fig. 12

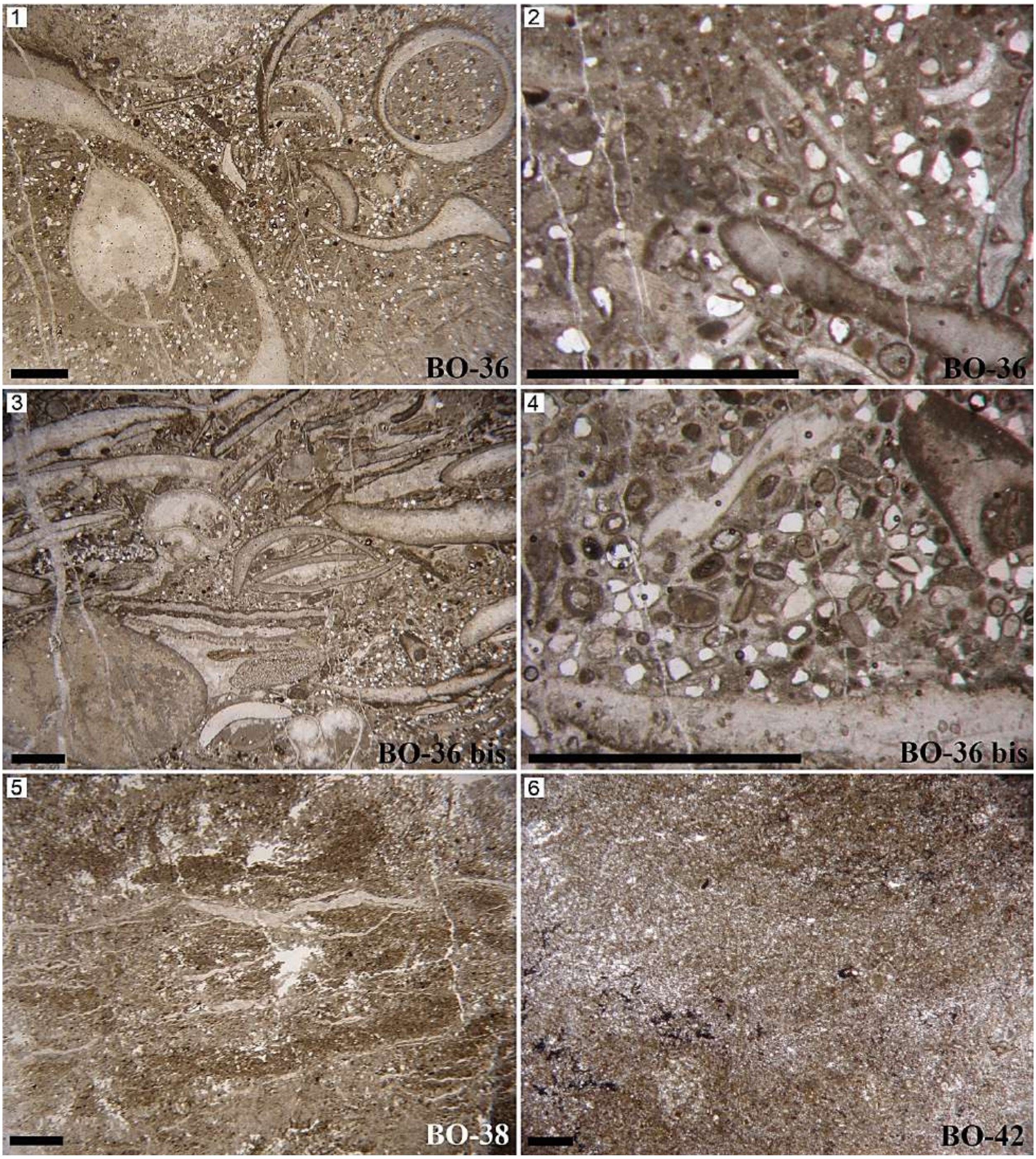

Fig. 13: Microfacies of Bioclastic Limestone Member, Oued Ayada Formation, at Boudouda, scale bar = 1 mm, part IV. **1.** Gastropod-brachiopod-extraclast floatstone with complete (bivalved) and incomplete shells; **2.** matrix of Bed 36, showing poor sorting of small bioclasts, some coated grains, abundant, 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).

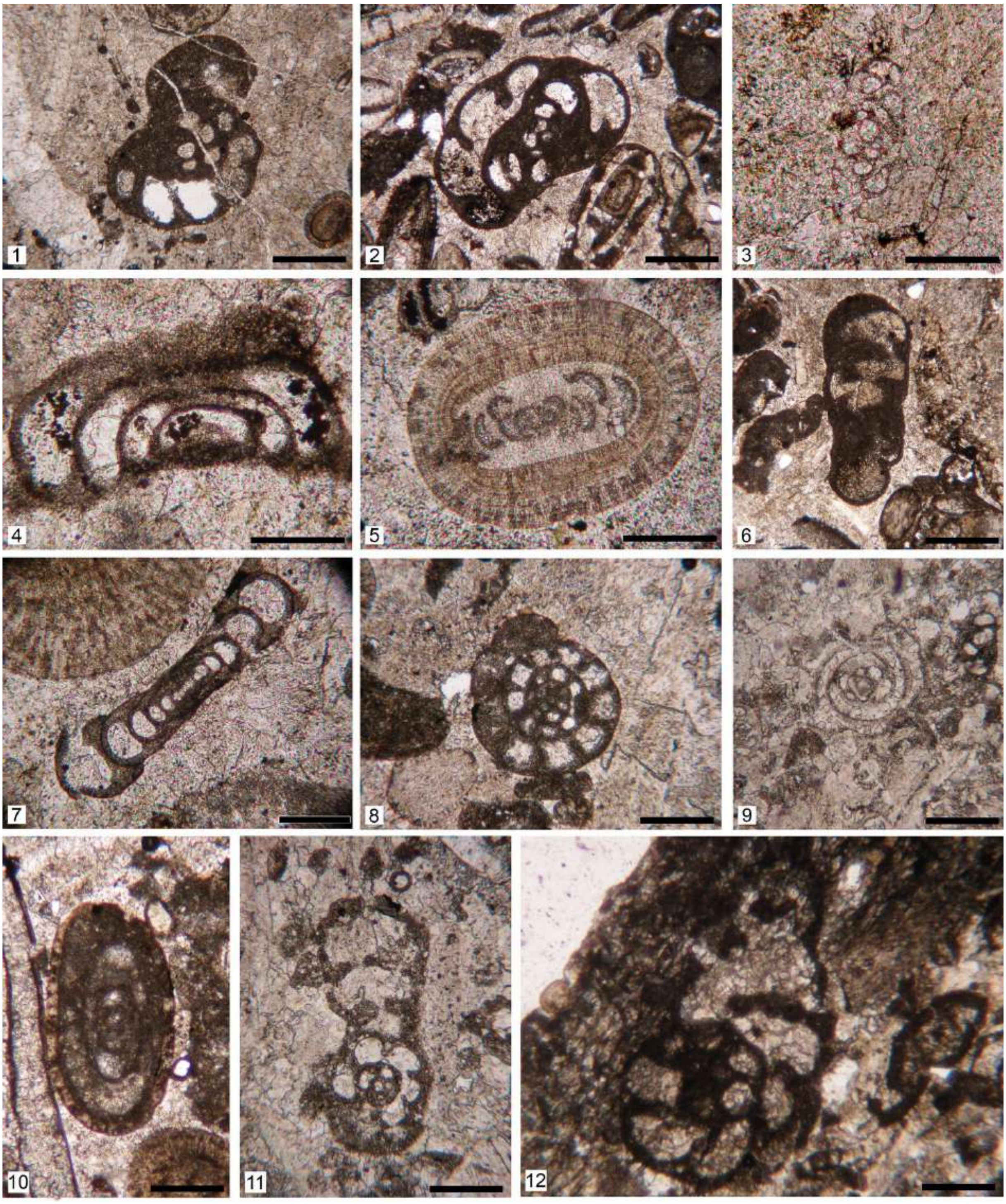

Fig. 14: Selected foraminifers from Beds 1 (1−8) to 3 (9−12) of the Bioclastic Limestone Member (Oued Ayada Formation) at Boudouda; scale bar for figures 1, 2, 6 = 400 microns, for figures 3, 4, 5, 7 = 100 microns, and for figures 8 to 12 = 200 microns. **1**. *Endothyranopsis compressa* transitional 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.

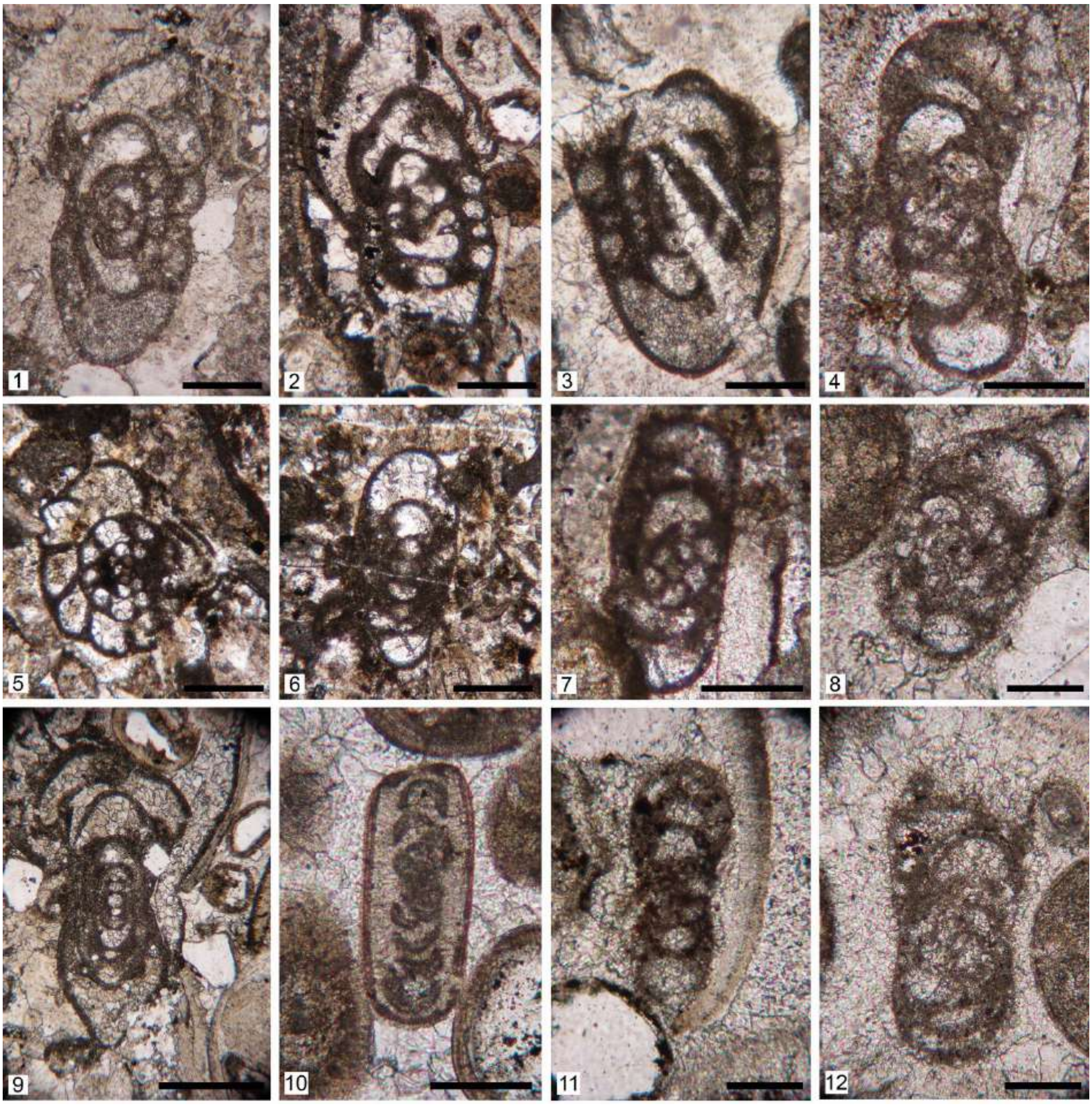

Fig. 15: Selected foraminifers from the Bioclastic Limestone Member (Oued Ayada Formation) at Boudouda; scale bar for figures 1−3, 5−6, 9 = 200 microns, and for figures 4, 7−8, 10−12 = 100 microns. **1**. *Pseudoendothyra* aff. *sublimis*, Bed 7; **2**. *Eostaffella parastruvei*, Bed 7; **3**. *Eostaffella* 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.

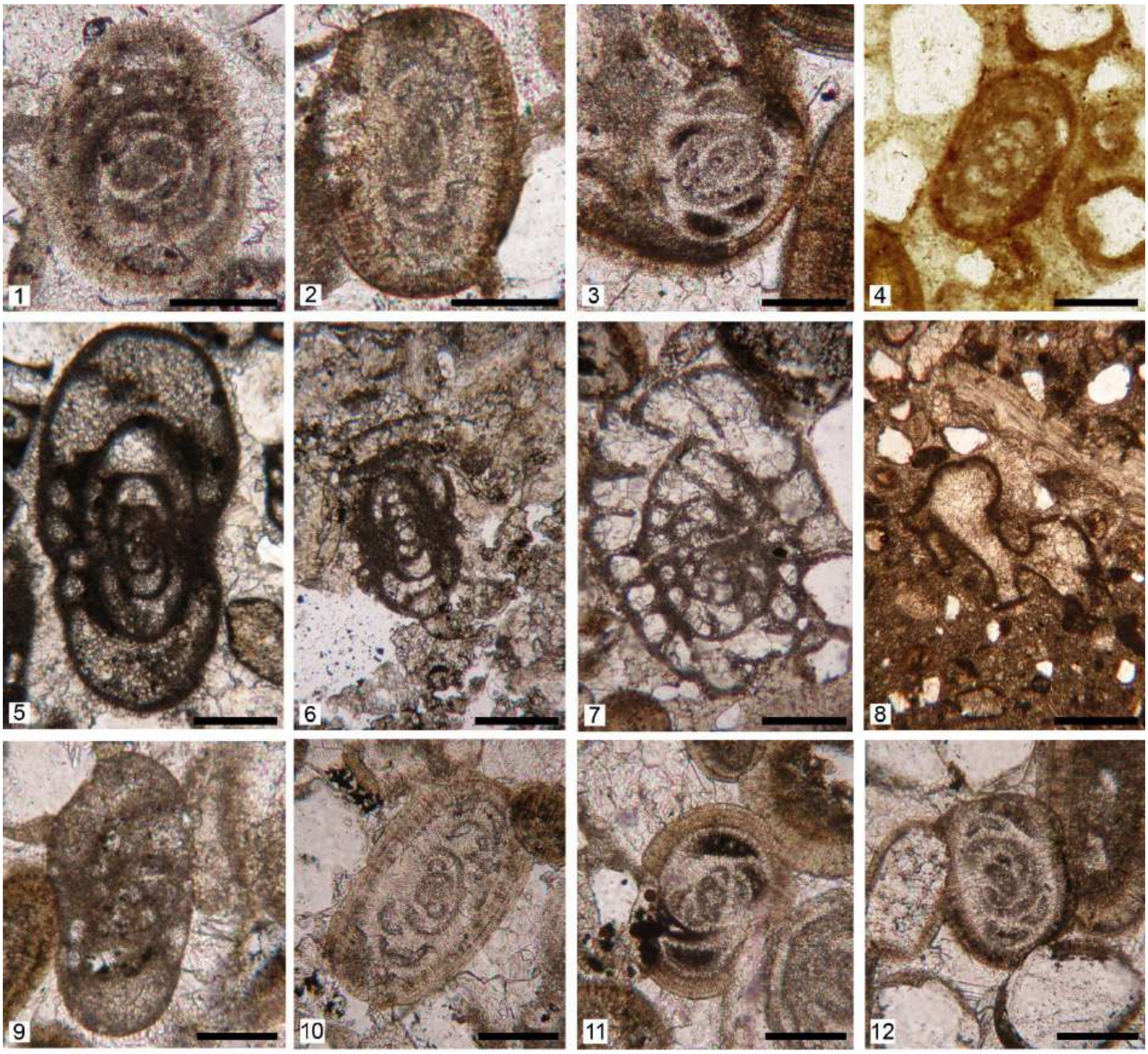

Fig. 16: Selected foraminifers from the Bioclastic Limestone Member (1-8) and Conglomerate Member (9-12) of the Oued Ayada Formation at Boudouda; scale bar for figures 1−2, 4, 9−12 = 100 microns, for figures 3, 5−7 = 200 microns and for figure 8 = 400 microns. **1**. *Archaediscus* sp. at *angulatus* 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)

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Devonian of the Mechra Ben Abbou region (Rehamna) – new data on the reef succession, microfacies, stratigraphy, and palaeogeography

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Fig. 1: View from the top of the Givetian limestone cliff at Sidi bou Talaa on the meandering Oum Er Rbia, which cuts off the outcrop at the eastern end.

Summary. The Devonian of the northeastern Rehmna, from Mechra Ben Abbou in the NW to the area north of Aïn el Melah in the southeast, has been dealt with in numerous publications and theses, but the precise ages, sedimentology, and terminology of numerous lithostratigraphic units were far from being resolved. Based on sampling for conodonts, brachiopods, other macrofauna, and microfacies, we report some progress. At Sakhrat et Taïra in the SE, a new shallow-water faunule with *Howellella* cf. *mercurii* confirms that significant synsedimentary block movements occurred locally in the lower Lochkovian. It is followed by a level with limestone turbidites and hostile shelf basin facies before quartzites indicate regression. The facies development differs clearly from the Lochkovian of Koudiat ed Diab in the north. The Pragian and Emsian of the whole region is characterized by neritic, storm-influenced, non-reefal shelf successions. This includes in the NE the Emsian Oued Kibane Formation, which may range just into the lower Eifelian. But the Foum el Mejez region lacks so far evidence of undoubted Middle Devonian fossils. The Middle Devonian Mechra Ben Abbou Formation is defined as a compact succession of shallow-water limestones. It is subdivided into the thin- to medium-bedded, upper Emsian to middle Eifelian, mostly crinoidal Bouchhada Member, the cherty and bioclastic upper Eifelian or lower Givetian Koudiat El Gara Member, and the lower/middle Givetian, massive, reefal Sidi bou Talaa

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Member. At Sidi bou Talaa, the latter is assigned to four facies assemblages: reef core limestone, seismically induced inner platform reef breccias, fenestral limestones, and thin-bedded lagoonal limestones. 38 species of reef builders (tabulate corals, chaetetids, stromatoporids, calcimicrobes) are regionally identified, 17 of them for the first time in Morocco. Due to regional uplift, non-deposition, condensation or reworking, there is no in-situ Rehamna record of upper Givetian and Frasnian strata. The silty-sandy middle part of the Oued Ater Member of the Foum el Mejez Formation yielded a new middle Famennian brachiopod fauna. It represents a fault-controlled narrow basin with prodelta facies and high subsidence that has no equivalents anywhere else in the Rehamna. At Gare Mechra Ben Abbou, the Givetian reef limestone was erosionally truncated in the upper Famennian, with stromatolite encrustations, karstification, and breccia formation by rockfall, followed by quartzites with *Mesoplica praelonga* coquinas. This Douar Nahilat Formation correlates with the quartzites of the Dalaa Member of the Foum el Mejez region to the east. A survey of the clast spectrum in the at least 500 m thick reddish breccia at Koudiat ed Diab yielded limited evidence for a Givetian and upper Frasnian age of eroded reefal limestone. Carboniferous clasts are rare but a brachiopod-bryozoan pebble with *Rhabdomeson* suggests that a part of the regional upper Viséan carbonate platform was reworked, too. This supports the long assumed post-orogenic age of the thick unit that represents massive rockfall talus after the main Variscan relief had formed.

1. Introduction

The Rehamna is an important but complex Palaeozoic massif in the SW of the Western Meseta, extending for more than 80 km in W-E and for more than 60 km in N-S direction, ending slightly more than 100 km to the south of Casablanca. Following a famous monograph edited by A. Michard in 1982, recent attention has been on the tectono-metamorphic evolution of the strongly deformed southern part (e.g., Chopin et al., 2014; Wernert et al. 2016). For Devonian palaeontologists and stratigraphers, the much less tectonized northern part, from Mechra Ben Abbou in the central north to Foum-el-Mejez in the northeast, and to the area north of the El Massira dam in the southeast (Fig. 2), is of much higher interest. This "Rehamna septentrionaux" lies east of the Western Meseta Shear Zone, which separates the Western Rehamna in the south (Pique et al. 1980).

After the pioneer explorations of Termier (1928, 1931), Delepine & Yovanovitch (1938), and Le Maître (1938), and early work by Gigout (1951, 1955a) and Gendrot (1973), Hollard et al. (1982) established the principle Palaeozoic stratigraphy of the region. Subsequently, the Devonian was studied intensively in the frame of Ph.D. theses, such as Rais-Assa (1984), Ben Bouziane (1995), and El Kamel (2004). These studies investigated many Palaeozoic sections, their sedimentology and structural geology, resulting in thorough cross-sections and reconstructions of the tectono-sedimentary history. However, there was little progress concerning biostratigraphy and the precise dating of facies changes. The available carbonate microfacies descriptions do not follow modern standard terminology and many identifications of neritic (brachiopods, trilobites) or reefal fauna (corals, stromatoporids) are now outdated and require revision.

In the frame of our overall refinements and reviews of Meseta biostratigraphy, facies, palaeogeography, and synsedimenatry tectonism, our work in the Rehamna concentrated on a few chosen representative sections and topics. These are a new approach to reef microfacies near Mechra Ben Abbou (Sidi bou Talaa and Gare Mechra Ben Abbou), including revised identifications of reef builders, revised dating of the Foum-el-

Mejez Devonian, attempts to improve the Lower Devonian stratigraphy at Sakhrat et Taïra (localities of EL KAMEL et al. 1992), and a preliminary inventory of reworked pre-Variscan clasts in the supposed post-Variscan conglomerate at Koudiat ed Diab. We are well aware that there is great potential for further investigations but available results, based on short field seasons from 2012 to 2018, are significant enough to combine them in this state-of-the-art chapter.

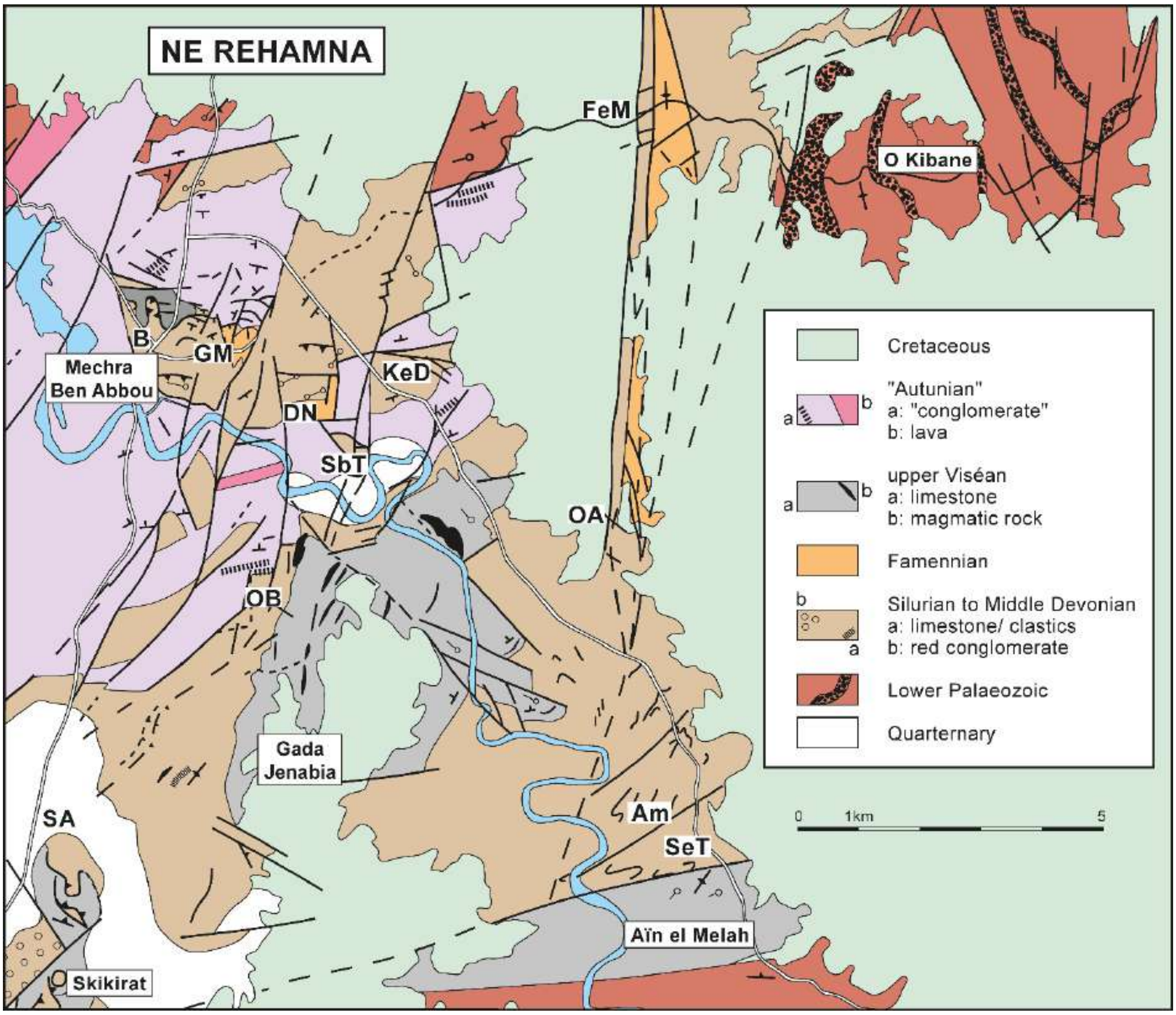


Fig. 2: Simplified geological map of the northeastern Rehamna, showing the position of studied or mentioned successions and localities. B = Bouchhada; DN = Douar Nahilat, FeM = Foum el Mejez, GM = Gare Mechra Ben Abbou, KeD = Koudiat ed Diab, OA = Ouled el Abid/Oued Ater, OB = Ouled Barka, SA = Sidi Abdallah, SbT = Sidi bou Talaa, SeT = Sakhrat et Taïra (re-drawn from MICHARD, Ed., 1982, fig. 32).

2. Devonian Research History of the northern Rehamna

TERMIER (1928, 1931, 1936): First investigations of the Palaeozoic of the Mechra Ben Abbou region.

DELEPINE & YOVANOVITCH (1938): Brief note on the discovery of Givetian reef limestone and Famennian quartzites at Mechra Ben Abbou.

LE MAÎTRE (1938): Note on Devonian limestone localities of the Mechra Ben Abbou region, with a record of upper Emsian brachiopods (*Euryspirifer paradoxus*) at the Oued Kibane, and Eifelian beds with *Calceola sandalina*, scutelluids and phacopids near the Gare Mechra Ben Abbou.

RICHTER & RICHTER (1943): Description of a Givetian "*Scutellum* cf. *costatum*" from Gare Mechra Ben Abbou.

LE MÂITRE (1947): Description of Eifelian rugose corals from Mechra Ben Abbou, including *"Schizophyllum" acanthicum* and (type locality) *Heliophyllum moghrabiense*.

ROCH (1950): Summary of the known evidence at the time, giving faunal examples for the recognized stages.

RICHTER & RICHTER (1950): Description of the Givetian proetid trilobite *Dechenella (Dechenella) gigouti* from a quarry (probably Bouchhada) at Mechra Ben Abbou.

GIGOUT (1951, 1955a, 1955b, 1956): Geological studies in the Rehamna with a detailed investigation of Devonian faunas.

TERMIER & TERMIER (1950b): Illustration of some Mechra Ben Abbou brachiopods.

TERMIER & TERMIER (1950d): Illustration of some Devonian trilobites from the Rehamna.

BÄCKER et al. (1965): Unpublished report on the Devonian and Lower Carboniferous of some Meseta region, including the northern Rehamna.

HOLLARD (1967): Summary of the published evidence, noting in a synthesized stratigraphic column the absence of upper Givetian to Frasnian strata.

ALBERTI (1967): Description of the odontopleurid trilobite *Isoprusia (Mauraspis) cyrius* from the assumed Eifelian (but perhaps Emsian) near Sidi Abdallah.

GENDROT et al. (1969) and GENDROT (1973): Description of reef facies and development at Sidi bou Talaa and Sidi Abdallah, also with some examples from Bouchhada.

ALBERTI (1969): Description of *Proetus (Proetus) prox umerbianus*, now a species of *Gerastos*, and of *Cornuproetus (Cornuproetus) cornutus marrakechensis* from Middle Devonian crinoid limestones (GIGOUT locality 1486); description of *Proetus (Proetus) rehamnanus*, another possible *Gerastos*, from Lower Devonian limestone south of Mechra Ben Abbou.

ALBERTI (1970): Description of the scutelluid *Paralejurus dormitzeri rehamnanus*, now a full species (see SCHRAUT & FEIST 2004 for supposed new material from the Emsian of the Anti-Atlas, which BASSE 2012 did not accept to be conspecific) and of *Phacops (Phacops) speculator*, now a species of *Austerops*, from the assumed Eifelian (or Emsian) near Sidi Abdallah.

JENNY (1974): Unpublished thesis on the geology and structural evolution of the Rehamna, including Devonian faunal records (e.g., from Foum el Mejez).

HOLLARD et al. (1982): Principles of Mechra Ben Abbbou Palaeozoic stratigraphy, with detailed section descriptions and important faunal lists.

RAIS-ASSA, R. (1984): Unpublished Ph.D. Thesis on the stratigraphy and structural geology of the northern Rehamna.

EL KAMEL et al. (1985) and EL KAMEL (1987, 2004): Thesis and monograph on the Palaeozoic of the Oulad Abbou (Coastal Block) and Mechra Ben Abbou regions, with a focus on lithostratigraphy, reef development and structural geology.

EL KAMEL & MULLER (1987): Study on the post-orogenic conglomerates of Mechra Ben Abbou that include reworked Devonian limestones.

RACHEBOEUF (1990a, 1990b): Record of the upper Pragian chonetid *Plebejochonetes buchoti* from two localities (Aïn Tolba and Aïn Aissa) of the Mechra Ben Abbou region.

EL KAMEL et al. (1992): Ordovician to Lower Devonian succession of the Aïn El Melah region SW of Mechra Ben Abbou, and its synsedimentary tectonism.

LEGRAND-BLAIN (1994, p. 82): Reference to GIGOUT´s Famennian brachiopod fauna from Mechra Ben Abbou.

EL HASSANI & BENFRIKA (1995, 2000): Summary of the northern Rehamna Devonian successions and their palaeogeography and synsedimentary tectonism.

BEN BOUZIANE (1995): Ph.D. Thesis on the Devonian sedimentary history and diagenesis of the western Meseta (Mechra Ben Abbou, Oulad Abbou, and Doukkala regions).

BENFRIKA (1999): Record of the mostly lower Emsian conodont *Caudicriodus celtibericus* from Koudiat ed Diab.

EL KAMEL & EL HASSANI (1999), and EL KAMEL et al. (2000, 2004): Impact of synsedimentary extensional tectonics on reef development at Sidi bou Talaa and comparisons with the Foum el Mejez succession.

PEDDER (1999): Redescription of LE MÂITRE´s "*Schizophyllum*" as the new species *Stringophyllum coenauberti*, and placing her *Heliophyllum moghrabiense* as a subspecies in *H. halli*.

JANSEN (2001): Brief comments on Rehamna brachiopods illustrated in TERMIER & TERMIER (1950b) and GIGOUT (1951).

MAMET et al. (1999): Reference to the occurrence of calcareous algae in the Mechra Ben Abbou reef limestones.

RAJI et al. (2004) and BENFRIKA et al. (2008): Abstracts noting the discovery of upper Emsian, Eifelian, and Givetian conodonts in the Bouchhada Quarry north of Mechra Ben Abbou.

BASSE & MÜLLER (2004): Re-illustration of *Dechenella gigouti* (based on the cast deposited at the Senckenberg Museum, Frankfurt a. M.).

NICOLLIN & BRICE (2004, p. 447): Brief reference to possibly Strunian age brachiopod faunas from Mechra Ben Abbou.

ADRAIN et al. (2008): Revision of koneprusiid trilobites, including *Isoprusia (Mauraspis) cyrius* from the Eifelian of Mechra Ben Abbou.

ABOUSSALAM et al. (2012): Abstract mentioning the discovery of Emsian conodonts at Foum-el-Mejez.

BASSE (2012): Type catalogue of North African trilobites, including the previously established Mechra Ben Abbou species.

FEDAN (2014): Catalogue of fossil collection in the Institut Scientifique (Rabat), including Devonian brachiopods from Rehamna sections, such as the Oued Kibane and Sidi Abdallah.

KHOLAIQ et al. (2015): Influence of synsedimentary faulting on the development of the Devonian-Lower Carboniferous Mechra Ben Abbou Basin.

OUKASSOU & NAUGOLNYKH (2021): Description of an unusual new plant from the uppermost Famennian Dalaa Member of Foum el Mejez.

Fig. 3: SE dipping quartzite marker cliff (Upper Member of Formation C sensu EL KAMEL et al. 1982, middle Member ST3 of Sakhra Touila Formation sensu EL KAMEL 2004) at Sakhrat et Taïra (= Sakhra Touila), close to the road to the El Massira dam (in the middle ground), underlain by shales and microconglomerates (Lower Member Formation C in the front), followed on the other side of the road (in the background) by siliciclastics and slump blocks of Formation E (= Members ST4-6), with A. EL HASSANI for scale.

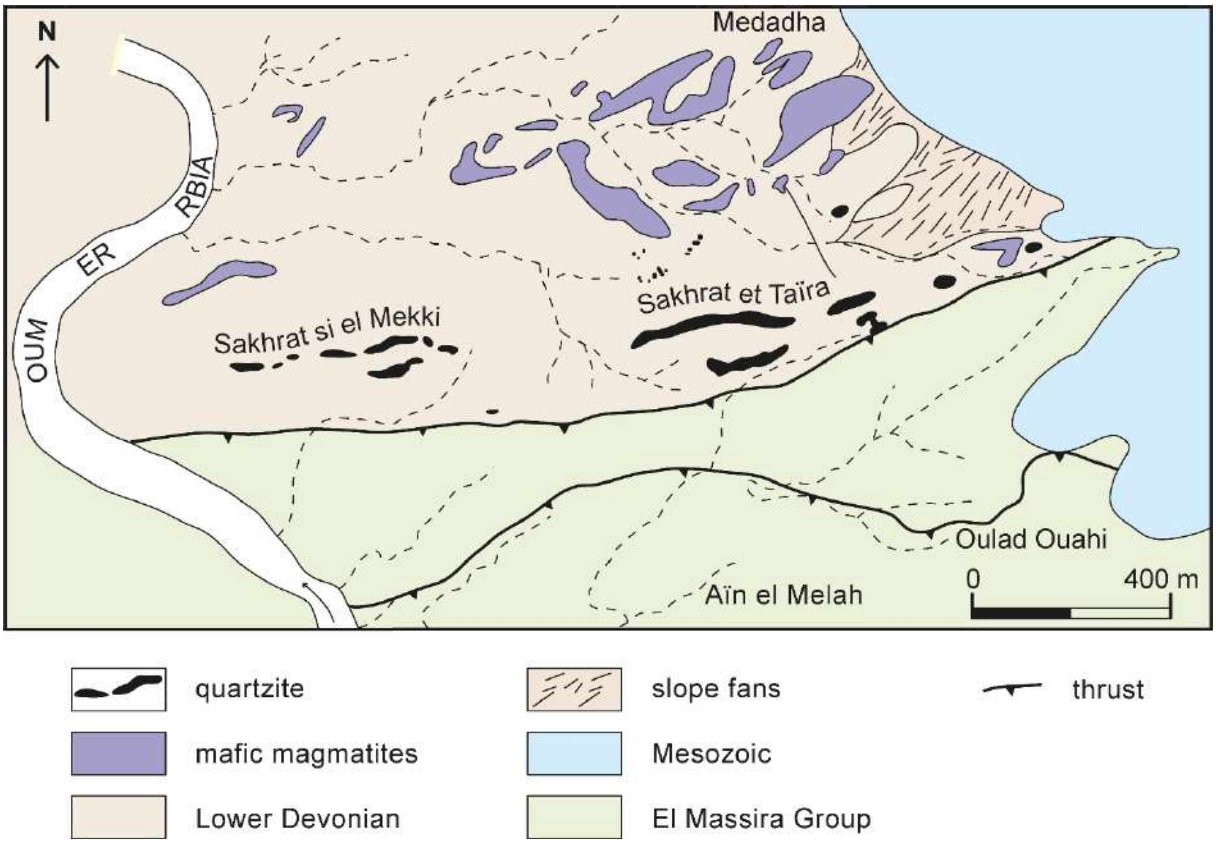


Fig. 4: Simplified geological map of the Aïn el Melah area from the Oum Er Rbia in the west to Sakhrat et Taïra in the east (re-drawn from EL KAMEL et al. 1982, fig. 2).

3. Lower Devonian at Sakhrat et Taïra

El Kamel et al. (1982) and El Kamel (2004) described the structurally complex Palaeozoic succession in the southeast of the "Rehamna septentrionaux". It is of special relevance for the understanding of the regional tectonic evolution because of its evidence for a long interval of earliest Devonian synsedimentary block faulting, resulting in slumping, olistolite embedding, and seismically triggered sediments, such as microconglomerates and turbidites. El Kamel (2004) used the different locality name Sakhra Touila. Since both studies included only limited data on ages, the precise timing of "Antevariscan" (Becker et al. 2015) tectonic episodes remained vague. Therefore, we re-visited the region in 2017 and tried to improve the local stratigraphy and facies history by conodont, macrofauna, and microfacies sampling. This was only partly successful.

The study area lies north of Aïn el Melah and east of the Oum Er Rbia (Fig. 4), ca. 21 km SE of Mechra Ben Abbou (Fig. 2). El Kamel et al. (1982) subdivided the succession into five informal formations (A-E) with member subdivisions. El Kamel (2004) introduced the term Sakhra Touila Formation, with a subdivision into six members (ST1-6). His section log shows a simple superposition sequence, in contrast to the earlier lithological log and cross-section (El Kamel et al. 1992, fig. 5) that assumed repetitions bound by faults. Our field survey and limited new data support the older interpretation.

A quartzite cliff forms a local marker level (Upper Member of Formation C = middle unit of Member ST3; Fig. 3), which was originally (El Kamel et al. 1992) regarded as Ordovician. Thick beds dip uniformly to the SE. El Kamel (2004, p. 43) noted arenitic to microconglomeratic grain size, cross-bedding, and iron mineralisations and nodules at the top. There is no fauna and, therefore, no biostratigraphic control. But limestones in the overlying Upper Member of Formation D (= upper part of Member ST3), which has restricted outcrop, yielded apart from orthocones and brachiopods top-Silurian conodonts and graptolites (det. N. Lazreq and S. Willefert).

The marker quartzite is underlain by reddish to black, microconglomeratic shale with dark, ferruginous pebbles (< 1 cm) and irregularly intercalated, ochre, dolomitized and partly decalcified limestones. These represent slump blocks and are fossiliferous. Apart from crinoid ossicles, we collected the negative of a favositid coral (Fig. 5.5) but conodont sampling remained unsuccessful. The coral is not stratigraphically useful but it proves a neritic, shallow-water setting. The lower contact of the quartzite is rather sharp (Fig. 3) and may be disconformable.

The lower Formation C occupies a gentle slope ending in a small depression, which, as depicted by El Kamel et al. (1992, fig. 5), seems to follow a fault zone because beds on both sides dip differently. Therefore, the "Upper Member" of Formation B (= Member ST2) is obviously older than its "Lower Member" (Member ST1). Formation B begins from SE to NW in a low slope with fossiliferous grey to black shales with intercalated siderite nodules and slump blocks consisting of brownish weathering calcareous sandstone. There is a small-sized neritic fauna preserved in light-grey to yellowish (limonitic) marl and limestone.

We found brachiopods (*Howellella* cf. *mercurii*, Fig. 5.1, undetermined atrypids, and others), crinoid ossicles, gastropods (calcite-shelled *Euomphalus* sp., Figs. 5.3-4, mold of turriform pleurotomariacean, Fig. 5.2, spirally striated bellerophontids), bryozoans (Figs. 5.6-5.7), and rare trilobites. *Howellella mercurii* is a lower Lochkovian index species (e.g., JANSEN 2016). Its occurrence in the northern Rehamna has been previously established by HOLLARD (1967) and HOLLARD et al. (1982). The new record confirms that Formation B (ST2) is younger than Formation D (ST3), in accord with the bedding orientation and the log of EL KAMEL et al. (1992), but disproving the simplified log of EL KAMEL (2004, fig. 23). We confirm the lower Lochkovian age of synsedimentary slumping and extensional tectonism, as postulated by EL KAMEL et al. (1992) and illustrated by EL KAMEL (2004, pl. 1).

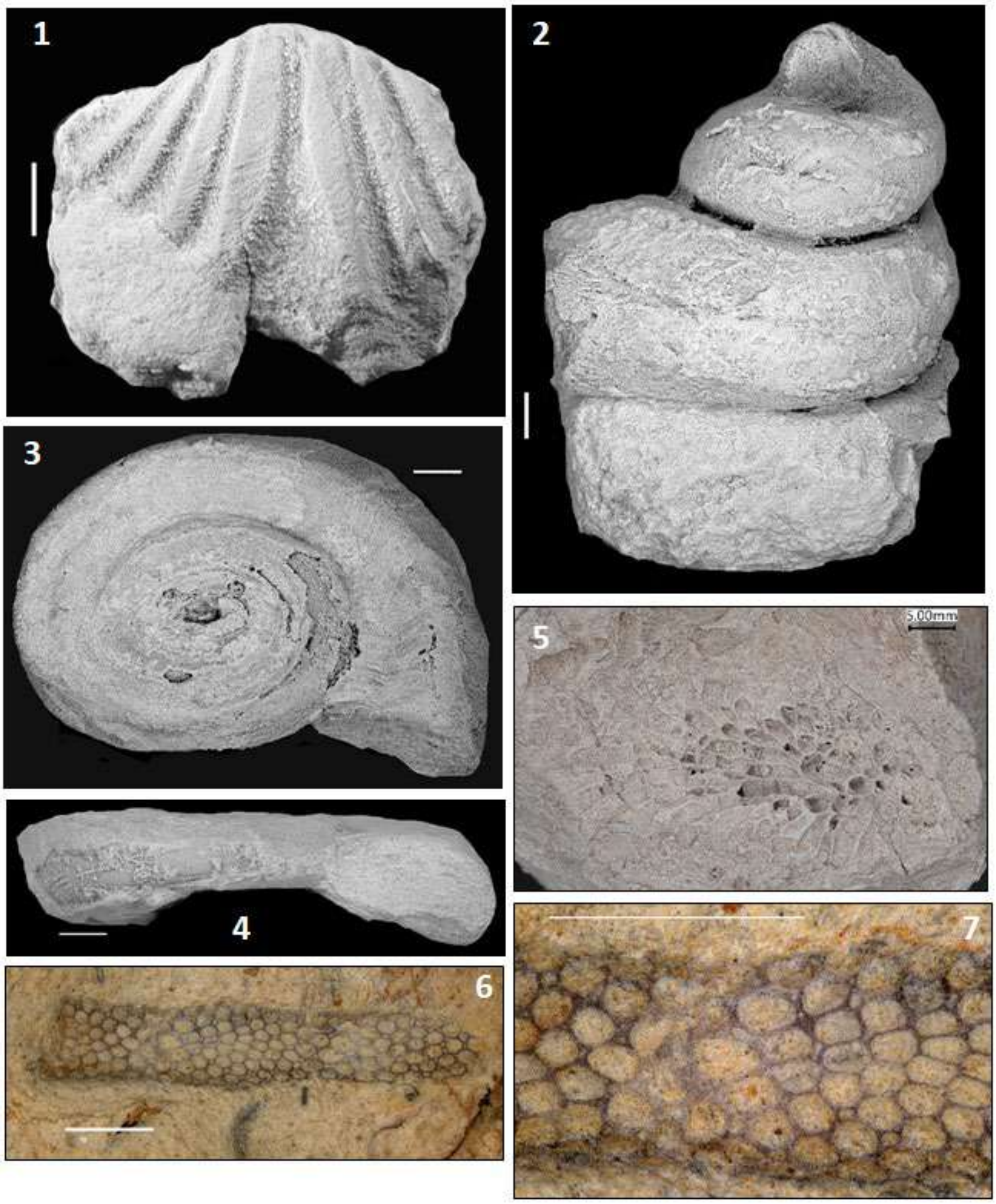
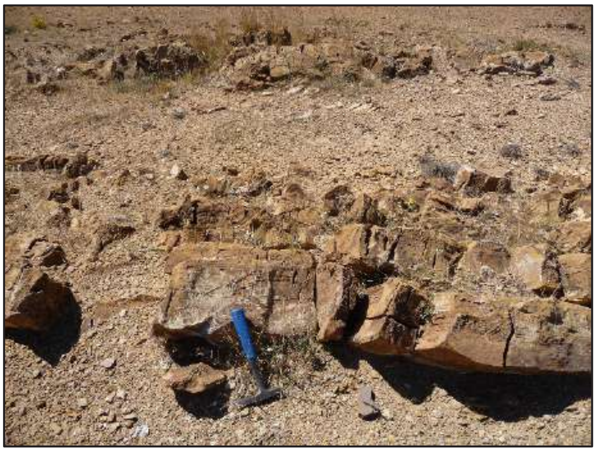


Fig. 5: Fossils from Sakhrat et Taïra (Sakhra Touila Formation sensu EL KAMEL 2004); 1-6 from the "Upper Member" of Formation B sensu EL KAMEL et al. (1992) = Member ST2, 7 from the Lower Member of Formation C (= lower Member ST3); scale bar = 2 mm if not specified. **1.** *Howellella* cf. *mercurii*, incomplete, SMF 102133; **2.** Pleurotomariid gastropod, GMM B6B.11.8; **3-4.** *Euomphalus* sp., upper and adoral views of calcitic shell, showing the outer upper whorl edge lying in a growth line sinus and the flat, very low-spired coiling, GMM B6B.11.9; **5.** *Favosites* sp. (negative imprint in decalcified limestone slump block), GMM.57.1; **6-7.** Branch of bryozoan colony, overview and detail, GMM B5A.4.1.

The upper part ("Lower Member") of Formation B occupies the crest of a low hill and the subsequent backslope to the NW. There are slumped masses of yellow to brownish limestone and calcareous sandstone. A thin-section (Fig. 6) consists of slightly peloidal and silty wacke-floatstone with micritized crinoid ossicles, rare tabulate corals, brachiopod and mollusk debris, and rare dacryoconarids. Conodont sampling was not successful. The setting was deep (subtidal) neritic.

Fig. 6: Thin-section of yellowish limestone from the lower part of Formation B at Sakhrat et Taïra, a slightly peloidal, silty, bioturbated wacke-floatstone with micritized, therefore hardly visible crinoid debris and other neritic fauna, impregnated by iron hydroxides.

Slightly higher follow alternating grey or brownish shales and calcareous turbidites with grading and cross-bedding (Fig. 7.2) as typical four Bouma cycles. Conodont samples were, again, barren. The dip of bedding varies and the solid beds are strongly fractured (compare El Kamel 2004, pl. I, fig. C). El Kamel et al. (1992) mentioned a syringoporid coral from the "base", which suggested a Devonian age. Apart from this shallow-water element, the turbidites represent a deeper and slope setting, probably reflecting the increasing block tilting and seismic events. At the top, yellow to reddish mudstones lack any fossils (Fig. 7.3) pointing to a hostile shelf basin facies. Recrystallization and iron impregnation proceeded from the many healed fractures.



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2

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Fig. 7: Field photos and thin-section of limestones in the upper part ("Lower Member") of Formation B sensu El Kamel et al. (1992; = "top" of Member ST1 of El Kamel 2004). **1.** Exposure of a succession of brownish weathering silty limestones dipping downslope; **2.** Details of a turbiditic bed, showing turbidite-typical Bouma cycles; **3.** Unfossiliferous, partly recrystallized, fractured and iron-impregnated mudstone, top of formation.

The subsequent lower part of Formation A ("Upper Member") has fewer yellowish limestones, which stand vertically. They crop out in the lower slope of the hill and on the next hill to the NW. Upslope, towards a farmhouse, follows the quartzitic "Lower Member" of Formation A (= lower ST1). It suggests a relative sea level fall by basin filling, after synsedimentary tectonism ended.

Formation E (= ST4-5) is poorly exposed on the SE side of the road to the El Massira dam. It resembles the Lower Member of Formation C in the presence of ochre, dolomitized and sandy slump blocks (see El Kamel 2004, pl. I) intercalated in micaceous, silty shales. No fossils were found. Above, a sandstone-quartzite level is followed by yellowish pelagic limestones with orthocones and *Zieglerodina remscheidensis* (det. N. Lazreq), which proved to be Lochkovian in age. We have not yet re-examined the higher parts of Formation E (= Member ST6), which is said to have more (or the same?) levels of quartzite and pelagic limestone with orthocones.

El Kamel (2004) described from the area a few hundred meters to the NW of Formation A, in his section Amdidih, a folded, cyclic and thick alternation of shales, thin sandstones and bioclastic limestones (compare Ben Bouziane 1995). The age of this Amdidih Formation is not well constrained. The reported (Gigout 1951, p. 56) tabulate coral *Cleistopora* and close relatives had a global distribution in the middle Lochkovian/Pragian interval (e.g., Plusquellec 1973; Boumendjel et al. 1996: Lochkovian record from southern Algeria; Frey et al. 2014: Pragian record from the Tafilalt). A lithologically similar, thick neritic succession occurs ca. 15 km to the NW and was described by Ben Bouziane (1995) and El Kamel (2004) as Ouled Barka Formation. Based on *Cleistopora*, *Hysterolites hystericus* and *Athyris undata* (reported by Gigout 1951) this unit falls mostly in the upper Pragian (see brachiopod zonation of Jansen 2016).

In summary, the tectonized area north of Aïn el Melah is a difficult terrain for Devonian stratigraphy. It requires more attempts to find conodonts or other stratigraphically relevant fossils (brachiopods, trilobites). Lower Devonian subsidence was high and episodically affected by block tilting, resulting in the interruption of dominant neritic facies by seismically triggered sedimentation. There were facies differences to the Lower Devonian of Koudiat ed Diab and Foum el Mejez in the north.

4. Lower/Middle Devonian of Mechra Ben Abbou

4.1. Lower Devonian

The Lower Devonian of the Mechra Ben Abbou region consists of alternating, cyclic silty shales and bioclastic limestones assigned to the Amdidih and Ouled Barka Formations (El Kamel 2004). Since Gigout (1951, 1955), Lochkovian to Emsian neritic faunas with brachiopods and trilobites are known but only a few of them have been revised (e.g., Racheboeuf 1990a; Adrain et al. 2008). A re-evaluation of brachiopods from Gigout´s (1951, p. 57) locality 191 suggests a Pragian age. The figured (his pl. 6, figs. 1-2) "*Spirifer hystericus*" is a species of the Pragian genus *Hysterolites*. The figured *Athyris undata* (pl. 6, figs. 29-30) resembles indeed *Septathyris? undata*, which is a lower Pragian species, known, for example, from the Lebanza Formation of the Cantabrian Mountains (Binnekamp 1965). "*Schizophoria provulvaria*" (pl. 5, figs. 7-9) is close to *Rhenoschizophoria provulvaria* but has been questionably linked with *Rh. torkozensis* that occurs in the Assa Formation (Rich 1) of the Dra Valley (Jansen 2001). "*Stropheodonta explanata*" (pl. 5, fig. 10, also Termier & Termier 1950b, pl. 79, figs. 12-14) belongs to the genus *Mclearnites*, possibly to *Mc. saharianus* JANSEN, 2001, which also occurs in the lower Pragian Assa Formation.

We visited briefly the Lower Devonian at Douar Bou Jemaa (GPS N32°38´39,7´´, W7°45´30,8´´). Exposed are middle-grey, coarse-grained, brachiopod-rich crinoidal limestones. Conodont samples were barren, obviously because of too shallow facies.

4.2. Middle Devonian of Sidi bou Talaa

HOLLARD et al (1982) introduced the Mechra Ben Abbou Formation for compact to massive limestones without shale/marl interbeds exposed in quarries around Bouchhada (= Bou Chehada) and in natural cliffs of the Mechra Ben Abbou region (Fig. 2). Other outcrops lie to the south at Ouled Barka and Sidi Abdallah (Fig. 2). Based on the faunal list of HOLLARD et al. (1982), updating the records of LE MÂITRE (1938, 1947) and GIGOUT (1951, 1955a), an Eifelian to middle Givetian range is well established. In lower parts, faunas with *Calceola sandalina* are locally typical. RAJI et al. (2004) reported *Icriodus corniger ancestralis* from well-bedded limestones in the lower part, a taxon that is restricted to the upper Emsian (e.g., ABOUSSALAM et al. 2015). Therefore, the influx of fine siliciclastics and change to a fully carbonatic platform occurred obviously high in the Lower Devonian (see also EL KAMEL 2004, fig. 45). The recognition of the pentamerid *Glyptogypa multiplicata* and the spiriferid *Paraspirifer cultrijugatus* by LE MÂITRE (1938, 1947; see also HOLLARD et al. 1982, tab. 2), if identified correctly, the latter species lends further support for the inclusion of beds at the Emsian-Eifelian transition (see range in JANSEN 2016).

The Mechra Ben Abbou Formation was subdivided by BEN BOUZIANE (1995) into Lower, Middle, and Upper Members, with Bouchhada North as the selected type-section. The 9 m thick, thin-bedded lower part is here named as **Bouchhada Member**, the more nodular middle part with characteristic chert nodules as **Koudiat El Gara Member**, named after a lateral section of BEN BOUZIANE (1995). The combination of both in a "Oulad Barka 2 Formation" is not possible from nomenclatorial reason; the term Ouled Barka Formation should be restricted to the cyclic Pragian-Emsian succession at Ouled Barka (see description by EL KAMEL 2004). The term "Sidi bou Talaa Formation" can be transferred as a member name for the massive reefal limestones, the main part of the Mechra Ben Abbou Formation.

Fig. 8: Overview of the Mechra Ben Abbou Formation at the southern end of Sidi bou Talaa, with the Bouchhada and Koudiat El Gara Members in the middle slope, and massive, cliff-forming reef boulders of the Sidi bou Talaa Member at the top.

We re-sampled the Sidi Bou Talaa section along the western bench of the meandering Oum Er Rbia, ca. 4 km SE of Mechra Ben Abbou village (Fig. 8). The reefal succession was first studied by GENDROT et al. (1969), who recognized pre-reefal cherty limestones, overlying bioclastic limestones with reefal corals, a biostrome stadium and fore-reef breccias, a patch of back-reef breccias, and lagoonal facies sheltered by a main belt of true reef (bioherm). Generally, we can confirm this analysis. But the later studies by EL KAMEL & EL HASSANI (1999), EL HASSANI & EL KAMEL (2000), EL KAMEL (2004), and EL KAMEL et al. (2004) showed a strong control of reef growth by synsedimentary tectonism. It resulted in seismically induced, episodic shedding of reef breccias from the reef crest (see local map of EL KAMEL 2004, fig. 46). All studies recognized the somewhat unusual close affiliation of high-energy mass flow deposition and of *Amphipora* Limestones as indicator of quiet back-reef settings.

Our investigations had several aims: 1. to provide some new biostratigraphical data, 2. to establish a meter-scale succession of reef macro- and microfacies, 3. to re-evaluate the local reef model, 4. to compare the recognized facies types with those of the contemporaneous Oued Cherrat and Al Attamna reefs (EICHHOLT & BECKER 2016), and 5. to supply modern taxonomic data for Rehamna reef builders, which are thought to be representative for the Meseta region.

Fig. 9: Crinoid pack-grainstone with partly washed out micrite matrix and some brachiopod debris, lower Bouchhada Member, Sidi bou Talaa.

4.2.1. Bouchhada Member

We estimated on the southern slope of Sidi bou Talaa (Fig. 8) for the exposed, rather flat lying Bouchhada Member a local thickness of 35-40 m. The base (at N32°38´10.3´´, W7°45´41.7´´) is covered. Typical are middle-bedded (up to 20 cm thick), light-grey, often coarse-grained crinoid pack-grainstones (Fig. 9) with rare, small gastropods and thick-shelled ostracods. The micrite was variably washed out by currents. Some dolomitization occurred and there are fine, calcite-healed fractures. EL KAMEL (2004) noted bioclasts of other neritic fauna, syntaxial cements and micritization of crinoid ossicles. The setting was a neritic middle carbonate ramp seawards from storm-ridden crinoid forests.

The lithofacies interpretation is supported by the conodont fauna, with a mixed dominance of *Linguipolygnathus linguiformis* (5 specimens) and *Icriodus regularicrescens* (four specimens, Fig. 11.1), accompanied by single *Polygnathus parawebbi* (Fig. 11.3) and *Neopanderodus perlineatus* (Fig. 11.2). Both *I. regularicrescens* and *Po. parawebbi* enter ca. in the middle of the Eifelian, within the *Po. pseudofoliatus* Subzone, but the second is more typical from the upper Eifelian *kockelianus* Zone onwards (GOUWY & BULTYNCK 2002). A second sample with *I. regularicrescens* (three specimens), *L. linguiformis* (five specimens), *Po. pseudofoliatus* (two specimens), and *Po. angusticostatus* confirmed the middle/upper Eifelian age. It is also in accord with conodonts reported by RAJI et al. (2004) and EL KAMEL (2004, p. 74), who found in addition to our species *Po. costatus, Tortodus kockelianus*, and a *Pelekysgnathus*.

Fig. 10: Large, brownish chert nodules weathering out of the Koudiat El Gara Member at Sidi bou Talaa.

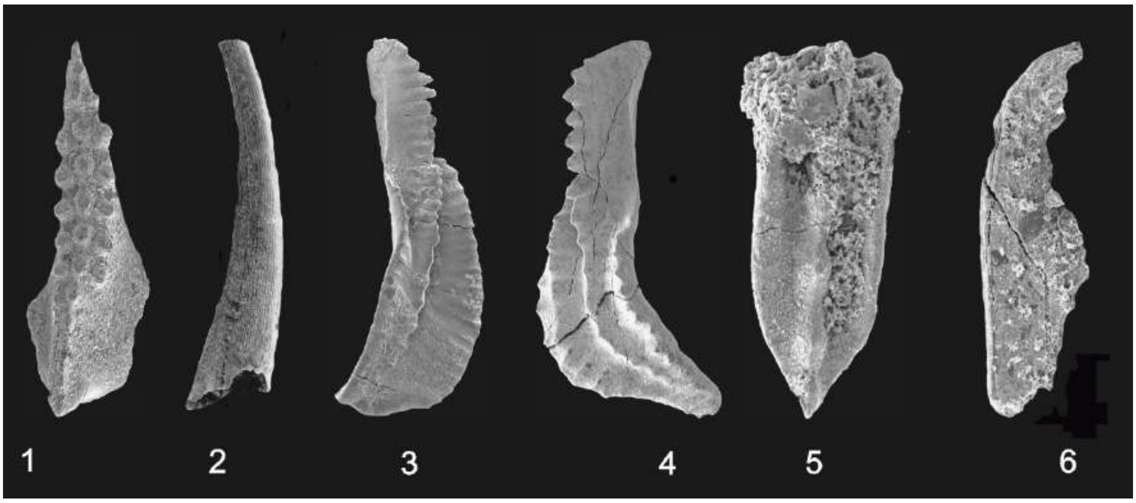

Fig. 11: Middle Devonian conodonts from the Bouchhada (1-3) and Koudiat El Gara Members (4-6) at Sidi bou Talaa, GMM B4C.2.111-116. **1.** *Icriodus regularicrescens*, x 60; **2.** *Neopanderodus perlineatus*, x 55; **3.** *Polygnathus parawebbi*, x 50; **4.** *Linguipolygnathus linguiformis*, x 27; **5.** *Po. varcus?*, only the platform, not showing the position of the basal pit, x 145, **6.** *Belodella resima*, poorly preserved, x 95.

4.2.2. Koudiat El Gara Member

The locally ca. 8 m thick second member of the Mechra Ben Abbou Formation is characterized by finer crinoid debris, partly thinner beds, and distinctive, brownish chert nodules that weather out on limestone surfaces due to surface karstification (Fig. 10). As suggested by previous authors, we assume diagenetic mobilization of sponge spicules although we did not observe these in thin-section. The microfacies is a strongly bioturbated, bioclastic wackestone (Fig. 12) with micritization of crinoids and all other bioclasts, which include fragments of brachiopods and tabulate corals, as well as some dacryoconarids, indicators of a deeper ramp position. The micritic matrix is partly peloidal or was locally washed out by minor currents. There are several generations of calcite-healed fractures.

A conodont sample from the lower part yielded one *L. linguiformis* (Fig. 11.4), two poorly preserved *Belodella resima* (Fig. 11.6), and a questionable, broken *Po. varcus* (Fig. 11.5). This faunule could be of Givetian age but the position of the Eifelian-Givetian boundary, especially of the level of the global Kačák Event, is currently not fixed and requires more samples.

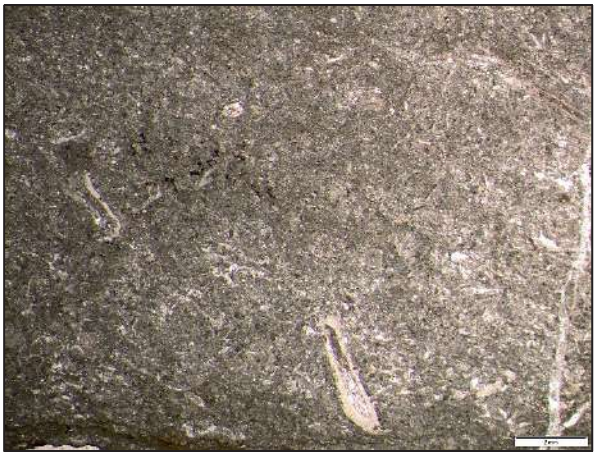

Fig. 12: Bioturbated, partly dolomitized bioclastic wackestone with micritization of crinoid debris and other small bioclasts.

4.2.3. Reefal Sidi bou Talaa Member

There is a gradual transition from thin-bedded to more massive limestones with abundant reef builders. The crest of the ridge represents the main, ca. 150 m thick reef succession characterized by a succession of “domes” (El Kamel & El Hassani 1999). Our logging progressed along the lower slope of the ridge, along the Oum Er Rbia (Figs. 13-14), representing the right part of the lithological column in El Kamel (2004, fig. 47). The section is dominated by brecciated slope deposits intercalated with back reef facies. This association characterizes the inner slope of a bioherm, which was steepened and episodically shaken by recurrent seismic events. Because of limited access along the Oum Er Rbia, the logging proceeded in two parts (Figs. 13-14, 17-18). The lower part centered around GPS N32°58´10.3´´, W7°45´41.7´´.

Fig. 13: Sampled succession of the lower Sidi bou Talaa Member along the Oum Er Rbia, showing breccia levels “crawling” downslope.

Four principle microfacies types are distinguished (compare Gendrot et al. 1969), which can be characterized as follows:

SBT F1, Brecciated inner slope limestone
(Figs. 15.1-5, 16.7-10; compare Gendrot et al. 1969, pl. 2, fig. 1, and El Kamel 2004)
Stromatoporoid-coral float-rudstone: Middle- to dark-gray brecciated limestones with clasts (diameter max. 20 cm) of bulbous and laminar stromatoporoids (e.g., *Pseudotrupetostroma* sp., *Clathrocoilona, Actinostroma*), and alveolitid corals. Some *Pseudotrupetostroma* sp. are bored by worm tubes (*Streptindytes* sp., Fig. 15.1). Secondary are fragmented branches of dendroid tabulate corals (*Scoliopora denticulata*) or broken dendroid stromatoporoids. Additional bioclasts are fragmented brachiopod shells and rare solitary rugose corals. The matrix consists of very slightly winnowed micrite.
Interpretation: Storm-influenced inner slope talus of reef core or platform domes, additionally destabilized by seismic activity (compare MF A2 of Eichholt & Becker 2016).

SBT F2, Reef core limestone
(Figs. 15.6, 19-20; compare El Kamel 2004)
Very thick bedded (up to 90 cm) stromatoporoid-coral boundstones. The middle-gray limestones are constructed by laminar and bulbous stromatoporoids (e.g., *Trupetostroma*, *Anostylostroma*, *Clathrocoilona*, *Actinostroma*), alveolitid corals (e.g., *Platyaxum*), and subordinate colonial rugose corals (e.g., *Sociophyllum* sp.) encrusting each other. Uncommon are chaetetid sponges (*Rhaphidopora*). The stromatopores reach a diameter up to 20 cm. Secondary reef builders are dendroid stromatoporids, especially *Stachyodes* and *Amphipora*, tabulate corals, and solitary Rugosa, which settled in niches between the main constructors. The matrix consists of slightly winnowed micrite. Clay seams and microstylolites are common (e.g., SBT upper part, at 12 m).
Interpretation: Reef core facies or reef dome facies with slopes within a wider platform (compare MF A5 of Eichholt & Becker 2016).

SBT F3, Back reef limestones with dendroid stromatoporids
(Figs. 15.7-8. 16.4-6, 21(compare Gendrot 1973)
Branching stromatoporid float-rud-bafflestone, (*Amphipora-Stachyodes* Bafflestone and *Stromatoporella* Bafflestone): Thin bedded, middle- to dark-gray limestone constructed by dendroid stromatoporoids (e.g., *Amphipora*, *Stachyodes*, *Stromatoporella, Clavidictyon*).

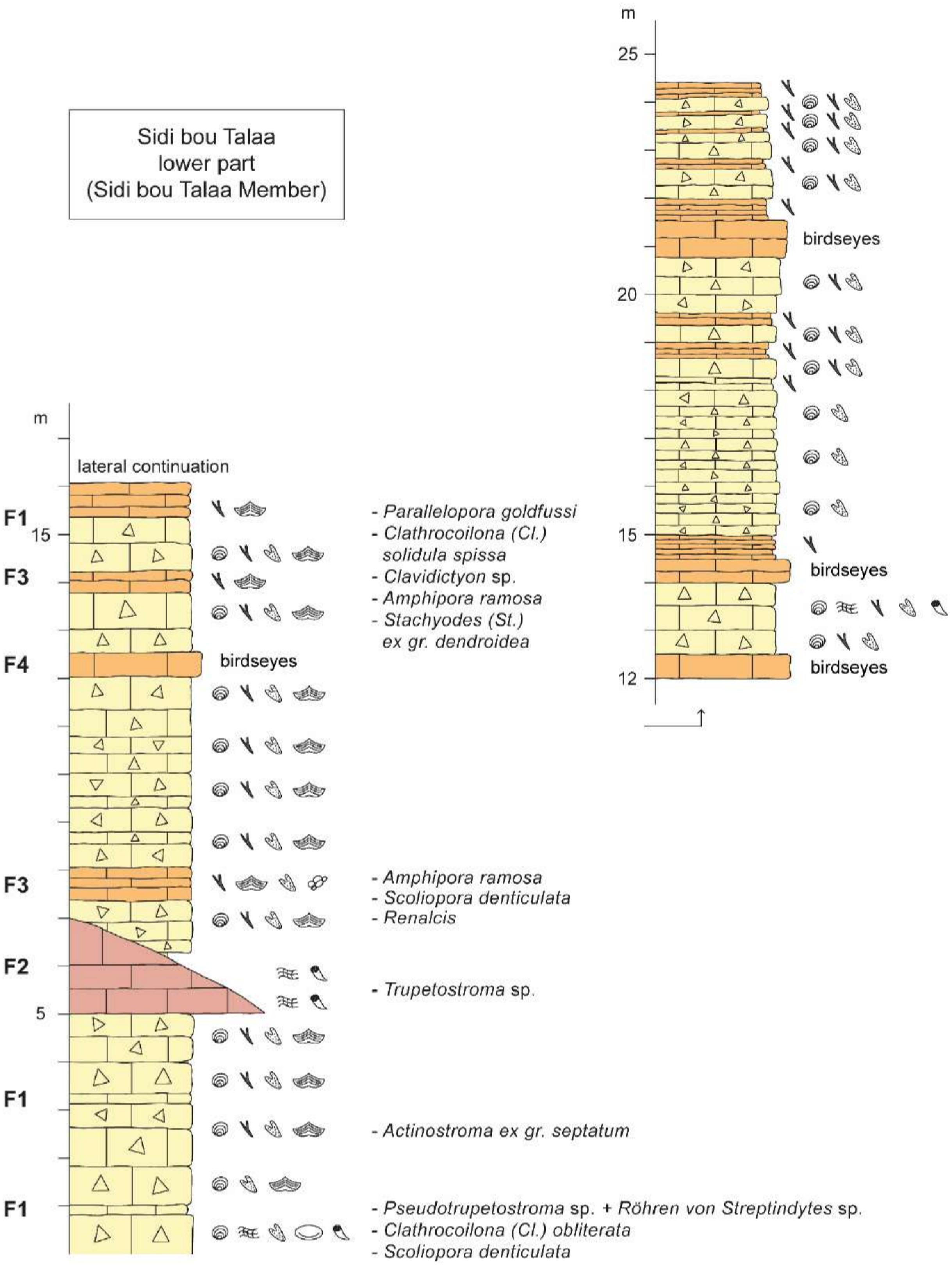

Fig. 14: Simplified macro- and microfacies log for the lower Sidi bou Talaa Member, showing the principle facies types (SBT F1-4), macrofauna observed in the field, and fauna identified in thin-sections. The dominance of reef breccias and their association with fenestral or *Amphipora*-rich lagoonal limestones is distinctive. For legend see Fig. 18.

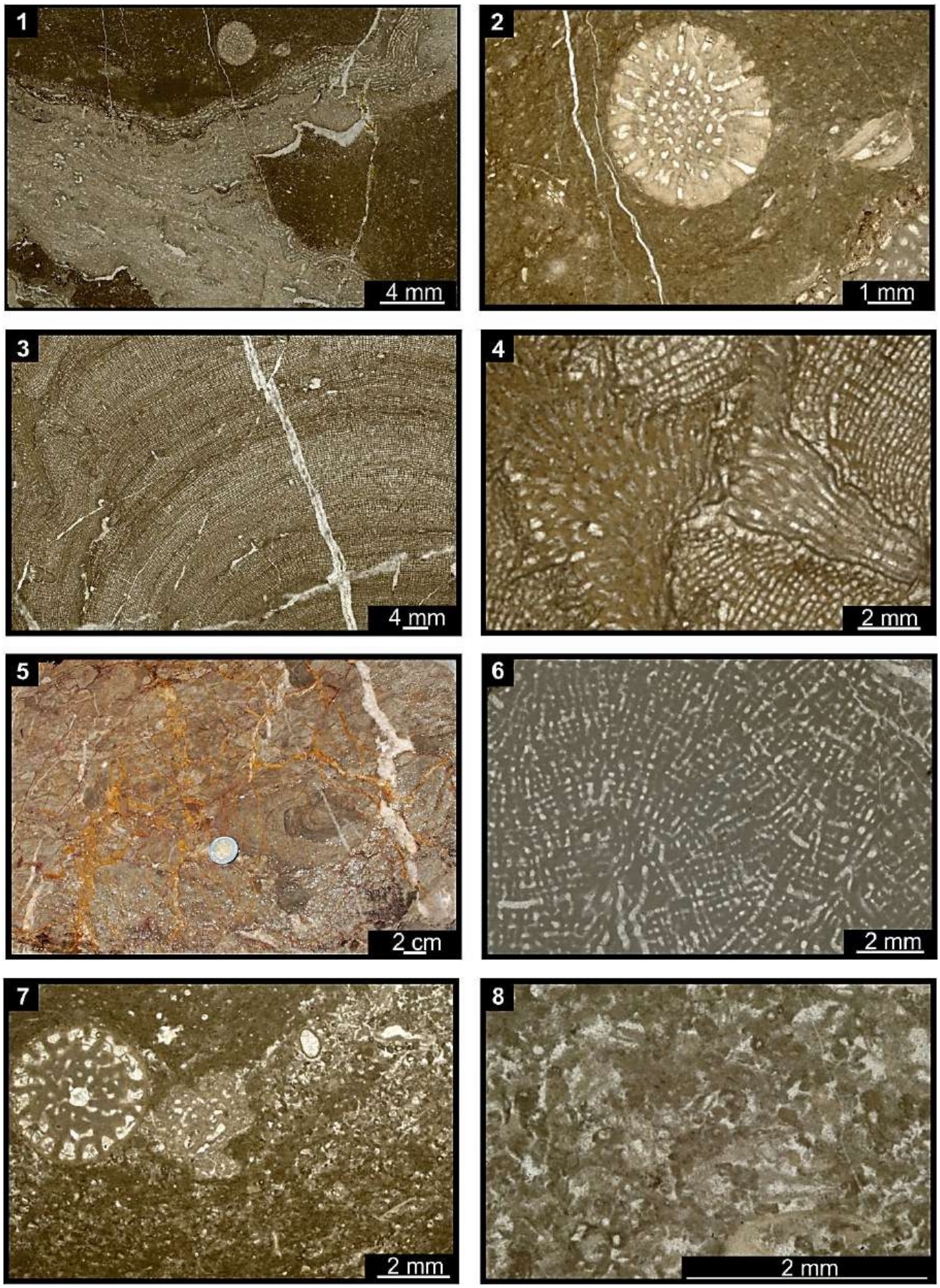

Fig. 15: Microfacies and reef fauna of lower 8 m of measured Sidi bou Talaa section, 1-5: SBT F1, reef breccia with stromatoporoid-coral float-/rudstone, 6 = SBT F2, reef core limestone, 7-8: SBT F3, lagoonal *Amphipora* bafflestone. **1.** Laminar stromatoporoid *Pseudotrupetostroma* sp. with "worm tubes" (*Streptindytes* sp.), overgrown by *Clathrocoilona (Cl.) obliterata*, at 1 m; **2.** Magnification of 1. with cross section of dendroid tabulate coral *Scoliopora denticulata*; **3-4.** Bulbous stromatoporoid *Actinostroma* ex gr. *septatum*, at 3 m (4 = magnification with alveolitid); **5.** Field photo of stromatoporoid-coral float-/rudstone, at 3 m; **6**. Stromatoporoid *Trupetostroma* sp., at 6 m; **7-8.** Cross section of dendroid stromatoporoid *Amphipora ramosa,* with parathuramminid foraminifera and supposed cyanobacteria *Renalcis* (magnified in 8.), at 7.8 m.

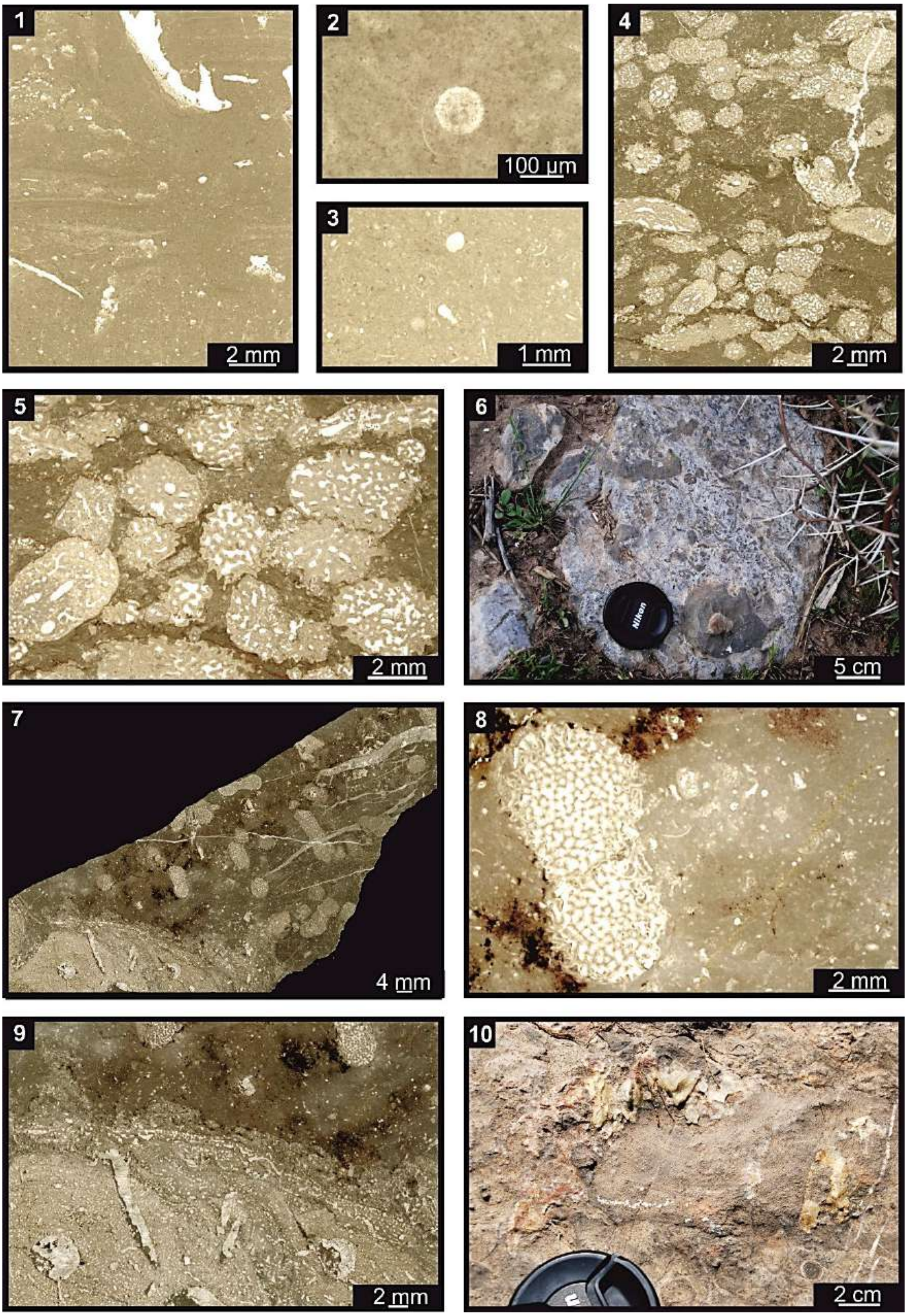

Fig. 16: Reef facies of lower Sidi bou Talaa Member between ca. 12 and 15.5 m, 1-3 = SBT F4, back reef bioclastic mud-wackestone, 4-6 = *Amphipora-Stachyodes* bafflestone, 7-10 = SBT F1, stromatoporid-coral float-rudstone. **1-3.** Bioclastic mud-wackestone with birdseye structures, archaespheres (2., enlarged), and shell fragments (3., enlarged), at 12.1 m; **4-5.** Cross sections of *Amphipora ramosa* and *Stachyodes (St.)* ex gr. *dendroidea* (on the left), at 14 m; **6.** Field photo of *Amphipora-Stachyodes* bafflestone, at 14 m; **7-10.** Stromatoporid-coral float-rudstone (10. = field photo) with laminar stromatoporids (*Parallelopora goldfussi, Clathrocoilona (Cl.) solidula spissa,* 9., enlarged) and dendroid stromatoporid bafflestone with *Clavidictyon* sp. (8., enlarged), at 15.3 m.

The preservation as in-situ baffelstone is very rare; the common facies type is float- or rudstones, which reflects recurring events with high turbulence. The additional fossil content is very low (shell fragments, parathuramminid foraminifers, and the supposed cyanobacteria *Renalcis*). The matrix consists of coarse-grained micrite and peloids.
Interpretation: Protected, calm back reef with episodic destruction by major storms (compare MF A6 of EICHHOLT & BECKER 2016).

SBT F4, Back reef fenestral (microbial) limestone

(Figs. 16-1-3; compare GENDROT 1973)
Back reef bioclastic mud-wackestone: middle to dark gray micrite with restricted macrofossil content. In thin sections occur shell fragments of small ostracods, gastropods, brachiopods, parathuramminids, and archaespheres. The limestones show "birdseye structures" filled with calcite cement and fenestral structures filled with micrite, peloids, or calcite cement. Some cavities are filled with geopetals (Fig. 16.1).
Interpretation: Quiet and calm but shallow environments within the restricted platform interiors, allowing the growth of benthic microbial aggregates (compare part of Facies F8 in CATTANEO et al 1993, Oued Cherrat).

As said above, inner reef talus dominates. At 5-6 m above our section base, it is interrupted by a tongue of stromatoporid boundstone with rugose corals, which suggests a reefal backstepping episode during transgression. We recognized in the lower part three thin intervals (at ca. 12 m, 14 m, and 21 m) of fenestral facies that reflect periods of lagoon shallowing (regression). The upper two are followed by *Amphipora* bafflestone, formed when relative-see level started to rise again. The more massive limestones of the logged upper succession (Fig. 17, starting at GPS 32°38´15.7´´, W7°45´32.2´´) are biohermal reef limestones, with one interval of more thin-bedded back reef limestones with *Amphipora* and *Stachyodes* at 14-15 m. Thin phases of lagoon expansion indicate an outwards progradation of true reef belt. Two breccia intervals at 15-19 m and 22.7 to 25 m show that synsedimentary tectonism was re-occurring throughout the reef growth. Our logging did not reach the section top.

Fig. 17: The logged, partly massive upper succession at Sidi bou Talaa, with Stephan EICHHOLT for scale.

The composition of the Rehamna reef fauna has last been summarized by HOLLARD et al. (1982, tab. 2). This list is outdated since the taxonomy of corals, chatetetid sponges, and stromatoporids has proceeded. Based on thin-sections, we recognized the following taxa at Sidi bou Talaa (* = new record for Morocco):

Stromatoporida:
Actinostroma ex gr. *septatum* LECOMPTE, 1951 (Figs. 15.3, 20.6)*
Actinostroma stellulatum NICHOLSON, 1886 (Fig. 21.5)*
Actinostroma verrucosum
Amphipora ramosa (PHILLIPS, 1841) (Figs. 15.7, 16.5, 20.2)
Anostylostroma sp. (Fig. 20.3)*
Clathrocoilona (Cl.) ex gr. *damnoniensis* (NICHOLSON, 1886) (Figs. 20.4-5)*
Clathrocoilona (Cl.) obliterata (LECOMPTE, 1951) (Fig. 15.1)*

Clathrocoilona (Cl.) solidula spissa (LECOMPTE, 1951) (Fig. 16.9)*
Clavidictyon sp. (Figs. 16.8, 21.7)*
Habrostroma ?sp.*
Parallelopora goldfussi BARGATZKY, 1881 (Fig. 16.7)*
Pseudotrupetostroma sp. (Fig. 15.1)*
*Stachyodes (St.) caespitosa** LECOMPTE, 1952 (Figs. 19.3, 20.8)
Stachyodes (St.) ex gr. *dendroidea* ETHERIDGE, 1918 (Figs. 16.4, 21.7)*
Stachyodes (St.) ex gr. *paralleloporoides* LECOMPTE, 1952 (Fig. 21.6)*
Stromatoporella sp. (Fig. 20.6)
Stromatoporella mudlakensis GALLOWAY in GALLOWAY & EHLERS 1960 (Fig. 21.2)*
Trupetostroma sp. (Figs. 15.6, 19.1)

Chaetetida
Rhaphidopora sp. (Fig. 19.6)

Tabulata:
Alveolites sp. (Fig. 15.4)
Auloporid (Fig. 21.3)
Platyaxum (Roseoporella) taenioforme (SCHLÜTER, 1889) (Fig. 20.7)*
Scoliopora denticulata (MILNE-EDWARDS & HAIME 1851) (Figs. 15.1, 19.5)*
Syringopora sp. (Fig. 19.6)

Rugosa:
Sociophyllum sp. (Figs. 20.4-5)
Mesophyllum (Cystiphylloides) sp. (Fig. 22)

Calcimicrobes
Renalcis sp. (Fig. 15.8)
parathuraminnids (Figs. 15.7, 16.2)

Dasycladaceae
Vermiporella sp. (Fig. 21.4)*

The *Stromatoporella mudlakensis* from the upper succession (13.5 m) is the unusual record of a North American taxon (GALLOWAY & EHLERS 1960) with short branches, unlike as in typical species of the genus. Biogeographic links with Michigan are also given by the *Clavidictyon*. Moroccan *Trupetostroma* were previously mentioned by JAKUBOWICZ et al. (2017) from the Givetian Aferdou el Mrakib reef in the southern Maïder (eastern Anti-Atlas). The only previous North African record of *Sociophyllum* was from the far distant "Zemmour noir" of northern Mauritania (COEN-AUBERT 2017). The Sidi bou Talaa assemblages are characterized by a dominance of stromatoporids and rarity of rugose corals, as typical for reef core to back reef facies. Favositids, alveolitids and heliolitids, which tend to dominate biostromes and initial reef stages, are more or less lacking. Somewhat unusual is the absence of thamnoporids, which are often closely associated with *Stachyodes* (see EICHHOLT & BECKER 2016 for Meseta examples). The reefal calcimicrobe *Renalcis* was first recorded from Morocco (Immouzer-du-Kandar, Middle Atlas basement) by ABOUSSALAM et al. (2020). Normally, it is more common in Frasnian reefs and typical for reef tops or marginal slopes. In our case, it is part of the talus that was shed into the lagoon.

Together with the GENDROT (1973) and HOLLARD et al. (1982) records of alveolitids (three taxa), heliolitids (three taxa), *Coenenites* (one species), *Thamnopora* (one species), favositids (three taxa), one additional species of *Actinostroma* (*Act. clathratum*), further chaetetids (two taxa), two further stromatoporids found at Gare Mechra Ben Abbou (see below), there is now a total of 38 reef building taxa (stromatoporids, tabulate corals, chaetetids, calcimicrobes, calcareous algae; rugose corals excluded) known from the Mechra Ben Abbou Formation. With respect to the limited number of thin-sections and sampled localities, this is probably only a part of the true local biodiversity. But it indicates that the alpha biodiversity was not low, as one may expect from a reef growing at relatively high palaeolatitude.

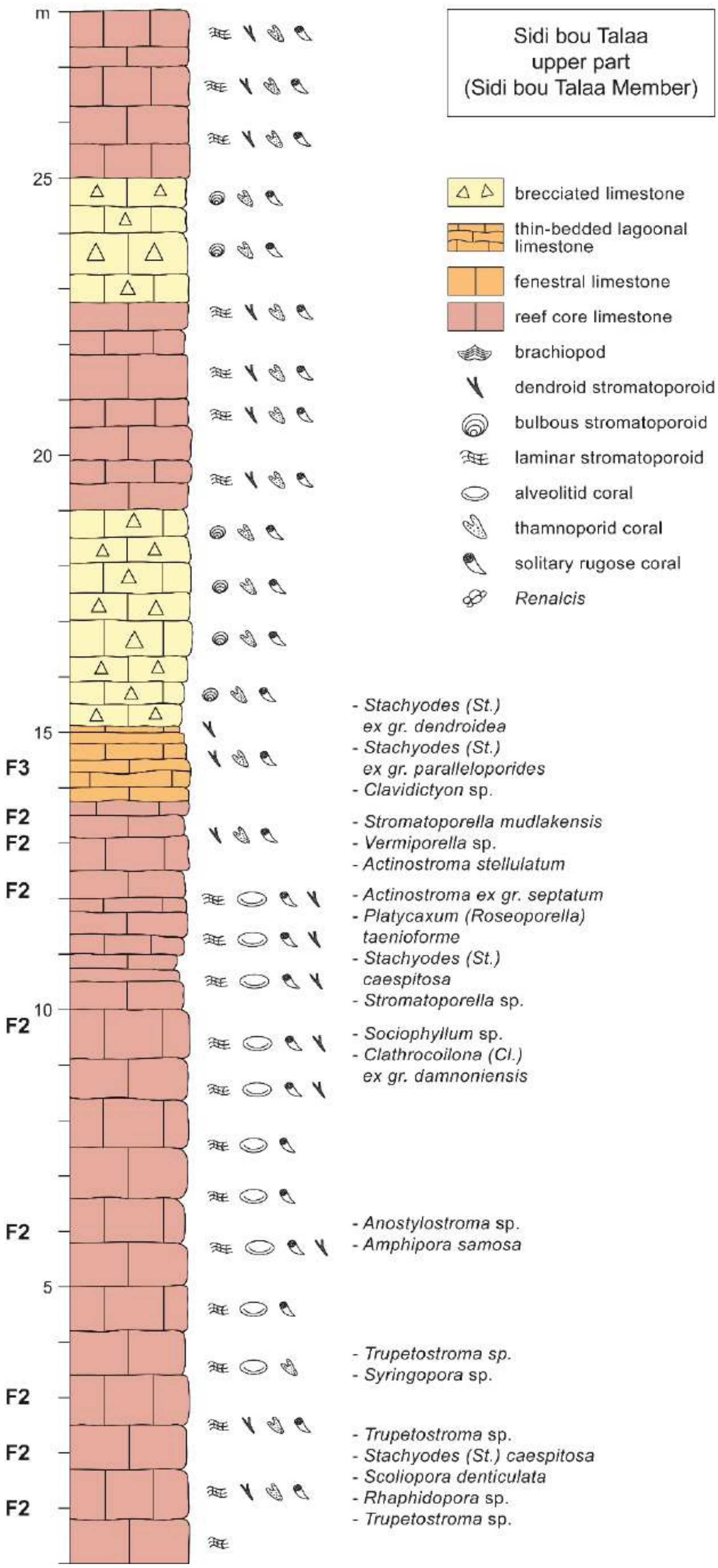

Fig. 18: Simplified macro- and microfacies log for the upper Sidi bou Talaa Member, showing the principle facies (SBT), macrofauna observed in the field, and fauna identified in thin-sections. Note the dominance of true reef facies indicating reef backstepping during transgressive phases.

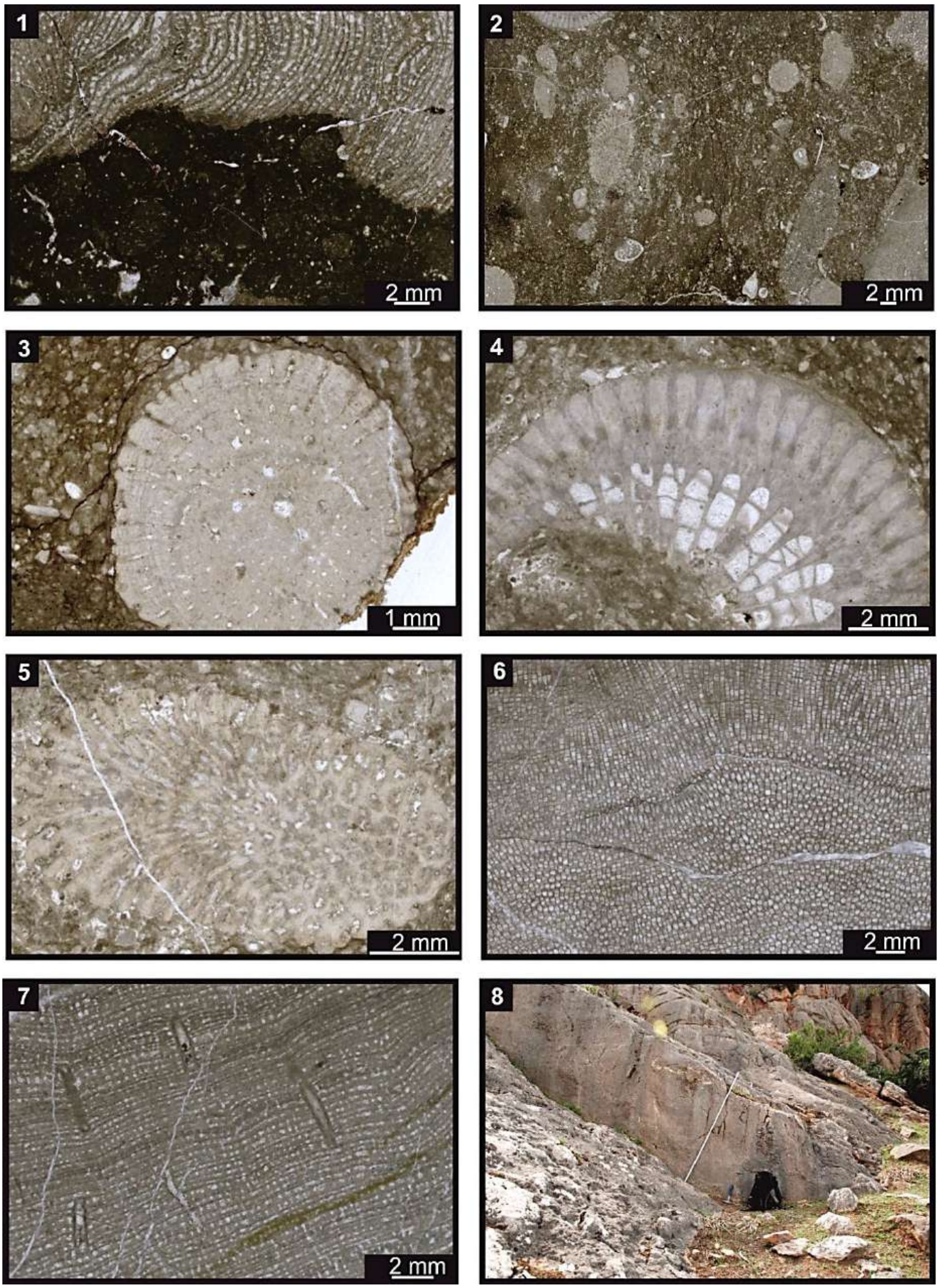

Fig. 19: Macro- and microfacies of upper part of Sidi bou Talaa Member (from base to 6 m), SBT MF2, stromatoporoid-coral boundstone with large laminar, bulbous and dendroid stromatoporids, and tabulate corals. **1.** *Trupetostroma* sp., at 1 m; **2-5.** Cross sections of dendroid stromatoporoids (*Stachyodes (St.) caespitosa*, enlarged in 3.), tabulate (*Scoliopora denticulata,* enlarged in 5.), and fragmentary solitary rugose corals (enlarged in 4.) within a bioclastic wacke-floatstone matrix, at 2 m; **6.** Chaetetid sponge *Rhaphidopora* sp. at 2 m; **7.** *Trupetostroma* sp. with tube-shaped corallites of *Syringopora* sp., at 3 m; **8.** Field photo of thick-bedded stromatoporid-coral boundstones, at 4-6 m.

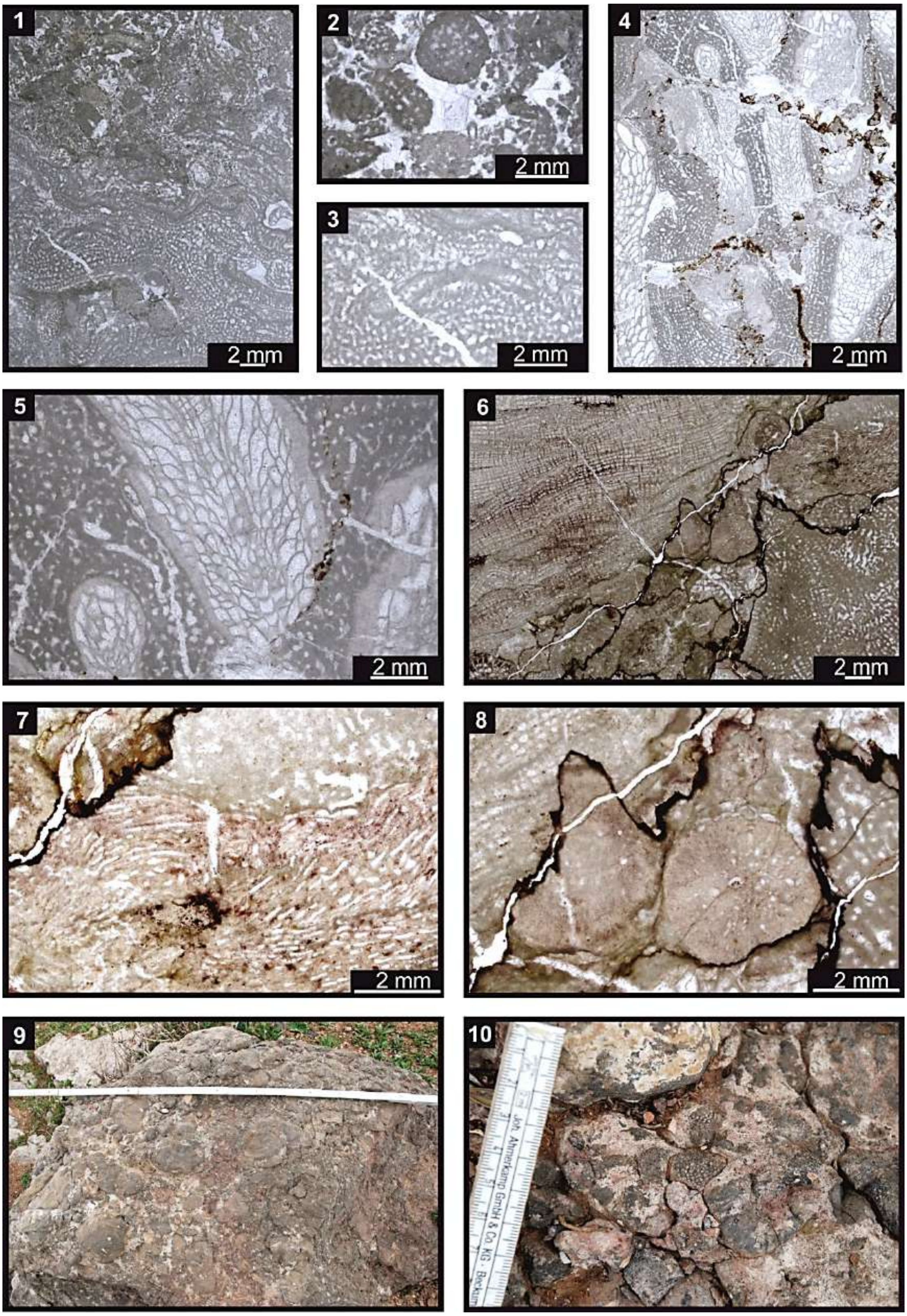

Fig. 20: Macro- and microfacies of upper part of Sidi bou Talaa Member (6-12 m), SBT MF2, stromatoporoid-coral boundstone with large laminar, bulbous and dendroid stromatoporids, and tabulate corals. **1-3.** *Anostylostroma* sp. (enlarged in 3.) encrusting delicate dendroid stromatoporoid branches (poorly preserved *Amphipora ramosa*, enlarged in 2.), at 6 m; **4-5.** Colonial rugose coral *Sociophyllum* sp. (enlarged in 5.) encrusted by *Clathrocoilona (Clathrocoilona)* ex gr. *damnoniensis*, at 10 m; **6-8.** *Actinostroma* ex gr. *septatum* (on the left in 6.), alveolitid *Platyaxum (Roseoporella) taenioforme* (top right corner in 6., enlarged in 7.), *Stromatoporella* sp. (at the bottom right in 6.), and *Stachyodes (St.) caespitosa* (enlarged in 8.), at 12 m; **9-10.** Field photos of slightly brecciated stromatoporid-coral rud-boundstones, at 12 m.

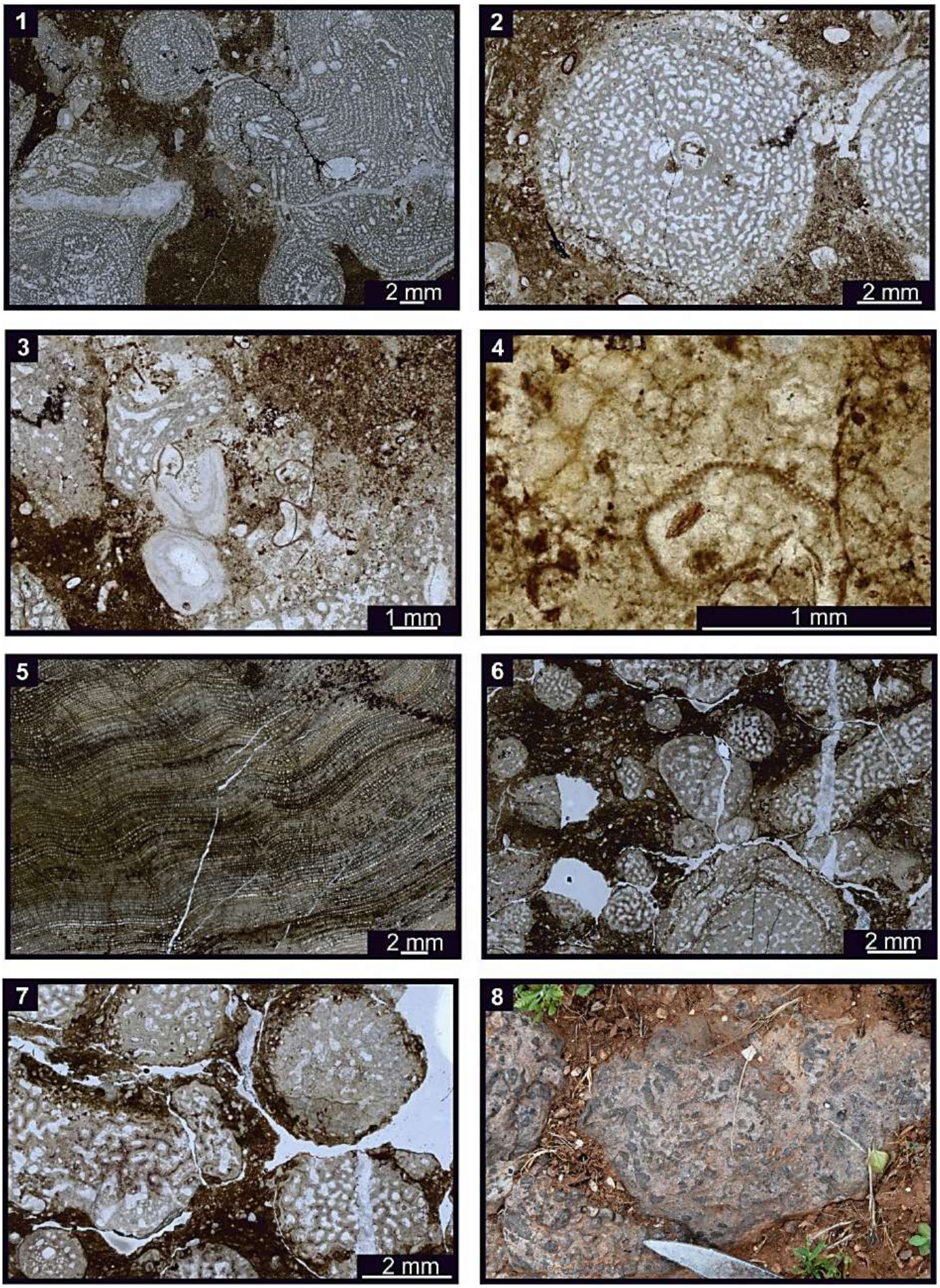

Fig. 21: Macro- and microfacies of upper part of Sidi bou Talaa Member (13-14 m), SBT MF 3, stromatoporoid-bafflestone. **1-4.** Bafflestone with dendroid stromatoporoid *Stromatoporella mudlakensis* (enlarged in 2.) fragment of auloporoid tabulate coral (enlarged in 3.), and a fragment of the dasycladacean green alga *Vermiporella* sp. (enlarged in 4.), at 13.5 m; **5.** *Actinostroma stellulatum*, at 13 m; **6-7.** Dendroid stromatoporids *Stachyodes (St.)* ex gr. *paralleloporoides*, *St. (St.)* ex gr. *dendroidea* (enlarged in 7., top right), and *Clavidictyon* sp. (enlarged in 7., left side), at 14 m; **8.** Field photo of stromatoporoid bafflestone, at 14 m.

The reef belt from the Meseta in the north to the "Zemmour noir" of northern Mauritania in the south had a published record of ca. 70 Givetian/Frasnian reef builders plus almost 90 rugose coral species, some of which (the phillipsastreids and cystiphyllids) may form biostromes or small mounds (e.g., WENDT 1993; NÜBEL & BECKER 2004; JAKUBOWICZ et al. 2017). Therefore, our high number of new Moroccan records (17 = ca. 2/3) just underlines the still poor taxonomic knowledge of Moroccan Devonian reefs. At least at the generic level, there is no difference to European Givetian reefs. EICHHOLT & BECKER (2016) emphasized that Oued Cherrat/Al Attamna reefs share the principle paleoecology and facies types of German reefs. With respect to the significant spatial difference (> 3.000 km) at the southern margin of the subtropical belt, this pattern has palaeoclimatic implications: the assumption of a very low climatic and palaeoecological gradient from the tropics into the middle latitudes. On the other side, as noted by JAKUBOWICZ et al. (2017), the Aferdou el Mrakib reef of the southern Maïder (Anti-Atlas), represents a rather different reef type than those of the Meseta.

The recognition of stringocephalids at 7.8 m (lower succession) confirms the established lower/middle Givetian age. RAJI et al. (2004) found *Po. varcus* and *Po. timorensis* in the Bouchhada quarry. The first is an index species of the middle Givetian (*rhenanus-varcus* Zone of BULTYNCK 1987). We tested brecciated limestones and beds with micrite matrix in the lower part of the Sidi bou Talaa Member without success for conodonts, which is no surprise since these are mostly lacking in reef core and backreef settings.

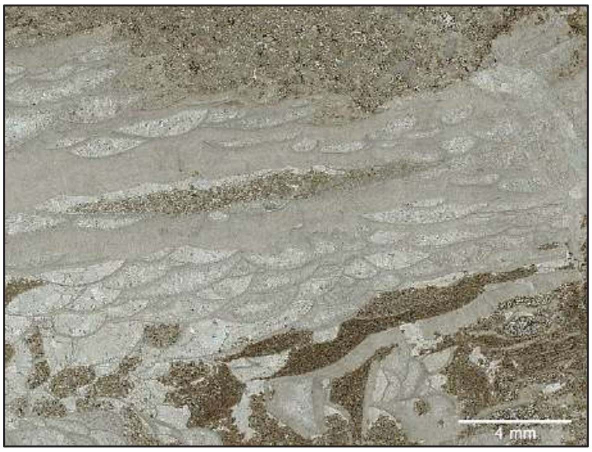

Fig. 22: Longitudinal section through a *Mesophyllum (Cystiphylloides)* from the northern top of Sidi bou Talaa.

Fig. 23: Fault-controlled upper (northwestern) end of the Sidi bou Talaa reef.

The poorly-bedded reef core limestones continue beyond our section log, with large boulders forming the crest of the ridge. At the top, the macrofauna evidence is sparse. In thin section, the only cystiphyllid (Fig. 22) was found. This peculiar group of rugose corals is rather diverse in the Ouihlane Reef of the northern Maïder, Anti-Atlas (SCHRÖDER & KAZMIERCZAK 1999). The sharp termination of reef blocks (Fig. 23) supports the interpretation of EL KAMEL (2004, map of fig. 46) that the reef top was cut off by a fault.

Fig. 24: The steeply dipping Lower Devonian (new) Oued Kibane Formation on the southern side of the main road to Sidi et Tnine (to the left), showing thin-bedded Lower and Upper Members and a massive, thick-bedded Middle Member dipping steeply to the right = west (Fouad El Kamel, Zhor Sarah Aboussalam and Julian Shahin Becker for scale at the section base, photo from April 2012).

5. Devonian at Foum el Mejez

After an interruption of Palaeozoic outcrops by Cretaceous cover (Fig. 2), the Devonian re-appears in the NE Rehamna in narrow, ca. N-S oriented graben structures at Foum el Mejez, with good exposures north and south of the Oued Kibane, ca. 9-10 km NE of Mechra Ben Abbou. These successions have previously been studied by Gigout (1955a), Bäcker et al. (1965), Jenny (1974), Hollard et al. (1982), and El Kamel (2004). El Kamel & El Hassani (2000) documented important phases of Lower Devonian tectonism, resulting in slumping, tilted blocks, decametric synsedimentary faults, and pillow structures. Despite this intensive past research, the precise dating of strata and the documentation of faunas is still poor. Separated by graben faults, a western limestone-dolomite succession (Fig. 24) and an eastern, Famennian siliciclastic sequence can be separated. The term Foum el Mejez Formation was introduced by Hollard et al. (1982) for the latter and, therefore, cannot be applied to the much older carbonates, as it was done by El Kamel (2004) or Oukassou & Naugolnykh (2021). Consequently, a new formation term, the Oued Kibane Formation, is introduced. El Kamel (2004, fig. 50) published a fine, detailed geological map of the Foum el Mejez Devonian, which illustrated the numerous, ca. SSW-NNE running normal faults that displace the overall graben structure (Fig. 25). Our limited field work aimed at new biostratigraphic, faunal and facies data but was restricted to the outcrops just north and south of the road to Sidi et Tnine in the NE.

Fig. 25: Series of limestone/dolomite ridges in the south of the sampled section at Foum el Mejez, illustrating the dislocation of the Oued Kibane Formation by normal faults.

5.1. Lower Devonian (new) Oued Kibane Formation

The calcareous to dolomitic Oued Kibane Formation has a total thickness of 50-60 m and can be subdivided into three members (Fig. 24). Our section at x = 283.35, y = 235.05 is identical with the western part of the cross-section of JENNY (1974) and HOLLARD et al. (1982, fig. 1.5). Beds dip constantly and steeply to the west. Below the formation lie poorly exposed and unfossiliferous siltstones, assigned by OUKASSOU & NAUGOLNYKH (2021) to the Sakhra Touila Formation. The up to 20 m thick **Lower Member** of the Oued Kibane Formation consists of middle-grey, thin-bedded, middle- to coarse-grained, partly dolomitic bioclastic limestones. Limestones may be separated by minor marl interbeds. Recrystallization was partly so strong (Fig. 26) that only remnants of crinoid fragments are poorly recognizable. EL KAMEL (2004) noted debris of brachiopods, crinoids, mollusks, corals, bryozoans, and trilobites. This points to a storm-ridden, neritic, open (non-reefal) carbonate ramp. This is in accord with our monotypic record of *Caudicriodus celtibericus* (six specimens, Fig. 27.1), which ranges from the top-Pragian to high in the lower Emsian (e.g., ABOUSSALAM et al. 2015). We assume a basal Emsian age for the time of carbonate platform initiation, which either reflects a deepening pulse, in accord with eustatic trends, or a weathering- and climate-related reduction of clastic influx.

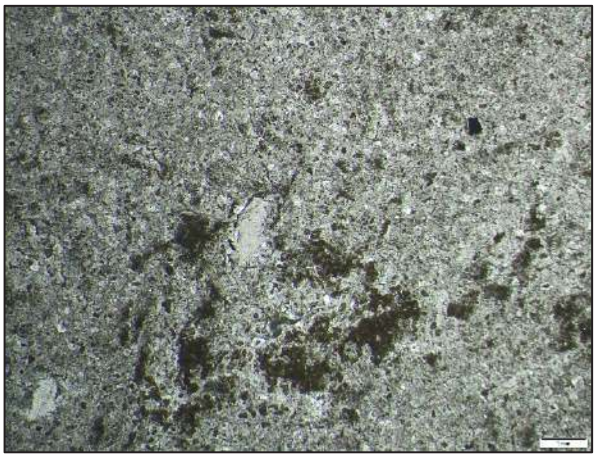

Fig. 26: Pseudosparitic thin-section from the lower part of the Lower Member of the Oued Kibane Formation showing the complete recrystallization that destroyed all local fossil record.

Fig. 27: Conodonts from the Oued Kibane Formation at Foum el Mejez, GMM B4C.2.117-118. **1.** *Caudicriodus celtibericus*, lateral process broken off, middle part of Lower Member, length = 0.6 mm; **2.** Corroded *Neopanderodus perlineatus* showing a very strong lateral depression (perhaps for venom transport) and only weak remnants of fine striation, top part of dolomitic Upper Member, length = 0.97 mm.

The 20-30 m thick **Middle Member** consists of thick-bedded to massive dolomitic limestones that are laterally affected by synsedimentary faulting, slumping and in-situ brecciation (El Hassani & El Kamel 2000). Macroscopically few fossils are visible apart from crinoid fragments but the niches of boulders are inhabited by large snakes, who leave impressive dry skins. In thin-sections, El Kamel (2004) observed a similar bioclast spectrum as in the Lower Member. There was a regressive trend towards a crinoid-dominated higher ramp position but no evidence for a biostrome setting as one may deduce from the term "peri-reefal" (e.g., Oukassou & Naugolnykh 2021). Accordingly, Hollard et al. (1982, p. 21) refer to a rather diverse neritic fauna from Le Mâitre (1938) and the unpublished report of Bäcker et al. (1965), including orthids, atrypids, pentamerids, *Glossinulus mimicus*, *Paraspirifer cultrijugatus, "Alatiformia" mischkei* (which is probably a species of a different genus), *Euryspirifer paradoxus*, favositids, and solitary corals. If identifications are correct, the four listed species provide an upper/uppermost Emsian age (see zonation in Jansen 2016).

Fig. 28: Field photo of thin-bedded, yellowish dolomites, Upper Member of Oued Kibane Formation at Foum el Mejez.

The 20-25 m thick **Upper Member** is an alternation of thin-bedded, decimetric, dolomitic limestones, yellowish dolomites (Fig. 28), and marls. The latter become more prominent in the upper half. El Kamel (2004) noted chert levels originating from the mobilized SiO_2 of sponge spicules. He also recorded debris of crinoids, mollusks, brachiopods, trilobites, and ostracodes. However, recrystallization and dolomitization destroyed all the original microfabric, especially in the upper part (Fig. 29). The environment returned to a deeper ramp setting. The top of the formation is sharp and possibly a fault contact.

None of the previous studies reported any Middle Devonian fossil from Foum el Mejez. Our conodont sample from the top of the Oued Kibane Formation yielded, despite the complete dolomitization, two specimens of *Neopanderodus perlineatus* (Fig. 27.2). This is a long-ranging shallow-water species and, based on its strong longitudinal furrow, may have been venomous (Szaniawski 2009). It has been found as a dominant form in the lower/upper Emsian and lower Eifelian of the Tiflet and Oued Cherrat successions (Benfrika et al. 2007; Becker et al. 2020a) or, far away, in Emsian beds of the Istanbul area (Saydam-Demiray & Çapcinoğlu 2012). It was also found to be common in a lower Givetian limestone of Dar Cheik el Mfaddel (Benahmed region) and in a basal Frasnian breccia at Aïn-al-Aliliga (Oued Cherrat). Since the Eifelian was characterized by deepening and by blooms of organic silica both at Mechra Ben Abbou and at Jebel Ardouz (see that chapter, this volume), we assume tentatively a basal Middle Devonian age for the Upper Member. However, there are no data to support a correlation of the middle/upper Oued Kibane Formation with the main reefal Mechra Ben Abbou Formation (Sidi bou Talaa Member). This has implications for the facies and palaeogeography model. There is no evidence for a west-east facies differentiation in the Middle Devonian. Currently, we know nothing about the upper Eifelian to Frasnian of the Foum el Mejez region. The important local phase of Eovariscan tectonism occurred in the lower/upper Emsian. This block faulting obviously masked the global Daleje Event, which is well-expressed in other Meseta regions (e.g., Oued Cherrat, Becker et al. 2020a) and possibly in the Benahmed region (see Benahmed chapter, this volume).

Fig. 29: Thin-section of a thin-bedded dolomitic limestone from the top of the Upper Member of the Oued Kibane Formation, showing the complete recrystallization and destruction of bioclasts.

5.2. Famennian Foum el Mejez Formation

Separated by a steep, ca. N-S running fault, the more than 200 m thick Foum el Mejez Formation lies nearly horizontally just 400-500 m NE of the steeply dipping Lower Devonian outcrop (Fig. 30). In our section, at x = 283.7, y = 235.3 (see map of El Kamel 2004), we estimated ca. 50 m of exposed fossiliferous laminated to cross-bedded silty shales, siltstones, and fine sandstones, followed rather sharply by massive quartzites. The section has previously been studied by Gigout (1955a) and Hollard et al. (1982, see cross-section in fig. 15.1). El Kamel (2004) used the term Dalaa Formation, which is pre-occupied by the Foum el Mejez Formation introduced by Hollard et al. (1982). Since Dalaa is the name for the quartzite hill top, it is suitable as name for the upper member. For the main lower part (El Kamel´s members OA1-3), the term Oued Ater Member is used, adopted from the Oued Ater Formation of El Kamel (2004). Its type locality is in the south of the Foum el Mejez Graben (Fig. 2) and was first studied by Hollard et al. (1982: Unit 3).

Fig. 30: Overview of the nearly horizontally bedded Oued Ater Member at Foum el Mejez, with Lea Amira Becker for scale (photo from April 2012). Quartzite blocks are debris from the Dalaa Member at the top.

5.2.1. Oued Ater Member

The main lithology is an alternation of greenish-grey silty shale and thin-bedded (up to 7 cm thick), greenish to yellowish-grey weathering, cross-bedded, fine sandstones with wavy lower and upper surfaces. A thin-section reveals very good sorting and variably amounts of fine quartz and iron mineral grains. Sandstones become more common in the upper ca. 40 m of the exposure, characterizing locally "Member D2" sensu El

KAMEL (2004). At this level, there are trace fossils and common brachiopods that are concentrated in specific intervals, especially at 35 to 30 m below the top. The preservation is at best moderate. Shells have been dissolved and molds and negatives are incomplete, distorted and abraded. We observed/collected (identifications by D. BRICE, Lille):

small orthids
cf. *Gastrodetoechia* sp. (Fig. 31.1A, 2)
Leptoterorhynchus sp. (cf. Fig. 31.1B)
cf. *Ptychomaletoechia* or *Sinotectiorostrum* sp. (Fig. 31.3)
cf. *Petasmaria* or *Porostictia* sp.
spiriferids indet. (Figs. 31.4-5)

The rhynchonellids are dominant. *Gastrodetoechia* is a middle to lower upper Famennian genus (SARTENAER 1967). *Leptoterorhynchus* was described from the middle Famennian of Poland and the Rhenish Massif (SARTENAER 1998). *Ptychomaletoechia* and *Sinotectirostrum* have long ranges through the Famennian (SARTENAER 1967). The type level of *Porostictia* is in the upper middle to lower upper Famennian of New Mexico (Percha Shale). In combination, our brachiopod collection from the lower part is assigned to the middle Famennian but higher parts of the member fall probably in the upper Famennian. We took some spore samples for C. HARTKOPF-FRÖDER (Krefeld) but results are not yet available. The environment was a prodelta on an open, subtidal shelf. The brachiopod-poor lower part may represent the lower Famennian although the reported bivalve *Buchiola* (BÄCKER et al. 1965; HOLLARD et al. 1982) has no stratigraphic value without a species-level identification. It indicates a deeper outer shelf biofacies. The change to brachiopod facies may well reflect the eustatically controlled Condroz Regression (BECKER 1993) at the lower/middle Famennian transition. As illustrated in the cross-section of HOLLARD et al. (1982, fig. 1.9), the Oued Ater Member has no equivalents in the west, which confirms the interpretation that it deposited in a subsiding fault zone, which was later transformed into the graben structure.

5.2.2. Dalaa Member

The Dalaa Member consists of coarse-grained, cross-bedded, light-grey to reddish weathering, thick-bedded and cliff-forming quartzites. It equals Unit 4a-c of HOLLARD et al. (1982, fig. 1.5). To the south, at Oued Ater (Fig. 2), conglomerates occur (EL KAMEL 2004). At Foum el Mejez, OUKASSOU & NAUGOLNYKH (2021) recognized three quartzite bars. Based on collections of GIGOUT (1955a; compare HOLLARD et al. 1982) and EL KAMEL (2004), there is a relatively diverse brachiopod fauna, including *Sphenospira julii*, other cyrtospiriferids that require revision, various productellids, *Mesoplica praelonga*, rhynchonellids, including *Centrorhynchus letiensis*, and *"Athyris royssi"*. The member clearly correlates with the similar quartzites of the Douar Nahilat Formation at Gare Mechra Ben Abbou (see below). The first listed species is regarded as the most characteristic uppermost Famennian ("Strunian") spiriferid of Europe (NICOLLIN & BRICE 2004; MOTTEQUIN et al. 2013). The types of the productid *Mesoplica praelonga* come from the uppermost Famennian (LE spore zone) Lower Pilton Formation of North Devon. But the species is wide-spread in the upper/uppermost Famennian, including Algeria and the Dra Valley (e.g., KAISER et al. 2004; NICOLLIN & BRICE 2004; BRICE et al. 2007). *Centrorhynchus* has a long range in the middle to uppermost Famennian but, as the other taxa, did not survive into the Carboniferous (BRICE et al. 2007; MOTTEQUIN et al. 2013). It occurs widely in Morocco, including the western

(Brice et al. 2007) and eastern Anti-Atlas (e.g., Becker et al. 2013b). The last listed species refers in fact to *Cleiothyridina deroissyi* (Léveillé, 1835), which is an upper Tournaisian species. The Foum el Mejez record is most likely based on a different athyrid; for example, there are older species of the genus *Cleiothyridina* (see, e.g., Mottequin 2008).

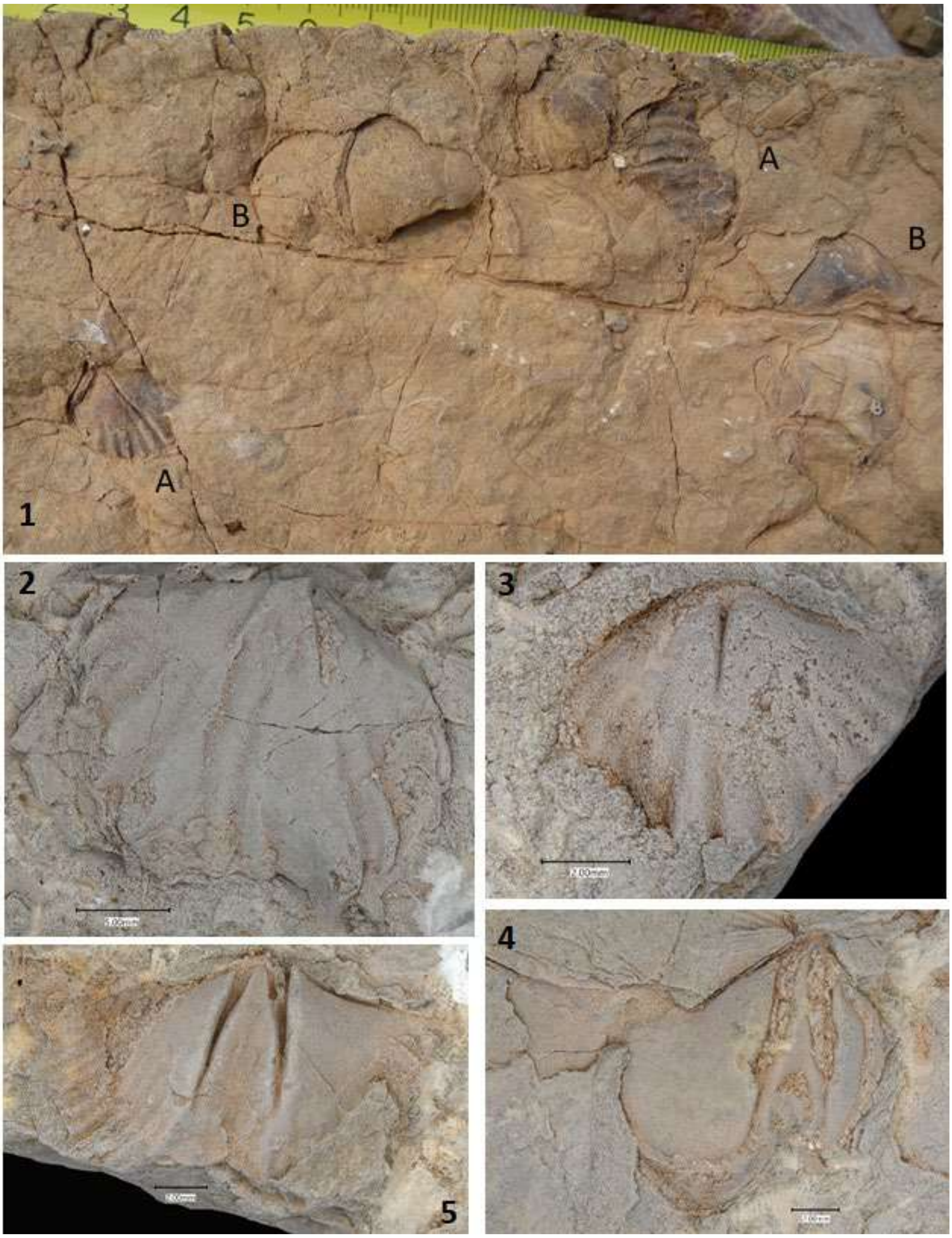

Fig. 31: Brachiopods from ca. 35 to 30 m below the top of the Oued Ater Member at Foum el Mejez (det. D. Brice, Lille). **1.** Field photo of a slab (GMM B5B.16.3) with several rhynchonellids (A = cf. *Gastrodetoechia*, B = *Leptoterorhynchus*): **2.** cf. *Gastrodetoechia* sp., GMM B5B.16.4; **3.** cf. *Ptychomaletoechia* or *Sinotectirostrum* sp., GMM B5B.16.5; **4-5.** Spiriferids indet., GMM B5B.16.6-7.

In summary, a "Strunian" age of the Dalaa Member is supported by the published brachiopod data but all previous records require confirmation by description or illustration. GIGOUT (1951, p. 64) mentioned from a locality named as Aïn Belmesk (loc. 633) "*Phacops* cf. *bergicus*", which refers to a species of the genus *Omegops* (see STRUVE 1976), a typical phacopid of the shallow-water "Strunian". The Dalaa Member is also the type-level of the unusual new plant described by OUKASSOU. & NAUGOLNYKH (2021). The environmental setting is interpreted as delta lobes prograding eastwards.

In their lateral section south of the Oued Kibane, HOLLARD et al. (1982) recorded two overlying units, which are currently not included in the Foum el Mejez Formation. Unit 5 was a thick silty shale, unit 6 a sandy calcarenite with gastropods, a poorly preserved goniatite, and spiriferids. EL KAMEL (2004, p. 92) did not consider a Tournaisian age but further work has to clarify their age.

6. Devonian at Koudiat ed Diab

Incorporating fossil reports by GIGOUT (1951, 1955a) and BÄCKER et al. (1965), HOLLARD et al. (1982) established a detailed Lower Devonian succession at Koudiat ed Diab (= Koudiat ed Dib), ca. 5 km ENE of Mechra Ben Abbou (Fig. 2). This, not the Ouled Barka section to the SW, as later proposed by BEN BOUZIANE (1995), is the type-section of the Koudiat ed Diab Formation. We tried to follow the HOLLARD et al. succession on the way to the "Autunian" conglomerate in the north but outcrops are episodic and we did not find all levels. Therefore, we took only few samples, which did not deliver a single conodont. Therefore, the Koudiat ed Diab Formation is only briefly summarized and commented on, from base to top.

1. Silty black or violet shales with thin or lenticular, dolomitic limestones with large orthocones and *Scyphocrinites* debris. This seems to be the widespread *Scyphocrinites* level at the Silurian-Devonian boundary (e.g., RÉGNAULT 1985), which, however, does not occur in the Sakhra et Taïra succession. With respect to the lower Lochkovian faunas occurring higher, Unit 1 may be Pridoli in age.
2. Yellowish to ochre, dolomitic limestone with orthocones and sandstone/quartzite, followed by a thick, un-numbered shale.
3. Thin sandstone, followed by shale with intercalated yellowish limestone with orthocones (up to 30 cm) and eventually bioclastic, fossiliferous limestone. The reported tentaculitoid *Volynites* (BÄCKER et al. 1965) has a long range in the Lochkovian (e.g., TRUYOLS-MASSONI 1995) to Frasnian (e.g., FARSAN 1974); it proves a Devonian (Lochkovian) age for the unit.
4. Silty shale with intercalated bioclastic limestone.
5. Rose-colored, cross-bedded quartzite, laterally conglomeratic.
6. Shales and dark siltstones with subordinate bioclastic limestone.
7. White to reddish, cross-bedded quartzite with plant remains and conglomeratic channels.
8. Silty shale (not numbered), followed by a 15 m wide area with alternating ochre marls and fossiliferous limestone with brachiopods, corals, trilobites, and bryozoans. Loc. 1314 of GIGOUT (1955a) yielded lower Lochkovian index species, such as *Howellella mercurii*, *Lanceomyonia borealiformis* (now type-species of *Ktenopotamorhynchus* SARTENAER, 2015), *Warburgella rugosa*, and *Acastella patula*. The latter was originally described from the Lochkovian Lmhaifid Formation of the Dra Valley (HOLLARD 1963b).
9. Silty shale (not numbered) followed by bioclastic limestone.
10. 5 m of bioclastic limestone, sampled without success for conodonts. In thin-section (Fig. 32), it is a moderately sorted crinoid-brachiopod grainstone with favositids, sparite matrix, and iron hydroxide impregnations. Ribbed rhynchonellids (Fig. 33) are common

but always incomplete. The setting was a storm-ridden shallow carbonate platform. From the lateral sample 184 of GIGOUT (1951), Pragian brachiopods were reported. These include *Torosospirifer rousseaui,* "*Hysterolites? nerei*" (possibly a *Dixonella* sp.), *Stenorhynchia nympha* (SARTENAER 2010 doubted that forms from outside Bohemia belong to this genus and species), and "*Euryspirifer* cf. *pellico*" (which ranges into the Emsian).

11. Poorly exposed interval of shales, thin limestones and sandstones in the slope below the cliff-forming Mechra Ben Abbou Formation.

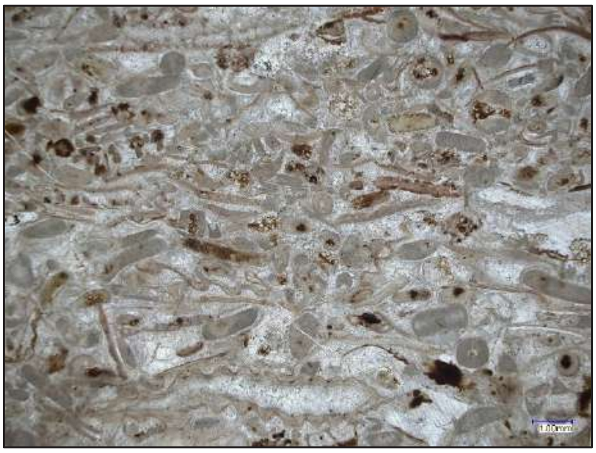

Fig. 32: Microfacies of ca. Unit 10 at Koudiat ed Diab, a poorly sorted crinoid-brachiopod grainstone deposited by storms on a shallow carbonate platform.

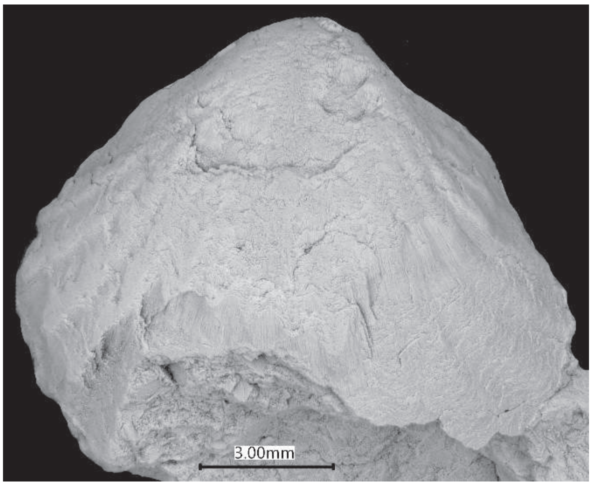

Fig. 33: Small rhynchonellid from Koudiat ed Diab, ca. Unit 10 sensu HOLLARD et al. (1982), GMM B5B.16.14.

7. Douar Nahilat Formation at Gare Mechra Ben Abbou

Following the initial discovery by DELEPINE & YOVANOVITCH (1938), the formal term Douar Nahilat Formation was introduced by HOLLARD et al. (1982) for often reddish (hematite impregnated) Famennian quartzites that truncate the Givetian reef limestones of the Mechra Ben Abbou Formation. The type section is at Douar Nahilat (Fig. 2), ca. 2 km SE of the railway station, on the southern slope of the Koudiat Forcha (see also GIGOUT 1951, BÄCKER et al. 1965, BEN BOUZIANE 1995: "Nahilat Formation"; EL KAMEL 2004). There, a thick alternation of silty shales, quartzites and conglomerates, partly including reworked Devonian limestones, was illustrated by HOLLARD et al. (1982, fig. 1.7). It was named as Koudiat el Forcha Formation by EL KAMEL (2004), which is a junior synonym.

We re-studied the unconformable contact between the Mechra Ben Abbou and Douar Nahilat Formation just northeast of the Mechra Ben Abbou railway station, at GPS N32°39´22.0´´, W7°46´53.1´´. The Givetian reef limestone is locally very massive and poorly bedded (Fig. 34), representing a true reef facies. Its top is a sharp, undulating, iron impregnated, erosional and karstification surface (Fig. 35.1). This suggests a long period of exposure, probably due to block tilting. The basal Douar Nahilat Formation consists of breccias mixing unsorted, variably sized, angular reef limestone clasts (Figs. 35.3-4), quartzite (Fig. 35.2), and a hematite-rich, partly laminated matrix (Fig. 35.6). Conodont sampling of both isolated clasts or of whole rock breccia was not successful. This is not surprising since Devonian biohermal reef facies normally lacks any conodonts. Thin-sections of reworked clasts yielded the stromatoporids *Stromatoporella* ex gr. *solitaria* NICHOLSON, 1892 (Fig. 35.4) and

Clathrodictyon (Synthetostroma) actinostromoides (LECOMPTE, 1951) (Fig. 35.5). Both species have not been recorded from Morocco so far. But *Stromatoporella* and *Clathrodictyon (Synthetostroma)* are in general wide-spread Middle Devonian genera/subgenera (e.g., STEARN et al. 1999). The first ranges only questionably into the Frasnian but has been identified in the lower Givetian of the Anti-Atlas (JAKUBOWICZ et al. 2018). The second ranges into the Frasnian in Czechia. The new records are not surprising since Moroccan Devonian stromatoporids have been studied poorly (MISTIAEN 1999).

Other important features are the interval brecciation of reworked clasts (Figs. 35.3, 6), partly complete recrystallization and lithification before reworking and re-sedimentation. The tight internal suturing (Fig. 35.6) suggests synsedimentary (Givetian) tectonism, as it is well-established at Sidi bou Talaa (see above). Other clasts consist of unsorted crinoidal pack-rudstone (Fig. 35.5), suggesting reef slope debris. The breccia represents a rockfall, followed by stromatolithic encrustation (Fig. 36) at a time of arid, lateritic weathering and a constant influx of iron-rich fluids. The tilted reef limestone formed obviously a coastal palaeocliff, which was transgressed after a long gap (upper Givetian to upper Famennian). In the overlying lower part of the Douar Nahilat Formation, we collected quartzite coquinas of *Mesoplica praelonga* (Fig. 37), an upper/uppermost Famennian marker productid. Their shells were removed in the carbonate undersaturated pore water. The created cavities were partly filled by authigenic hematite grains (Fig. 38). A very good sorting of quartz grains and monotypic faunas are typical for nearshore sand bars.

From the type-locality of the formation, DELEPINE & YOVANOVITCH (1938) and GIGOUT (1951) listed a richer brachiopod fauna, including *Whidbornella caperata, Productella subaculeata, Centrorhynchus letiensis, Sphenospira julii*, and others. This fauna clearly falls in the uppermost Famennian (see MOTTEQUIN et al. 2013). However, it needs to be stressed that the documentation is poor and modern taxonomic revisions are required. For example, the also listed "*Rhynchonella pleurodon*", now the type-species of *Pleuropugnoides* FERGUSON, 1966, is a Lower Carboniferous species (e.g., PARKINSON 1969).

Fig. 34: Givetian reef limestone (main slope with massive limestone boulders), followed in the middle ground by a more reddish weathering hill formed by resistant quartzites of the lower Douar Nahilat Formation.

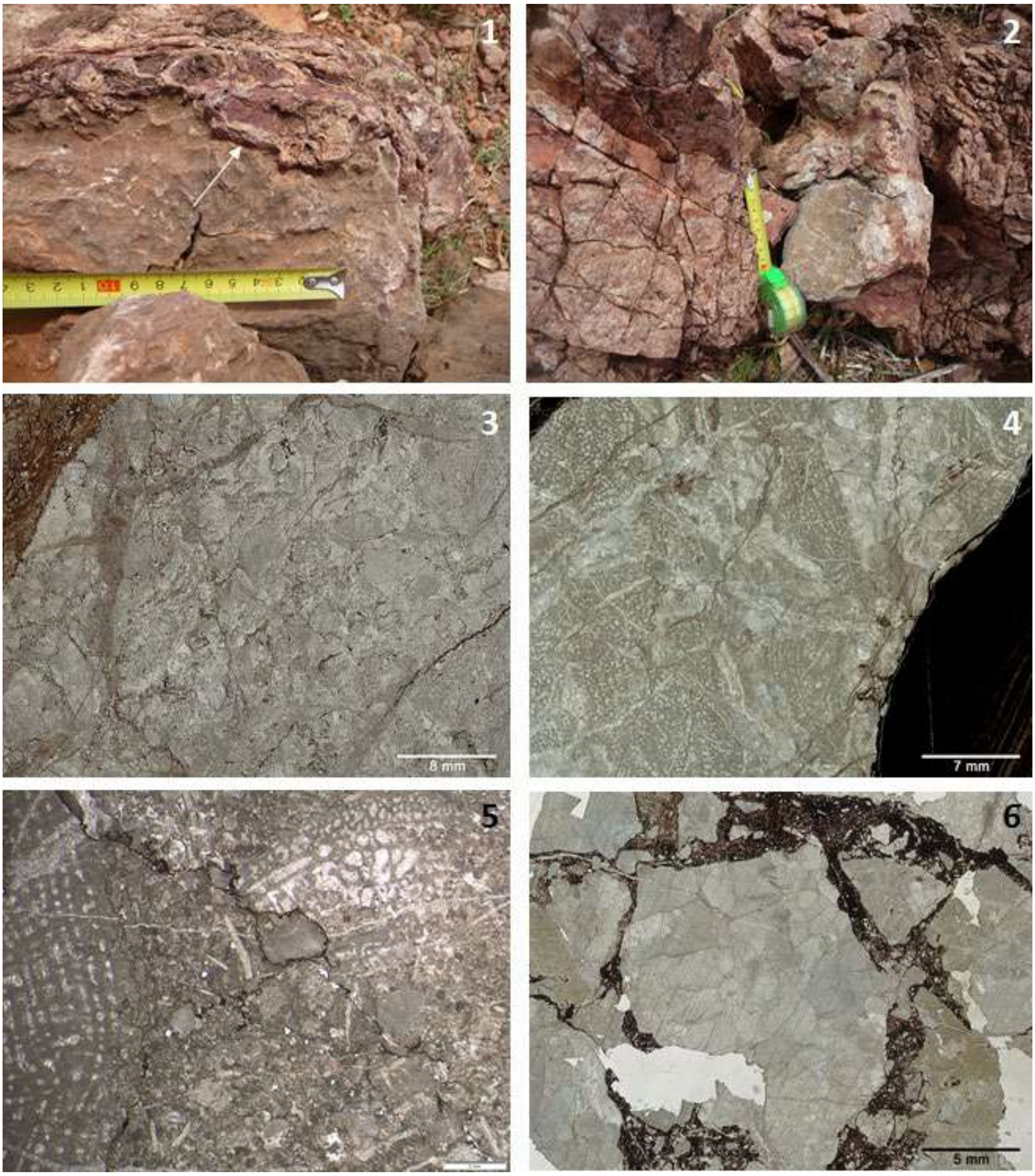

Fig. 35: Field photos and thin-sections of the brecciated and disconformable base of the Douar Nahilat Formation at Gare Mechra Ben Abbou. **1.** Undulating truncation surface (white arrow) between the top reef limestone and the reddish (hematite-impregnated) basal Douar Nahilat Formation; **2.** Breccia in the lower part of the latter with angular clasts of reef limestone (e.g., right next to the measuring tape) between quartzites; **3.** Block of internally brecciated and recrystallized intraclast rudstone within the basal breccia, with stromatolithic and hematitic encrustation (upper left); **4.** Reworked block of reef limestone with *Stromatoporella* ex gr. *solitaria*; **5.** Unsorted reef breccia (intraclast-crinoid pack-rudstone) with the stromatoporid *Clathrocoilona (Synthetostroma) actinostromoides* (left), evidence for double reworking in the breccia unit; **6.** Unsorted rockfall breccia consisting of strictly angular, internally brecciated, recrystallized limestone clasts and iron-mineralized matrix.

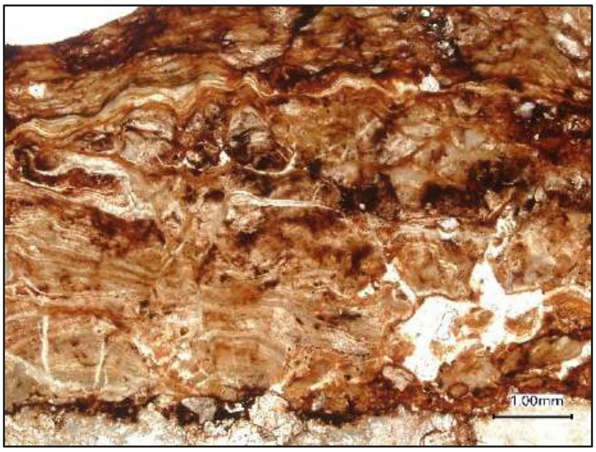

Fig. 36: Encrustation of a reworked block of recrystallized reef limestone (at the base) by iron stromatolites, breccia at the base of the Douar Nahilat Formation, Gare Mechra Ben Abbou.

Fig. 37: Iron-stained quartzite coquina with the upper/uppermost Famennian productid *Mesoplica praelonga*, lower part of Douar Nahilat Formation at Gare Mechra Ben Abbou, GMM B5B.16.8.

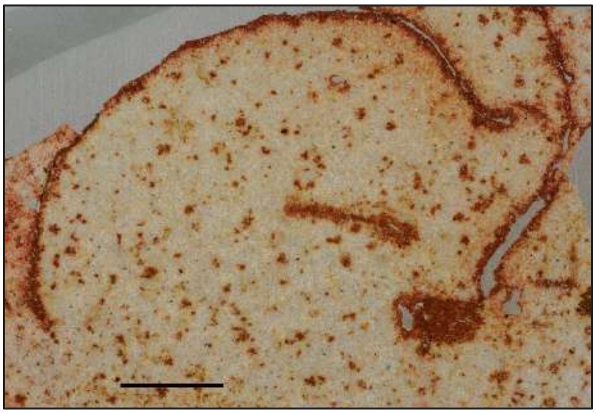

Fig. 38: Thin-section of the *Mesoplica* coquina at Gare Mechra Ben Abbou, showing the good sorting of quartz and coating of the brachiopod mold by hematite grains, embedded convex-up and leaving a part of the secondary porosity created by shell dissolution.

Fig. 39: Unsorted, coarse breccia north of Koudiat ed Diab, dominated by angular clasts of Devonian limestone, with reddish clastic matrix in interspaces.

8. “Autunian conglomerate” at Koudiat ed Diab

More than 500 m thick breccias crop out in boulders and ledges north of the Koudiat ed Diab Lower Devonian (Fig. 39). HOLLARD et al. (1982) suggested a fault contact. In the regional absence of any fossils from the matrix, an “Autunian” age was assumed based on the correlation with other regions, such as the Jebilet. EL KAMEL & MULLER (1987) distinguished two un-named formations separated by an angular disconformity. We logged briefly the clasts spectrum, in the hope to find Devonian lithologies that are not common in Rehamna outcrops, and in search for Carboniferous pebbles that could constrain the maximum reworking age. We also looked for double reworked clasts, consisting themselves of conglomerate/breccia, which were not found. Quartzites are subordinate to limestone clasts. The size of the latter ranges from 25 to 45 cm. Recognized clasts include:

1. Light-grey, well-rounded Ordovician quartzites.
2. Reddish, well-rounded quartzites.
3. Light-grey micritic limestone.
4. Middle-grey, detrital limestone.
5. Dark-grey, fine-grained brachiopod limestone.
6. Yellowish, dolomitized coquinas limestone.
7. Light-grey platform limestone with *Stringocephalus*-type, very thick-shelled brachiopods (Fig. 40), probably representing Givetian reef facies.
8. Coarse-grained, crinoidal debris limestone.
9. Colony of *Frechastrea pentagona* (Fig. 41) surrounded my middle-grey micritic to wackestone matrix with thick- and double-shelled ostracods and coral debris.
10. Red weathering, strongly iron-impregnated brachiopod-bryozoan rudstone (coquina) with the trepostome *Dyscritella* and the cryptostome *Rhabsomeson* (Fig. 42).

There is no sorting and only little reddish (hematite-rich) microconglomeratic matrix in interspaces. This suggests deposition by rockfall and during arid conditions with lateritic weathering. The rounding of the assumed Lower Paleozoic quartzites shows that they were moved for a long time along a shore or in rivers before they were mixed with the angular to subrounded Devonian material which originated from the immediate vicinity. The colonial rugose coral *Frechastrea pentagona* occurs typically rather late in the upper Frasnian of the Ardennes (see review by Coen-Aubert 2015). Closely related forms, which previously were regarded as subspecies, occur widely in the upper Frasnian of Europe and also in South China. A supposed previous North African record of the genus was *Fr. goldfussi* from the Smara region (Rodríguez Mellado 1948; Hernández Sampelayo 1948). These specimens belong to *Phillipsastrea* ex gr. *irregularis* (see May 2008), which is also a Frasnian taxon (of North America). Its recognition in a clast at Koudiat ed Diab is remarkable since the Rehamna reef complexes were so far not known to range above the middle Givetian.

Fig. 40: Light-grey limestone with *Stringocephalus*-type, very thick-shelled brachiopods (probably Givetian).

Since phillipsastreids are typical for deeper photic biostromes (e.g., Nübel & Becker 2004), mounds and drowned reefs (e.g., Poty & Chevalier 2007), we must assume that the uplifted Mechra Ben Abbou reef was locally and episodically flooded during the upper Frasnian sea level maximum. Therefore, a more intensive sampling campaign has the potential to recover Frasnian conodonts from the breccia unit.

The trepostome bryozoan genus *Dyscritella* is a typical Carboniferous-Permian genus. From the middle to uppermost Famennian, only a few forms have been described (e.g., Tolokonnikova et al. 2014, 2015). The situation is more distinctive for the genus *Rhabdomeson*. There are two problematical species from the Devonian of China, but it characterizes especially the Viséan to Serpukhovian interval, followed by later Upper Carboniferous to Upper Permian representatives. Since there are no Rehamna outcrops with Famennian limestones, the bryozoan clast can be assigned to the shallow-water limestones of the mostly upper Viséan Bled Mekrach Formation (see, e.g., El Kamel & El Hassani 2006). It proves that the reworking post-dated the upper Viséan and suggests that the uplift occurred during the subsequent main Variscan tectophase, with redeposition in a fast subsiding, early post-orogenic "intramountain" basin, which is the common interpretation for a long time.

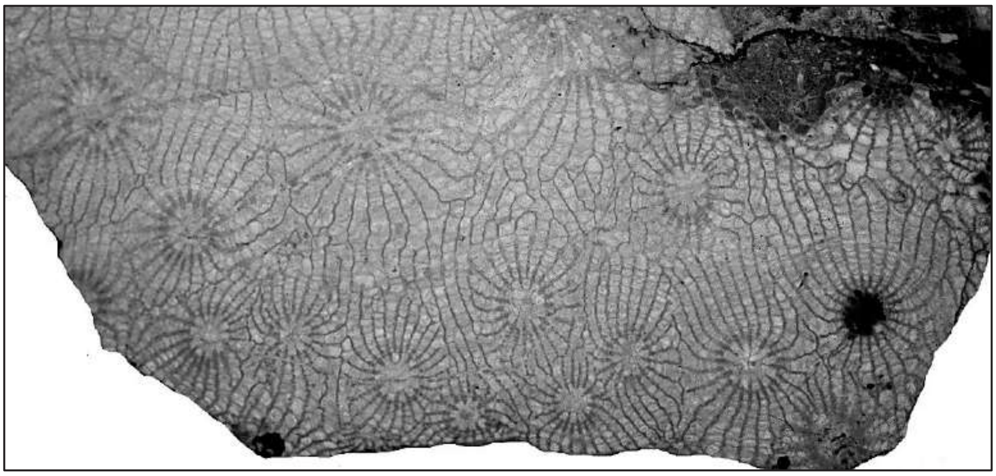

Fig. 41: Thin-section of a Frasnian *Frechastrea* colony (*Fr. pentagona* Goldfuss, 1826, GMM B2C.57.2) embedded in dark-grey bioclastic limestone and reworked in the Koudiat ed Diab breccia.

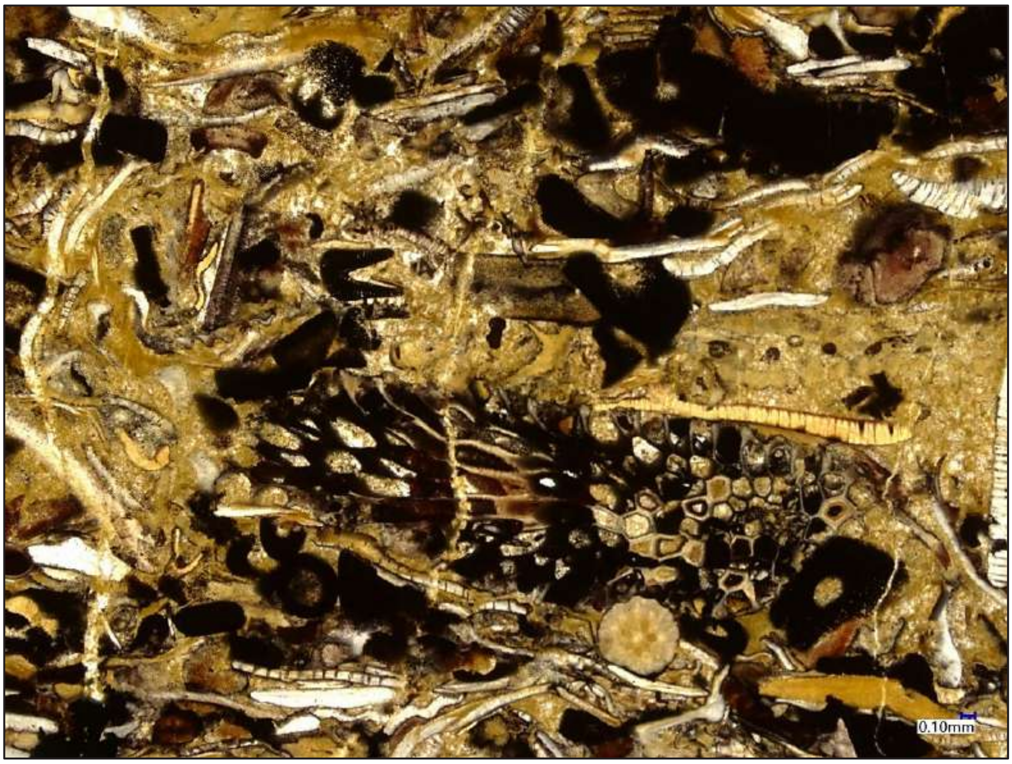

Fig. 42: Thin-section of a strongly iron impregnated rudstone with thick-shelled, punctate brachiopod fragments, the trepostome *Dyscritella* (large branch in the lower half) and the cryptostome *Rhabdomeson* (small circular cross-section just below).

9. Regional facies development of northern Rehamna Devonian

The top-Silurian is known from pelagic, black scyphocrinitid-orthocone facies in the north (Koudiat ed Diab, HOLLARD et al. 1982) and mixed neritic-pelagic limestones with graptolites and orthocones in the southeast (Formation D of EL KAMEL & EL HASSANI 1992). The Lochkovian/Pragian of the northeastern Rehamna belonged to a mixed carbonatic-siliciclastic neritic, open, subtidal but storm-influenced shelf. It continued the palaeogeographic setting of Oued Cherrat to Benahmed regions in the north. In the southeast (Sakhrat et Taïra), the Lochkovian was affected by strong synsedimentary block faulting, creating a shelf basin with slumping, gravitational movement of olistolite blocks, and turbidite shedding. Therefore, there was some transition towards the pelagic outer shelf setting of the Jebilet further to the SE. This trend suggests a western source of silt/ sand (Imfout Ridge, e.g., BEN BOUZIANE 1995).

During the Emsian, the clastic influx decreased gradually. In the Foum el Mejez region, a shallow-water carbonate ramp was established in the lower Emsian. Due to regression, there was a peak development in the upper Emsian (Middle Member of Oued Kibane Formation). The deepening of the global Daleje Event left regionally no clear sedimentary signature, which is also true for the Jebilet (see following chapter, this volume). In the upper Emsian neritic brachiopod-trilobite facies prevailed throughout the study region, differentiated by synsedimentary tectonism at Foum el Mejez. The latter supports the view that the graben structure had an early structural origin.

The Eifelian Choteĉ and Kačák Events have also not yet been recognized regionally, which is typical for neritic facies, where detailed bed-by-bed facies, faunal and geochemical studies are required to detect them (e.g., BROCKE et al. 2016; KÖNIGSHOF et al. 2016). Such high-resolution studies are still to be conducted in the Mechra Ben Abbou, Ouled Barka, and Sidi Abdallah regions. Nodular bedding and sponge blooms indicate a minor deepening in the top-Eifelian.

The overall Givetian regression and the severed siliciclastic influx enabled the establishment of a wide reef platform, with subsidence fully compensated by fast bioherm growth. Wide-spread reef breccias document recurrent seismic events, which appear to have started earlier than in the Oued Cherrat-Al Attamna-Mdakra regions (EICHHOLT & BECKER 2016; BECKER et al. 2020a) to the north, where they characterize the upper middle Givetian to basal Frasnian interval. There was non-deposition in the uplifted Foum el Mejez area. Block tilting terminated eventually everywhere in the Rehamna reef growths, leading to current-controlled non-deposition, karstification, and stromatolite encrustation. Based on Frasnian colonial rugose corals (in the post-orogenic Koudiat ed Diab breccia), small reef patches must have formed locally during the upper Frasnian eustatic high.

There are no Frasnian sections in the Rehamna and nothing is known about regional effects of the Frasnian-Famennian boundary events. However, synsedimentary faulting created at Foum el Mejez a narrow and shallow shelf basin that received in the lower to upper Famennian fine prodeltaic detritus from the west (Oued Ater Member). It gradually filled up the basin, so that delta lobes of the quartzitic Douar Nahilat Formation prograded to the area in the uppermost Famennian (Dalaa Member). Some of the tilted Givetian reef blocks formed shoals and island with steep slopes, where mixed quartzite-reef limestone breccias formed by rockfall. The Devonian-Carboniferous boundary interval has not yet been sufficiently studied.

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The Devonian and Viséan transgression in the Eastern Jebilet (Moroccan Meseta) – review and new data

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Fig. 1: Lower Devonian succession of Section Jaïdet West (western limb of anticline) with Stephan EICHHOLT for scale in the foreground. Silurian/Lochkovian black shales of the (new) Jebel Smaha Formation at the base are followed by folded and slumped, upper Lochkovian to Emsian yellowish nodular limestones of the (new) Jaïdet Formation reaching the hill crest.

Abstract. Based on new field work, sampling for conodonts, ammonoids, and microfacies analysis, the allochthonous Lower/Middle Devonian stratigraphy and facies history of the Eastern Jebilet NNE of Marrakech is revised and refined. Silurian to Pragian partly siliceous black shales are assigned to the new Jebel Smaha Formation, which yielded HUVELIN (1977) in its upper part graptolites of very different age (lower/middle Lochkovian in the W, up to the upper Pragian in the E). In the Jaïdet region, upper Lochkovian to upper Emsian nodular limestones with deep neritic to pelagic faunas form the new Jaïdet Formation, which deposited in an outer shelf setting. In the Middle Devonian, this basin deepened by increased subsidence, resulting in a thick, poorly fossiliferous siltstone succession, initially and locally with hypoxic *Zoophycos-Chondrites* ichnofauna, later with limestone turbidites (new El Kahla Formation). Currently, there is no biostratigraphic proof of Upper Devonian strata in the Eastern Jebilet; the youngest known conodonts fall in the top middle Givetian *ansatus* Zone but the thick upper El Kahla Formation is not dated. With the help of corals, foraminifers, and bryozoans, detrital and microbial coral limestones at the base of the thick carbonate platform at Koudiat Lahmara (Tekzim Formation)

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can be dated as upper Viséan (Cf6γ1, upper Asbian). An associated basal conglomerate contains reworked pebbles of an older (lower/middle Viséan) platform. The transgressive oldest allochthonous limestones of the Tekzim Formation correlate probably with goniatite shales of the (par)autochthonous upper Kharrouba Formation, which also record an upper Asbian deepening episode. With shallowing upwards in the top Asbian/Brigantian, the carbonate platform prograded basinwards, leading to local top-Kharrouba inner shelf limestone deposition before the onset of wildflysch conditions.

The allochthonous Lower Devonian of the eastern Jebilet shows significant similarities with the Skoura region at the southern margin of the High Atlas and, slightly less distinctive, with the Azrou-Khenifra Basin in the east. They belonged to the same outer shelf basin but the timing and effects of Eovariscan block movements were regionally different. The Eastern Jebilet source region and Skoura successions experienced major facies changes and synsedimentary tectonic events around the Lower/Middle Devonian transition. Originally, both may have represented different sides of the same tilted block. There were no close palaeogeographic relationships of the Jaïdet source area with the western Jebilet (Jebel Ardouz) or the Rehamna to the north. Only the upper Viséan transgression led to a more uniform palaeogeography characterized by shallow-water carbonate platforms throughout the southern and eastern parts of the Western Meseta.

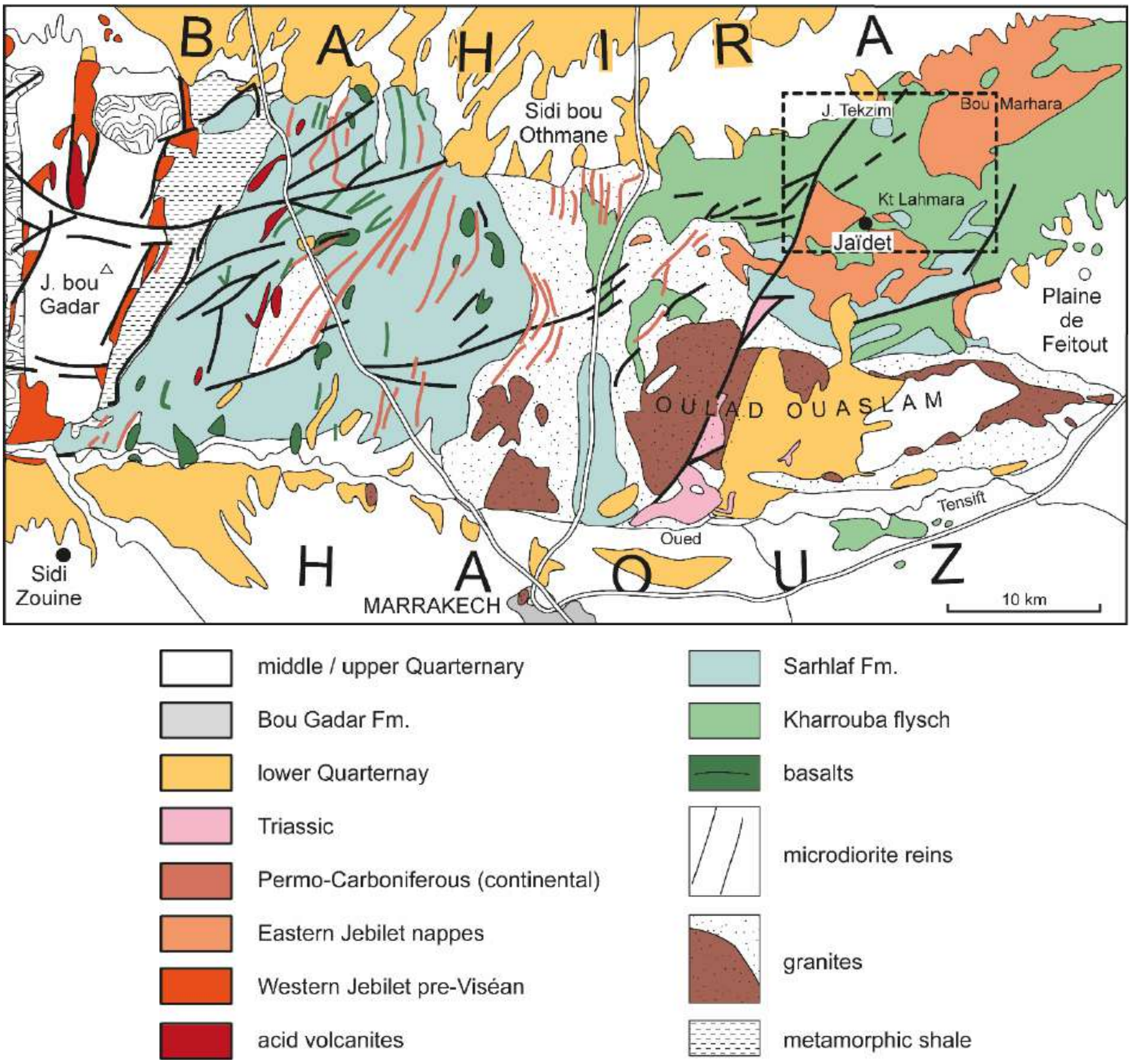

Fig. 2: Simplified geological overview of the central and western part of the Eastern Jebilet showing the position of the study area (rectangular field) SE of Sidi bou Othmane and SSW of the Jebel Tekzim; extracted from the geological map of the Central Jebilet, 1 : 100 000, by HUVELIN (1972).

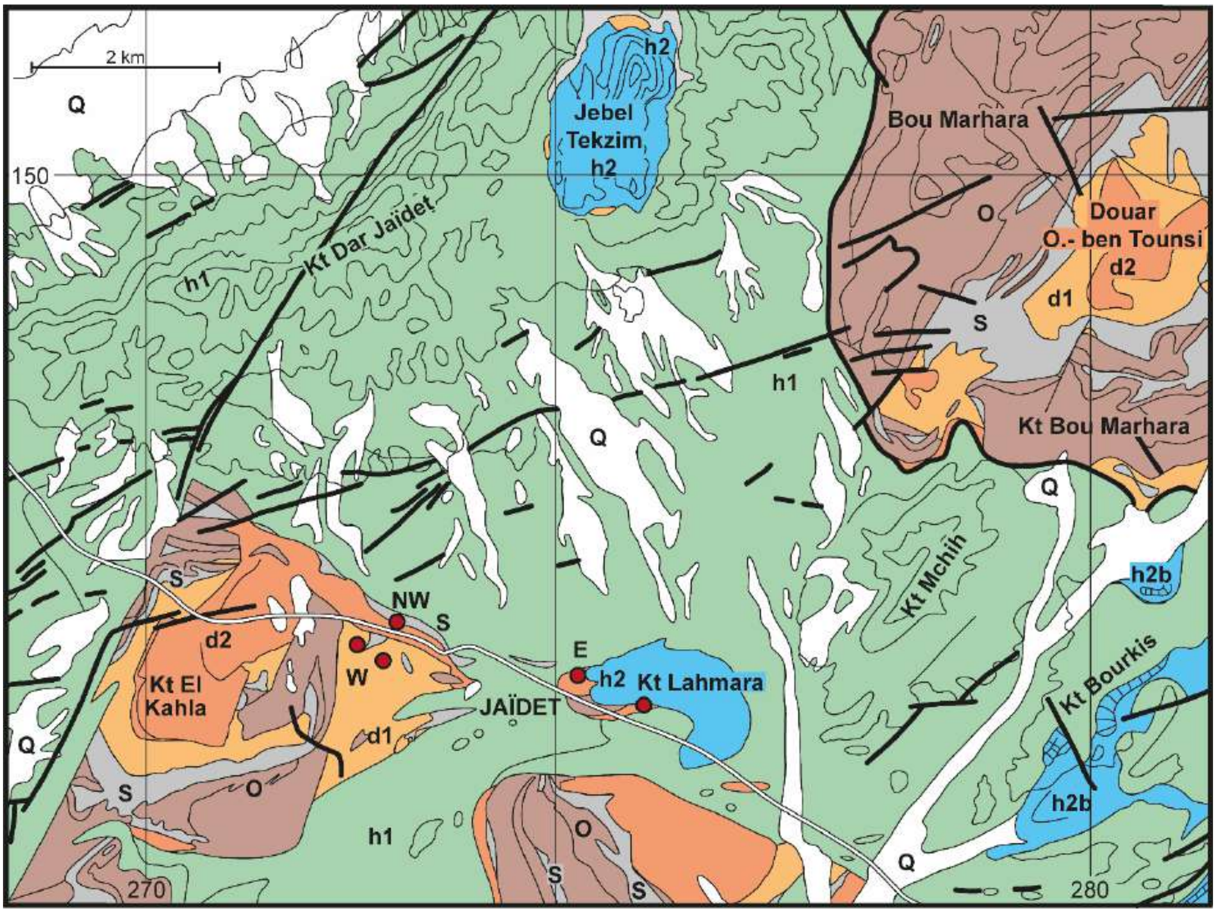

Fig. 3: Position of studied localities (circled red dots) on the simplified geological map of the Jaidet-Jebel Tekzim-Bou Marhara region ESE of Sidi bou Othmane in the Eastern Jebilet. O = Ordovician quartzites, S = Silurian to Lochkovian Jebel Smaha Formation, d1 = Lochkovian to Emsian Jaïdet Formation, d2 = Middle Devonian El Kahla Formation, h1 = Viséan Kharrouba Formation ("Kharrouba Flysch"), h2 = transgressive upper Viséan Tekzim Formation s. str., h2b = regresive shallow-water limestones (Tekzim Fm. s.l.) in the top Kharrouba Formation, Q = Quarternary; re-drawn from a magnified extract of the geological map of the Central Jebilet by P. HUVELIN (1972).

1. Introduction

The Jebilet forms a more than 150 km wide, west-east trending Variscan Massif stretching in the NW to the NE of Marrakech in the southern part of the Western Meseta. The north-south extension of the Palaeozoic belt varies between ca. 20 km (just north of Marrakech) and 45 km (at the western end). The Jebilet is structurally subdivided into western, central, and eastern parts (see HUVELIN 1977) but authors disagree on boundary positions. The Western Jebilet is characterized by Lower Palaeozoic strata overlain unconformably by Upper Carboniferous post-tectonic clastics, the Central Jebilet by the Viséan slate complex of the Sarhlef Series, imbedded massif sulfide deposits and volcanics, and late Variscan granites, and the Eastern Jebilet by the autochthonous Carboniferous Kharrouba Flysch, Viséan carbonates of the Tekzim Formation, nappes with Ordovician-Devonian strata, and a large granite in the south. The lithologically and structurally distinctive Sidi bou Othmane region (Fig. 2) north of Marrakech has been regarded as an eastern part of the Central Jebilet (e.g., EL HASSANI 1980, 1982). By contrast, ESSAIFI et al. (2001, fig. 1, 2003: fig. 1) and DELCHINI et al. (2018) included it in the Eastern Jebilet, using the NNW-SSE trending Marrakech Shear Zone as the boundary (see map of BEAUCHAMP et al. 1989, fig. 2). There was no continuity of the Palaeozoic of the Jebilet with the High Atlas in the south or with the Rehamna to the north; these regions were separated by block faults.

Moderately deformed and fossiliferous Devonian strata are restricted to nappes in the Eastern Jebilet, especially of the Jebel Tekzim (= Teksim)-Jaïdet-Bou Marhara region 40-45 km NNW of Marrakech (Figs. 2, 3). The Devonian of the Western Jebilet refers mostly to the Jebel Ardouz, which represents a distinctive sedimentary and structural unit (see Jebel Ardouz chapter, this volume). Isolated Devonian olistolites have been reported from the Skhirat Formation in the eastern part of the Western Jebilet (HUVELIN, 1977; TAHIRI 1984; MAYOL 1987). These are poorly described and dated, include the "red conglomerate", and have been compared with the Jebel Ardouz Devonian.

The Devonian succession of the area east of Sidi bou Othmane (typical Eastern Jebilet) was described in the monograph by HUVELIN (1977). In the subsequent more than 30 years, no data concerning its biostratigraphy, sedimentology, and faunal content have been added, whilst there was very active research on the Jebilet structural geology, magmatism, and metamorphism. We conducted new field work in the Jaïdet area (Fig. 3) in spring 2012 and 2017, including bed-by-bed logging, sampling for conodonts, ammonoids, associated fauna, and for carbonate microfacies. This was extended to the basal beds of the unconformably overlying Lower Carboniferous at Koudiat Lahmara ca. 1 km east of Jaïdet (Fig. 3). This section was previously studied by HOLLARD et al. (1977) and ANDRÉ (1986) but we attempted to refine the nature and age of the local Carboniferous transgression. We did not re-investigate the subsequent main upper Viséen carbonate platform succession nor laterally the siliciclastic Kharrouba Flysch or the "Schistes du Sarhlef" of the Central Jebilet.

2. Research History of the Eastern Jebilet

RUSSO (1917): Discovery of allochthonous Lower Devonian strata north of the Jebel Tekzim based on brachiopods and bivalves.

TERMIER (1942): Recognition of the upper Viséan with foraminifers (including *Climacammina*) at the Jebel Tekzim.

ROCH (1950): References to the RUSSO and TERMIER faunas from the Jebel Tekzim.

PERMINGEAT (1951): New data on the Jebilet Viséan and recognition of Pragian pelagic facies with orthoconic cephalopods and dacryoconarids (identified by G. & H. TERMIER) at Koudiat-er-Reïet (near Koudiat Lahmara) and Sidi Daoud (ca. 3.5 km west of Jaïdet).

PERMINGEAT (1954): Note on the shallow-water Viséan in the south of the Eastern Jebilet (Jebel Oulad Abid south of the Oued Tensift).

HUVELIN (1967): Initial study on the Jebilet nappe movements.

HUVELIN (1972): Geological map of the Jebilet.

HUVELIN (1977): Monograph on the geology, mineralogy, magmatism, mineral deposits, and tectonics of the Jebilet.

HOLLARD et al. (1977): Viséan stratigraphy and discussion of the age of nappe movements; with detailed macro- and microfauna lists for shales of the Kharrouba Formation (*Goniatites crenistria, Posidonia becheri*), limestones of the Tekzim Formation (Jebel Tekzim, Koudiat Lahmara, Douar Oulad ben Tounsi, Bou Marhara), limestones at the top of the Kharrouba Formation (Koudiat Bourkis), and the shallow-water Viséan of the Jebel Oulad Abid in the south.

Bordonaro et al. (1979): Comparison of the sedimentary history of the Jebilet with the Huelva Basin of southern Spain.

Gaillet (1979): Discussion of the correlation between the Central Jebilet Sarhlef Series and Eastern Jebilet Kharrouba Flysch, recognizing structurally overlying Viséen carbonates as new Tekzim Formation.

El Hassani (1980, 1982): Thesis and publication on the mapping, lithostratigraphy, with refined formation terminology, and tectonics of the Sidi Bou Othmane region between the typical Central and Eastern Jebilet successions.

Pique (1981): Placing the Eastern Jebilet as a southwestern extension of the Variscan Azrou-Khenifra belt into his “Meseta centre-orientale”.

Gaillet & Bordonaro (1981): Structural geology of the Central Jebilet (including the western part of the re-defined Eastern Jebilet).

Zarhaoui (1981): Unpublished thesis on the stratigraphy and nappes of the Jebel Tekzim area.

El Hassani & Zahraoui (1982): Note on the tectonic transport of Ordovician to Devonian onto Carboniferous substratum before the major phase of Variscan deformation and metamorphism.

Graham (1982a): Sedimentological analysis of the more than 2.000 m thick, shallowing upwards upper Viséan Kharrouba Flysch between Koudiat Mchich and Koudiat Bourkis east of Koudiat Lahmara (for location see Fig. 3).

Graham (1982b): Sedimentology of the shallow-water upper Viséan at Jebel Oulad Abid in the south of the Eastern Jebilet.

Beauchamp (1984): Stratigraphic and sedimentological analysis of the Kharrouba Flysch succession at Mourhar el Beida west of the Jaïdet region, and comparisons with the High Atlas Viséan.

Beauchamp & Cortinat (1985): Sedimentology of shallow-water sandstones and calcarenites in the southern part of the Eastern Jebilet.

André (1986): Sedimentology of the mixed carbonate-siliciclastic to reefal upper Viséan at Koudiat Lahmara.

Beauchamp & Izart (1987): Common tectono-sedimentary model for Lower Carboniferous basins of the Meseta, including the Jebilet.

Tourani & Beauchamp (1987): Sedimentology of the Carboniferous flysch of the Central Jebilet.

Oukemeni (1987): Unpublished thesis on the Carboniferous nappes of the Eastern Jebilet.

Essemani (1988): Unpublished thesis on the sedimentology of the Carboniferous of the Eastern Jebilet.

Nouidar (1988): Unpublished thesis on sedimentology and tectonics of the Viséan platform limestones of the Jebel Tekzim.

Vachard (1988): New Viséan foraminifer data for the Kharrouba Flysch.

Bamoumen (1988): Unpublished thesis on the deformation of the nappes of the Central and Eastern Jebilet.

Beauchamp et al. (1989): Analyses of the gravity-induced upper Viséan sedimentation of the Jebilet, from turbidites and debris flows of the extensional Eovariscan interval to olistostromes and klippen/nappe movements of the compressional main Variscan stage.

Izart et al. (1997): Sequence and biostratigraphy of the Lower Carboniferous of the Eastern and Central Jebilet and correlations with the contemporaneous High Atlas successions.

El Hassani & Benfrika (1995, 2000): Summary of the Jebilet Devonian.

Bamoumen et al. (2008): Comparison of the upper Viséan of the Jebilet and Azrou-

Khenifra Basin based on the tecto-sedimentary and magmatic evolution.

YAHYAOUI & ESSAIFI (2011): Excursion guidebook showing the Devonian nappe at Jaïdet and mass flow breccias.

IZART et al. (2017): New summary of the Viséan basin of the Jebilet to High Atlas.

DELCHINI et al. (2018): New reconstruction of the Variscan tectono-metamorphic and magmatic evolution of the Jebilet (partly based on stratigraphic assumptions that have no factual base and neglecting some previously published details concerning the Devonian/Carboniferous contacts and Viséan biostratigraphic ages).

ARIBA (2019): M.Sc. Thesis on the structural geology and metamorphism of the Sidi bou Othmane region.

CÓZAR et al. (2020a): Discussion of previously published Viséan ages for Central and Eastern Jebilet strata, commenting on the foraminifer data of ESSAMANI (1988) and IZART et al. (1997, 2017), and on interpretations by DELCHINI et al. (2018).

3. Geological overview of the Eastern Jebilet

The Eastern Jebilet is dominated by the Lower Carboniferous Kharrouba Flysch, which shows a shallowing upwards trend from a turbidite-rich siliciclastic lower-middle succession to shallow-water sandstones and cross-bedded bioclastic limestones in the upper part (e.g., GRAHAM 1982a; BEAUCHAMP 1984; IZART et al., 1997; BEAUCHAMP et al. 1989). The sediment transport direction was to the northwest, indicating a NE-SW trending shoreline in the area SE of the Jebilet, where there is no Palaeozoic surface outcrop. An overlying widespread olistostrome complex, e.g., of the Jebel Kharrouba (BEAUCHAMP et al. 1989), marks a change of the tectono-sedimentary regime high in the upper Viséan (e.g., BEAUCHAMP & IZART 1987). This culminated in the movement of klippen and glide nappes consisting mostly of Ordovician to Middle Devonian strata. This interpretation is fully supported by the irregular and angular contact between Ordovician/Devonian blocks and the underlying Kharrouba Formation (HUVELIN 1972; Fig. 3). The allochthonous Lower/Middle Palaeozoic was originally deposited in the east/southeast but the transport distance is not known. Synsedimentary facies and structural relationships with Silurian/Devonian outcrops further to the southeast (Skoura region at the southern foot of the High Atlas) and east (Azrou-Khenifra Basin; see PIQUE 1981; BAMOUMEN et al. 2008) will be discussed later. Based on the youngest known foraminifers from the olisthostrome at the top of the Kharrouba Formation (Cf6δ/Cf7; IZART et al. 1997), tectonic uplift in the source region, leading to basin slope steepening and gravitational transport, probably occurred in the higher Serpukhovian. However, true Cf7 (Namurian) foraminiferes have not been documented from the region. In any case, the klippen and nappe movements occurred before the onset of the main Variscan deformation and metamorphism (EL HASSANI & ZAHRAOUI 1982). BEAUCHAMP et al. (1989) ascribed this interval to the onset of a compressional stage.

The sedimentary and structural relationships between the single basin of the Kharrouba Flysch and westwards lying, more than 1.000 m thick Sarhlef Series (e.g., BORDONARO et al. 1979; GAILLET 1979; BEAUCHAMP & IZART 1987; BEAUCHAMP et al. 1989), and the shallow-water to reefal limestones of the Tekzim Formation are controversial. In the eastern Jebilet, it is important to recognize Viséan limestones that occur in different tectonic and sequence stratigraphic contexts, as discussed by HUVELIN (1977) and HOLLARD et al. (1977).

Later, GAILLET (1979), GAILLET & BORDONARO (1981) and DELCHINI et al. (2018) assumed that a widespread mixed clastic-calcareous Tekzim Formation overlies in general the Kharrouba Formation and Sarhlef Series, which include both strata of upper Viséan (Asbian) age (HUVELIN 1961, 1977; HOLLARD et al. 1977; IZART et al. 1997; PLAYFORD et al. 2008). However, the typical Tekzim Formation (e.g., Jebel Tekzim, Koudiat Lahmara, Bou Marhara) occurs at least partly in unconformable and transgressive but not necessarily tectonic contact with the underlying Devonian. Especially important is a locality 1.5 km ESE of Douar Oulad-ben-Tounsi, where HOLLARD et al. (1977) proved that upper Viséan sandy and bioclastic limestones eroded directly into Lower Devonian griotte limestones, resulting in reworked Devonian clasts swimming in the Viséan calcarenite matrix. This evidence suggests to keep a distinction between allochthonous carbonates of the type Tekzim Formation, which transgressed the Devonian and which were obviously part of klippen/nappes, and the (par)autochthonous shallow-water limestones that deposited during regression in the upper part of the Kharrouba Flysch (e.g., GRAHAM 1982a: Koudiat Bourkis, Unit 8). The latter limestones were dated by IZART et al. (1997: Koudiat Mchih = ca. Koudiat Bourkis and Koudiat Kouchina in the east) as Cf6γ (= V3bγ = ca. lower Zone 16i = top MFZ 13 to lower MFZ 14 sensu POTY et al. 2006, upper Asbian; see correlation charts of HERBIG 2006, fig. 4, and CÓZAR et al. 2020a, fig. 1). The same age is known from some limestones embedded in the Sarhlef Series (VACHARD in ZAIM 1990; quoted in BEAUCHAMP et al. 1989) whilst others unexpectedly proved to be of Upper Devonian age (LAZREQ et al. 2021). Metamorphosed limestones embedded in the Sidi bou Othmane Formation (EL HASSANI 1980, 1982; ARIKA 2019) have not yet been dated biostratigraphically. In this wider context, new data for the transgression at the base of the thick Tekzim Formation at Koudiat Lahmara (see ANDRÉ 1986) were hoped to shed further light on the age relationships between the different Viséan limestone occurrences.

4. Devonian sedimentary and faunal succession

HUVELIN (1977) outlined the principle Devonian litho- and biostratigraphy of the Eastern Jebilet but our data provide further precision, especially since the conodont and ammonoid scales and chronostratigraphy developed significantly in the meantime. Previous records of graptolites, brachiopods, and trilobites have to be re-evaluated. Also, no formal lithostratigraphic units were proposed originally. HUVELIN (1977) showed lateral variability of facies and faunas from west to east in the Eastern Jebilet. Different successions than at Jaïdet were described from Bou Marhara and Douar Oulad-ben-Tounsi (ca. 8 km NE of Jaïdet, Fig. 3), the Jebel Smaha at the NE end of the Eastern Jebilet (SW of El Kelâa des Srarhna), and from Douar Abichat (ca. 11 km S of El Kelâa des Srarhna). The increasingly shaly facies towards the east suggests that allochthonous blocks representing shallower settings were transported farthest to the west. Neritic faunas listed by RUSSO (1917) from the Jebel Tekzim underline an Emsian facies differentiation in the source region. The new lithostratigraphic terminology for the Jaidet region follows HUVELIN´s “Termes inférieur, moyens and supérieur”. A revised stratigraphic model for the wider regional correlation, updating HUVELIN (1977, figs. 17-18), is depicted in Fig. 4.

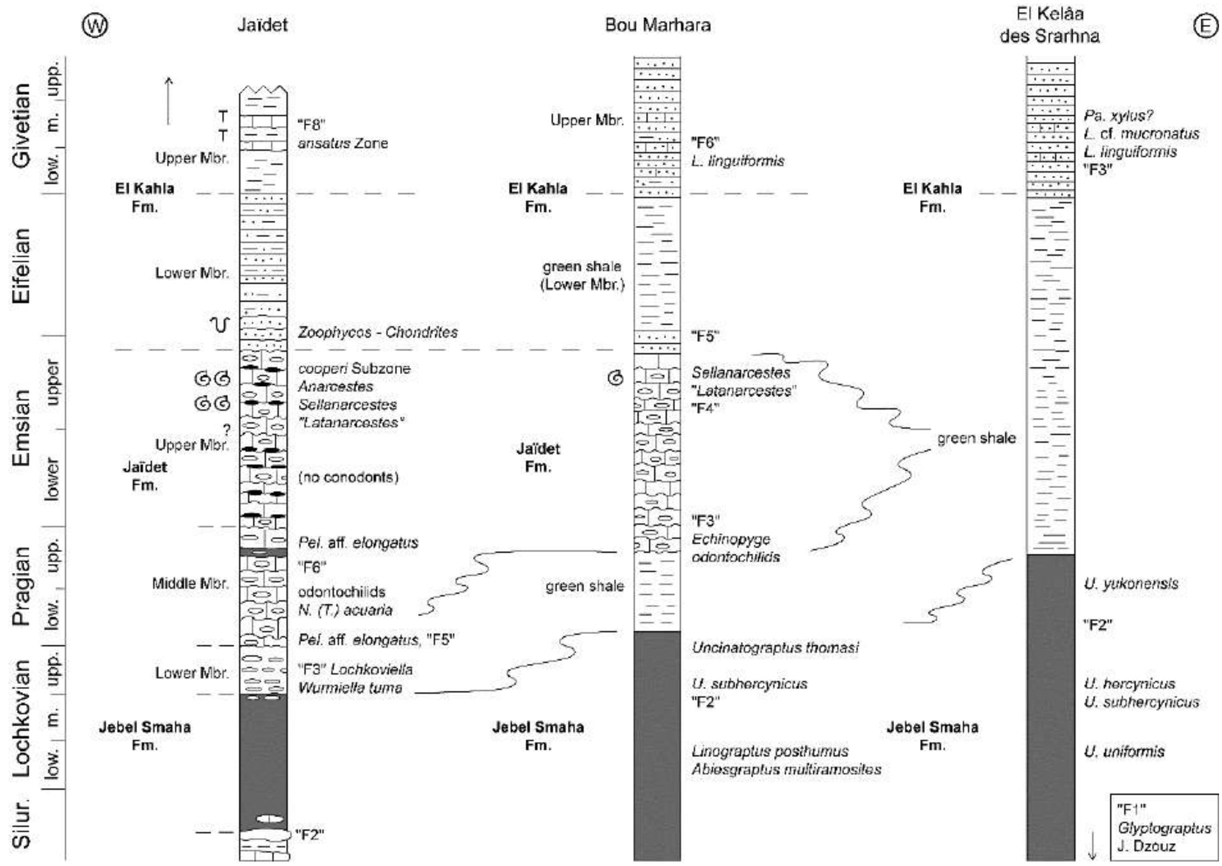

Fig. 4: New model for the litho-, bio- and chronostratigraphic correlation of the Silurian-Devonian of the Eastern Jebilet, based on HUVELIN (1977), a re-evaluation of his faunas, and on our new data. Vertical scale against chronostratigraphy, not against thicknesses.

The Lower/Middle Devonian is best exposed on the two limbs of an anticline with roughly northeast-southwest trending axis at ca. 1.2 km WNW of Jaïdet, just south of the main road (Figs. 1, 3), here called Section Jaïdet West (compare HUVELIN 1977: p. 42 and summary fig. 17, also YAHYAOUI & ESSAIFI 2011, figs. 3A-B). GPS coordinates are N31°52´39.1´´, W7°48´19.7´´. The succession is the type-locality of two new lithostratigraphic units, the top-Lochkovian to Emsian Jaïdet Formation (with three informal members) and the Middle Devonian El Kahla Formation (with two members).

4.1. Jebel Smaha Formation (Silurian to Lochkovian/Pragian)

A package of poorly fossiliferous black shales forms in Section Jaïdet West a wide depression and the core of the anticline, as a case of relief inversion. The exposed part has a thickness of more than 10 m (Fig. 1). In the upper part, there is the transitional, ca. 50 cm thick Bed 1, composed of calcareous, organic-rich black shale with numerous limestone nodules (Fig. 5).

The black shale of Section Jaïdet West belongs to HUVELIN´s “Termes inférieur” and can be interpreted as an upper tongue of his more widespread “Phtanites et schistes à Graptolithes”, For this unit, the new term Jebel Smaha Formation is based on the Jebel Smaha succession SW of El Kelâa des Srarhna, ca. 33 km NE of Jaïdet. HUVELIN (1977, 45-46, figs. 15, 18B) described for this locality 100-120 m of partly siliceous bluish to black shales with graptolites that overly Upper Ordovician quartzites.

Fig. 5: Boundary between the black shales of the Jebel Smaha Formation and the brownish weathering basal Jaïdet Formation (top of photo) formed by the transitional Bed 1 (at the hammer) with numerous limestone nodules sitting in black calcareous shale matrix (partly covered by nodule debris).

The age of the Jebel Smaha Formation appears to be strongly diachronous from west to east (Fig. 4). In the Jaïdet region, it is apparently underlain (no direct contact described) by upper Silurian sandy shales and alternating bioclastic limestones with large-sized orthocones and bivalves (*Vlasta, Cardiola*; det C. BABIN in HUVELIN 1977; his "F2" from Jaïdet). Slightly to the west, at Koudiat El Kahla, HUVELIN (1977, p. 43) mentions a lower Ludlow graptolite fauna from possibly contemporaneous green shales. The upper range of the Jebel Smaha Formation in the Jaïdet region is constrained by the upper Lochkovian age of the overlying basal Jaïdet Formation (see below).

In the Bou Marhara Syncline NE of Jaïdet (Fig. 3), the upper part of the Jebel Smaha Formation yielded graptolites that could represent three successive levels (HUVELIN 1977, fig. 18A, "F2" from Bou Marhara). *Abiesgraptus* and *Linograptus* are genera that do not range above the middle Lochkovian *Uncinatograptus praehercynicus* Zone (e.g., JAEGER 1978), while *U. subhercynicus* is typical for the middle/early upper Lochkovian (not top Lochkovian) *U. hercynicus* Zone (see also JAEGER 1989). Finally, *U. thomasi* is a lower Pragian index species. The combined evidence suggests a younger range of the Jebel Smaha Formation than at Jaïdet. However, it should be stressed that the Jebilet graptolites have not been properly described or figured, and a revision would be important.

For the El Kelâa des Srarhna region, HUVELIN´s graptolite data suggest an even longer range of the Jebel Smaha Formation. The lower part yielded at Douar Abichat a lower Silurian assemblage (middle/upper Llandovery, fig. 18B, "F1"). The upper part at the Jebel Smaha produced *Uncinatograptus uniformis*, the basal Lochkovian index species. However, other monograptids from the same "F2" (see his fig. 18B) signal a much younger age. *Uncinatograptus subhercynicus* and *U. hercynicus* fall in the middle to early upper Lochkovian *hercynicus* Zone (see zonal review of JAEGER 1989). The record of *U. yukonensis*, if identified correctly, even suggests an upper Pragian age (LENZ 1989), contemporaneous with conodonts faunas from the Lower/Middle Members of the Jaïdet Formation to the west (see below). Until the Eastern Jebilet graptolites are revised, a strong diachroneity of the Eastern Jebilet graptolite shales is the most likely interpretation. It has to be stressed that the Jaïdet Formation is missing from the northeastern part of the Eastern Jebilet and its interval could be well represented by different facies. Other easternmost Jebilet localities (section Rass-el-Kebir/Jebel Dzouz) contain also a different Lower Silurian facies, sandstones and white to rose graptolite shales with a lower Llandovery *Glyptograptus* fauna ("F1" of HUVELIN´s fig 18B).

4.2. Jaïdet Formation (upper Lochkovian to upper Emsian)

The base of the new Jaïdet Formation is marked in Section Jaïdet West, at the base of Bed 2 (Figs. 6-7), by the onset of brownish weathering nodular shales. The argillaceous matrix of the limestone nodules is light-grey; the organic-rich black facies ended sharply. The formation can be subdivided lithologically into three members.

4.2.1. Lower Member

The Lower Member comprises thin-bedded and strongly weathering nodular shales (Beds 2-10) and is locally ca. 4.5 m thick. It correlates with HUVELIN´s "Schistes et calcaires à Trilobites". Characteristic is a macrofauna of orthoconic cephalopods, bivalves typical for pelagic facies (*Panenka*), and trilobites (see HUVELIN´s "F3-4" in fig. 17). Bed 2 yielded a small conodont fauna with *Belodella resima* (Fig. 8.1; dominant, > 50 % of the assemblage), *Wurmiella wurmi* (Fig. 8.2-3), *W. tuma* (Fig. 8.4-5), and *Panderodus* sp. (Fig. 8.6, 23.5 % of the assemblage). The locally common single cone genera *Belodella* and *Panderodus* are not helpful for biostratigraphy. *Wurmiella wurmi* is long-ranging in the Lochkovian (e.g., VALENZUELA-RÍOS et al. 2015) but survived into the lower Pragian (e.g., WEDDIGE 1987; SLAVÍK & HLADIL 2004). *Wurmiella tuma* enters in the middle Lochkovian (e.g., MURPHY et al. 2004) and disappears at the Lochkovian-Pragian boundary in South China (WANG et al. 2018; compare top-Lochkovian range in CORRADINI & CORRIGA 2012) but cf. specimens were recorded from the basal Pragian of Bohemia (SLAVÍK et al. 2012).

Locally, a relative sea level fall ended gradually the black shale deposition by increased bottom turbulence and ventilation. This is supported by the microfacies of Bed 2 (Fig. 9.1), a bioturbated, flaser-bedded, recrystallized (microsparitic) bioclastic wackestone with poorly preserved dacryoconarids (probably nowakiids) lacking any orientation, ostracods, rare mollusk shells, and small to large idiomorphic pyrite cubes. It indicates calm deposition on a deep, subphotic outer shelf carbonate ramp with restricted benthos. The pyrite formed during early diagenesis under hypoxic conditions within the sediment, followed later first by micrite recrystallization, then by weak dolomitization.

HUVELIN (1977) reported three groups of trilobites from the Lower Member of the Jaïdet Formation. His "F3" fauna included harpids ("*Harpes* sp."), phacopids (*Reedops miser,* "*Phacops (?Denckmannites)* sp. C aff. *akouchensis*" sensu ALBERTI 1970), and proetids (*Prodrevermannia rabatensis senior*). *Reedops miser* is the type-species of the upper Lochkovian marker genus *Lochkovella* CHLUPÁČ, 1972, which is common in the Rabat-Tiflet Zone of the northern Western Meseta (ALBERTI 1969, fig. 50, 1970, p. 144). The second phacopid was originally described from the top Lochkovian (*Paranowakia intermedia* Zone) black nodular limestones of the Ben Slimane region (ALBERTI 1970). It was re-named by ALBERTI (1981a) as *Phacops (Reedops?) slimanensis*, re-assigned to the subgenus *Prokops* by ALBERTI (1983), and regarded as a representative of the genus *Boeckops* (or possibly *Prokops*) by BASSE (2012, p. 155). The *Prodrevermannia* is also known from the Ben Slimane upper Lochkovian (ALBERTI 1970).

HUVELIN´s "F4" fauna from the upper part of the Lower Member at Jaïdet included only "*Phacops (Reedops)* sp. A aff. *akouchensis*". This taxon was listed as *Lochkovella* sp. A in CHLUPÁČ (1977) but was re-described as *Phacops (Prokops) benziregensis ezzhiligensis* by ALBERTI (1983), who gave as type-level nodular shales of the Ezzhiliga area of the northern Meseta. The associated *Paranowakia geinitziana* is the index species of the terminal Lochkovian dacryoconarid subzone but the species just straddles the Lochkovian/Pragian boundary (e.g., ALBERTI 1981b, 1995; BECKER et al. 2020a).

In summary, the combined conodont-trilobite evidence places the Lower Member in the upper to uppermost Lochkovian.

Fig. 6: Lower and Middle Members of the Jaïdet Formation (boundary just above the hammer) in the western limb of Section Jaïdet West. The formation base is marked by the sharp color change at the base of Bed 2 in the lower third of the photo.

4.2.2. Middle Member

The Middle Member of the Jaïdet Formation is marked in Section Jaïdet West by a strong decrease of shale content and a change to cliff-forming solid, beige to orange weathering, nodular griotte limestones (Figs. 6, 7, 10). The fresh limestone is much darker (middle- to dark-grey). The clear regressive trend seems to correlate with the eustatic fall at the Lochkovian-Pragian boundary (e.g., CHLUPÁČ & KUKAL 1988; BECKER et al. 2020a). It was named by TALENT et al. (1993) as global "end-*Pesavis* Event" and by WALLISER (1996) as "Lochkovian-Pragian Boundary Event". The Middle Member equals the lower part of HUVELIN´s "Calcaires rognoneux et calcaires griottes à Tentaculites". Macrofauna is sparse in our section but HUVELIN (1977) reported from several localities trilobites and various bivalves (*Panenka, Kralowna, Praecardium, Pterochaenia, Eoplectodonta*). Locally, the bedding is irregular and suggests slumping (Fig. 1), as observed by HUVELIN (1977) in the Bou Marhara Syncline.

A Pragian age is known since the record of its index dacryoconarid, *Nowakia (Turkestanella) acuaria,* by G. & H. TERMIER (in PERMINGEAT 1951). A small new conodont fauna from the base (Bed 7) yielded only a single conodont similar to but not identical with *Pelekysgnathus elongatus*, here identified as *Pel.* aff. *elongatus*. Typical and cf. specimens of *Pel. elongatus* occur in the middle Lochkovian of the Cantabrian Mountains (e.g., GARCÍA-LÓPEZ et al. 2002; VALENZUELA-RÍOS et al. 2015) and in the Barrandian (SLAVÍK et al. 2012). But both conspecific or related (aff.) forms cross the Lochkovian-Pragian boundary in the Anti-Atlas (PLODOSWKI et al. 2000) and in the Armorican Massif of Western France (WEYANT et al. 2010). Therefore, our new Jaïdet specimen does not contradict a basal Pragian age for the basal Middle Member. HUVELIN´s "F5" fauna from this level at Jaïdet included *Odontochile*, which in modern taxonomy could refer to a species of several related genera/subgenera (BUDIL et al. 2009). But none of these enter before the Pragian.

The microfacies of Bed 7 (Fig. 9.2) differs from the basal Lower Member by the lack of microsparitization and a minor increase of benthic fauna. Middle- to dark-grey, partly dolomitized mudstone with rare crinoid debris, a bivalved ostracod and very fine shell debris overlie light- to middle-grey bioclastic wackestone with nowakiids, ostracods, and fine mollusk filaments. The median-sized phragmocone of an orthocone was filled by several generations of light to dark-grey mudstone with rare nowakiids and idiomorphic pyrite. There is a strange, sparite-filled, multichambered, partly biserial microfossil with very thin walls and a pointed tip, resembling a calcareous foraminifer.

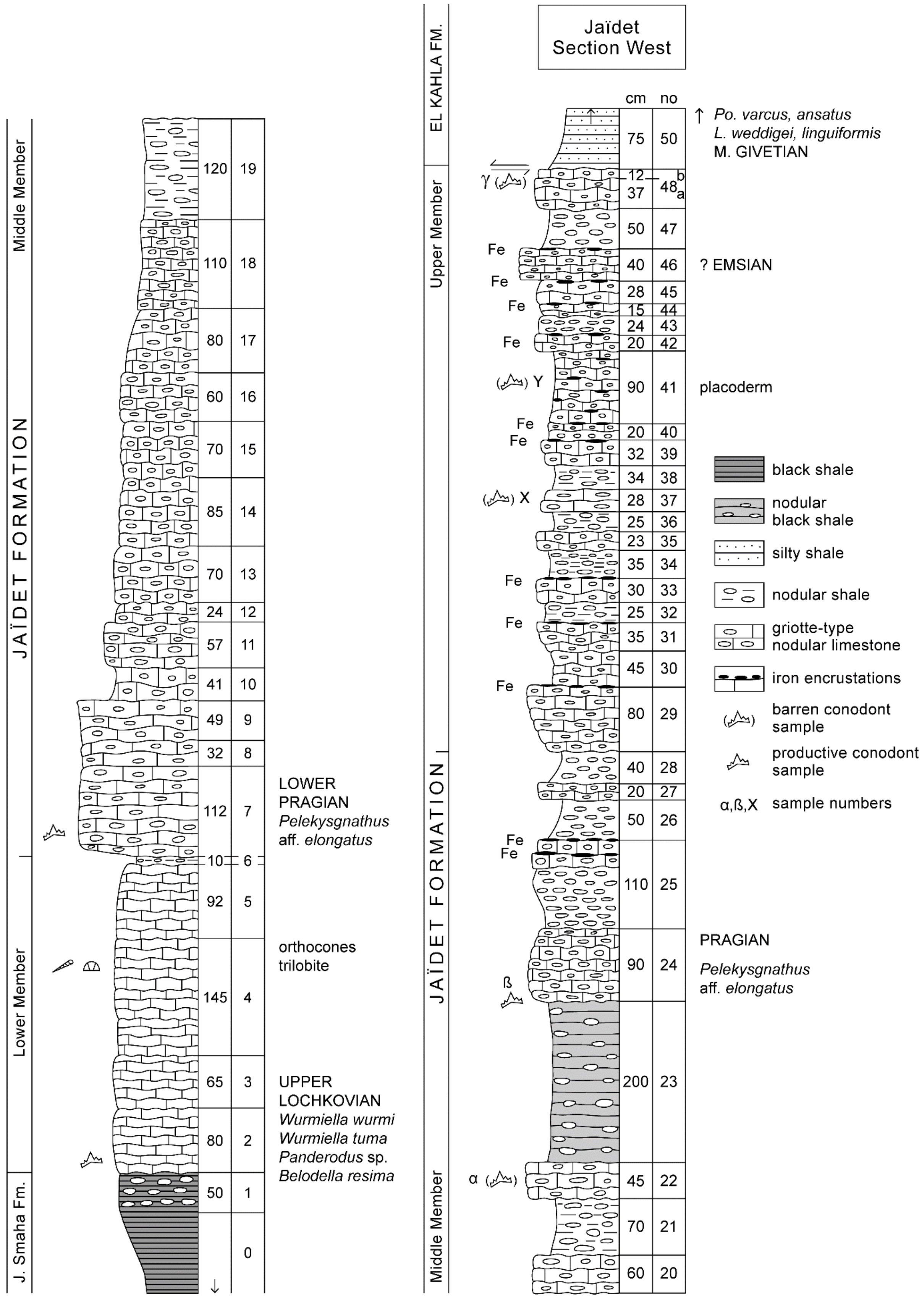

Fig. 7: Lithostratigraphy and position of conodont samples (unproductive levels in brackets) in the Jaïdet Formation of the western limb of Section Jaïdet West.

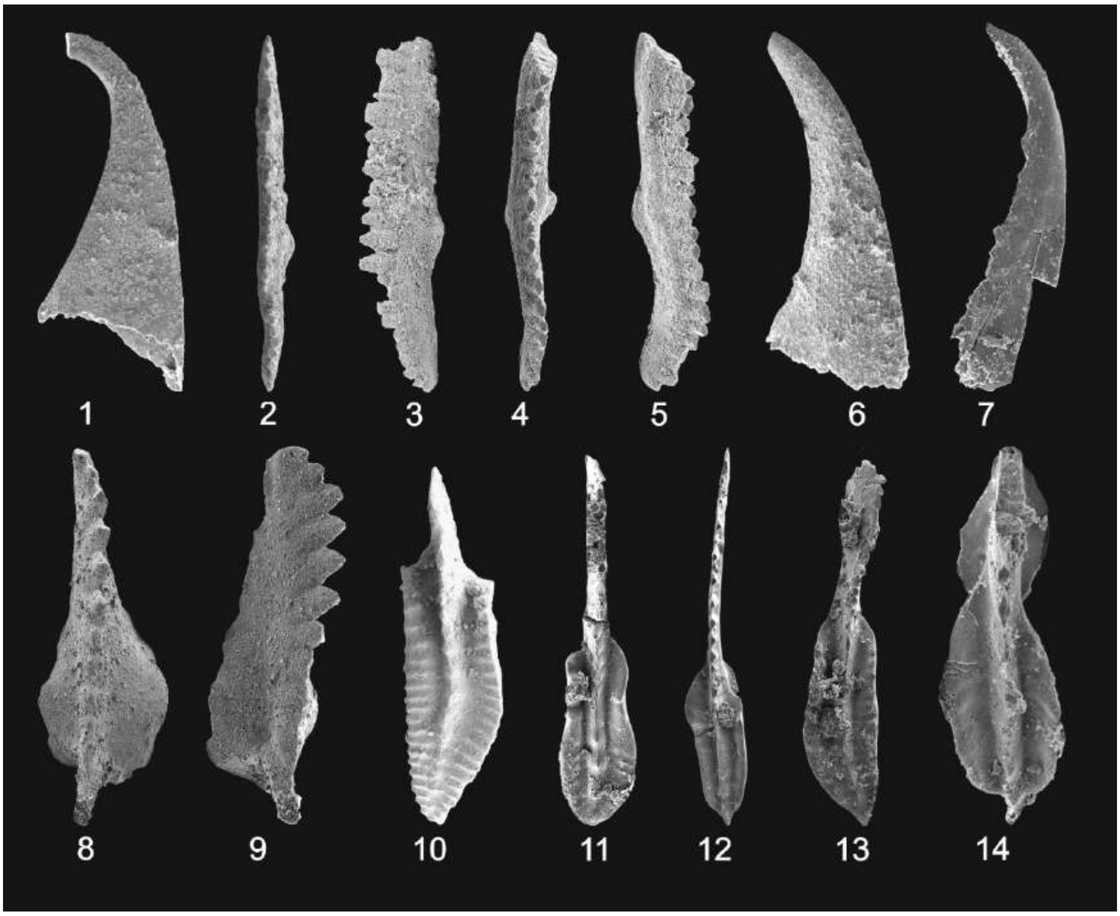

Fig. 8: Lower/Middle Devonian conodonts from the Jaïdet region, 1-6 = base of Lower Member of the Jaïdet Formation (Section Jaïdet West, Bed 2), 8-9 = Middle Member of Jaïdet Formation (Section Jaïdet West, Bed 24), 7 and 11-14 = El Kahla Formation (Section Jaïdet West), 10 = Upper Member of Jaïdet Formation (Section Jaïdet Northwest, main goniatite level); GMM B4C.2.138-148. **1.** and **7.** *Belodella resima*, both x 55; **2-3.** *Wurmiella wurmi*, x 35; **4-5.** *W. tuma*, x 40; **6.** *Panderodus* sp., x 55; **8-9.** *Pelekysgnathus serratus* aff. *elongatus*, x 55; **10.** *Linguipolygnathus cooperi cooperi*, x 30; **11.** *Po. ansatus,* x 55; **12.** *Po. timorensis*, x 55; **13.** *Po. xylus*, x 55; **14**. *Polygnathus varcus*, x 65.

Fig. 9: Microfacies of Section Jaïdet West (western limb). **1.** Bed 2, basal Jaïdet Formation: light-grey, bioturbated, flaser-bedded, microsparitic, slightly dolomitic, bioclastic wackestone with poorly preserved dacryoconarids, ostracods, and small to large idiomorphic pyrite cubes; **2.** Bed 7, basal Middle Member of Jaïdet Formation: middle-grey bioclastic wackestone with nowakiids, ostracodes, and mollusk filaments overlain by dolomitized mudstone with rare crinoid fragments, which also fills an orthocone (upper part) that includes a serially multichambered, sparitic microfossil and pyrite cubes; **3.** Bed 24, upper part of Middle Member: brownish-grey, flaser-bedded and bioturbated wackestone with abundant nowakiids, two-shelled ostracods, mollusk and crinoid debris, and channels of nowakiid packstone; **4.** Bed 37, Upper Member: light-grey, micritic, bioturbated nowakiid wacke- to packstone with a few bivalved ostracods, mollusk filaments, and crinoid ossicles; **5.** Bed 41, Upper Member: massive placoderm bone floating in a flaser-bedded, light- to middle-grey, bioturbated mud-wackestone with mollusk debris and pyrite; **6.** Top of Upper Member: bioturbated nowakiid wacke-packstone with middle- or dark-grey micrite matrix, small orthocones, and partially subparallel orientation of dacryoconarids (lower right corner); **7.** Lower El Kahla Formation: monotonous, bioturbated, light-grey, unfossiliferous, well-sorted siltstone with idiomorphic pyrite; **8.** Upper El Kahla Formation: laminated to cross-bedded, unfossiliferous, silty mudstone.

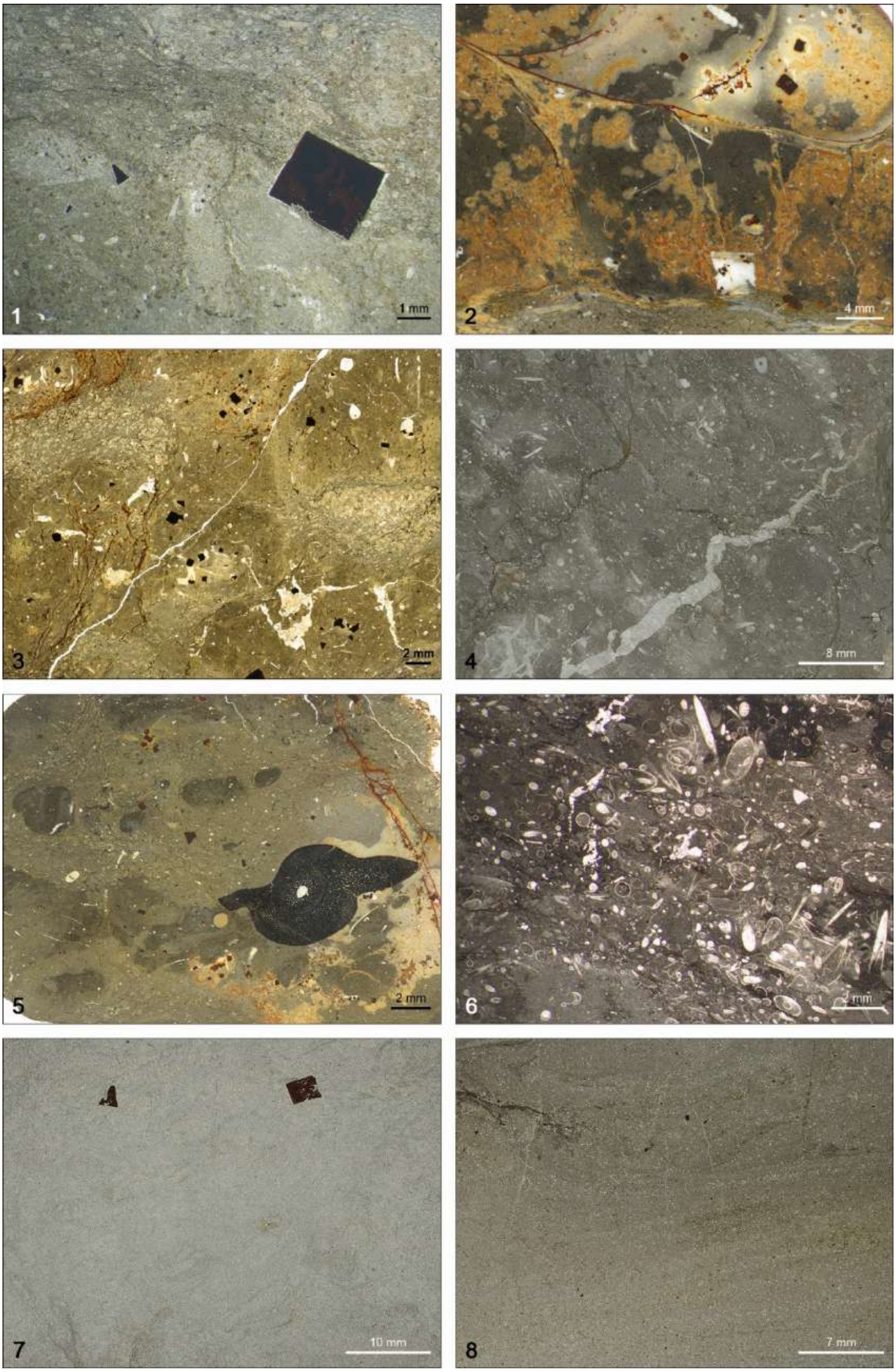
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Fig. 10: Solid, cliff-forming, orange to beige weathering griotte limestones of the Middle Member of the Jaïdet Formation (Pragian), western limb of Section Jaïdet West, with a hammer and A. El Hassani for scale, and the main road in the distance behind him.

In the Bou Marhara succession to the NE, Huvelin (1977) noted a ca. 50 m thick green shale package with bivalves between the Jebel Smaha and Jaïdet Formations. Based on the local record of a lower Pragian graptolite in the upper Jebel Smaha Formation (*U. thomasi*; see discussion above), the solid, rather condensed nature of the overlying Bou Marhara griotte, with an upper Pragian trilobite record (see below), the best interpretation is that the green shale unit correlates with the lower part of the Middle Member of the Jaïdet Formation of Section Jaïdet West (Fig. 4). It is important that the Jaïdet Formation is currently unknown from the El Kelâa des Srarhna region of the northeastern part of the eastern Jebilet (see Huvelin 1977).

In the higher part of the Middle Member at Section Jaïdet West, several intervals of grey nodular shale (e.g., Beds 19 and 21) are intercalated. These indicate minor deepening episodes. Especially distinctive is a ca. 2 m thick dark-grey shale with only few limestone nodules (Bed 23). It underlies the more massive Bed 24 with our Sample ß, that yielded a second *Pel.* aff. *elongatus* (Figs. 8.8-8.9). Although it differs morphologically from the *Pel. serratus* Group that is so characteristic for late lower to early upper Pragian strata (e.g., Weddige 1987; Slavík 2004), it can be used as evidence for an age below the top Pragian. Huvelin (1977) reported accordingly the upper Pragian marker phacopid *Reedops intermedius* from the solid griotte limestones of Douar Oulad-ben Tounsi, as a part of his "F3" fauna of the Bou Marhara Devonian. A second spot with *Odontochile cristata* and *Reedops* was assigned to the lower Emsian but, if the first was correctly identified, a Pragian age was true (see Budil et al. 2009). A third spot produced *Reedops, Zlichovaspis*, and the rare asteropygid *Echinopyge*. The first two genera occur both in the Pragian and lower Emsian (e.g., Chlupáč 1977; Budil et al. 2009). *Echinopyge* was originally described as an endemic and monospecific genus from the supposed upper Emsian of Bithynia, western Turkey (Haas 1968). However, the outdated Bithynian Devonian stratigraphy had to be revised. The *Echinopyge* level, the Kurtdoğmus Formation, underlies the Dede Formation, which is famous for its lower Emsian ammonoid fauna (Erben 1965). Ziegler (1971) recorded *Caudicriodus curvicauda* and *Icriodus angustoides angustoides* from the Kurtdoğmus Formation, which proved a Pragian age, which resolved the contradiction. As a conclusion, Pragian trilobites are common in the Middle Member of the Jaïdet Formation whilst undoubted Emsian species have not yet been found.

1

2

Fig. 11: Details of microfacies of Bed 24. **1.** Well-preserved *Now. (Turkestanella) acuaria* occurring without clear orientation in yellowish wacke-packstone, picture width ca. 3.5 mm; **2.** Channel of nowakiid packstone with partial bottom current orientation.

The microfacies of Bed 24 (Fig. 9.3, 11) is distinctive because of the rather dark and brownish color of the limestone and its high abundance of well-preserved nowakiids (*Now. (T.) acuaria*), either in cloudy wackestone parts without clear orientation of shells (Fig. 11.1), characteristic for the absence of bottom currents, or in channels with coquinas (packstones, Fig. 11.2). The restricted benthos consists of two-shelled ostracods, gastropods, minor mollusk and crinoid debris. This typifies the setting of a pelagic outer shelf carbonate platform or ramp affected episodically by contourites. Sedimentation rates were low and the seafloor was mostly oxic, allowing constant bioturbation by non-shelly benthos.

4.2.3. Upper Member

The Upper Member of the Jaïdet Formation is defined in Section Jaïdet West, western limb, by an increasing amount of iron encrustations (goethite/limonite), often filling burrows. It embraces Beds 29-49, with a thickness of ca. 7.5 m. The solid griotte beds and intercalated nodular shales first form an upper cliff and then continue in the top part of the western backside. Macrofauna is locally very poor. The top of the member and formation is cut off by a fault, as indicated by a change of strike direction. All conodont samples proved to be barren (Fig. 7), which leaves a large uncertainty concerning the age. A lower Emsian age is tentatively assumed for the lower part of the Upper Member. It is rather unusual that outer shelf griotte-type limestones contain no conodonts at all. However, rarity or absence of index forms has also been observed in some Emsian successions of the Anti-Atlas (ABOUSSALAM et al. 2015).

The representative Bed 37 (Fig. 9.4) is a light-grey, micritic nowakiid wacke- to packstone with a few bivalved ostracods, mollusk, crinoid, and trilobite debris. In parts of the thin-section, a subparallel current orientation of the nicely ribbed dacryoconarids can be observed. In Bed 41 (Fig. 9.5), variably light- or middle-grey nodules of fine, bioturbated mud-wackestone with some nowakiids and mollusc debris are surrounded by channel-like nowakiid wacke-packstones. The sample sectioned a massive placoderm bone. At the top, Bed 48 is characterized by bioturbation-controlled strong lateral and vertical changes of nowakiid abundances (wacke- to packstone) and variably dark, organic-rich or lighter/middle-grey micrite matrix. As below, subparallel orientations and cone-in-cone stacking of dacryoconarids indicate episodic seafloor currents, probably contourites. The macrofauna consists of orthocones with pointed phragomocone apexes (pseudorthoceratids) and a small amount of crinoidal debris. In general, there is a restricted microfacies variability in the Jaïdet Formation.

The eastern limb of the anticline at Jaïdet West shows a reduced thickness for all three members of the Jaïdet Formation. A large, loose block with typical iron encrustations of the Upper Member displays the corroded horizontal section of an anarcestid (Fig. 12; compare HUVELIN 1977, p. 42). It provides firm evidence for an upper Emsian age for the upper part of the Upper Member. However, it is intriguing that no equivalent of the basal upper Emsian Daleje Shales, which is so well developed in the eastern Anti-Atlas (e.g., ABOUSSALAM et al. 2015) and Skoura Devonian (see Skoura chapter), can be recognized in the Jaïdet region.

Fig. 12: Corroded and iron-stained horizontal cross-section of an upper Emsian anarcestid with typical very low whorls exposed on the surface of a loose block of the Upper Member of the Jaïdet Formation, eastern limb of Section Jaïdet West (scale in cm).

4.3. Upper Emsian at Section Jaïdet Northwest

A rich upper Emsian goniatite fauna was collected in Section Jaïdet Northwest, situated just north of the main road at the 14 km marker, and just west of a small piste that curves northwards around a school building (GPS N31°52´43,0´´, W7°48´6,6´´). The sections starts with black shales in the north (asumed Jebel Smaha Formation, Fig. 3), followed by ca. 12 m thick, vertically bedded nodular limestones of the Jaïdet Formation exposed in low ridges and cliffs. Anarcestids occur in-situ on bedding planes of the upper ca. 3-4 m. Their preservation on burrowed bedding surfaces is rather poor but two groups are present, possible sellanarcestids with very low whorls (Fig. 13), and possible "*Latanarcestes*" with higher whorls (Fig. 14). Such an association was noted by HUVELIN (1977) from the Bou Marhara Syncline and is typical for the upper Emsian zone LD IV-C of the eastern Anti-Atlas (Maïder), eastern Dra Valley, and Cantabrian Mountains (e.g., BECKER & HOUSE 1994b; EBBIGHAUSEN et al. 2011). However, the poor preservation and restricted number of specimens require to be cautious concerning the precise zone.

Fig. 13: Corroded anarcestid (probably *Sellanarcestes*) on a strongly bioturbated bedding surface with overprinted *Thalassinoides*-type burrows of the upper Jaïdet Formation at Section Jaïdet Northwest (coin diameter = 25 mm).

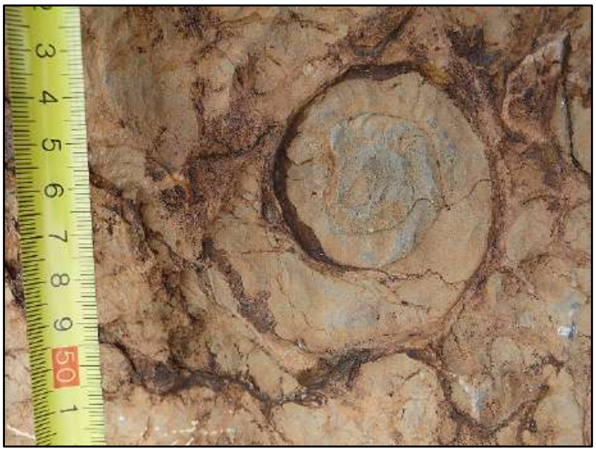

Fig. 14: Corroded different anarcestid with higher whorls (probably "*Latanarcestes*") from the same bedding surface as Fig. 13 (scale in cm).

A much richer fauna weathers out of subsequent less prominent nodular beds on the slope towards the road (Fig. 15). It consists of (bl = black matrix, dg = dark-grey matrix, mg = middle grey matrix, lg = light-grey matrix):

Fig. 15: The most goniatite-rich, more nodular griotte limestones at the top of the Jaïdet Formation of Section Jaïdet Northwest; Stephan EICHHOLT for scale.

"*Latanarcestes noeggerathi*" auct. (common, 55 % of the specimens, Figs. 16.1-4, bl-dg-lg)
Praewerneroceras n. sp. (Fig. 16.5-6, bl)
Sellanarcestes aff. *perfectus* (Fig. 16.7-8, dg-mg)
Sellanarcestes draensis (Fig. 16.11-12, dg)
Sellanarcestes sp. indet. (dg-mg-lg)
Anarcestes cf. *simulans* (lg-ochre)
Anarcestes cf. *crassus* (Fig. 16.9-10, dg-mg)
Achguigites sp. (Fig. 16.13, mg-lg)
orthocones (mg)
Panenka div. sp. (strongly corroded, mg-lg)
phacopid indet.
crinoid stem pieces (dg)
Linguipolygnathus cooperi cooperi (Fig. 8.10)

Again, the preservation is poor. All specimens are corroded, lack any shell remains and inner whorls, and are often laterally distorted. Specimens are variably preserved in black to light-grey or ochre weathering limestone. This indicates that they come from different beds within the several meters thick package. Identifications are based on sutures and rough shell parameters. The specimen identified as *An.* cf. *crassus* (Figs. 16.9-10) is more involute than typical representatives from Bohemia. For *Praewerneroceras* n. sp. (Figs. 16.5-6) and *Sell.* aff. *perfectus* (Figs. 16.7-8) see the taxonomic notes at the end. The specimen identified as *Sell. draensis* (Figs. 16.11-12) agrees with the Tata region types of EBBIGHAUSEN et al. (2011) in the rather narrow umbilicus (32 %) and thick whorls at ca. 30 mm diameter.

The Jaïdet Northwest assemblage resembles closely the faunas from the *An. simulans* and *An. crassus* Zones of Oufrane in the Tata region (LD IV-D). These extend to the upper Emsian of the Skoura region (see Skoura chapter) and to the Tafilalt (KLUG 2002). The form commonly identified as "*Latanarcestes noeggerathi*" (auct.) (Figs. 16.1-4) occurs widely in the eastern to western Anti-Atlas (e.g., BULTYNCK & HOLLARD 1980; BECKER & HOUSE 1994b; KLUG 2002; BECKER et al. 2004d, 2018b) and is most typical for the oldest anarcestid zone. However, it has previously been recorded from younger *Sellanarcestes-Anarcestes* assemblages, e.g., from the western Dra Valley (BECKER et al. 2004d) and Celtiberia, Spain (HOLLARD & HOUSE in BULTYNCK 1979). At Jaïdet Northwest, its dominance in comparison with the two other anarcestid genera is distinctive.

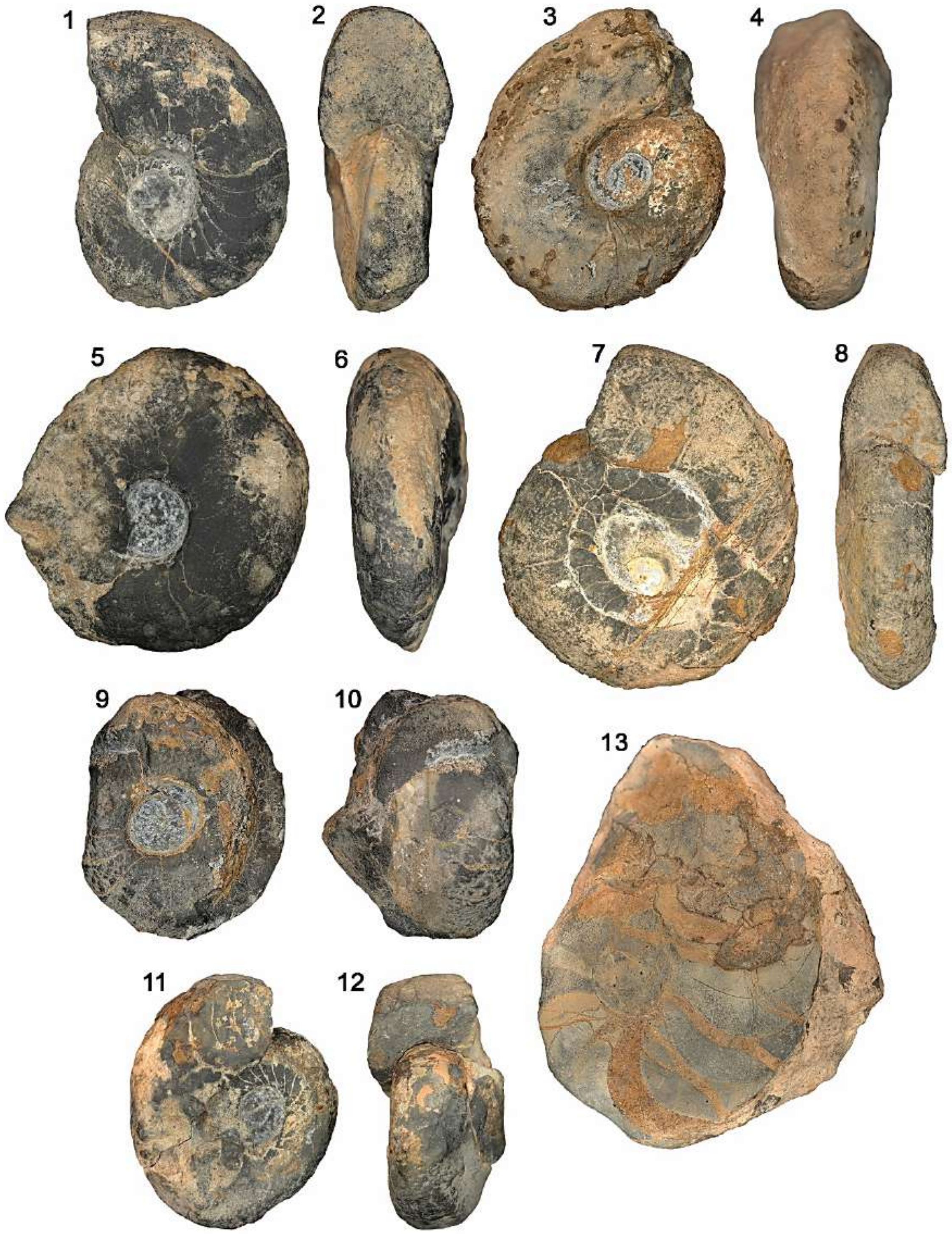

Fig. 16: Upper Emsian goniatites from the top of the Jaïdet Formation at Section Jaïdet Northwest; GMM B6C.54.183-189. **1-4.** "*Latanarcestes noeggerathi*" auct, lateral (1, 3), adoral (2), and ventral views (4), showing elliptical distortion and rather high whorls (with WER > 2.0), x 1; **5-6.** *Praewerneroceras* n. sp., lateral and ventral views, x 1.3; **7-8.** *Sellanarcstes* aff. *pefectus*, lateral and adoral views, showing the moderate whorl overlap and compressed cross-section at maturity, x 1; **9-10.** *Anarcestes* cf. *crassus*, lateral and adoral views of a small specimen, x 1.3; **11-12.** *Sellanarcestes draensis*, lateral and adoral views of a juvenile, x 1.3; **13.** *Achguigites* sp., lateral view of strongly corroded specimen with distinctively different fillings of successive phragmocone chambers by sparite, light-grey micrite, medium-grey micrite, or yellowish weathering micrite, x 1.

Following the original illustration (von BUCH, 1832) and refined knowledge of its type-locality, the true *Lat. noeggerathi* of the southern Rhenish Massif is a very different Eifelian anarcestid that is probably congeneric with *Diallagites* KLUG, 2002. This explains our quotation in inverted commas; a taxonomic revision is inevitable.

Achguigites KLUG, 2002 (Fig. 16.13) is known from the *An. simulans* Zone of the Tafilalt and western Dra Valley (EBBIGHAUSEN et al. 2011). Its occurrence at Jaïdet is, therefore, not surprising. Poorly preserved goniatites were used as conodont sample. We only found the index species of the *cooperi cooperi* Subzone (Fig. 8.14), the level of youngest *Sellanarcestes* in the Tafilalt (ABOUSSALAM et al. 2015).

The upper Emsian pelagic goniatite facies of Jaïdet differs strongly from the Devonian brachiopods and bivalves found by RUSSO (1917; identifications by C. DEPÉRET) in micaceous siltstones and sandy limestones of the Jebel Tekzim, ca. 6 km to the NNE. The quoted "*Spirifer esquerrae*" refers to the type-species of the delthyridoid genus *Boucotiellina* GARCIA-ALCALDE, 2004 (Cyrtiopsidae), which comes from the upper Emsian of León, Cantabrian Mountains. The listed *Orthis beaumonti*, also a Cantabrian species, was subsequently placed in the schizophoriid genus *Pachyschizophoria* JANSEN, 2001, which also occurs typically in the upper Emsian (e.g., JANSEN 2016). In the absence of detailed descriptions or later revisions, the reliability of the original identification is unclear. HUVELIN (1977) noted that dacryoconarid limestones do also occur at the Jebel Tekzim. However, in any case must there have been partly a shallower, neritic Emsian facies in the source region in comparison with the Jaïdet region source. The Carboniferous tectonic transport was heterogeneous, displacing material from different contemporaneous units (neritic facies, pelagic griotte facies, deeper shelf shales) towards the adjacent Jebel Tekzim and Jaïdet regions (in the west) and towards El Kalâa des Srarhna/Jebel Smaha (in the east). This may reflect an original palaeogeographic differentiation in the source region.

4.4. El Kahla Formation (Eifelian/Givetian)

The new El Kahla Formation is introduced for the thick succession of siltstones, fine sandstones, shales and turbiditic limestones that overlie the griotte facies of the Jaïdet Formation. The name is taken from Koudiat El Kahla, ca 1-1.5 km W of Section Jaïdet West, where the formation occupies a wide syncline (Fig. 3).

4.4.1. Lower Member

At Jaïdet West, the non-calcareous "Lutites gréso-micacées verdâtres" of HUVELIN (1977) form a Lower Member. The eastern limb exposes a gradual transition from nodular limestones to solid, yellowish or orange weathering, dark grey calcareous siltstones with abundant trace fossils. Large *Zoophycos* burrows are common (Fig. 17); other bedding surfaces expose deposit feeding fodinichnia resembling *Chondrites targionii* (det. M. BERTLING, Münster; Fig. 18). The producer of *Zoophycos* may have been a polychaete worm (ZHANG & ZHAO 2016) that inhabitated a wide range of marine settings. *Chondrites* is long known to have been adapted to hypoxic facies and often occurs in the deepest bathymetric part of trace fossil successions (BROMLEY & EKDALE 1984), although it also had a wide total palaeoecological range (SEILACHER 2007). Devonian *Zoophycos-Chondrites* co-occurrences are characteristic for low diversity ichnofossil assemblages from grey to dark, organic-rich mudstones of deeper shelf settings, where the size of burrows decreases with oxygenation (SEDORKO et al. 2018). This fits the Jaïdet occurrence. In the southern Tafilalt, large-sized *Zoophycos* are common in upper Eifelian organic-rich black marls and turbiditic limestones at the Tafilalt Platform margin, which also reflect a hypoxic setting (El Khraouia, BECKER et al. 2013a). There, they also overlie directly condensed nodular limestones. Elsewhere in North Africa, contemporaneous *Zoophycos*-*Chondrites* assemblages characterize the dysoxic Middle Member of the Chefar El Ahmar Formation of the Ougarta region (Algeria; BOUCHEMLA et al. 2020).

The sudden change of ichnofauna at the Jaïdet/El Kahla Formation boundary reflects a break of trophic conditions in the sediment, opening new, intense feeding opportunities. This was probably caused by the significant increase of sedimentation rates, with a rapidly rising influx of fine siliciclastics and associated organic matter. Relationships of *Zoophycos* blooms with early land plant evolution, as proposed by KOTAKE (2014), are unlikely. The Moroccan occurrences predate the "greening of the land" by the spread of trees and forests.

Fig. 17: Bedding surface of orange-beige weathering siltstone of the basal El Kahla Formation with large *Zoophycos* feeding traces, eastern limb of Section Jaïdet West.

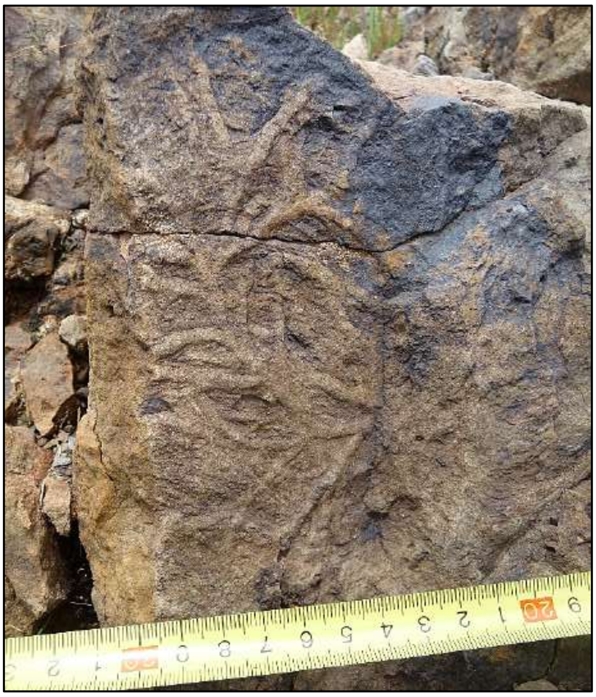

Fig. 18: Complexly branching feeding traces resembling *Chondrites targionii* on a surface of the El Kahla Formation, just above a *Zoophycos* level (to the right), eastern limb of Section Jaïdet West (scale in cm).

On the western limb at Jaïdet West, the main part of the Lower Member (the base is lacking by fault contact) consists of unfossiliferous greenish to dark-grey silty shales and siltstones. A thin-section from higher parts (Fig. 9.7) shows a very monotonous, light-grey facies of well-sorted silt particles with a minor pyrite content, lacking any fossil debris. The seafloor was hostile.

The basal part of the El Kahla Formation includes in the Bou Marhara Syncline (HUVELIN 1977, fig. 18A) a 15-20 m thick "flysch greseux" composed of siltstones/fine sandstones alternating with green shales and "conglomerates" with flat nodules, which are made of dark phosphate and limestones with dacryoconarids ("F5"). The main Lower Member comprises up to 150 m of green shales, which is a higher thickness than at Koudiat El Kahla (50-100 m, HUVELIN 1977, p. 45).

The age of the Lower Member is not really established. The position between the top-Jaïdet Formation levels with upper Emsian goniatites and Givetian limestones (see below) suggests a top Emsian to Eifelian age. A contradiction comes from a lense with the "F7" fauna of Jaïdet (HUVELIN 1977, p. 42). It included various small brachiopods and two trilobite genera (*?Reedops* and *Odontochile*) that normally do not occur above the lower Emsian. The fossiliferous lense was either allochthonous/reworked (possible), the trilobites were incorrectly identified (possible), or the top of the Jaïdet Formation is strongly diachronous within a small area (rather unlikely).

4.4.2. Upper Member

HUVELIN´s "Schistes et calcaires gréseux à Tentaculites" (Jaïdet succession) and lateral "Schistes siliceux polychromes, grés et calcaires gréseux à lits convolutes" (Bou Marhrara Syncline, Kelâa des Srarhna region) are assigned to an Upper Member of the El Kahla Formation. Characteristic are siltstones with intercalated sandy limestones with grading, lamination, cross- and convolute bedding, as typical for turbidites (Fig. 19, thin-section of Fig. 9.8).

At Jaïdet West, the alternation of shales and dark-grey turbidites is ca. 11 m thick but the outcrop ends abruptly on the NW slope of the hill. HUVELIN (1977) suggested a thickness for the complete unit of more than 370 m for the Bou Marhara and of ca. 400 m for Koudiat El Kahla.

The age for the lower part of the member is well constrained by a new conodont fauna from Jaïdet West. It is the richest among our mostly sparse or even unproductive Eastern Jebilet conodont samples, with eight species (specimen numbers in brackets):

Belodella resima (1, Fig. 8.7)
Polygnathus varcus (2, Fig. 8.14)
Polygnathus xylus (4, Fig. 8.13)
Polygnathus ansatus (2, Fig. 8.11)
Polygnathus pseudofoliatus (3)
Polygnathus timorensis (8, Fig. 8.12)
Linguipolygnathus linguiformis (9)
Linguipolygnathus weddigei (1)

Fig. 19: Turbiditic limestone with cross-bedding in the Upper Member of the El Kahla Formation at Section Jaïdet West (scale in cm).

The forth listed species is the index taxon of the middle Givetian *ansatus* Zone (ABOUSSALAM 2003; = former Middle *varcus* Zone). HUVELIN (1977, p. 42) mentioned conodonts in his "F8" fauna from the lower part of the Upper Member in the Jaïdet succession, but gave no details. The corresponding "F6" fauna from the Bou Marhara Syncline (see his fig. 18A) included only *L. linguiformis*, which ranges from the ca. middle Eifelian to the top of the middle Givetian. His "F3" fauna from the Marfa hill SW of Douar Abichat, identified by J. LE FEBRE, included, apart from ramiform elements, *L. linguiformis*, *L.* cf. *mucronata*, "*Po.* cf. *angusticostata*", and "*Po. robusticostata*?". The second species supports an *ansatus* Zone age although there are rare records from the upper part of the underlying *rhenanus-varcus* Zone (BULTYNCK 1987; see discussion in BRETT et al. 2018). The third and fourth species are Eifelian taxa that should not co-occur with *L. mucronatus*. Their cf./? quotations exclude any stratigraphic value.

Currently, there is no record of Eifelian to lower Givetian conodont faunas from the Eastern Jebilet but sampling has not been intensive.

With respect to the high thickness of strata following in the Upper Member the known conodont levels, it is well possible that the clastic El Kahla Formation reached the upper Givetian or Upper Devonian. This has to be clarified by a further search for limestones in higher levels, for example in the core of the Koudiat El Kahla syncline. The recent discovery of Frasnian and lower Famennian strata in the Central Jebilet (LAZREQ et al. 2021) added an incentive for further work.

Fig. 20: Western end of Koudiat Lahmara ca. 1 km east of Jaïdet, with poorly exposed siliciclastics (perhaps upper El Kahla Formation) in the foreground, with S. EICHHOLT for scale, lenticular limestones of the basal Tekzim Formation in the lower slope, and the main crest of "Piton Ouest " (sensu ANDRÉ 1986; Hill 685) in the back.

5. Carboniferous transgression at Koudiat Lahmara

Studies by HUVELIN (1977), HOLLARD et al. (1977) and ANDRÉ (1986) investigated the Viséan carbonate facies (Tekzim Formation sensu GAILLET 1979) of Koudiat Lahmara, ca. 2-3 km east of Jaïdet (Figs. 3, 20). There are three hills north, northeast, and east of the Ben Brahim settlement (ANDRÉ 1986, fig. 3), just north of the main road. Our sampling focused on "Hill 685" or the "Piton Ouest", where the laterally discontinuous oldest limestones (see ANDRÉ´s Units 1-4) are exposed on the gentle lower NW slope (Fig. 21). GPS coordinates are N31°52´4.2´´, W7°46´2.0´´. We specifically sampled two oldest lenses for fauna and microfacies. Their contact with underlying shales and siltstones is not exposed and somewhat obscure (Figs. 20, 21). There is no indication for a thrust plane. The geological map of HUVELIN (1972), the hypothetic cross-section of HUVELIN (1977, fig. 32), the discussion in ANDRÉ (1986, fig. 3), and our observations suggest that the lenticular or slumped limestones bodies lie unconformably but without a fault on fine siliciclastics (possibly El Kahla Formation). Laterally, unconformable contacts both with Ordovician quartzites and breccia bearing top parts of the Kharrouba Formation were mapped. The likely interpretation is that the mixed carbonate-siliciclastic to reefal complex of the local Tekzim Formation represents an allochthonous shallow-water klippe/nappe complex that glided together with Ordovician blocks in the final phase into the Kharrouba Flysch basin (compare BEAUCHAMP & IZART 1987). Our irregular limestone blocks could be detached olistolites. A similar situation seems to apply to the Jebel Tekzim (see HUVELIN 1977, fig. 31), where Ordovician and Silurian slices and Devonian carbonate olistolites were shown to lie in Viséan shales, which underlie the type Tekzim Formation limestones. This complex thrusted onto the Kharrouba Flysch or glided into it after breccia formation had started. We have not yet re-studied this outcrop.

Fig. 21: Irregular and lenticular distribution of the oldest limestones of the Tekzim Formation at the western end of Koudiat Lahmara.

The lowest Carboniferous rocks studied by us consist of unsorted and polymict conglomerates with a high content of iron encrustations (Figs. 22.1-2) and cross-bedded, light-grey crinoidal grainstones (Fig. 22.3). The latter are interpreted as tempestites, which accumulated with the conglomerates in a dynamic, transgressive near-shore setting. Reworked material of an older carbonate platform, quartzite and chert pebbles mixed with carbonate and quartz sand during a time of high influx of land-derived iron solutions. ANDRÉ (1986) described the intercalation of limestones and sandstones embedded in fine siliciclastics within his Units 1 and 3-4 while conglomerate was described from Unit 2. We cannot assign our samples specifically to one of his units.

Fig. 22: Limestones of basal Tekzim Formation at the western end of Koudiat Lahmara**. 1.** Alternating and intergraded iron-rich conglomerate and crinoidal limestones; **2.** Details of the conglomerate showing the lack of sorting and grading; **3.** Details of laminated to cross-bedded, tempestitic crinoidal limestones.

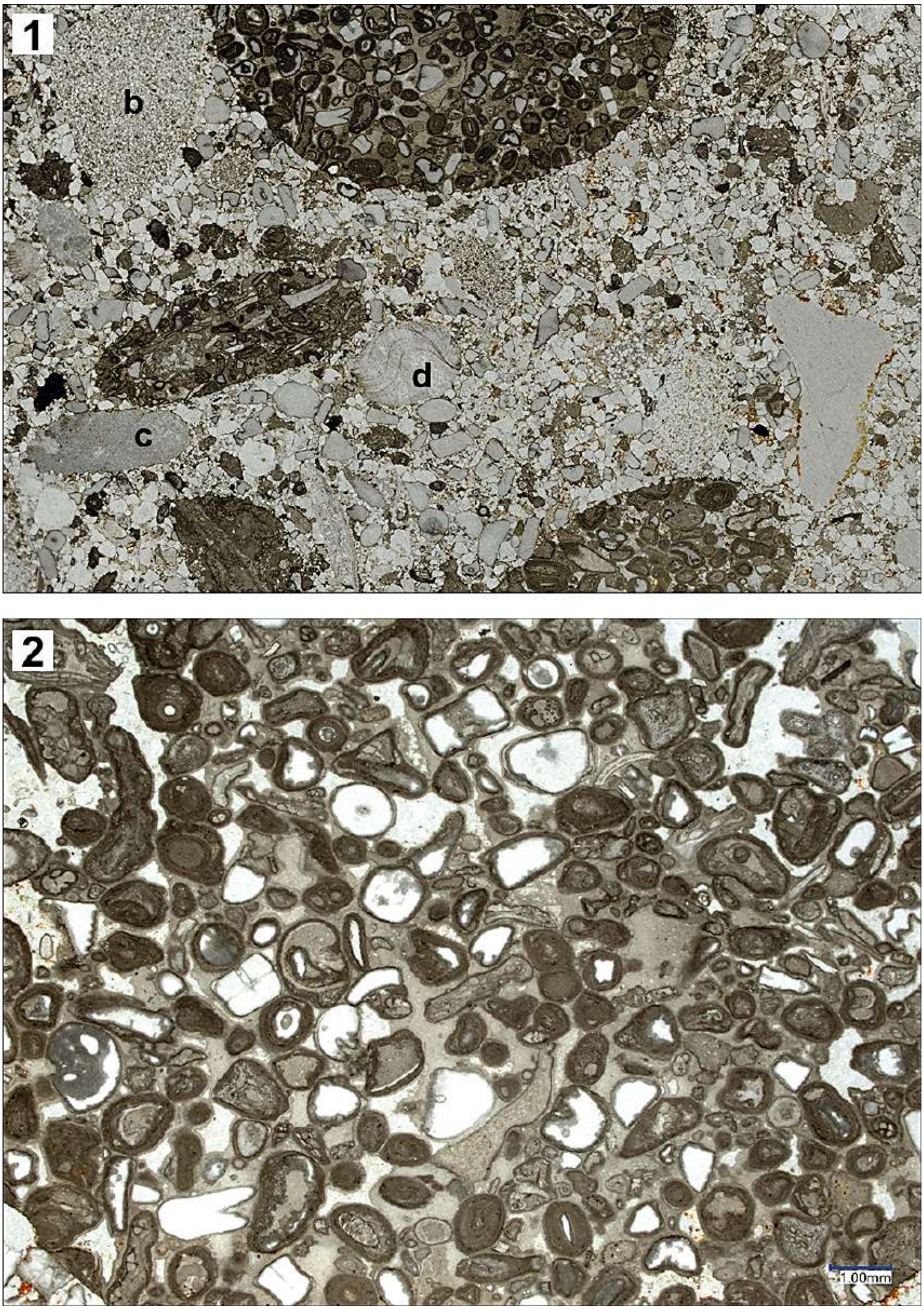

Fig. 23: Microfacies of a conglomerate from the base of the Tekzim Formation at Koudiat Lahmara West. **1.** Overview showing the poor sorting, with four types of pebbles (relative dark coated grain-ooid grainstone with micrite matrix, b = light-grey, fine calcisiltite, c = middle-grey “micrite”, d = sparitic fossil fragment) sitting in a matrix of calcisiltite and calcarenite grains, with dominant angular to rounded crinoidal clasts and some darker extraclasts, and sparite between them; picture width = 3 cm; **2.** Details of the calcarenitic coated grain-ooid grainstone, showing the variably thin or thick, dark micrite rims around crinoid pieces, intraclasts, foraminifers, algal and bryozoan fragments and shell pieces, with a dense, partly washed out micrite matrix.

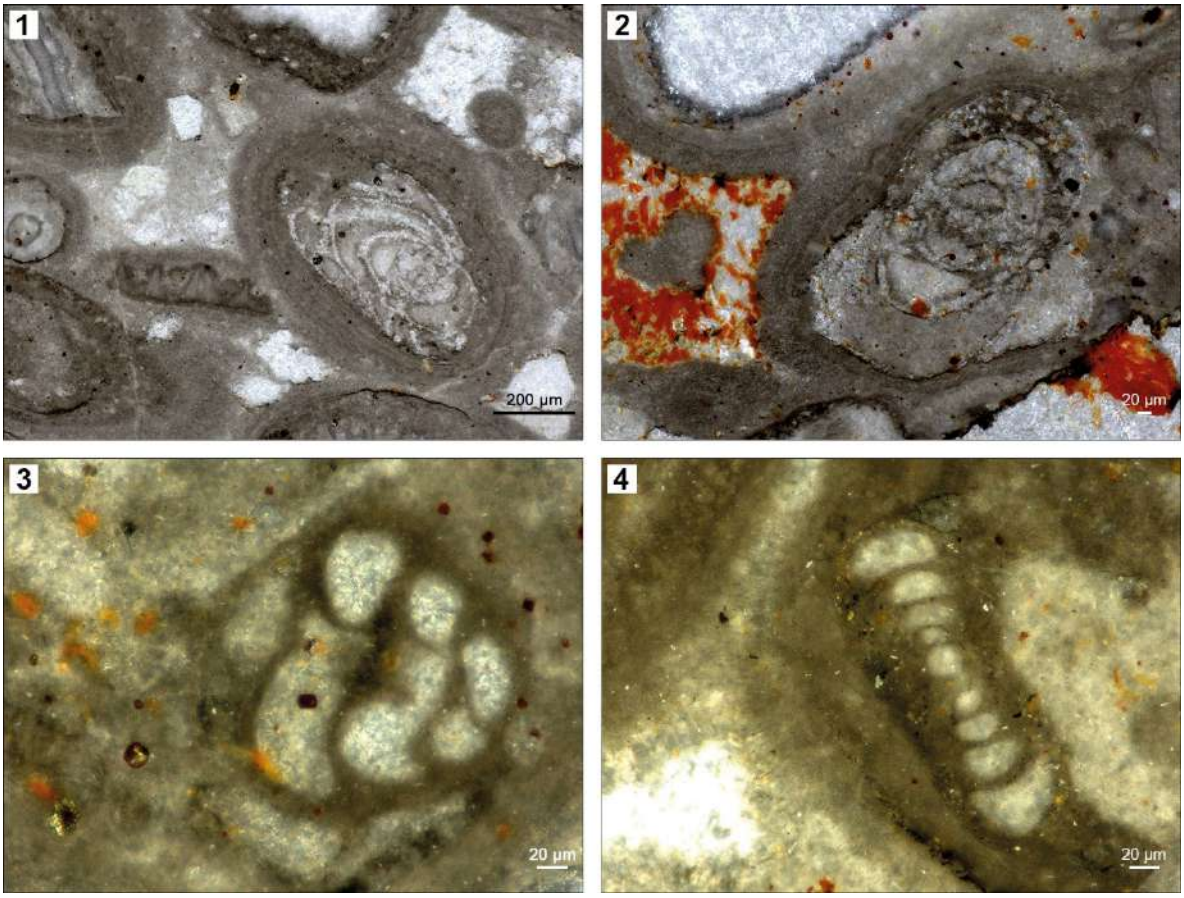

Fig. 24: Coated foraminifers from within oolithic grainstone pebbles in the basal conglomerate at Koudiat Lahmara West. **1.** *Eoparastafella* ex gr. *concinna* (or *Eostaffella radiata*); **2.** *Eoparastafella* ex gr. *florigena*; **3.** *Pseudotaxis* sp. (?*P. sussaicus*); **4.** *Lapparentidiscus* sp.

Thin-sections confirm a rather complex palaeoenvironmental setting with several episodes of reworking and redeposition. As an example for the lowest lenticular limestones, Fig. 23 illustrates a moderately coarse conglomerate. Spherical or flat, well-rounded pebbles of 5-20 mm size float in a poorly sorted calcisiltite to calcarenite (grainstone) matrix with sparite between the grains (Fig. 23.1). Due to compaction, the variably angular (dominant), subrounded or rounded grains are often in stylolithic contact. They consist mostly of crinoid detritus but there are subordinate darker extraclasts, which are small-sized pebble fragments.

Four types of extraclasts can be distinguished: relatively dark coated grain-ooid grainstones, finer, light-grey calcisiltite, sparitic shell fragments, and medium-grey, dense carbonate (probably echinoderm remains). The first type (Fig. 23.2) shows internally a partly washed out very dense and fine micrite matrix and moderately sorted, mostly 0.5 to 2 mm large, rounded to subangular grains with variably thin or thick micrite rims. Apart from ooids, there are coated crinoid ossicles and fragments, encrusted pieces of bryozoans and algae, limestone intraclasts, coated foraminifers, and rare shell filaments. Other pebbles within coarse conglomerate consist of very different, micritic, light-grey, bioturbated mud-wackestone with isolated crinoid ossicles, small brachiopods, and rare gastropods. They represent a calm neritic setting below normal storm wave base.

The conglomerate genesis is reconstructed to have experienced the following phases:

1. A first very shallow to coastal carbonate platform with the adjacent growth of algae, bryozoan colonies, corals, crinoids, shoreline erosion of even older limestone, and deposition of crinoid sand with foraminifers.
2. Erosion of this first platform and first re-deposition, where heterogeneous detrital grains were bored and coated by cyanobacteria, including ooid growth, in a continuing very shallow setting.
3. Re-deposition of the coated grains and ooids in a moderately calm setting together with micrite, which was only partly washed out by bottom turbulence. Laterally, micritic wackestone facies with an in-situ neritic facies prevailed.
4. Lithification of the coated grain limestone and of adjacent micritic wackestones and calcisiltites (minor channel deposits).
5. Second reworking and formation of polymict limestone pebbles in a shallow, high energy environment.
6. Third re-deposition jointly with younger crinoid and pebble debris in an unsorted debris flow (major storm or tsunami deposit) intercalated between shallow-water, crinoidal tempestites.

The age determination has to recognize the reworked nature of foraminifers from within the pebbles/coated grains. They are not very abundant but include at least four taxa: *Eoparastafella* ex gr. *concinna* (or *Eostaffella radiata*, Fig. 24.1), *Eoparastafella* ex gr. *florigena* (Fig. 24.2), *Pseudotaxis* sp. (possibly *Ps. sussaicus;* Fig. 24.3), and *Lapparentidiscus* sp. (Fig. 24.4). This assemblage suggests a lower/middle Viséan age. It represents new indirect evidence for a pre-upper Viséan carbonate platform in the Eastern Jebilet source region, which has been lost by subsequent reworking. Lower/middle Viséan carbonate platforms had a restricted distribution in the Meseta in comparison to the upper Viséan (Rodríguez et al. 2020; Cózar et al. 2020a). The lack of foraminifers in the conglomerate matrix prevents a direct dating of the re-deposition and transgression but it is constrained by the age of the immediately adjacent coral limestones.

Lenses and large blocks of fossiliferous, middle- or dark-grey microbial and detrital coral limestones (Fig. 25) lie also in the lower slope. They may have moved on the slope but André´s section of the Piton Ouest does not show this lithology in the main cliff (only in the distant Piton Nord).

Fig. 25: Field photo of a Viséan biostromal (microbial) limestone slab with the phaceloid rugose coral *Siphonodendron*, basal Tekzim Formation, Koudiat Lahmara West (scale in cm).

Thin-sections (Figs. 26-30) display a close intercalation of different microfacies. Some corals (Fig. 27) are embedded in clotted, micritic, partly brecciated microbial bindstone, partly with sparite-filled fenestral fabrics and sponge spicules (Fig. 30.8). Associations of calcimicrobes and sponges are typical for many microbial limestones. The bindstones are truncated by minor channels (Fig. 27.1, 28) filled with often poorly sorted, intra- and bioclastic packstones (calcisiltites to calcarenites). Bioclasts include crinoid debris, bryozoan fragments, ribbed brachiopod shells, and some foraminifers (Figs. 30.1-7). Typical is orange to reddish Fe dolomite, especially in grain interspaces. Some double-valved brachiopods are filled by the same packstone. Dark-grey packrudstones around other corals (Figs. 26.1, 29.3, 29.6) include coated grains, ooids, rare calcispheres, and micrite matrix.

Many Rugosa are concentrically encrusted by several generations of laminoid microbial fabric (e.g., Figs. 27.1, 27.2), sometimes finally by the attached foraminifer *Tetrataxis* sp. (Fig. 27.2) and by bryozoans (Fig. 27.4). The latter occur as abundant fragments both in the packstones and within brecciated microbial bindstone (Figs. 29.2. and 3). Foraminifers are rather rare in the dark limestones and often poorly preserved. The overall environmental setting was a current- and storm-influenced inner platform within the photic zone. Therefore, conodont sampling was not successful. We found no redeposited Devonian clasts. The microfacies differences between coral matrix from adjacent blocks suggests an original small-scale topography and mixing of material by storm transport. Based on a low number of thin-sections, the fauna is as follows:

Palaeosmilia murchisoni (Figs. 26.1-2)
Axophyllum pseudokirsopianum (Fig. 26.3)
Pareynia sp. (Fig. 27.4)
Siphonodendron irregulare (Fig. 27.1-3)
Multithecopora sp. (Fig. 28)
Auloporida indet. (Fig. 27.3)
Fistulipora parvilabrum (Figs. 29.1-2)
cf. *Ratingella* sp. (Fig. 29.3)
Saffordotaxis cf. *incrassata* (Figs. 29.4-5)
"*Anisotrypa* " sp. (Fig. 29.6)
fenestrate bryozoans
rhabdomesine bryozoans
various brachiopods indet.
Archaediscus convexus (at *concavus* stage, Fig. 30.1)
Pseudoendothyra ornata (Fig. 31.3)
Pseudoendothyra struvei (Figs. 31.1-2)
Ungdarella uralica (Figs. 30.1-3, 6; common)
Omphalotis minima (Fig: 30.4, rare)
Tetraxis sp. (Figs. 27.2, 30.5, rare)
Pseudoammodiscus sp. (Fig. 30.7, rare)
Endothyridae indet.
monaxone sponge spicules (Fig. 30.8)

An upper Viséan age for the pack-rudstone matrix or channels is indicated by the presence of *Pseudoendothyra* and by the locally common *Ungdarella uralica*. The latter is the index species of the Cf6γ1 or lower V3bγ Zone low in the upper Asbian (Cfm7; see Cózar et al. 2020a, fig. 1). This seems to be slightly younger than the Zone 15 age (lower Asbian, V3b, see correlation of Herbig 2006, figs. 4, 6) given by Hollard et al. (1977) for his Sample 7 from Koudiat Lahmara, which also yielded *Pseudoendothyra*. It was taken at the younger southern corner of the ridge. André (1986) recorded additional microfauna from Koudiat Lahmara: *Anatolipora* sp., *Archaediscus, Bruusia, Aoujgalia variabilis*, and *Textularia ribosa*. It was also placed in V3b/Zone 15.

The corals and bryozoans support the foraminifer age. *Palaeosmilia murchisoni* and *Siphonodendron irregulare* are typical corals in the shallow-water upper Viséan of the Moroccan Meseta. In the eastern part of the Western Meseta, they are known from the southern part of the Azrou-Khenifra Basin (Khenifra region: Aretz & Herbig 2010; Somerville et al. 2012, Rodríguez et al. 2012, Said et al. 2013), and from its northeastern termination (Adarouch area: Said et al. 2007, 2011). In the Eastern Meseta, both taxa are known from the Jerada Basin (Aretz 2010). It has to be stressed, however, that both widespread taxa in general have longer ranges. *Palaeosmilia murchisoni* enters at the base of the Viséan (see Semenoff-Tian-Chansky 1974); in Morocco, youngest occurrences have been reported from the lower Bashkirian of the Adarouch area and from south of the Dra Valley in the northern Zag Basin (Rodríguez et al. 2013a, 2013b, 2015). *Siphonodendron irregulare* enters in the middle Viseán (e.g., Poty 1981). South of the Dra Valley it became extinct in the uppermost Brigantian (Rodríguez et al. 2013a), but in the Adarouch area it continued throughout the Serpukhovian (RODRÍGUEZ et al. 2015, 2016).

Axophyllum pseudokirsopianum was established from the "Djenien" (lower Namurian = Serpukhovian) of the Algerian Sahara (SEMENOFF-TIAN-CHANSKY 1974). In northwestern Africa, it was mentioned from the southeastern Tafilalt (ARETZ et al. 2013) and from the uppermost Viséan (Brigantian) and Serpukhovian of the northern border of the Zag Basin, south of the Dra Valley (RODRÍGUEZ et al. 2013a: "*Axophyllum* ex gr. *pseudokirsopianum*", included in the nominate species by RODRÍGUEZ & SOMERVILLE 2015). The taxon was mentioned with aff.-notation from different localities in the Khenifra-Azrou Basin, eastern Western Meseta (SAID et al. 2013); it was also figured but not described from the Tiouinine reef (RODRÍGUEZ et al. 2012). However, these findings were obviously accepted by RODRÍGUEZ & SOMERVILLE (2015) to belong to the nominate species. Opposed, a single specimen from the Jerada Basin, Eastern Meseta (ARETZ 2010), shows a very extensively developed lonsdaleoid dissepimentarium and remains with doubts (*Axophyllum* aff. *pseudokirsopianum,* see RODRÍGUEZ & SOMERVILLE 2015).

Pareynia, a genus also established by SEMENOFF-TIAN-CHANSKY (1974) from the upper Viséan of the western Algerian Sahara, is rarely reported from Morocco. It was mentioned from the upper Viséan Tiouinine reef south of Khenifra (RODRÍGUEZ et al. 2012) and described from the upper Viséan of the Jerada Basin, Eastern Meseta (ARETZ 2010). *Multithecopora* is an auloporid tabulate coral that is widespread in the upper Visean and occurs up to the Pennsylvanian (e.g., CORONADO & RODRÍGUEZ 2014). In the Western Meseta, it is known from upper Viséan coral reef facies of the Khenifra region (RODRÍGUEZ et al. 2012) and from the Serpukhovian of the Adarouch area (RODRÍGUEZ et al. 2015, 2016). The coral faunula of Koudiat Lahmara consists of taxa known from the Saharan platform and Meseta, but the faunal content, especially of the higher limestone units, needs further investigation.

The Viséan bryozoans of the Meseta have hardly been studied; they are locally rather diverse. The cystoporate *Fistulipora parvilabrum* and cryptostomate *Saffordotaxis incrassata* are both known from the upper Viséan of the Montagne Noire, southern France (Roque Redonde, ERNST et al. 2015a). The incrusting trepostome *Ratingella* is normally an Upper Devonian genus (ERNST et al. 2015b). The morphological similarities of the much younger Koudiat Lahmara specimens are large but a firm identification requires more material. The second trepostome genus, *Anisotrypa*, occurs in the Viséan of China, eastern Europe (Ukraine), and North America, but our material does not fit the described species.

In summary, the new faunal record from coral limestones of the basal Tekzim Formation fits well to the upper Viséan carbonate platforms of other Meseta regions.

Based on correlations in the Rhenish Massif (e.g., HERBIG 2006), a Cf6γ/V3bγ, upper Asbian age gives a rough correlation with the *Goniatites crenistria* level in the adjacent Kharrouba Formation (HUVELIN 1977; HOLLARD et al. 1977). The basal Tekzim Formation at Koudiat Lahmara and the Eastern Jebilet goniatite shale may represent correlative transgressive episodes (Fig. 32). The conglomerates and coral limestones mark the re-onset of deposition after erosion and reworking. In the facies model of GRAHAM (1982a, p. 191), green shales (mudstones) of the upper Kharrouba Formation, which yielded the goniatites in adjacent localities (e.g. at Koudiat Jaïdet, Fig. 3), record an important and rapid transgressive phase.

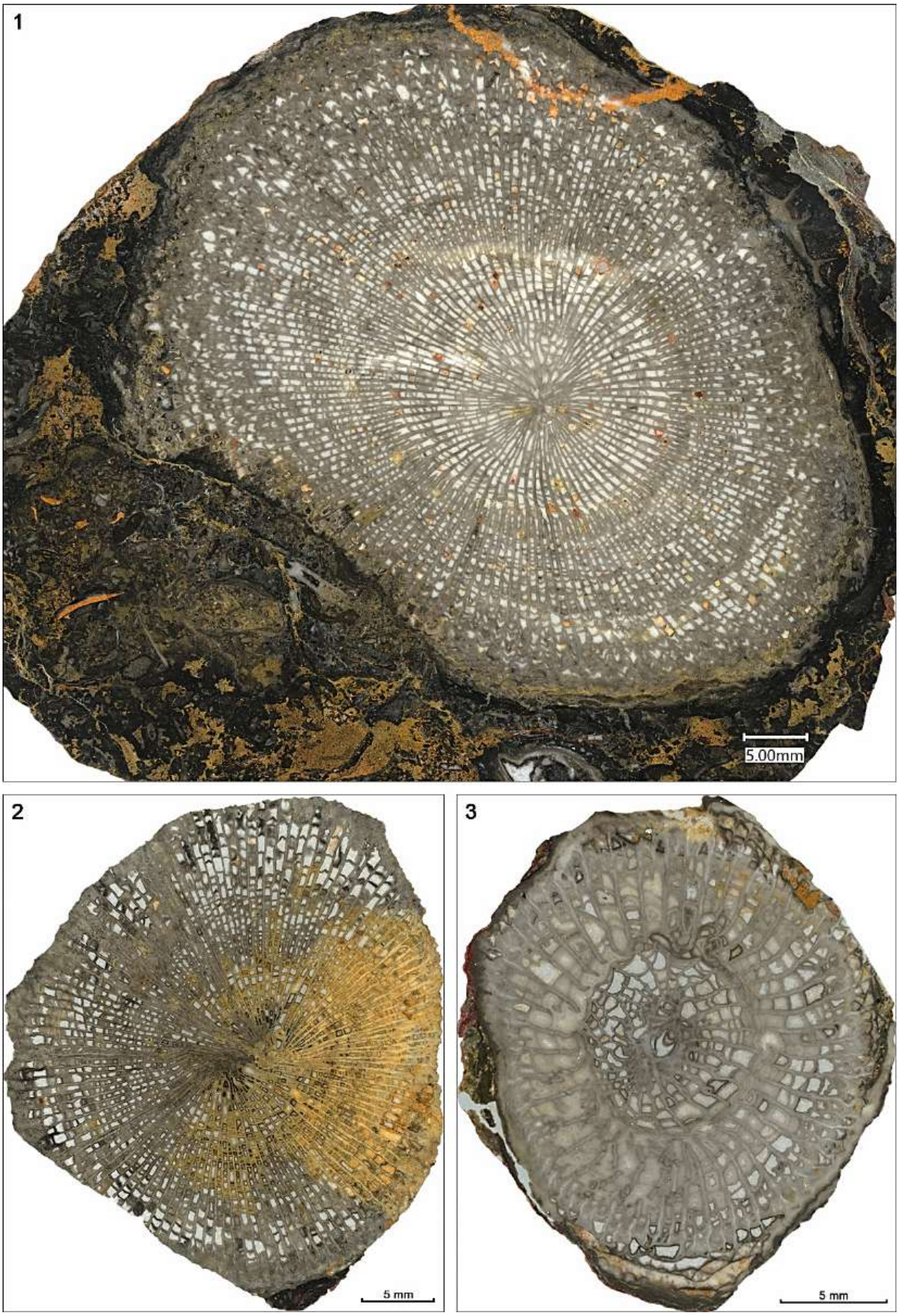

Fig. 26: Solitary rugose corals from the basal Tekzim Formation at the western end of Koudiat Lahmara. **1-2.** *Palaeosmilia murchisoni*; **3.** *Axophyllum pseudokirsopianum.*

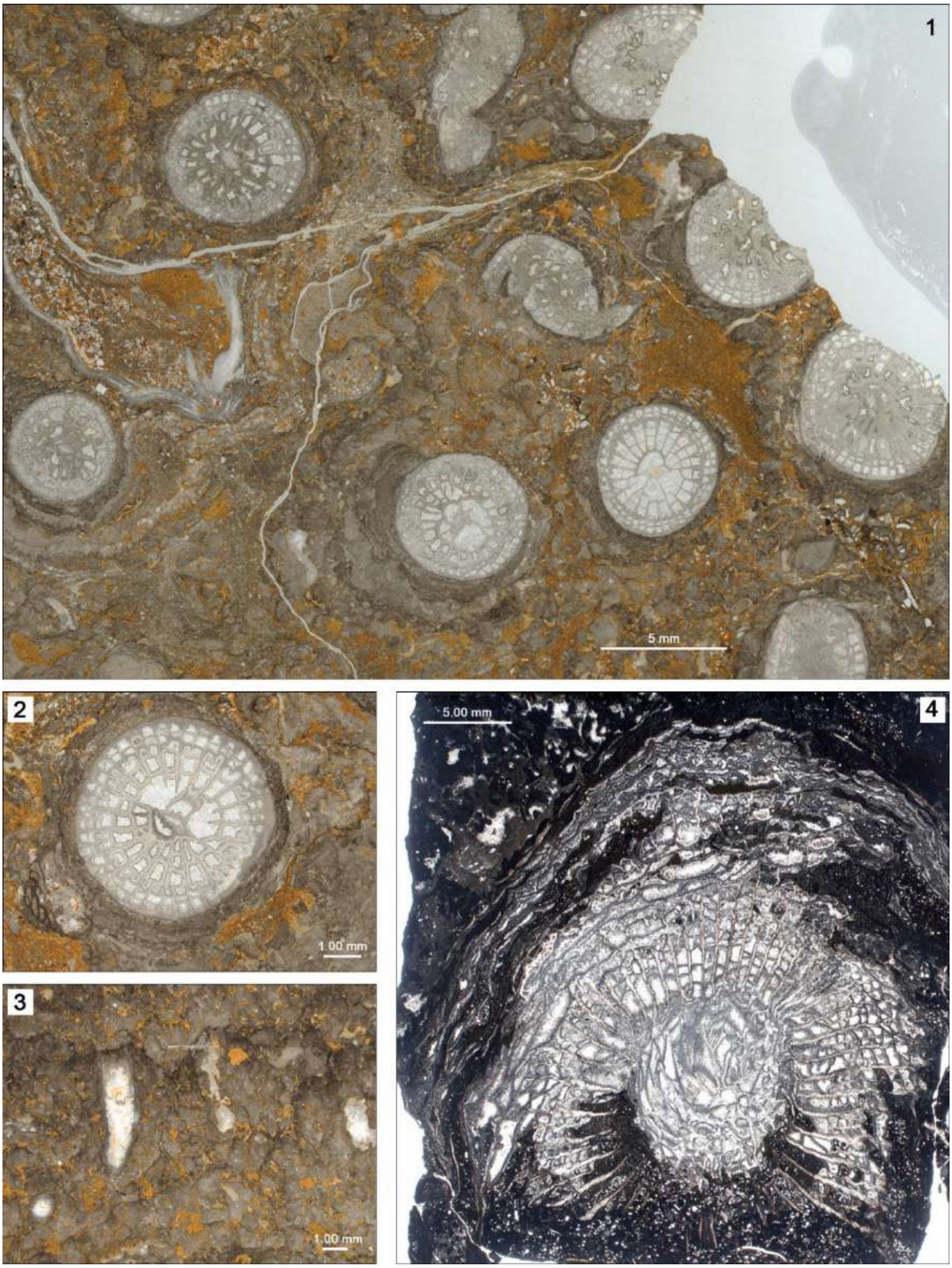

Fig. 27: Phaceloid rugose coral *Siphonodendron irregulare* and microbial fabrics of "*Osagia* type" from near the base of the Tekzim Formation at Koudiat Lahmara West. **1.** Overview of *Siphonodendron* colony embedded in partly brecciated microbialite, truncated by calcarenite channels with fragmentary brachiopods; **2.** Details of a *Siphonodendron* irregular polypar showing strong concentric microbial encrustation and final attachment (lower left) of the foraminifer *Tetrataxis*; **3.** Longitudinal sections of auloporid tabulate coral in growth position within microbial boundstone; **4.** *Pareynia* sp., fragmentary preserved specimen with partly exfoliated outer part of dissepimentarium within organic-rich, microbial boundstone matrix.

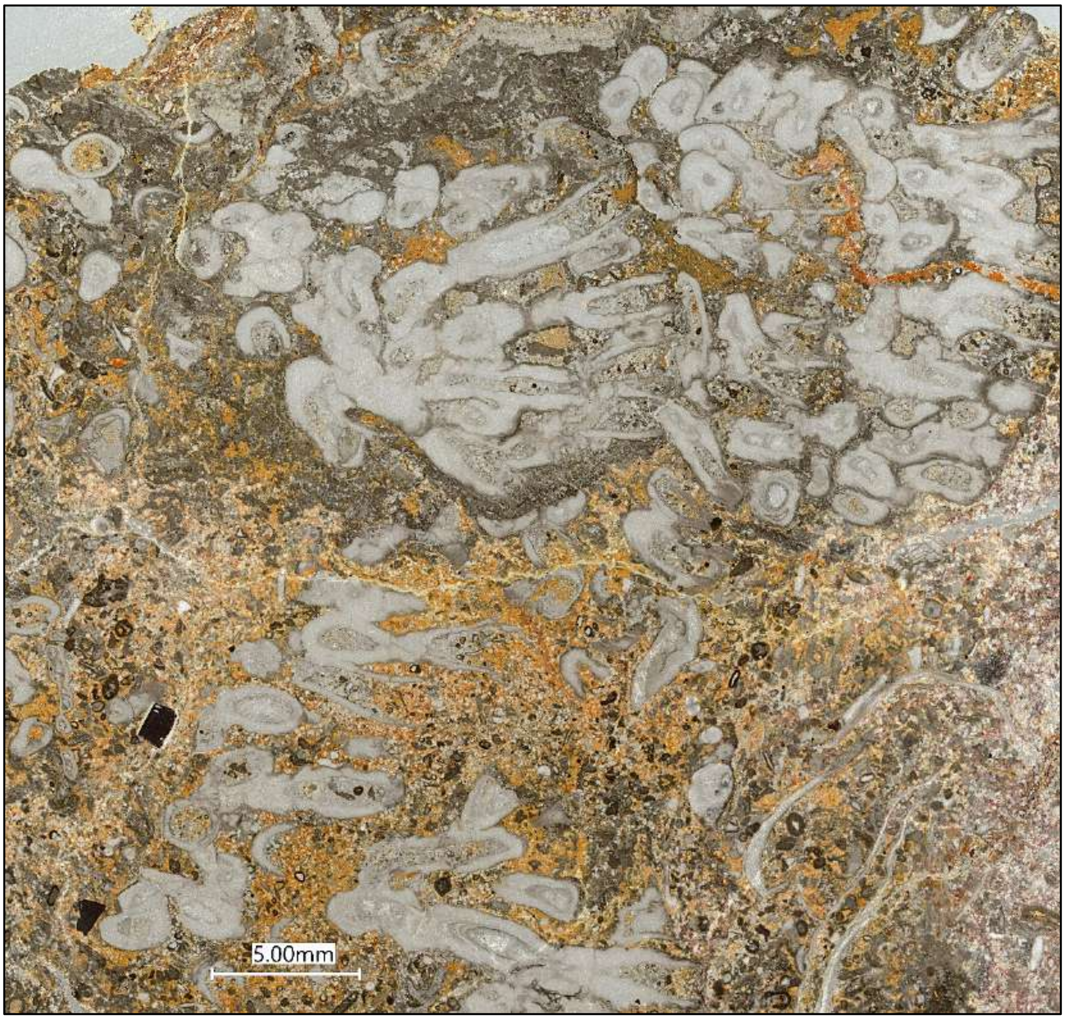

Fig. 28: Auloporid tabulate coral *Multithecopora* from the basal Tekzim Formation at Koudiat Lahmara West partly surrounded by middle-grey microbial limestone or by bioclastic/lithoclastic grainstone, with abundant orange-weathering iron dolomite in interspaces.

It is likely that the thick higher, sandy, crinoidal and eventually biostromal part of the Koudiat Lahmara carbonate platform correlates with the regressive shallow-water limestones near the top of the Kharrouba Formation, e.g., at Koudiat Bourkis. (GRAHAM 1982a, Fig. 3). These were also dated as Cf6γ (IZART et al. 1997: Koudiat Mchih). But the Koudiat Bourkis record of *Climacammina* in HOLLARD et al. (1977) indicates the younger MFZ 15 (upper V3c = Cf6δ, Brigantian; e.g., POTY et al. 2006, CÓZAR & SOMERVILLE 2020). *Climacammina* was also reported from the Jebel Tekzim, which provides a correlation of the type Tekzim Formation and the limestones at Koudiat Bourkis.

The available data contradict the assumption that the Tekzim Formation is generally younger than the Kharrouba Flysch, as shown in DELCHINI et al. (2018). Allochthonous oldest Tekzim limestones are probably time equivalents of higher parts of the Kharrouba Formation. The reworked limestones record an older Carboniferous transgression in the region. In this context, the dating of a limestone in the lower Kharrouba Formation as middle Viséan (ESSEMANI 1988; IZART et al. 1997) should be re-considered (see critical evaluation by CÓZAR et al. 2020a).

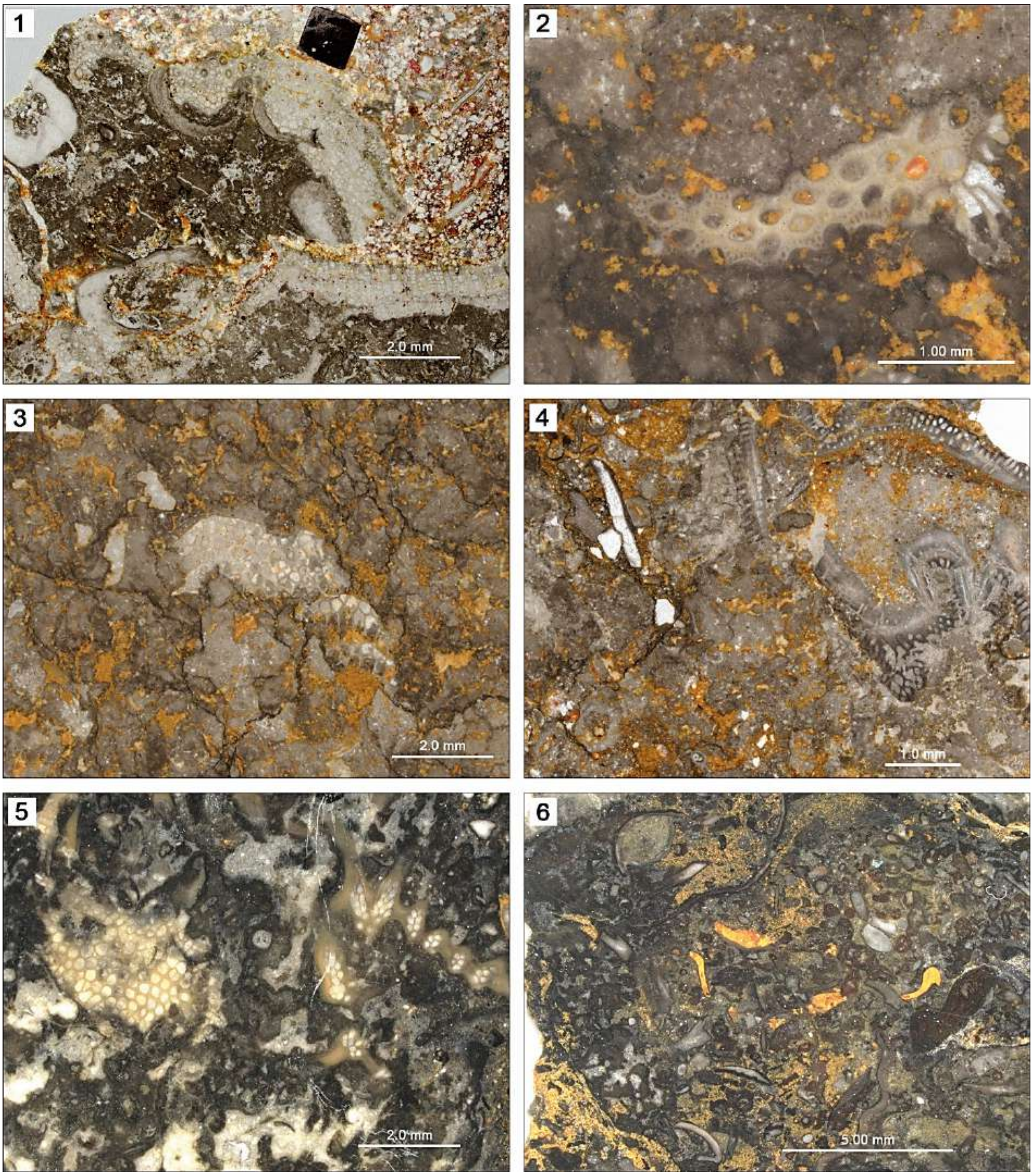

Fig. 29: Bryozoans and microfacies from coral limestone in the basal Tekzim Formation at Koudiat Lahmara West. **1.** *Fistulipora parvilabrum*, partly overgrown by microstromatolites, *Multithecopora* thin-section; **2.** *Saffordotaxis* cf. *incrassata*, *Siphonodendron* thin-section; **3.** ?*Ratingella* sp., *Siphonodendron* thin-section; **4.** Cross-section of unidentified fossil with "punctate" shell arising from a dense, laminated skeletal base, *Siphonodendron* thin-section; **5.** "*Anisotrypa*" sp., bioclastic pack-rudstone around a solitary rugose coral; **6.** Poorly sorted intra- and bioclastic pack-rudstone with micrite matrix, brachiopods, crinoid debris, abundant thick-rimmed coated grains, and secondary, orange-colored dolomitization, matrix around *Palaeosmilia* (see thin-section of Fig. 26.1).

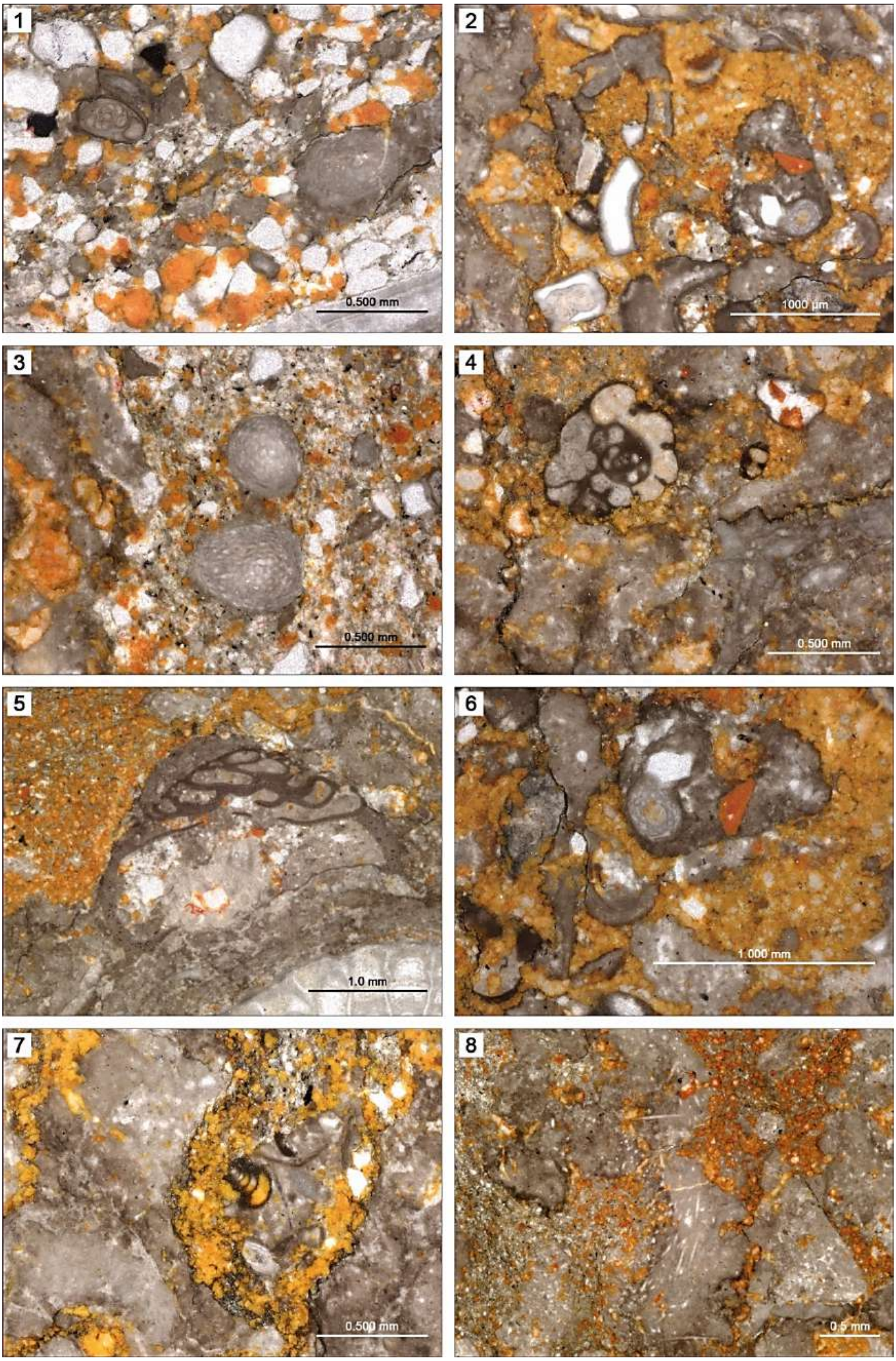

Fig. 30: Foraminifers and sponge spicules from between the *Siphonodendron* colony (Fig. 27.1), basal Tekzim Formation at Koudiat Lahmara West. **1.** *Archaediscus convexus* (at *concavus* stage, left) and *Ungdarella uralica* (right); **2.** *Pseudoendothyra* sp. and *U. uralica* (above); **3.** and **6.** *U. uralica*, illustrating the local abundance of the species, **4.** *Omphalotis minima*, **5.** *Tetraxis* sp., **7.** *Pseudoammodiscus* sp.; **8.** Monaxon spicules in fragmented microbial intraclasts.

6. Palaeogeographic trends and regional comparisons

There are no similarities of the facies developments between the Eastern Jebilet and both the Jebel Ardouz and the northern Rehamna (see Rehamna and Jebel Ardouz chapters). Relationships with the "Azrou-Khenifra Basin" to the east, which currently includes allochthonous nappes and supposed (par)autochthonous outcrops, and the Skoura region in the southeast are discussed in stratigraphic order.

6.1. Lower Devonian

The Lower Devonian of the source region of the Eastern Jebilet nappes was characterized by facies differentiation. The black graptolite shale facies (Jebel Smaha Formation) formed in an anoxic and eutrophic outer shelf basin that stretched over most of NW Gondwana. The anoxia lasted variably until the upper Lochkovian to upper Pragian, if graptolite identifications in HUVELIN (1977) are correct. Equivalent graptolite shales are known from the Mrirt-Ziyar Nappe (e.g., WILLEFERT 1963; FRANCOIS et al. 1986). However, there is so far no record of the megaplanctonic scyphocrinitids in the Eastern Jebilet, which characterize in many other regions the Silurian-Devonian transition (e.g., RÈGNAULT 1985). In the Skoura region (see Skoura chapter), correlative Silurian graptolite shales turn into lower/middle Lochkovian black shale and limestone alternations with giant nautiloids. This different nautiloid facies was terminated by a distinctive, tectonically triggered reworking event that has no match at Jaïdet.

Stepwise regressive trends ended black shale deposition in the Eastern Jebilet source region by improving the ventilation and reducing the accumulation of fine detritus due to bottom turbulence. The overlying condensed nodular shales and limestones of the Jaïdet Formation represent a subphotic outer shelf ramp with pelagic to deep neritic faunas. Especially after the eustatic Lochkovian-Pragian boundary regression, pelagic griotte facies with nowakiid blooms prevailed, but obviously not in the source region of the nappes of the Kelâa des Srarhna region, where only shales are currently known. The Pragian/Emsian transition remained very indistinctive in terms of microfacies, but the macrofauna declined strongly. Rather surprisingly, the transgressive global Daleje Event at the lower/upper Emsian boundary could not be recognized so far in the Eastern Jebilet. Either we have overlooked a shale unit or its sedimentary expression was overprinted by extreme condensation. Such a case was observed by us in the condensed Lower Devonian succession at the Jebel ben Arab northwest of Azrou (new data, see BECKER & EL HASSANI 2020, p. 22). In the Eastern Jebilet, further research is required to solve the Daleje Event question. The upper Emsian is regionally characterized by a marked bloom of pelagic fauna.

In the succession of the Mrirt-Ziyar Nappe, the nodular Submembers A-C of the Anajdam Member (Bou Nebedou Formation; BECKER et al. 2020b) are a close equivalent of the lower/middle Jaïdet Formation. Locally (e.g., at Ziar), there are shale and siltstone intercalations. But Daleje Shale equivalents (Submember D) are recognizable in the Mrirt-Ziar Nappe. Griotte limestone facies returned in the upper Emsian of the Mrirt region but anarcestid faunas are extremely rare there (e.g., AGARD et al. 1958: record from Brouha Akellal). Griotte equivalents of the Jaïdet Formation are also well-developed in the Skoura region, where they show stronger cyclicity. The subsequent green Daleje Shales are very thick at the southern foot of the High Atlas and form a landmark. Especially similar to the Eastern Jebilet are the upper Emsian

"*Latanarcestes*"-*Sellanarcestes*-*Anarcestes* faunas, which are known since ROCH (1939).

6.2. Middle Devonian

The Middle Devonian of the Eastern Jebilet (source region) is characterized by a gradual deepening of the outer shelf basin. A rapid discharge of fine siliciclastics ended the condensed griotte facies. The provenance of this detritus is unclear since the Eifelian of the eastern Dra Valley to the south is characterized by continuing condensed pelagic facies (e.g., EBBIGHAUSEN et al. 2004, 2011). In the Skoura region, there was a marked Eovariscan block faulting and reworking phase starting near the Emsian/Eifelian boundary. Perhaps, the Eastern Jebilet source region belonged to the subsiding northwestern part of the same tilting block. On the uplifted Skoura part, Eifelian erosion and slumping was followed by basal Givetian condensed limestones with some syntectonic conglomerates. Towards the east, in the Azrou-Khenifra region (Mrirt-Ziyar Nappe), the Eifelian is very differently developed. It continues the griotte facies or is missing due to a long time of non-deposition (BECKER et al. 2020b). The transformation of the El Kahla Formation into a Givetian turbiditic, flyschoid basin, therefore, gives a strong palaeogeographic separation from the (eastern) Azrou-Khenifra Basin and southern High Atlas base. However, turbiditic limestones and dark shales indicate better links with the still insufficiently studied (par)autochthonous Middle Devonian outcrops that represent the former shelf basin west of the Azrou and Mrirt-Ziyar nappes (e.g., Bou Khedra, Jebel ben Arab; see BECKER & EL HASSANI 2020).

6.3. Upper Devonian/Tournaisian

Currently there are no rocks of proven Frasnian to Tournaisian age in the Eastern Jebilet. In the Central Jebilet, a partial Frasnian-Famennian range of the Sarhlef Formation was recently shown by LAZREQ et al. (2021). For the hardly studied limestones within the Sidi bou Othmane Formation, there is so far no age control; they may well be of upper Viséan age (see EL HASSANI 1982). Although DELCHINI et al. (2018, p. 3) admit that the stratigraphic relationships between the Sidi bou Othmane and Kharrouba Formations are unclear, they propose that the first underlines the second. This interpretation should be tested by sampling of the metamorphozed limestones. The same applies to an assumed Upper Devonian age for quartz phyllites of the Rhira Formation at the western margin of the Central Jebilet. As mentioned above, we do not rule out that the upper part of the El Kahla Formation falls in the Upper Devonian. In this respect, the discovery of lower Famennian conodonts in metamorphic limestones of the Jbel Gueliz in Marrakech, which lies south of the Central Jebilet (LAZREQ 2017), was intriguing.

A near absence of in-situ Frasnian to Tournaisian strata, resulting from major Eovariscan uplift, reworking and non-deposition, is typical for the Skoura region. In its eastern part, at Asserhmo, there is an extremely polymict Eovariscan conglomerate with reworked Givetian/Frasnian corals, Frasnian brachiopod limestones, and upper Famennian pelagic limestones (see Skoura chapter). Only these clasts preserved the post-sedimentary disrupted, complex Upper Devonian history of that region.

In the Ziyar and Mrirt regions of the southern "Azrou-Khenifra Basin", the upper Givetian to Frasnian are present, but in strongly condensed and incomplete pelagic platform facies (e.g., BECKER et al. 2020b). Unlike as in the Eastern Jebilet, the lower to upper Famennian of Mrirt and Ziyar is well-developed and represented by fossiliferous, thick pelagic griotte facies (e.g., LAZREQ 1992; BECKER & HOUSE 2000c; HÜNEKE

2001). Corresponding rocks can be found as reworked clasts in the upper Viséan olistostrome east of the Jebel Tabainout, which lies west of the Khenifra Nappe (BECKER et al. 2020b). The uppermost Famennian and most of the Tournaisian are lacking or are extremely incomplete in the Mrirt-Ziyar Nappe, due to the next phase of Eovariscan block movements and reworking. Only locally in the (par)autochthonous part of the "Azrou-Khenifra Basin" (Bou Khedra between Mrirt and Azrou, BOUABDEDLLI 1989, HABIBI 1989; localities west of Khenifra, CÓZAR et al. 2020b and RODRÍGUEZ et al. 2020), Carboniferous continuous sedimentation commenced in the upper Tournaisian to basal Viséan.

In summary, there is no good match between the Eifelian to Tournaisian of the Eastern Jebilet, Skoura region and Azrou-Khenifra Basin, which reflects very different synsedimentary block movements.

6.4. Viséan

In the source region of the Eastern Jebilet, a shallow-water carbonate unit existed once in the lower/middle Viséan but it was subsequently destructed by erosion and reworking. Currently, its main record are the reworked pebbles within the younger transgression conglomerate at Koudiat Lahmara. Although the foraminifer record from the reworked pebbles is restricted, there are clear differences to the foraminifers from the matrix of the coral limestones from near the base of the Tekzim Formation. In principle, there are chances to find this "lost lower/middle Viséan platform limestones" as olistolithes within the upper Kharrouba Flysch. The age of the base of the Kharrouba Formation is not yet known. It should be re-considered whether assumed middle Viséan limestones within its lower part (IZART et al. 1997: cf5 (V2b) fauna at Koudiat Kouchina) correlate with the reworked carbonate interval (Fig. 32). CÓZAR et al. (2020a) concluded that the reported faunas are too poor to provide a reliable middle Viséan age. Lower Viséan shallow-water limestones were rare in the Meseta but middle Viséan platform limestones had a moderately wide distribution, e.g., in the autochthonous central-western part of the "Azrou-Khenifra Basin" (Jebel Bouechchot) as well as in the Skoura region (see CÓZAR et al. 2020b).

A main Viséan transgression occurred in the Eastern Jebilet, including the source region of nappes/klippen, in the top lower to upper Asbian. As emphasized above, HOLLARD et al. (1977) provided important evidence for a direct transgression on Lower Devonian strata. Based on records of *Stacheoides* and *Pseudoendothyra*, the age is at least upper Cf6ß (Cfm6, upper V3bß). A slightly younger pulse (*Ungdarella uralica* Zone, Cf6γ1 = lower V3bγ = Cfm7 = upper MFZ 13) is preserved at Koudiat Lahmara by the re-onset of nearshore limestone deposition after the reworking of the older platform. Within the lateral upper Kharrouba Formation, a probably correlative (Fig. 32) transgressive episode is marked by green shales with upper Asbian goniatites. These still require documentation in the light of the recent significant advances in Moroccan upper Viséan goniatite taxonomy and biostratigraphy (KLUG et al. 2006, 2016; KORN et al. 2007; KORN & EBBIGHAUSEN 2008). For example, the oldest goniatites from Sidi Lamine (Khenifra region) were shown by KORN (2017) to include *Goniatites sphaericus*, a slightly younger (top Asbian) species than *Gon. crenistria*. Other goniatites from Sidi Lamine are clearly younger (Brigantian; see DELEPINE 1941 and ROCH 1950; e.g., "*Gon. striatus*") but have not yet been revised.

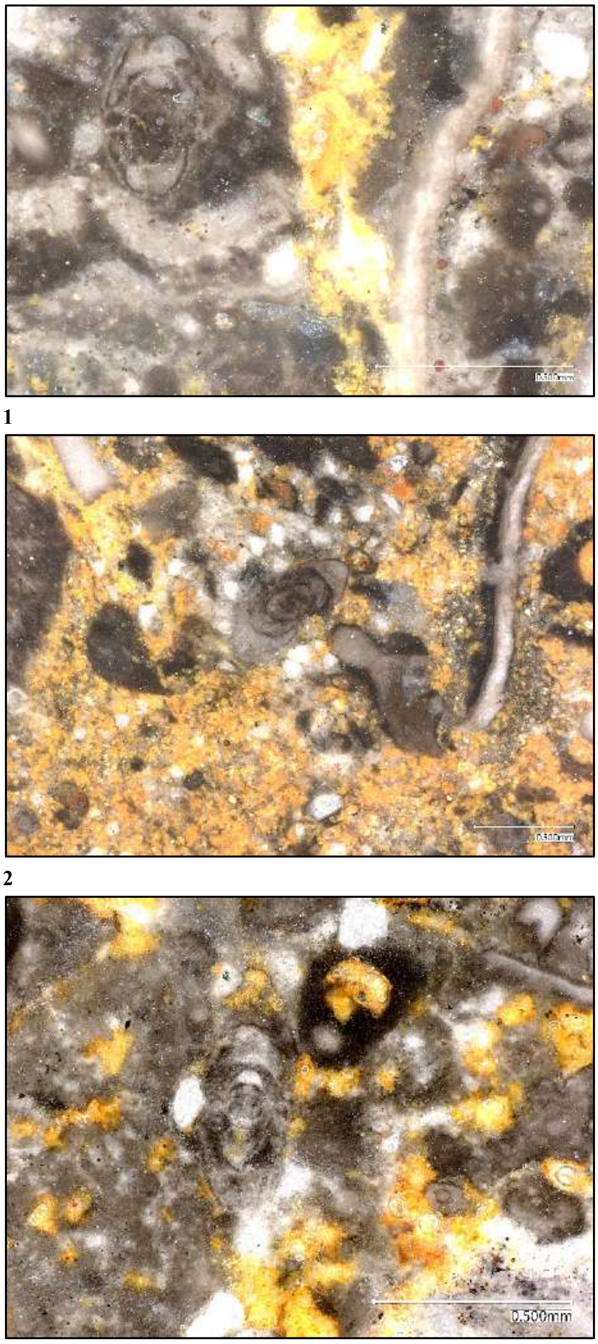

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Fig. 31: Foraminifers from the matrix around a *Palaeosmilia* (1-2; see Fig. 26.1) or *Multithecopora* (3, see Fig. 28), basal Tekzim Formation at the western end of Koudiat Lahmara. **1-2.** *Pseudoendothyra struvei;* **3.** *Pseudoendothyra ornata*.

It is tempting to compare the microbial coral limestones and the subsequent thick Tekzim Formation described by André (1986) with the upper Viséan coral-bearing shoals and build-ups of the Khenifra region (Aretz & Herbig 2010; Somerville et al. 2012; Rodríguez et al. 2012; Said et al. 2013). However, the latter were ecologically and taxonomically more diverse and started to grow slightly later (?upper Asbian to Brigantian; Said et al. 2013) as part of a deepening succession. In the Haouz region south of Marrakech (El Moussira), there was only a crinoidal to microbial shoal without corals at the time (Aboussalam et al. 2017). In the Skoura region, the stratigraphy and facies development of the upper Viséan is still poorly studied (e.g., Laville 1980). Since Roch (1939), upper Viséan goniatites are known from greenish to black shales, which may correlate with the Eastern Jebilet goniatite shales. But, again, their fauna was never documented.

Since we studied only locally the initial transgression, we will not comment on the higher upper Viséan-Serpukhovian sedimentary, magmatic and structural evolution of the Kharrouba Flysch basin and its palaeogeographic relationships within the Jebilet and beyond in the Western Meseta (for this see Huvelin 1977; Beauchamp & Izart 1987; Beauchamp et al. 1989; Izart et al. 1997, 2017; Essaifi et al. 2003; Bamoumen et al. 2008; Delchini et al. 2018; Cózar et al. 2020a).

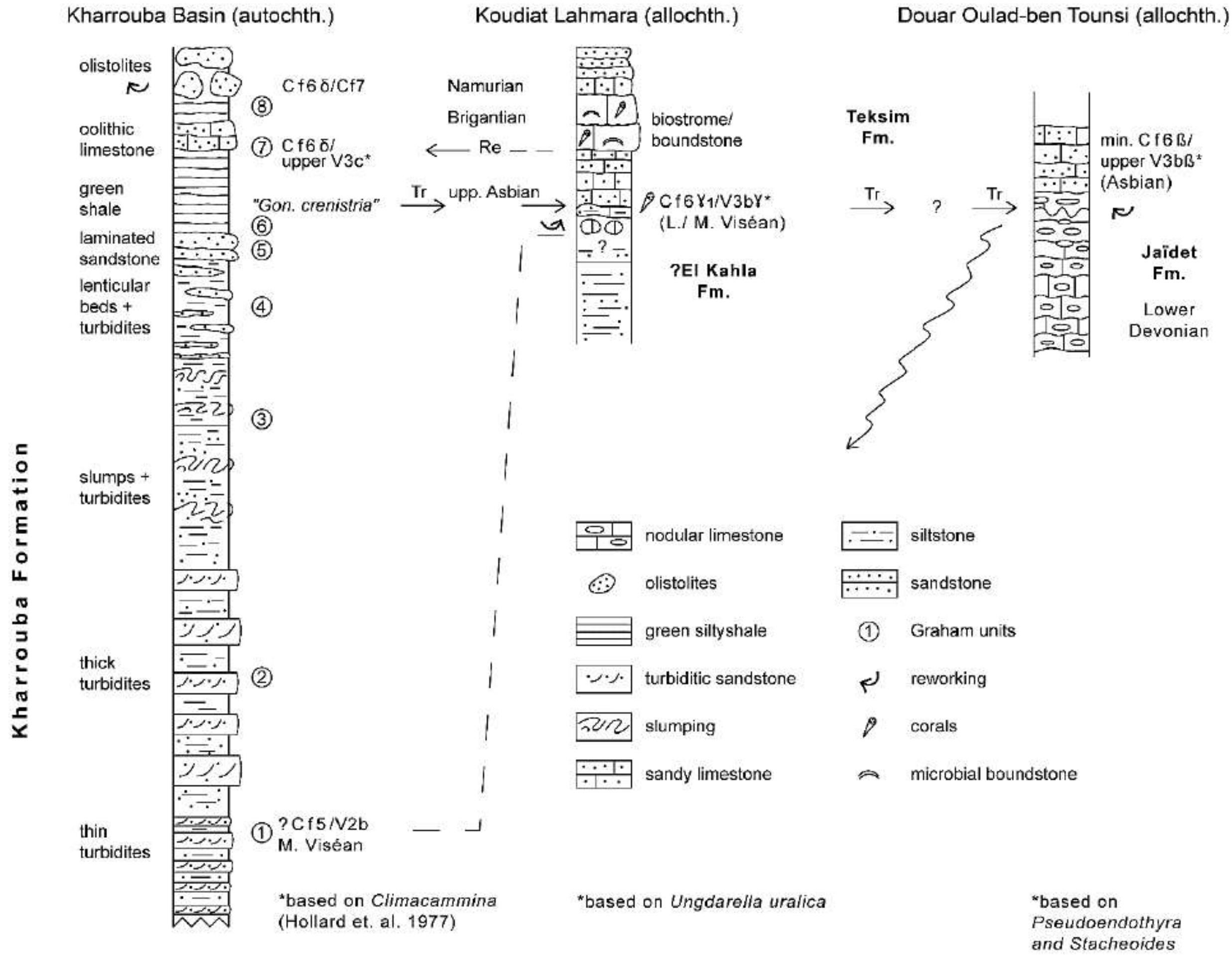

Fig. 32: Sketch (not to scale of thicknesses or absolute time) illustrating the currently assumed correlation between Viséan successions of the Kharrouba Flysch (e.g., Koudiat Mchich/Koudiat Bourkis, see GRAHAM 1982a and IZART et al. 1997), Koudiat Lahmara, and the locality 1.5 km ESE of Douar Oulad-ben Tounsi of HOLLARD et al. (1977).

7. Taxonomic notes

7.1. Ammonoids (RTB)

***Praewerneroceras* n. sp.**
Figs. 16.5-6

Description: A single goniatite (GMM B6C.54.185) from the top nodular limestones at Jaïdet Northwest, incompletely preserved in dark-grey micrite, is convolute, compressed, with gently rounded flanks, and narrowly rounded venter. Sutures consist of a shallow L-lobe on the lower flanks, a wide, low, asymmetric saddle on the mid- and outer flanks, and a narrow, diverging E-lobe. The umbilical wall is short and steep. The preserved part of the body chamber occupies ca. the last half whorl. The phragmocone is crushed on one side.

Conch parameters: Diameter (dm) 36 mm, whorl height (wh) ca. 11.5 mm, whorl width (ww) ca. 14 mm, umbilical width (uw) ca. 10 mm; wh/dm = ca. 0.32, uw/dm = 0.28, ww/dm = 0.39, ww/wh = ca. 0.9.

Discussion: The specimen differs from all named upper Emsian species by the combination of a compressed conch, convolute coiling, and *Anarcestes*-type outer sutures with subumbilical L-lobe and wide external saddle. The only similar genus is *Praewerneroceras*, which type-species from the upper Emsian of Bohemia, *Prae. suchomastense* CHLUPÂČ & TUREK, 1983, has much thicker whorls. The basal upper Emsian

Prae. hollardi Becker & House, 1994b from the Tafilalt, which may not be con-generic (compare Klug 2002), is characterized by very shallow outer sutures. The new specimen may represent a form that is intermediate from "*Lat. noeggerathi*" auct., which is also compressed and convolute, but which differs by higher whorl expansion and its wide L-lobe that occupies in the associated Jaïdet specimens all of the flank (see Figs. 16.1-4). With respect to the poor preservation, open nomenclature is applied until more material becomes available, and until further revision of early anarcestids from southern Morocco.

Occurrence: Restricted to the upper Emsian of Jaidet.

***Sellanarcestes* aff. *perfectus* Chlupâč & Turek, 1983**

Figs. 16.7-8

Discussion: A few corroded sellanarcestid from Jaïdet Northwest (e.g., the figured GMM B6C.54.186) are rather evolute (uw/dm = ca. 0.45) and compressed (ww/dm = ca. 0.30, ww/wh = ca. 0.90 at 54 mm dm), with a rather high whorl expansion rate (WER = 1.7). They are morphologically intermediate between *Sell. draensis* (with always lower WER ratios) and *Sell. neglectus* (with mature uw/dm < 0.40 and ww/dm < 0.30; see Chlupâč & Turek, 1983 for the type population and Ebbighausen et al. 2011 for Dra Valley representatives). *Sellanarcestes ebbighauseni* Klug, 2002 from the Tafilalt, *Sell. cognatus* Chlupâč & Turek, 1983, and *Sell. applanatus* (= *tenuior*, see Ebbighausen et al. 2011) also keep very low WER ratios throughout ontogeny. The Bohemian *Sell. certus* Chlupâč & Turek, 1983 is always thicker (ww/dm between 0.40 and 0.44 at the same size). The conch of *Sell. perfectus* Chlupâč & Turek, 1983 resembles *Sell. neglectus* but the original description includes a few specimens (L19337 and L19325, Chlupâč & Turek, 1983, tab. 28) with wider umbilicus and compressed cross-section at maturity. Since typical *Sell. perfectus* have more strongly embracing whorls, the form from Jaïdet Northwest is identified as *Sell*. aff. *perfectus*.

Occurrence: Upper Emsian of Bohemia and the eastern Jebilet.

7.2. Conodonts (RTB & ZSA)

***Pelekysgnathus* aff. *elongatus* Carls & Gandl, 1969**

Figs. 8-9

Discussion: The Spanish holotype of *Pel. elongatus* is characterized by two main, inclined posterior teeth and six much smaller and lower, anterior teeth. Paratypes may possess only a single posterior tooth and seven alternating very small or moderately large triangular teeth. In our specimens (e.g., the figured GMM B4C.2.143), the main tooth is directed posteriorly and followed by up to 11 teeth that form a convex, cockscomb type pattern, with the largest and highest teeth located ca. a third from the anterior end. A similar convex pattern, but with shorter free denticle ends, was illustrated by Weyant et al. (2010) in a *Pel*. aff. *elongatus* from the basal Pragian of the Armorican Massif (L´Armorique Formation).

It is likely that the Jaïdet specimens represent a distinctive taxon but since the variability of Lochkovian/Pragian pelekysgnathids is not well established and since we have only two specimens that are not well-preserved, we keep them in open nomenclature. Further sampling may provide better material. The Pragian *Pel. serratus* Group differs has fewer teeth (ca. six) and a marked, deep incision separating the posterior main tooth.

Occurrence: Restricted to the Pragian of the eastern Jebilet.

7.3. Rugose corals (by H-GH)

***Pareynia* sp.**

Fig. 27.4

Description: The single, slightly oblique cut transverse section is fragmentary preserved. The alar diameter is about 35 mm, the diameter of the tabularium about 22 mm, and the diameter of the axial structure about 9.3 mm. There are 50 quite thick major septa; minor septa are short. The partly exfoliated, extensive lonsdaleoid dissepimentarium comprises almost half of the corallite diameter. External narrow, naotic dissepiments are internally replaced by large, but still narrow lonsdaleoid dissepiments. The typical axophylloid, irregular axial structure is without visible median plate.

Discussion: Only two upper Viséan species were recognized by SEMENOFF-TIAN-CHANSKY (1974): *Par. splendens* (type species) and *Par. gangamophylloides*. RODRÍGUEZ & SOMERVILLE (2015) added a third, smaller species, *Par. Viacrucense,* from the lower Serpukhovian (Pendleian) of southwestern Spain. The present specimen approaches the holotype of *Pareynia splendens densa* (SEMENOFF-TIAN-CHANSKY 1974, pl. 64, fig.1), but clearly differs from *Par. splendens* from the Jerada basin with predominantly large, globose lonsdaleoid dissepiments (ARETZ 2010). The fragmentary preservation of our specimen excludes specific determination. However, it has to be stressed that, as elsewhere, the genus occurs in microbial dominated buildup facies (ARETZ 2010).

Occurrence: Upper Visean of Algeria and Morocco (Western and Eastern Meseta), lower Serpukhovian (Pendleian) of southwestern Spain (RODRÍGUEZ & SOMERVILLE 2015), upper Viséan of Belgium (DENAYER et al. 2011); China (fide RODRÍGUEZ & SOMERVILLE 2015).

***Axophyllum pseudokirsopianum* SEMENOFF-TIAN-CHANSKY, 1974**

Fig. 26.3

Description: The specimen from Koudiat Lahmara has an alar diameter of 20 mm, narrow, inconspicuous dissepimentarium with few isolated lonsdaleioid dissepiments, wide tabularium, and large axial structure, 8.5 mm in diameter. The axial structure is dominated by long septal lamellae; a median plate is inconspicuous. The axial structure is separated from the tabularium by an inner wall composed of thickened dissepiments, and the tabularium from the dissepimentarium by a thin stereoplasmatic thickening. The only partially preserved epitheca is thick (0.5-0.6 mm). 42 major septa; minor septa are short to long, continuing ¼ to ¾ through the tabellarium.

Discussion: The specimen shows the typical features of the species. The transverse section is almost identical to the paratype material of "*Axophyllum pseudokirsopianum* nov. sp. forma *media*" in SEMENOFF-TIAN-CHANSKY (1974, pl. 57, fig. 3). It is also very similar to the description in HERBIG (1986) and a specimen figured in RODRÍGUEZ & SOMERVILLE (2015, fig. 15g), though in our transverse section the median plate is almost not discernable and lonsdaleoid dissepiments are less developed.

Occurrence: Upper Viséan to Serpukhovian of Algeria and Morocco (Western Meseta, Anti-Atlas: Tafilalt, Zag Basin; aff. Eastern Meseta), uppermost Viséan (Brigantian) of southwestern Spain (RODRÍGUEZ & SOMERVILLE 2015), upper Viséan of the Malagides/Betic Cordillera (HERBIG 1986), upper Viséan of Belgium and Britain (see RODRÍGUEZ & SOMERVILLE 2015).

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The Devonian of Jebel Ardouz (Mzoudia region, SW Moroccan Meseta) – new data on stratigraphy, facies, and palaeogeography

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Fig. 1: Cliff of thin- and thick-bedded Givetian shallow-water limestones (new Mzoudia Formation, Koudiat Kébir Member) at the northern end of the Jebel Ardouz (Koudiat Ferjane). In the distance (to the south), the ASMAR Mzoudia cement factory is visible.

Abstract. The long-known Devonian of the Jebel Ardouz west of Marrakesh, and just north of Mzoudia, is composed of an allochthonous stack of clastic and carbonate rocks that were thrusted onto each other from the northeast. New biostratigraphic data prove an age range of sedimentation from the lower Eifelian to ?upper Famennian. The lowest, western thrust unit is composed of reddish sandstones and conglomerates/breccias (new Ardouz Formation) deposited originally by rockfall and debris flows on the slope of a repeatedly active fault scarp. Limestone clasts yielded sandstones of unknown age, Eifelian, Givetian and lower/middle Frasnian conodonts, and encrusted reef corals. Re-sedimentation may have occurred in the upper Frasnian or post-dated the Famennian. The "red conglomerates" record a block that was strongly tilted by Eovariscan extensional tectonics, forming on the uplifted side a small island. Exhumation, erosion down into Eifelian carbonates, and a long phase of reworking (pebble formation, hematite impregnation and encrusting) occurred in an arid, lateritic, terrestrial-fluvial to coastal high-energy setting. The overlying middle unit consists of a lower Eifelian to middle Givetian, shallowing upwards carbonate ramp (new Mzoudia Formation, with the new Koudiat Ferjane and Koudiat Kébir Members). Middle Givetian regression resulted in the growth of a biostrome with patch reefs. The middle thrust unit experienced no Eovariscan reworking but upper Givetian uplift resulted in an episode of non-deposition. Following poorly known non-reefal Frasnian strata (still un-named Upper Member), the upper thrust unit on the eastern side of Jebel Ardouz (new Oued el Biad Formation) consists of shallow-water, open marine sandstones/quartzites with brachiopod

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coquinas, which originally transgressed unconformably the carbonate platform. Shedding of sand from a W/NW source (Imfout Ridge) balanced subsidence. The Jebel Ardouz Devonian differs considerably from the Devonian of the High Atlas Basement (to the south), the Safi region (to the west), and allochthonous eastern Jebilet (in the east). A similar association of carbonate platform blocks truncated by conglomerates or brachiopod-rich quartzites is developed in the Mechra Ben Abbou succession of the rather distant northern Rehamna. But comparable, poorly studied Devonian blocks have been mentioned from the geographically intermediate Skhirat region of the Jebilet.

1. Introduction

In the southwestern Meseta, an isolated, ca. SW-NE running Devonian outcrop belt lies at the Jebel Ardouz (= Jbel Ardouz) in the Mzoudia region, ca. 45 km W of Marrakesh. It was discovered during mapping by ROCH (1930). Middle Devonian limestones are of economic importance and are quarried for cement production at the southern end (Koudiat Kébir to Koudiat Lahalima and Koudiat Aalama, Fig. 2) by the ASMAR company since 1974. In terms of regional geology, the 3.8. km long exposure has been included in the Western Jebilet (HUVELIN 1977), which main distribution begins ca. 15 km to the north, just north of the Oued Tensift. The main Western Jebilet consists of Lower Palaeozoic strata and unconformably overlying post-Variscan units. Some isolated Devonian olistolites have been reported from breccias of the Skhirat Formation in the eastern part of the Western Jebilet (Jebel Bou Gader, HUVELIN 1977; TAHIRI 1984; MAYOL 1987). They have been compared with the Jebel Ardouz Devonian but are still poorly known and dated. There is a fundamental difference of Devonian sediments and facies in the Eastern Jebilet (see Jaïdet chapter). The Jebel Ardouz Devonian represents a distinctive allochthonous thrust pile that was originally linked with the rather distant (ca. 125 km) northeastern Rehamna carbonate succession around Mechra Ben Abbou (EL KAMEL et al. 1992; EL KAMEL 2004; EICHHOLT et al., this vol.). This palaeogeographic relation was already known to HOLLARD (1967) and HUVELIN (1977).

Following a first section description by GENDROT et al. (1969), a refined lithostratigraphy and facies succession of the Jebel Ardouz was established by TAHIRI (1980a, 1980b, 1982, 1983), who also investigated the structural geology, recognizing thrust units separated by mylonitic zones. However, his studies lacked new biostratigraphic data. Therefore, it was not possible at the time to place the peculiar "red conglomerate" at the western base of the ridge in its correct stratigraphical position. This has implications for the understanding of the original palaeogeography, syn- and postsedimentary structural evolution. Our field work in the period from 2012 to 2018 aimed to provide for the first time a bed-by-bed succession, conodont dating of facies changes, and a carbonate microfacies-based reconstruction of the palaeoenvironments. New brachiopod collecting contributes to the dating of the quartzites on the eastern side of the ridge. An inventory of clasts within the basal conglomerate was made in order to reconstruct re-working and re-deposition patterns. Since previous authors recognized only informal lithostratigraphic units, these are here formally named (three new formations, two new members), using local geographic terms.

Most recently, the intensive sampling of the limestone succession for conodonts by BOUARI et al. (2021) provided much richer Givetian faunas than our fewer samples, which aimed at the dating of facies changes. Their data improved significantly the local conodont stratigraphy but did not include samples from Eifelian beds or from the "red conglomerate". We fully support the intention of BOUARI et al. (2021) to preserve at least a part of the section as an important part of

Moroccan Natural Heritage. We hope that this contribution provides further weight to the initiative. The Jebel Ardouz is a unique and internationally relevant archive of the Devonian carbonate platform of the southwestern Meseta and of the complex interplay of Eovariscan and main Variscan deformations that shaped Palaeozoic rocks. It should be kept as an important locality for geological excursions and could play a significant role in the developing geotourism.

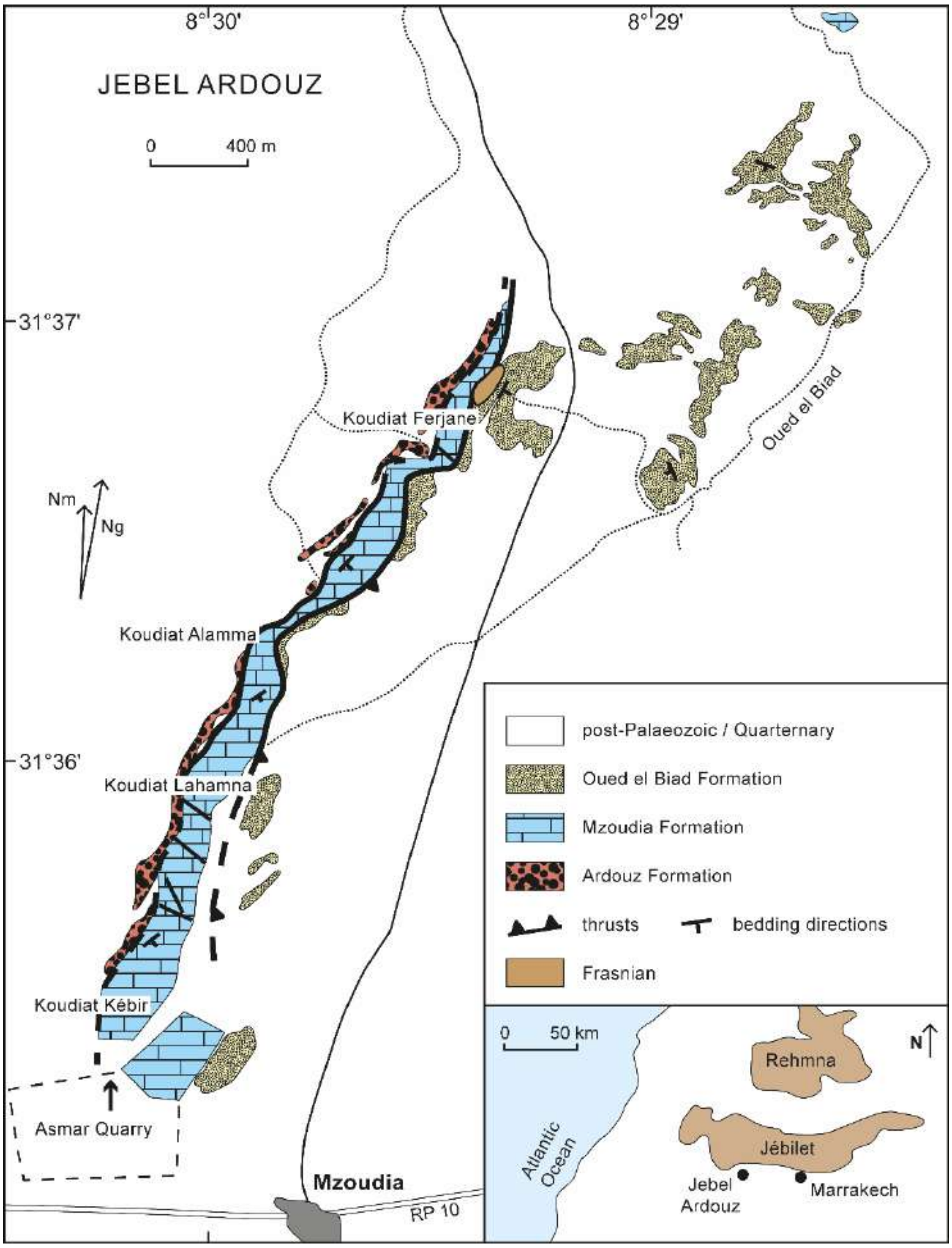

Fig. 2: Geology of the Jebel Ardouz north of Mzoudia, re-drawn from TAHIRI (1983, fig. 1); for the present-day extent of the quarry see BOUARI et al. (2021, fig. 2d).

Research History

LAUNAY (1903, pp. 309-310): Mentioning a possible quarrying of the Givetian limestone ("marbre") at Jebel Ardouz back to Roman time (quoted in HUVELIN 1977).

ROCH (1930): Discovery of the Devonian succession consisting of a basal, assumed unfossiliferous conglomerate and quartzite, followed by shallow-water limestones with brachiopods, corals, and chert, overlain by quartzites with spiriferids, supposed atrypids, and "*Streptorhynchus devonicus*".

MORET (1931, p. 83): Reference to the report of E. ROCH in a wider study on the geology of the Marrakech region.

TERMIER (1936, p. 382): Repetition of the succession described by E. ROCH, assuming a Frasnian age for the upper quartzites based on the "*Streptorhynchus*" record.

HOLLARD (1967): Brief reference to the "Koudiat Ardouz" succession, emphasizing the faunal similarity with the Mechra Ben Abbou Devonian in the NE Rehamna.

GENDROT et al. (1969) and GENDROT (1973): Survey of Devonian reefs of the Meseta, including mapping and a summary of the Mzoudia Devonian, with a record of stromatoporid bind- and framestone.

HUVELIN (1977): Review of the Jebel Ardouz Devonian, assigning the coral limestone to the Middle Devonian or Frasnian, the overlying sandstones with brachiopods to the Famennian, and considering a Lower Devonian age for the "red conglomerate".

TAHIRI (1980a, 1980b, 1982, 1983): Detailed studies on the Jebel Ardouz, refining the lithostratigraphy and describing the complex structural geology.

CORNÉE et al. (1987, fig. 7): Correlation of the Palaeozoic of the western High Atlas region, including the Mzoudia Devonian.

EL HASSANI & BENFRIKA (1995, 2000): Reviews of the Meseta Devonian, including a brief summary of the Mzoudia succession, quoting from an unpublished report of KERGOMARD (1970) an Eifelian age for the basal limestone [confirmed here].

ABOUSSALAM et al. (2012) and BECKER et al. (2015): Abstracts mentioning the discovery of Frasnian conodonts in the Jebel Ardouz conglomerate.

EICHHOLT & BECKER (2016): Reference to the reef facies at Jebel Ardouz in the compilation of Meseta Devonian reef occurrences.

BECKER et al. (2017): Report on new sampling in the Jebilet region, illustrating the "red conglomerate" at the base of Jebel Ardouz.

BECKER & EL HASSANI (2020): Reference to the Jebel Ardouz-Mechra Ben Abbou relationships in the project introduction.

BOUARI et al. (2021): New data on general stratigraphy, Givetian conodonts, and structural geology in a plea to protect parts of the Jebel Ardouz exposure as part of the Moroccan natural heritage.

3. Structural Geology

The Jebel Ardouz constitutes the western flank of a non-cylindrical, relatively complex synclinal structure. It shows at its base several fault planes underlain by mylonites, with overlaps that cut across the whole series, particularly at the bottom. They are associated with decimetric training folds at the base of Koudiat Ferjane (TAHIRI 1983). The axis of this synform shows some variation in its direction, N-S in its northern part and NNE in its southern end. It is an allochthonous complex, coming ca. from the north and settling in an N-S to NNE-SSW direction.

In this area, TAHIRI (1983) distinguished two main faults: the first one at the base is mylonitic and draws, cartographically, a curved line on a relatively smooth topography and is, therefore, interpreted as a sub-horizontal fault. The associated training folds confirm, in addition to the mylonite structure, a flat displacement of the Jebel Ardouz towards the south. The second fault is located within Devonian reef limestones; it limits the limestone formations towards the east through a subhorizontal basal truncation by a limestone mylonite signature.

In the ASMAR cement quarries, centimetric to decimetric folds are observed in the marl-limestone facies, with N-S to NE-SW directions, locally associated with a rough cleavage that is limited to the fold hinges.

4. Sedimentary and Faunal Succession

The new subdivision into formations, members, and submembers follows the lithostratigraphic units first noted by ROCH (1930) and refined by TAHIRI (1983) and BOUARI et al. (2021). For all units, the type-section is the measured Koudiat Ferjane section at the northern end of the Jebel Ardouz. The succession is described according to stratigraphic ages, not in the west-east sequence of the three thrust units.

4.1. Lower Devonian

Contradicting previous assumptions that were based on simple superposition (e.g., HUVELIN 1977; TAHIRI 1983), we did not encounter any evidence for Lower Devonian strata in the Jebel Ardouz region, not even as reworked clasts. It has to be assumed that thrusting detached the Middle/Upper Devonian successions completely from underlying older beds. There are no borehole data available to us, although it is possible that the cement factory may have explored their resource potential by drilling. The local lack of Lower Devonian is intriguing because the next closest, weakly/moderately deformed Devonian outcrops, the eastern Jebilet to the ENE (HUVELIN 1977; see Jaïdet chapter), the Western High Atlas basement to the S (CORNEE et al. 1990; new data), and the Devonian of Safi to the W (e.g., BEUN et al. 1992; BULTYNCK & SARMIENTO 2003) consist mostly of Lower Devonian rocks. This isolates the Jebel Ardouz Devonian and points to an allochthonous present-day position.

4.2. Mzoudia Formation (Middle Devonian)

The new Mzoudia Formation is defined by the onset of (partly dolomitic) limestones and has a total thickness of ca. 70 m. It equals the “Formation calcaire” of TAHIRI (1983) and “Formation 2” of BOUARI et al. (2021). The age is lower Eifelian to middle Givetian. Characteristic are numerous and several generations of calcite-filled veins, thin marly interbeds, late diagenetic dolomitization, and some karstification. The mostly thin-bedded, argillaceous or siliceous lower part is assigned to the new Koudiat Ferjane Member, the cliff-forming, thicker-bedded to biostromal upper part, the main target of the intensive quarrying, to the new Koudiat Kébir Member. Both can be subdivided into submembers.

Fig. 3: View from the top of Koudiat Ferjane down the western slope and into the subsequent plain, with L. BAIDDER, Z. S. ABOUSSALAM, and L. A. BECKER as small figures at the base for scale. The limestone ridge in the lower slope is formed by Bed -62. The thin-bedded rocks further out in the plain (causing a color change) are the banded, post-Devonian calcretes/dolocretes that surround the ridge on the western to northern side.

4.2.1. Koudiat Ferjane Member

This new member includes the mostly thin- or irregularly bedded limestones on the lower to middle western slope of the limestone cliff (Bed -78 to -16, Figs. 3-4). Unfortunately, the lower boundary is covered. The outcrop gap to the “red conglomerate” below amounts to more than 10 m of thickness. In agreement with TAHIRI (1983) and BOUARI et al. (2021), we assume a thrust plane lying at the formation and member base. There are also normal or oblique faults that displace limestone laterally along strike.

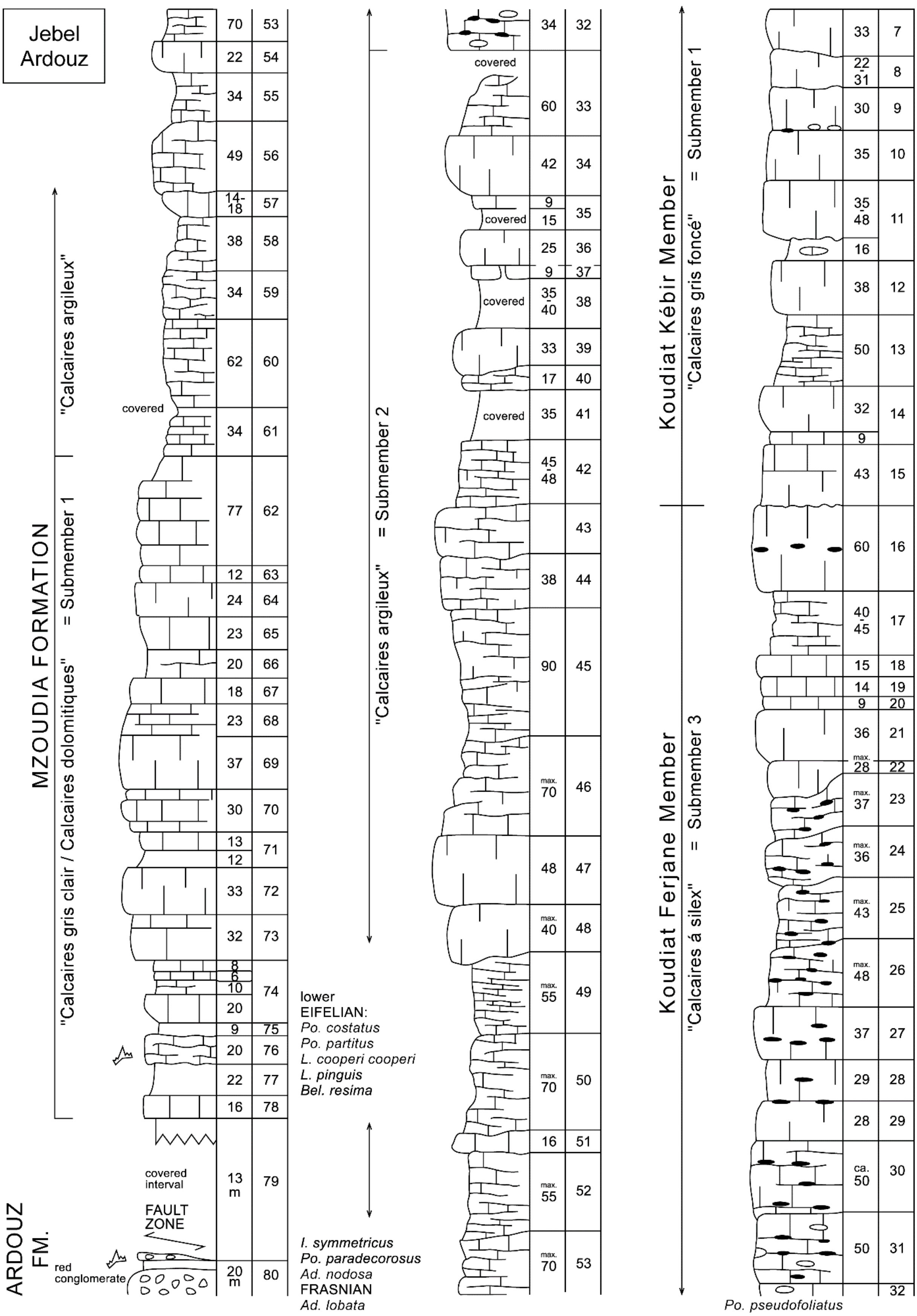

Fig. 4: Section log for the lower part of the (new) Mzoudia Formation at Koudiat Ferjane (northern Jebel Ardouz), showing the position of conodont samples and the lithological units of TAHIRI (1983); legend see Fig. 7.

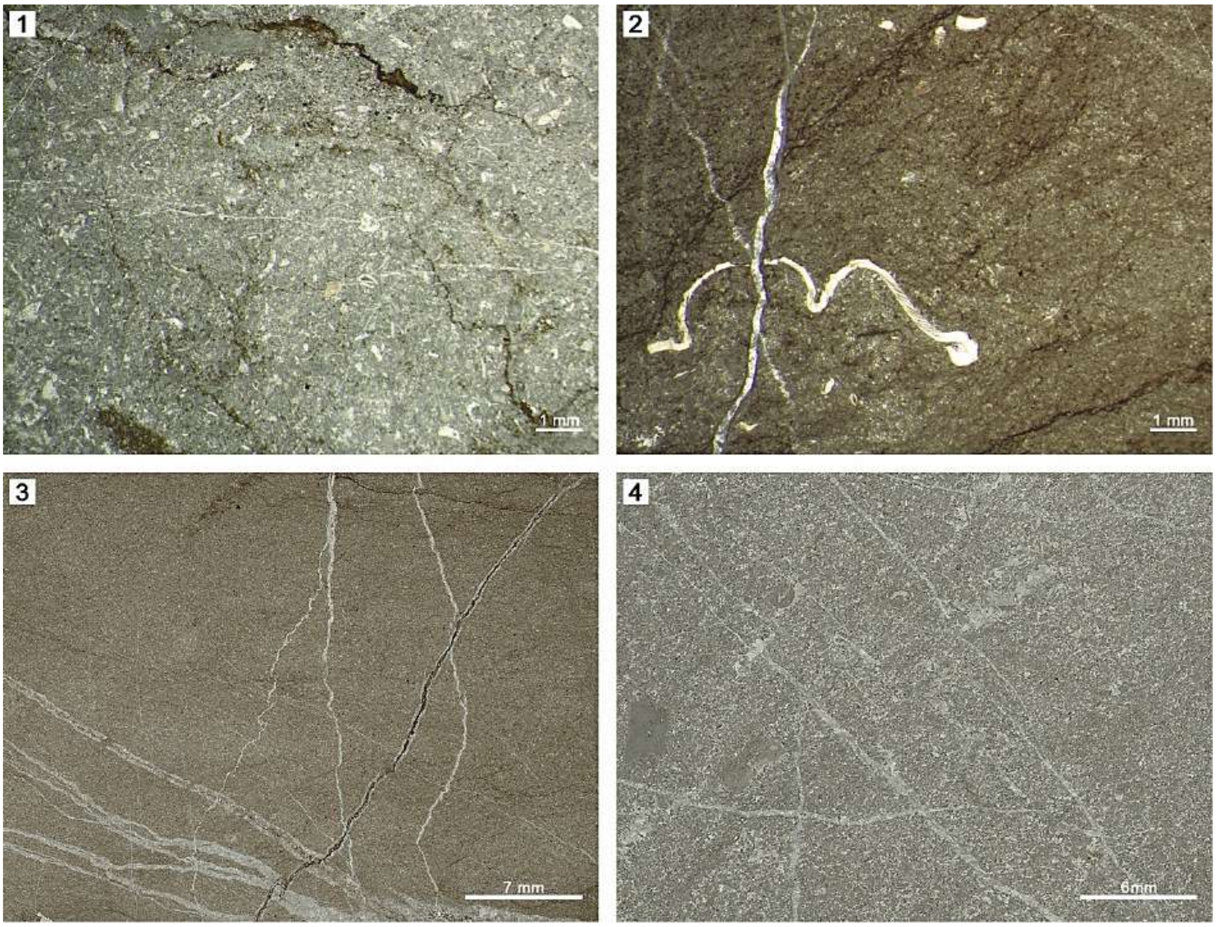

Fig. 5: Microfacies of the Mzoudia Formation at Koudiat Ferjane. **1.** Flaser-bedded, bioturbated, bioclastic wacke-packstone with abundant re-crystallized crinoid pieces and shell-debris, micritic matrix, and pressure solution stylolites, lower Eifelian (basal Koudiat Ferjane Member); **2.** Flaser-bedded, slightly bioturbated, middle-grey peloidal mudstone with the cross-section through a trilobite, lower part of cherty Submember 3 of Koudiat Ferjane Member, probably upper Eifelian; **3.** Almost unfossiliferous recrystallized mudstone (microsparite) with several generations of calcite veins, Sample M, lower part of Koudiat Kébir Member, Submember 1, lower Givetian; **4.** Light-grey peloidal and bioclastic grainstone with poorly preserved crinoid remnants, Koudiat Kébir Member, upper Submember 1, middle Givetian *ansatus* Zone.

Following TAHIRI (1983) and BOUARI et al. (2021, subunits 1-2), it is possible to subdivide the succession into submembers. Our detailed section log was measured near the northern end of the ridge (Figs 1, 3), at GPS N31°36´41,6´´, W8°29´19,7´´ (coordinates fixed at Bed 1). It transects the steep western slope, crosses the top and ends with the last dolomitic boulders on the upper eastern slope. The log does not include more thin-bedded limestones and marls on the upper eastern slope, which contact with the reefal limestones is somewhat obscure and possibly faulted. The section of BOUARI et al. (2021) lies ca. one km to the south.

At the base, TAHIRI (1983) mentioned a level of thin-bedded brownish dolomites with coral remnants that we did not find. It has to be emphasized that the section base is poorly exposed with only few places with dolomitized limestones, where the bed-by-bed logging could begin. Our (Fig. 4) log combines TAHIRI´s “Calcaires gris-clair” and “Calcaires dolomitiques” to a 5-7 m thick **Submember 1** (= first unit of Formation 1 sensu BOUARI et al. 2021). The dip fluctuates between 45° and 90°. Characteristic are light-grey, beige weathering, flaser-bedded, ca. 10-25 cm thick, partly dolomitized, detrital limestones. We did not see any intercalated sandstone beds in our section; the red sandstones of BOUARI et al. (2021, fig. 2b) were shown in their figs. 2a and 2c to crop out laterally. The microfacies of the lower part is bioturbated, poorly sorted and recrystallized bioclastic wacke-packstone with variably sized crinoid fragments, partly only preserved as “ghosts”, rare ostracods and dacryoconarids, and strongly crushed shell debris (Fig. 5.1). It represents storm beds deposited on the lower part of a neritic carbonate ramp. This interpretation is supported by the deeper-water polygnathid biofacies of Bed -76. We found *Polygnathus costatus* (six specimens, Fig. 6.3), *Po. partitus* (two specimens, Fig. 6.4), *Linguipolygnathus pinguis* (1 specimen, Fig. 6.5), *L. linguiformis* (three specimens, Fig. 6.6), *L. cooperi cooperi* (three specimens, Fig. 6.2), and *Belodella resima* (two specimens, Fig. 6.1). This fauna clearly falls in the lower Eifelian *costatus* Zone/Subzone, just postdating the global Choteĉ Event level. This is the first firm evidence for Eifelian strata at Jebel Ardouz and for the wider Jebilet region. BOUARI et al. (2021) did not sample the lower limestones (their Beds 5-9).

Submember 2 is the “Calcaires argileux” of TAHIRI (1983). Characteristic are thin, flaser-bedded, light-grey detrital limestones, interrupted occasionally by thicker beds (Beds -48, - 47, -39, -34; 25–48 cm thick, Fig. 4), which can serve for orientation in the field. There is very little macrofauna and some argillaceous intervals are covered. The slight trend towards more muddy sedimentation indicates a minor deepening trend, lasting from 5-20 m above the section base.

The 7 m thick **Submember 3** consists of TAHIRI´s “Calcaires à petit Silex“ and “Calcaires à gros Silex” (= ca. 10 m thick lower part of the second unit of BOUARI et al. 2021). The name-giving chert nodules can be larger than 5 cm and occur in parallel with the bedding in most of the lower and median beds (Beds -32 to –23). They are last seen in the 60 cm thick, massive Bed -16. They probably derived from diagenetic remobilization of organic SiO_2, such as sponge spicules, but these were not observed in our few thin-sections. The microfacies is a rather dull, flaser-bedded, middle-grey, peloidal mudstone with several isolated cross-sections of trilobites and very rare, recrystallized crinoid fragments. This fauna suggests a deep neritic setting, positioned lower on the ramp than for Submember 1. Some agglutinating foraminifers (*Psammosphaera* and *Tolypammina*) suggest low accumulation rates. A conodont sample from the base yielded five *Po. pseudofoliatus* Morphotype ß (Fig. 6.11) and two *L. linguiformis*. The first is a form that has a long range in the middle Eifelian to middle Givetian (e.g., BELKA et al. 1987; ABOUSSALAM 2003; VODRÁŽKOA & SUTTNER 2020). The second ranges from the lower Eifelian to the middle/upper Givetian boundary. Currently, we cannot correlate the basal Givetian sample of the section of BOUARI et al. (2021, Sample 10 with *I. obliquimarginatus* and *Po.* aff. *ensensis*, probably *hemiansatus* Zone) with our succession. In their section, Submember 3 was ca. 10 m thick.

4.2.2. Koudiat Kébir Member

With Bed -16, solid to massive, first medium-, later light-grey, flaser-bedded limestones begin, which can be up to 80 cm thick (Bed 19, Figs. 7, 9.1). They form the ca. 25 m thick **Submember 1** of the Koudiat Kébir Member (Figs. 4, 7, 9.1-3; “Calcaires gris foncé” of TAHIRI 1983). In the lateral section of BOUARI et al. (2021), it correlates with ca. 10 m darker-grey limestones in the middle part of second unit (of the second formation) and the following ca. 20 m of bluish-grey limestones, the main level exploited by the cement quarry. Apart from crinoid ossicles/debris, rare brachiopods (Fig.

10.2) and solitary rugose corals (Bed 10), the macrofauna is poor. Dolomitization and karstification occur; complex, calcite-healed fractures are very common (Fig. 8).

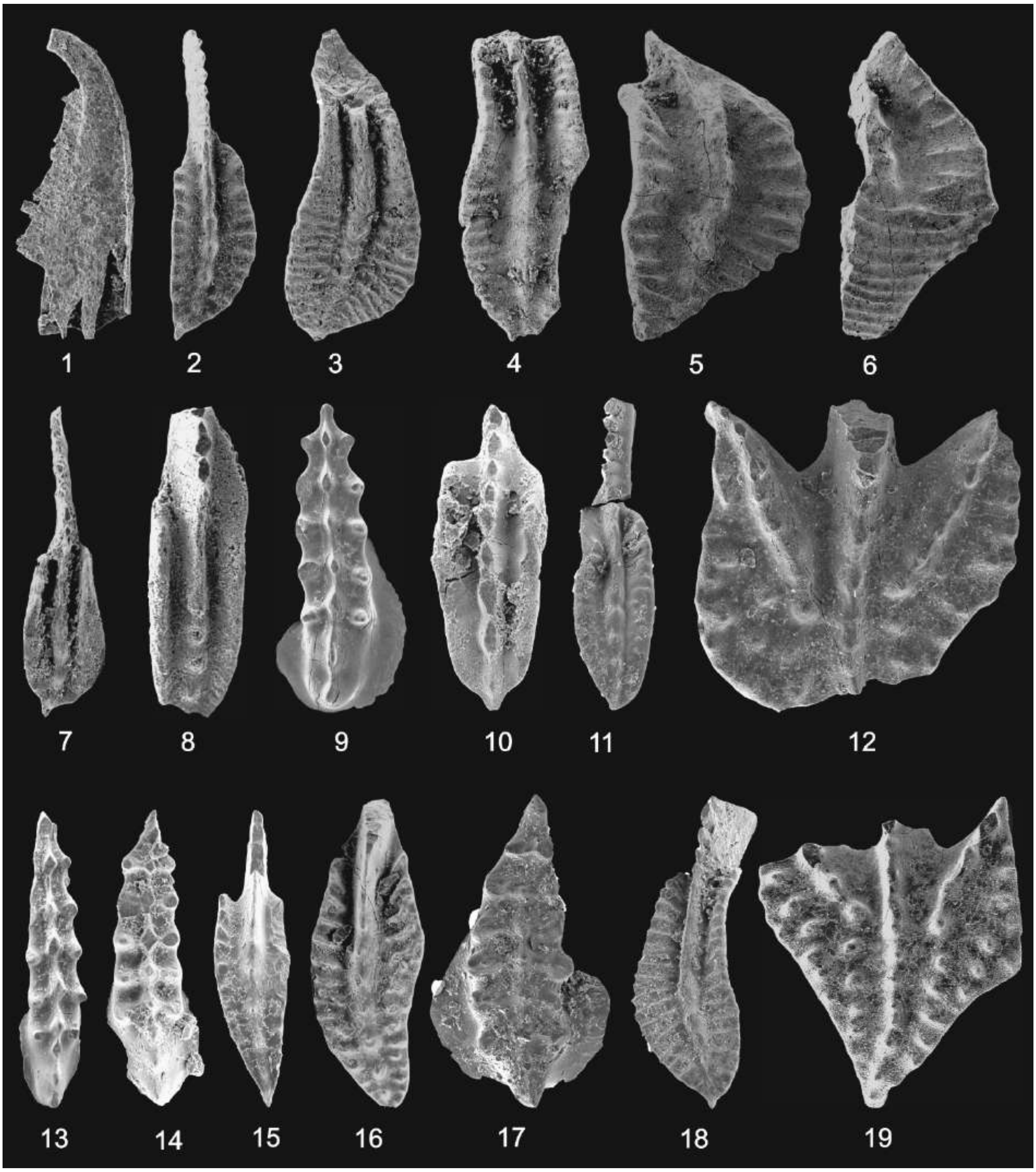

Fig. 6: Eifelian to Frasnian conodonts from Koudiat Ferjane (Jebel Ardouz), 1-6 = lower part of Koudiat Ferjane Member, Bed -76, *costatus* Zone, 7 = lower part of Koudiat Kébir Member (Submember 1, Beds -3/-4), 8-10 = top part of Submember 1 of Koudiat Kébir Member, ca. Beds 64/65, *ansatus* Zone, 11 = lower part of cherty Submember 3 of Koudiat Ferjane Member, ca. Bed -31/-32, 12-18 = upper part of "red conglomerate" (top Ardouz Formation), mixed Eifelian/middle Frasnian fauna; GMM B4C.2.119-137. **1.** *Belodella resima*, x 65; **2.** *Linguipolygnathus cooperi cooperi,* x 65; **3.** *Polygnathus costatus*, x 50; **4.** *Po. partitus,* x 45; **5.** *L. pinguis,* x 38; **6.** *L. linguiformis,* x 45; **7.** *Po. xylus,* sample M, x 75, **8.** *Po. timorensis*, x 105; **9.** *Icriodus regularicrescens,* x 90; **10.** *Po. xylus,* x 105; **11.** *Po. pseudofoliatus*, Morphotype ß x 50; **12.** *Ancyrodella. lobata*, x 70; **13-14.** *I. symmetricus*, straight narrow and curved, slightly wider morphotypes, x 70; **15-16.** *Po. paradecorosus*, narrow and slightly wider morphotypes, both x 70; **17.** *I. subterminus* Morphotype α, x 75; **18.** *Po. costatus*, X 60; **19.** *Ad. nodosa*, x 60.

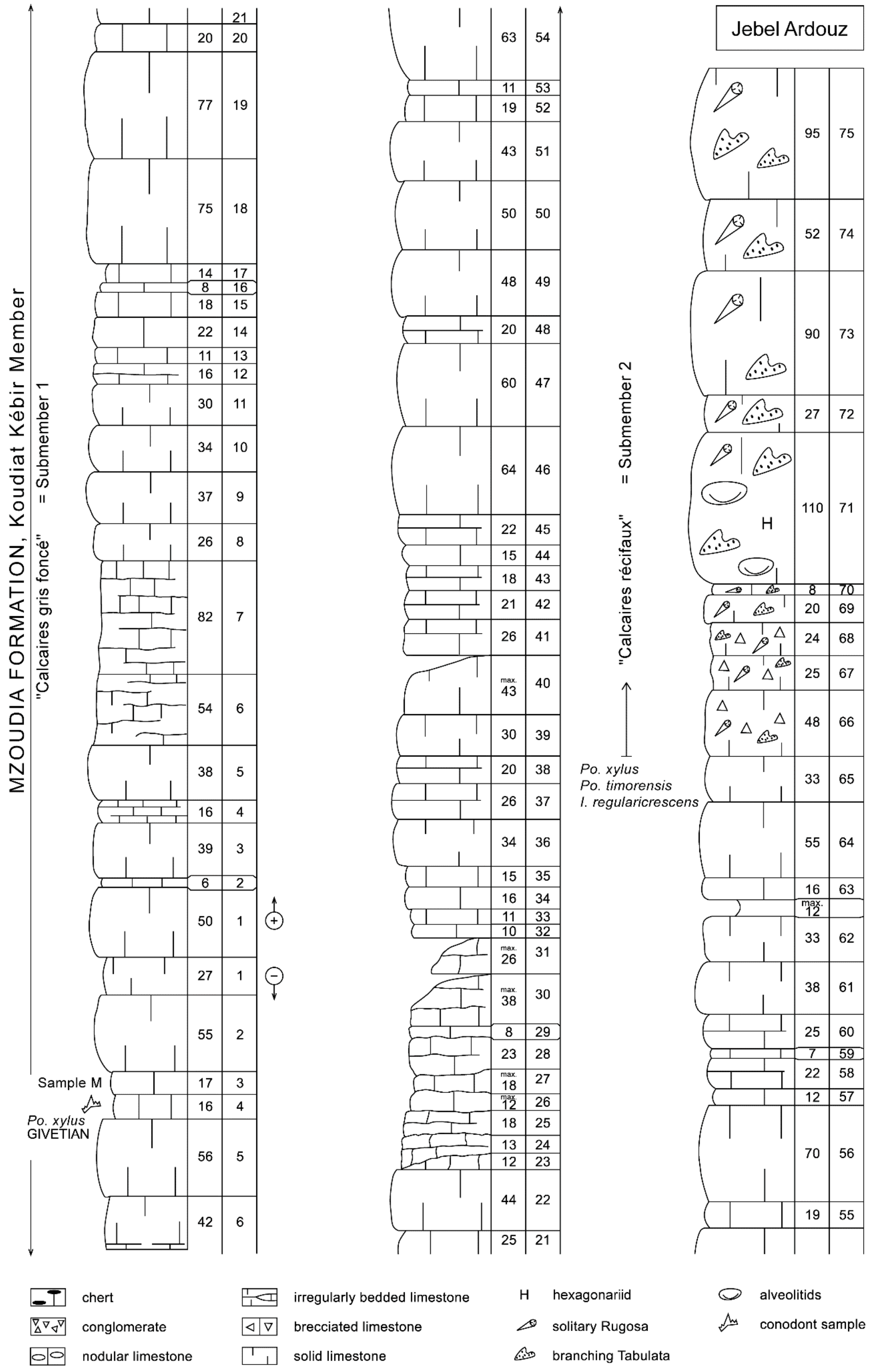

Fig. 7: Upper part of the section log through the Mzoudia Formation (Koudiat Kébir Member), showing the approximate position of conodont samples and the units of TAHIRI (1983).

Fig. 8: Lower part of the Koudiat Kébir Member, showing thin interbeds with stylolitic boundaries between the main, massive detrital beds and the complex pattern of tectonically triggered calcite veins.

The base of the Koudiat Kébir Member falls in the lower Givetian, which local regressive trend agrees with the eustatic curve. In the higher western cliff, thicker limestones are commonly separated by thin interbeds (Fig. 8), which took much of the diagenetic pressure solution. The microfacies of Sample M, from ca. 4.7 m above the base, is an almost unfossiliferous micro- to pseudosparitic mudstone. It indicates that deposition still occurred on a deeper part of the carbonate ramp. The only conodont found, a *Po. xylus* (Fig. 6.7), signals that higher parts of the lower Givetian (*timorensis* Zone) have been reached. This agrees with the more intensive sampling of BOUARI et al. (2021), where *Po. xylus* was found both in the *timorensis* and *rhenanus/varcus* Zones of the lower to lower middle Givetian. Higher in Submember 1, they fixed the bases of the *difficilis* (sensu BULTYNCK 1987) and *ansatus* (= Middle *varcus*) Zones. Therefore, the section has potential for the study of conodont faunas across the proposed lower/middle Givetian substage boundary. This is another important reason for its protection.

The coarser crinoid beds represent storm layers and underline an overall regressive trend. At the top, the microfacies includes bioclastic and peloidal pack-grainstones with mostly fragmented shell debris and recrystallized crinoid fragments (Fig. 5.4). This lithofacies suggests deposition under permanent but slightly fluctuating current conditions. Mud peloids originate by the reworking of clumped micrite aggregates and represent “pseudopellets” sensu FAHRAEUS et al. (1974) or small intraclasts. A conodont fauna from the top yielded *Po. xylus* (Fig. 6.10), *Po. timorensis* (Fig. 6.8), and *I. regularicrescens* (Fig. 6.9), giving an age no older than the *timorensis* Zone but all three species range higher. In the lateral section of BOUARI et al. (2021), the *ansatus* Zone begins well below the top of Submember 1.

Submember 2 (“Calcaires récifaux” of TAHIRI 1983; third unit of the second formation in BOUARI et al. 2021) is defined by the onset of light-grey, mostly thick-bedded limestones with variably abundant reef organisms, such as solitary rugose corals, colonial Rugosa, including large, flat hexagonariids (Fig. 9.4), and tabulate corals, such as alveolitids, thamnoporids (Figs. 9.5-6), and favositids. Brachiopods and crinoids (Fig. 9.5) are associated in grain-floatstones. Some beds are rich enough in corals to be called biostromal (see the thamnoporid bafflestone of BOUARI et al. 2021, fig. 3e). The setting of Beds 66-75 (Fig. 10.1) consisted of coral gardens growing on the upper ramp during increasing regression.

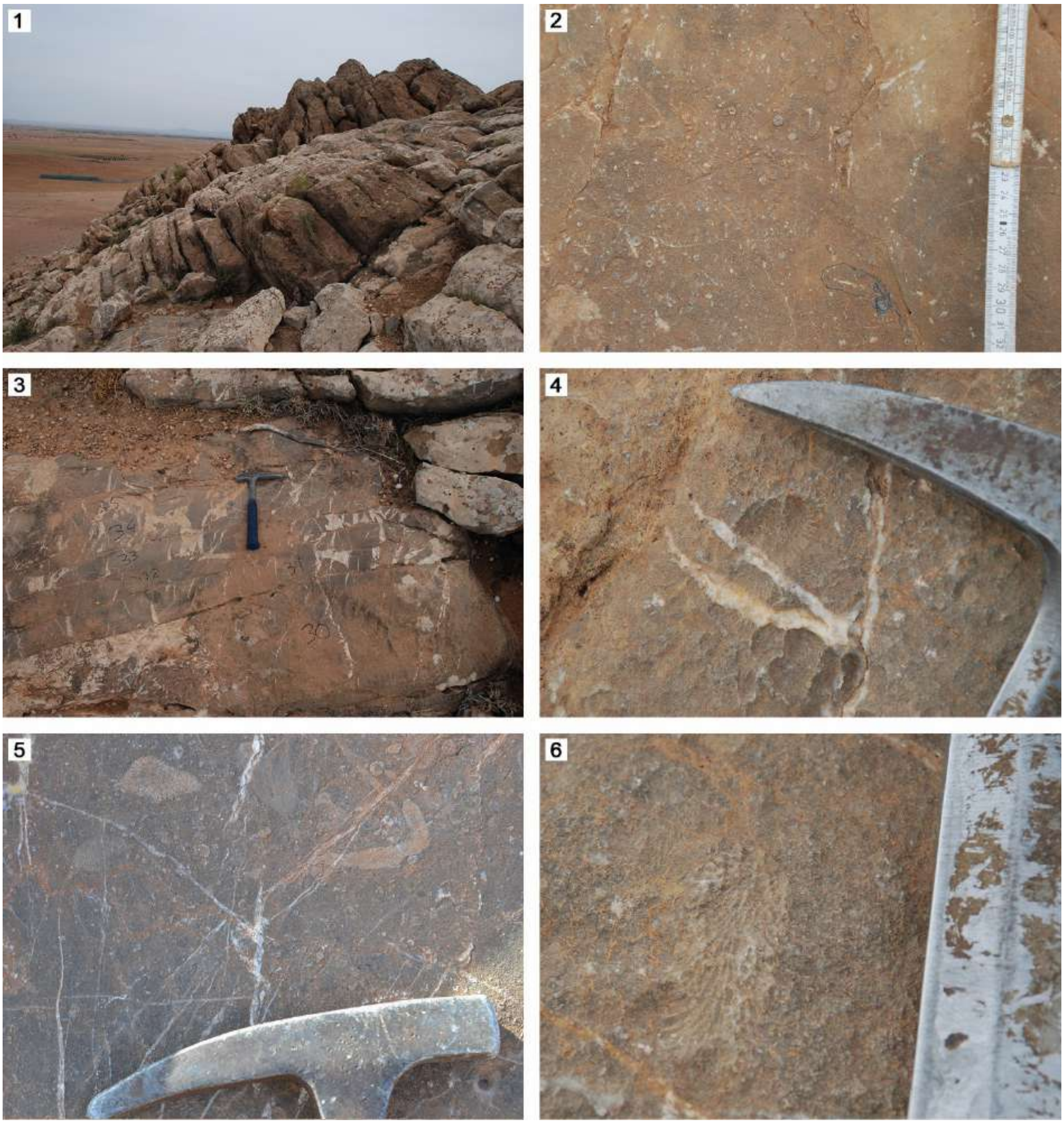

Fig. 9: Field photos of the Koudiat Kébir Member of the Mzoudia Formation. **1.** The medium- to thick-bedded, poorly fossiliferous Submember 1 forming the upper part of the western cliff at the northern end of Koudiat Ferjane; **2.** Crinoidal, light-grey limestone with a poorly preserved, dark-shelled brachiopod in the main part of Submember 1; **3**. Intercalated interval of thin-bedded detrital limestone (Beds 30-35) in the middle of Submember 1; **4.** Large hexagonariid colony in the lower part of Submember 2 (Bed 71); **5.** Crinoid-thamnoporid floatstone; **6.** Example for the common thamnoporids in the main part of Submember 2.

GENDROT et al. (1969) and GENDROT (1973) documented stromatoporoid bind- and rudstones (compare Fig. 10.3) from the middle part of Jebel Ardouz and suggested a bioherm setting. The mapped small areas of true reef facies are interpreted as elevated patch reefs on a biostromal platform. Dominant lagoonal facies, which is an essential bioherm feature, was not recorded. There are also no fore-reef breccias.

The complete thickness is difficult to measure due to dolomitization and lateral irregular bedding (Fig. 10.2). BOUARI et al. (2021) estimated ca. 25 m in their section. According to ROCH (1930), the Givetian index genus *Stringocephalus* has been found.

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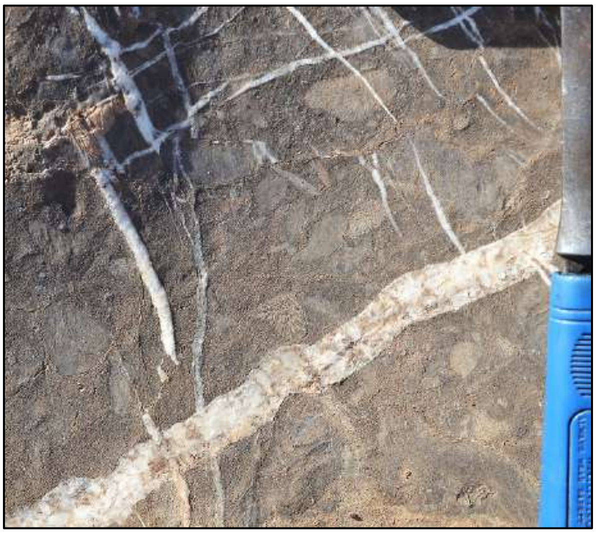

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Fig. 10: Outcrop photos of the reefal Submember 2 of the Koudiat Kébir Member at the northern end (eastern slope) of Koudiat Ferjane. **1.** Thick-bedded, measured section (see section log), showing the probably fault-related sharp upper end, where the car is parked; **2.** Irregularly-bedded massive upper part at the track winding upslope Koudiat Ferjane; **3.** Stromatoporid-thamnoporid rudstone, crossed by a thick calcite vein.

Conodonts from the top still belong to the *ansatus* Zone. This rejects previous considerations of a possible Frasnian age (TERMIER 1936; HOLLARD 1967; HUVELIN 1977; TAHIRI 1983). Conodont sampling in our section was not successful; Givetian biostromal facies is commonly very poor in conodonts.

4.2.3. Un-named Upper Member

The top of Submember 2 of the Koudiat Kébir Member is irregular, dolomitic, and poorly exposed (Fig. 10.1). TAHIRI (1983) separated as “Marnocalcaires” an overlying unit of yellowish, thin-bedded limestones and marls with some brachiopods. BOUARI et al. (2021) suggested that these are separated from the reefal succession by a fault. HOLLARD in GENDROT et al. (1969, p. I-12) and HOLLARD et al. (1982, p. 26) identified Frasnian goniatites (*Manticoceras*) from limestones overlying the reef facies. This implies that the reef platform was drowned, at least episodically, in Frasnian time, which is supported by our new record of reworked non-reefal Frasnian beds (see below). Further studies are needed; therefore, the informal Upper Member is left un-named. The contact with the overlying Famennian quartzites is covered.

4.3. Ardouz Formation (Frasnian)

This new formation equals the “Formation argilo-gréseuse et conglomératique rouge” of TAHIRI (1983) and “Formation 1” of BOUARI et al. (2021). Previously, it was said to be unfossiliferous and of possible Lower Devonian age (ROCH 1930; HUVELIN 1977). But in fact, it includes isolated crinoid ossicles and encrusted reefal corals (Fig. 11) as well as conodonts from embedded limestone clasts. These show that it is younger than the Mzoudia Formation, which was thrusted from the NE onto it.

In general, outcrops of the Ardouz Formation are small and discontinuous at the base of the western slope of the elongated, ridge (Figs. 2, 3). In the plain, the succession begins with mostly covered reddish to mauve, slightly micaceous siltstones and intercalated sandstones lenses. Bouari et al. (2021) suggested a thickness of 25 m for their first unit of their first formation. The main, upper unit consists of lenticular reddish sandstones and coarse, polymict, red, hematite-rich conglomerates/breccias forming ledges (Figs. 12.1-2) or boulders. The complete thickness is at least 20 m. The matrix of the "red conglomerate" is either iron crusts (Fig. 12.3) or hematite-rich sandstone, with coarse-grained quartz grains, red, hematitic limestone (Fig. 11), or fine-grained conglomerate (Figs. 12.4-5, 13.1). Angular to subrounded limestone clasts may reach a size of 20 cm, sandstone clasts are smaller (up to 8 cm). There is no sorting or grading within subunits. Pebble rounding, especially of sandstones, and thin ferromanganese seams (coating), require a long interval of agitated coastal residence before re-deposition. The (pre-thrusting) transport distance was probably not far. Matrix-poor layers (Figs. 12.3, 13.2) represent rockfall deposits at a steep palaeoslope. Sandy conglomerates (Figs. 12.4-5), which grade into red sandstones and carbonate, result from debris flows triggered by recurrent synsedimentary seismic activity at an active fault scarp adjacent to an uplifted palaeohigh/island. This Eovariscan block faulting episode predated considerably the later overthrusting. The following clast types have been identified:

-- (sub)rounded, thin- or cross-bedded, reddish, rose-colored to brownish, fine-grained sandstones, partly with very thin calcareous fissures, without any fauna, sometimes with patchy hematite impregnations;
-- white or reddish, unfossiliferous, coarse-grained quartzites, sometimes impregnated by hematite, grain contacts often stylolithic, often crossed by fine calcite veins;
-- red, laminated siltstones;
-- small dark pebbles/clasts (iron mineralisations);
-- isolated tabulate corals (thamnoporids, flat *Squameofavosites* colony, Fig. 11);
-- isolated crinoid ossicles;
-- reddish, micritic, bioclastic wackestone with shell filaments and crinoid debris;
-- flaser-bedded, greenish to middle-grey, micritic limestone (poorly fossiliferous, peloidal, sometimes slightly silty mudstone), often with complex calcite veins (Fig. 12.1);
-- middle-grey mudstone with authigenic pyrite, rare shell filaments or trilobite fragments (Fig. 12.3);
- light to middle grey, bioclastic wackestone, partly with dacryoconarids;
- light-grey, coarse-grained crinoid limestone (grainstone).

Variably sandstone (Fig. 12.2) or limestone clasts dominate in specific layers. The latter agree mostly with the microfacies types seen in the Koudiat Ferjane Member and in Submember 1 of the Koudiat Kébir Member. Exceptional are the reddish wackestone pebbles and red limestone matrix. These, as well as the hematite-enriched sandy matrix, represent distinctive facies types developed immediately before re-deposition. The abundant iron arrived in solution and/or as very fine detritus from an arid source (island) with lateritic weathering. Due to the limited number of thin-sections, the clast spectrum may not be complete. But is important to note, which rock types are not present. This is true for limestones enclosing reef organisms and fossiliferous quartzites of the type found in the Oued el Biad Formation on the eastern side of the ridge (see below). All reworked sandstones lack fossils, which prevents their dating. They may have been derived from an uplifted and detached Lower Paleozoic souce, which implies that we should continue the search for reworked Lower Devonian clasts.

Especially important is the recognition of different generations of calcite-healed fractures. Yellowish or brownish fractures may cross all clasts of the conglomerates and are post-depositional (main Variscan) in age. Many limestone pebbles show white calcite veins of different size, width and direction that end at the pebble margins. These must have formed prior to exhumation and re-deposition. The limestones clasts were already fully lithified, which may occur very early in diagenesis, and fractured by Eovariscan deformation before they were exhumed.

The depositional age of the Ardouz Formation has to be deduced from the age range of clasts, their spectrum, the nature of the matrix, and aspects of post-sedimentary tectonics and allochthonous transport. The fact that the conglomerates occur at the base of an allochthonous thrust staple rules out a post-orogenic age, as it has been accepted for widespread reddish conglomerates and breccias of the NE Rehamna (e.g., HUVELIN 1977; EL KAMEL & MULLER 1987).

We sampled – without success – a few individual large limestone pebbles and – with more success - the fine-grained upper "red conglomerate". As expected, the latter yielded mixed conodont assemblages. The Eifelian is represented by *Po. costatus* (three specimens, Fig. 6.18), the lower/middle Givetian possibly by *L. linguiformis* (two specimens) and *Bel. resima* (one specimen), and the lower/ middle Frasnian by *I. subterminus* Morphotype α (eight specimens, Fig. 6.17), *I. symmetricus* (nine specimens, straight and curved morphotypes, Figs. 6.13-14), *Po. paradecorosus* (four specimens, narrow and wider forms, Figs. 6.15-16), *Ancyrodella nodosa* (one specimen, Fig. 6.19), and *Ad. lobata* (one specimen, Fig. 6.12). While the entry of *Ad. nodosa* defines the *nodosa* Zone near the top of MN Zone 4 (top lower Frasnian, ABOUSSALAM & BECKER in PISARZOWSKA et al. 2020), the latter enters in the upper part of MN Zone 6 sensu KLAPPER (1989) or in the middle Frasnian *Ag. ancyrognathoideus* Zone; it also defines des alternative *lobata* Zone (PISARZOWSKA et al. 2020). The presence of Frasnian conodont was confirmed by re-sampling in separate years. The genus *Squameofavosites* has not been mentioned so far from North Africa but is in general widely distributed in the Lower and Middle Devonian (e.g., POHLER 2002). But it is not known from the Frasnian (NOWIŃSKI 1976; BIRENHEIDE 1985). This shows that its block was reworked, from time equivalents of the biostromal upper Mzoudia Formation.

Fig. 11: Flat, 7.5 cm large colony of a favositid (possibly *Squameofavosites* sp., det. A: MAY) with concave margin, encrusted on and by hematitic, sandy limestone, upper "red conglomerate" (upper Ardouz Formation), GMM B2C.57.3.

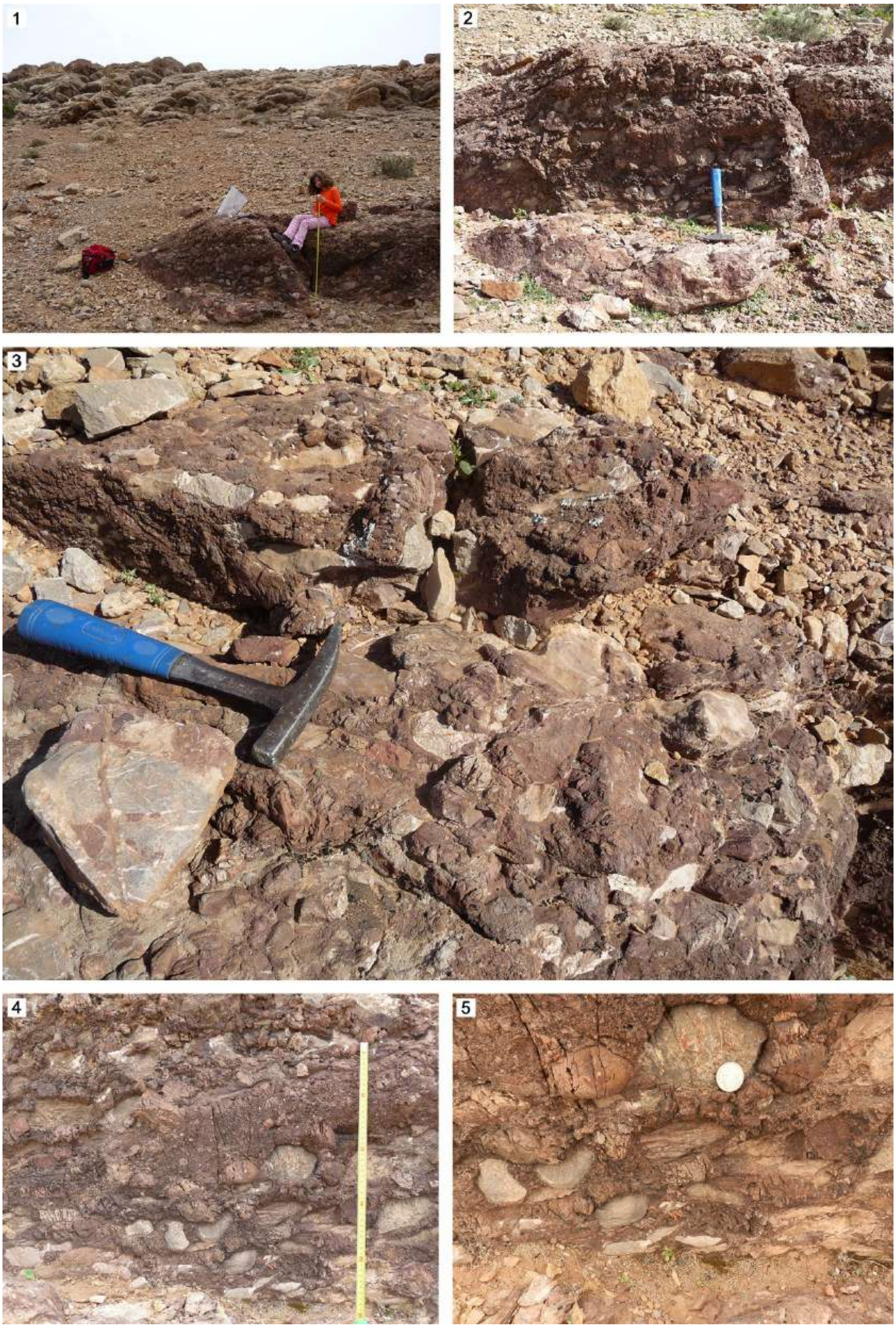

Fig. 12: Field photos of the “red conglomerate” (upper Ardouz Formation) at the base of the western slope of Koudiat Ferjane. **1.** Overview (photo from April 2012, with Lea Amira BECKER for scale) showing the “red conglomerate”, the > 10 m outcrop gap above, followed by the basal Mzoudia Formation in the background; **2.** Detail of the “red conglomerate” showing a local differentiation into a strongly iron-encrusted, solid lower part and a matrix-rich, more intensively reddish upper part; **3.** Lateral outcrop showing large, light-grey, angular to subrounded limestone clasts encrusted in several layers by hematite; **4-5.** Details of the matrix-rich upper part of 2., with light-grey Middle Devonian limestone clasts, up to ca. 10 cm large, embedded in red, hematite impregnated fine conglomerate to sandstone (note the same clasts and its size in both figures).

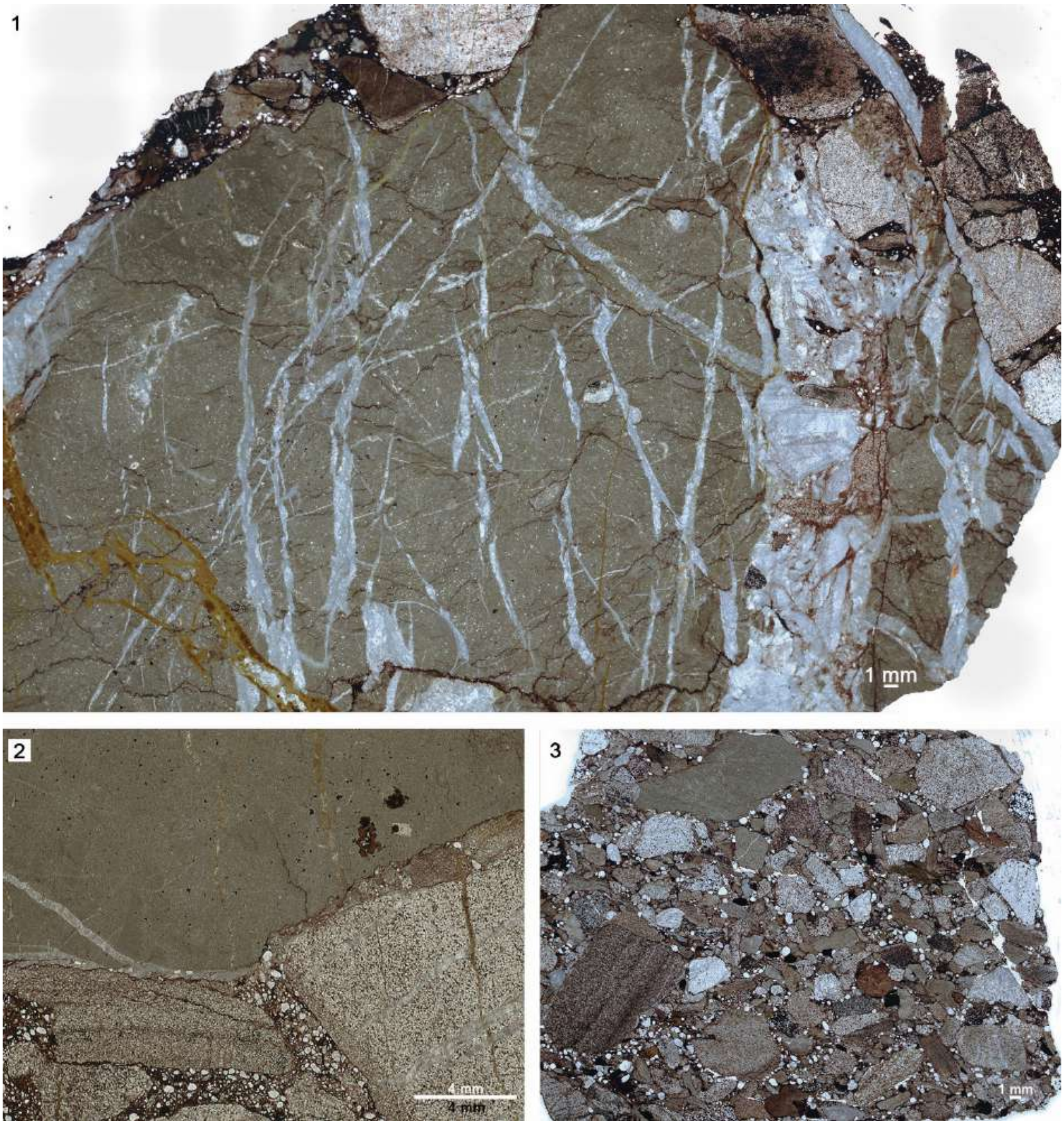

Fig. 13: Microfazies of the "red conglomerate" (upper Ardouz Formation). **1.** Strongly unsorted conglomerate with large limestone clast consisting of flaser-bedded, peloidal, slightly silty mudstone with rare large mollusk shell (lower left center) and three directions of thin to thick calcite veins ending at the clast margins (pre-dating reworking and re-deposition), surrounded by pebbles of light-grey, fine-grained quartzite (top and upper right), red, fine-grained sandstone (top), and hematite-rich fine conglomerate matrix (upper left); **2**. Coarse-grained conglomerate from the top of the formation, with a subrounded, middle grey, unfossiliferous mudstone with small and large authigenic pyrite, in pressure solution contact with subangular, medium-grained, partly cross-bedded sandstone, with coarse quartz grains and hematite as matrix between the clasts; **3.** Small-grained conglomerate with dominant light- to middle-grey or reddish, partly laminated sandstones, mostly in stylolithic contact, often with fine, dark ferromanganese seams, a small pebble of red bioclastic wackestone (lower center), and a flaser-bedded, greenish-grey calcareous mudstone at the top.

Combining the evidence of encrusted Givetian corals, middle Frasnian conodonts, and the absence of clearly Famennian clasts, we must consider an upper Frasnian (possibly lower/middle Famennian) age for the main period of uplift, pebble formation, iron impregnation, and downslope shedding. At this time, a peak of synsedimentary tectonism can be recognized in some other parts of the Meseta (southern Oued Cherrat, BECKER et al. 2020a: Ain-as-Seffah) and in the eastern Anti-Atlas (e.g., WENDT & BELKA 1991; BAIDDER et al. 2008). The red conglomerate of the Al Attamna is older (EICHHOLT & BECKER 2016). We cannot exclude that several phases of synsedimentary tectonics are hidden within the Ardouz Formation. Upper Givetian uplift may have interrupted reef growth and sedimentation in the source region of both the Ardouz and Mzoudia Formations. If the reworked quartzites are Famennian in age, the main block tilting correlates with the widespread post-Devonian Eovariscan phase.

4.4. Oued el Biad Formation

The gentle eastern slope of the ridge and adjacent plain as well as further outcrop patches at some distance (Fig. 2) are occupied by a thick sequence of mostly beige to light-grey, hard, thin-bedded to massive quartzites and sandstones. This new Oued el Biad Formation equals the “Formation gréso-quartzitique” of TAHIRI (1983), who measured a thickness of ca. 70 m, while BOUARI et al. (2021) suggested recently 130 m. As shown by TAHIRI, the outcrops west and east of the piste towards Douar Ben Mansour in the north, form a wide syncline. We collected only from the lower part and will, therefore, not repeat TAHIRI´s succession assigned to six members. In thin section, there are well-sorted, quartz sandstones with middle grain size (Fig. 14), compacted to quartzite. The sediment maturity is high; there are no feldspars or rock fragment grains.

The formation is famous for its scattered brachiopod coquina beds. Their calcitic shells were completely dissolved in carbonate undersaturated pore water during early diagenesis, creating a secondary porosity. Within the created narrow cavities, the molds were coated by limonite/goethite precipitated from the pore water (Fig. 15). Mass accumulation and convex-up preservation suggest localized, diversity-poor nests of specialists adapted to nearshore, shallow-subtidal sand bar habitats, which were destructed by recurrent subtropical storms. Since most of the quartzite is poorly fossiliferous, poor living conditions resulting from constant sand movements prevailed.

Fig. 14: Thin-section of brachiopod coquina in the lower Oued el Biad Formation, showing numerous, uni-valved, limonite/goethite-coated brachiopod molds lying in a strongly sorted, yellowish quartz grain matrix, with secondary cavities created by the shell dissolution.

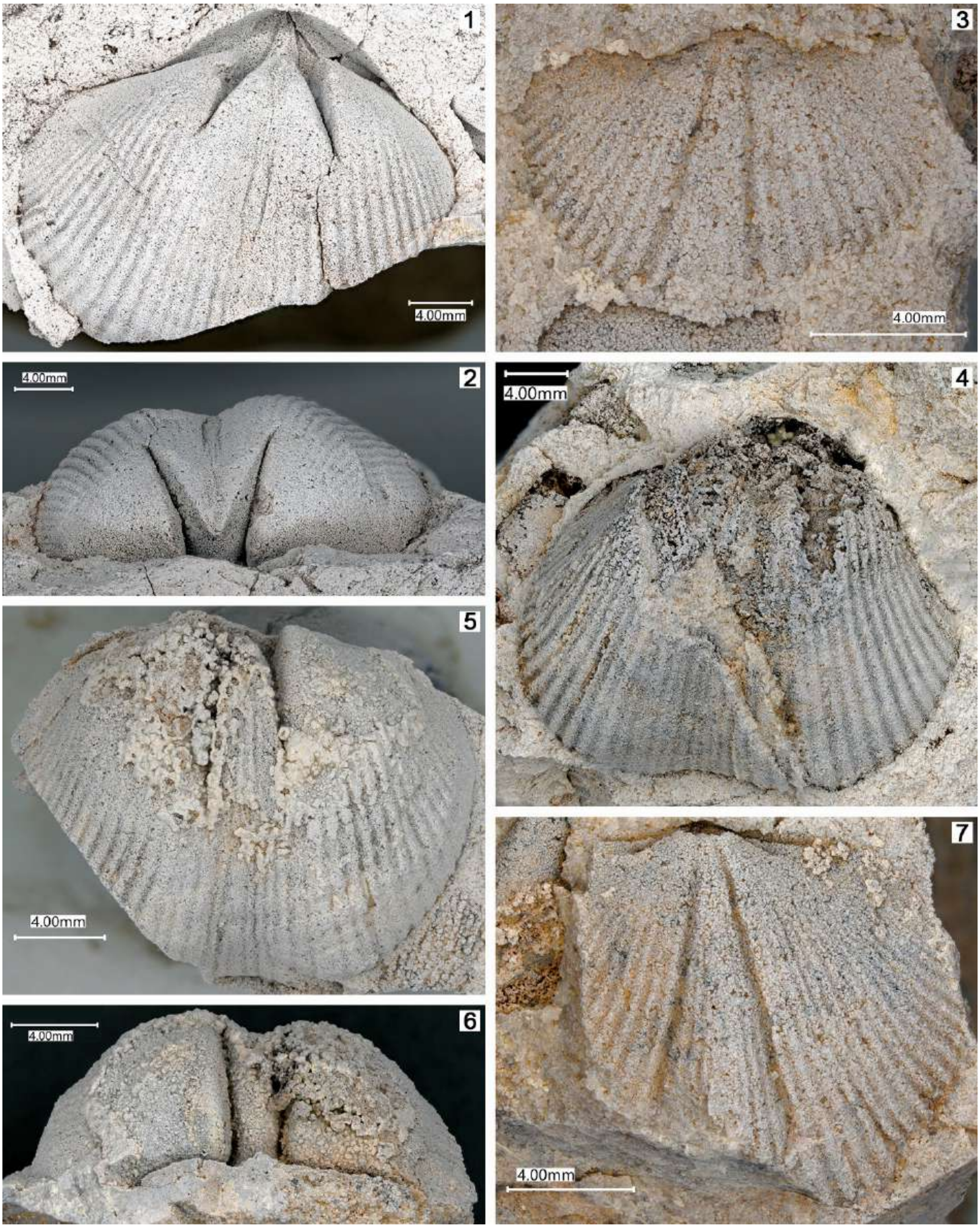

Fig. 15: Spiriferid brachiopods from the lower part of the Oued el Biad Formation; GMM B5B.16.9-13. **1-4.** Cyrtospriferinae gen. indet.; **5-6.** Cyrtiopsinae gen indet., **7.** Cyrtospiriferidae indet.

ROCH (1930: p. 142) reported *Streptorhynchus devonicus*, *Atrypa* sp., and *Spirifer verneuilli* from the "grauwackes du Djebel Ardouz" (Oued el Biad Formation), unfortunately, without any illustration, as is the case of most of the Palaeozoic species cited by him. He stated that the identifications of the Jebel Ardouz material were controlled by P. PRUVOST and A.-P. DUTERTRE in comparing it with that of GOSSELET'S collection from the Boulonnais area (northern France), which is now deposited at the Musée d'Histoire naturelle de Lille. The ROCH material is not curated at the Université de Grenoble Alpes and may have remained at Rabat.

A small new brachiopod collection consists of internal moulds of dissociated, incomplete dorsal and ventral valves. Two taxa are recognized but the poor state of preservation precludes a generic identification (e.g., due to the lack of microornament and incompletely known outline). The Cyrtiopsinae gen. indet. (Figs. 15.5-6) are represented by one ventral internal mould characterised by a hinge line shorter than the valve width, deep and poorly delimited sulcus, long, intrasinal, and relatively thin dental plates delimiting a narrow muscle field, more than 18 simple ribs per flank (exact number unknown), and 8–9 thinner ribs in the sulcus. Specimens of the Cyrtospiriferinae gen. indet. (Figs. 15.1-4) differ markedly by their wider sulcus and strongly divergent, posteriorly thickened dental plates. Their simple ribs (ca. 15) are coarser on the flanks.

An Upper Devonian age can be inferred based on the collected Cyrtospiriferidae, but the alleged presence of atrypides, which remains uncontrolled, would indicate a Frasnian age for a part of the Oued el Biad Formation, as these spire-bearers did not cross the Frasnian–Famennian boundary. It is not excluded that the single specimen identified by ROCH (1930) as '*Atrypa* sp.' was confused with a costate rhynchonellid. The orthotetides from the Oued el Biad Formation were ascribed to a species from the Frasnian of Ferques (Boulonnais area, northern France) previously misidentified as *Orthis crenistria* var. *devonica* VON KEYSERLING, 1846, which is a form from northern Russia (Pechora region; e.g., RIGAUX 1908). It was later renamed by BRICE (1988) as *Eoschuchertella ferquensis*. However, the Moroccan material should be re-investigated.

The presence of small Cyrtiopsinae in the new collection may suggest a Famennian age, as observed in Western Europe (Belgium, Germany) and South China. However, the revision of ROCH'S (1930) specimens is required to control the presence (or otherwise) of atrypids and Frasnian orthotetides within the Oued el Biad Formation. Another possibility to be checked is that a part of ROCH´s brachiopods may have come from the non-reefal Upper Member of the Mzoudia Formation, where brachiopods were briefly noted by TAHIRI (1983), not from the subsequent Oued el Biad Formation

The sandy material was not transported far from or along an uplifted coastal region (island) with exposed Lower Paleozoic siliciclastics. Climate conditions of erosion, recycling and re-deposition differed strongly from the source region of the red sandstones and conglomerates of the Jebel Ardouz Formation.

Fig. 16: Thin-section of yellowish, wavy-laminated calcrete to dolocrete with embedded silt grains from the plain immediately west of Koudiat Ferjane.

4.5. post-Devonian

The plains in the west to the northeast of Koudiat Ferjane are occupied by yellowish, partly dolomitic, thin-bedded, wavy laminated limestones without any fauna. In thin-section

(Fig. 16), they show a variable, small content of angular silt grains. The complete lack of any fossil suggests that these represent geologically young, terrestrial (pedogenic) calcretes to dolocretes. BOUARI et al. (2021, fig. 4b) illustrated a rectangular system of fractures without displacement.

5. Facies development

In the lower to upper Eifelian, a deep neritic carbonate ramp with reduced sedimentation of lime mud existed in the source region of the middle thrust unit, positioned at some distance to the N/NE. The setting was rather oligotrophic and did not nourish a rich fauna. There were several minor deepening episodes, one at the base of the argillaceous Submember 2 of the Koudiat Ferjane Member, one in its upper part (Beds -46 to -40), and one in the cherty Submember 3 (Beds -26 to -23). Conodont sampling is still to incomplete to correlate one of them possibly with the eustatic deepening of the top-Eifelian Kačák Deepening. Trophic conditions improved slightly in Submember 3, supporting some trilobites and, probably, siliceous sponges.

In the lower to lower middle Givetian, oligotrophic conditions dominated, resulting in very poor macrofaunas. Massive beds of the Koudiat Kébir Member reflect a shallowing trend, which finally led to the foundation of coral gardens. Laterally, patches of true reef facies developed (GENDROT et al. 1969). More work has to be done on the local taxonomic composition of reef builders. The biostromal episode ended abruptly still within the middle Givetian, but the faulting masks the reason behind this. A Frasnian transgressive episode is recorded by the open, deep neritic to shallow pelagic ancyrodellid-polygnathid conodont faunas and the local *Manticoceras* level (HOLLARD et al. 1982).

Possibly later in the Frasnian, Eovariscan uplift created an island with arid and lateritic weathering of exhumed siliciclastics. Parts of the already lithified and fractured carbonate platform became exposed, too, near the active fault scarp. In the high-energy environments along the shore, sandstones, quartzites, uplifted deep neritic to biostromal limestones and overlying lower/middle Frasnian strata turned into angular clasts and rounded pebbles, which were impregnated and encrusted by iron-rich fluids. They mixed with finer hematite, lime and quartz sand and pebbles. The first fine (red silt- and sandstone), later increasingly coarse debris was shed downslope during recurring seismic episodes. Unfortunately, the substratum of the Ardouz Formation is missing because of the basal (most western) thrust zone.

The top-Frasnian to upper Famennian interval is stratigraphically poorly constrained. During regression, quartz sand sheets prograded outwards and covered the Middle Devonian carbonate ramp. The environment was hostile to benthic fauna apart from some brachiopod specialists, which flourished in patches. Sand delivery and subsidence were more or less in balance for a long time period. The uppermost Famennian to Lower Carboniferous history of the Jebel Ardouz remains unknown (unless the un-dated quartzites of the “red conglomerate” were reworked from the upper Famennian). The light-grey to sometimes whitish conodont color (high CAI) suggests that both the western and middle unit were originally overlain by a thick sediment staple.

6. Regional Comparisons

The supposed Middle Devonian of El Moussira, south of Marrakesh (HOLLARD in GAILLET 1986), was re-studied by ABOUSSALAM et al. (2017) and found to belong entirely to the Lower Carboniferous.

Preliminary new sampling could not confirm the presence of Middle Devonian limestones in the Western High Atlas basement at Talmakent (CORNÉE et al. 1990) or at Ida ou Zal (DE KONING 1956). However, the first has a r

ecord of Frasnian pelagic facies with goniatites (*Manticoceras*).

There is no evidence that the thick crinoidal limestone sequence (Khemis-n´Gha Formation) of the Safi region extends above the Lower Devonian (e.g. BULTYNCK & SARMIENTO 2003). New conodont samples from the strongly dolomitized top were not productive. However, large domal stromatolites or stromatopores (see BECKER & EL HASSANI 2020, fig. 10) show that the extensive neritic shoal gradually shallowed upwards, ending with a biostromal or microbial nearshore setting. In small depressions, an iron-rich dolomite breccia of unknown age covers the crinoidal platform (BECKER & EL HASSANI 2020, fig. 11).

In the strongly tectonized Bou Gader region of the Jebilet, Devonian sediments are still poorly known but are said to resemble the Jebel Ardouz lithologies (HUVELIN 1977; TAHIRI 1984; MAYOL 1987). Here lies potential for a better understanding of the palaeogeography in the southwestern Meseta. In the parautochthonous Devonian of the eastern Jebilet, at Jaidet, the Givetian has been identified in a flyschoid turbiditic facies (BECKER et al., this vol.), which is utterly different from the succession at Jebel Ardouz.

Very similar Middle Devonian occurs at a present-day distance of more than 100 km to the northeast, in the Mechra Ben Abbou region of the Rehamna (e.g., GIGOUT 1951, 1955; HOLLARD et al. 1982; BEN BOUZIANE 1995; EL KAMEL 2004; EICHHOLT et al., this vol.). Due to the significant post-sedimentary crustal shortening by folding and thrusting, the original spatial distance was perhaps twice as large. The Middle Devonian successions of Jebel Ardouz and Sidi bou Talaa are similar, with clear equivalents of the Mzoudia Formation composing members of the Mechra Ben Abou Formation. Comparable are also the overlying, mature and well-sorted, brachiopod–rich quartzites of the Oued el Biad and Douar Nahilat Formations (e.g., at Gare Mechra Ben Abbou, see Rehamna chapter). However, their stratigraphical correlation is not yet proven.

The Jebel Ardouz and Mechra Ben Abbou Devonian deposited originally in a single sedimentary basin. Differences of reef facies reflect original lateral differentiation. In both regions, reef growth terminated in the middle Givetian, obviously due to Eovariscan uplift. This was followed by a long phase of non-deposition and extreme condensation, with a very restricted record of localized Frasnian carbonate accumulation during transgressive episodes. Subsequent Eovariscan block tilting led to further gaps (no Kellwasser beds known), erosion, reworking and re-sedimentation. It was followed in graben positions (Foum el Mejez) by the accumulation of prodelta siliciclastics. The upper Famennian progradation of deltaic sandbars re-distributed probably eroded Lower Palaeozoic clastic material. The source seems to have been in the W/NW, the Imfout Ridge (e.g., BEN BOUZIANE 1995; EL KAMEL 2004). It is easier to feed the Jebel Ardouz and Mechra Ben Abbou sand bars from a common source in the west than to derive their material from the Anti-Atlas far in the south, especially because of the large gap of any Famennian sediment in the intervening western High Atlas region. The recently discovered Famennian of the Marrakech (LAZREQ 2017) and Central Jebilet (LAZREQ et al. 2021) regions represent deep shelf basin facies, which excludes an origin from the E/NE. Modern provenance studies would be helpful to further clarify the Famennian palaeogeography of the western Meseta.

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Devonian and the Carboniferous transgression in the Skoura region, Sub-Meseta Zone, Morocco

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Fig. 1: View on the Silurian-Devonian cliff below the Taliouine (= Tiliwine) village ca. 30 km N of Ouarzazate (Skoura region, southern foot of High Atlas), with Silurian black shale in the main slope, followed by yellowish weathering Pragian to lower Emsian nodular limestone and more solid cyclic pelagic limestones forming the cliff top (new Imi-n-Tazaght Formation), and greenish Daleje Shale equivalents (new Tizi-n-Ouourti Formation) in the background, below the reddish Permo-Triassic beds.

Abstract. The Sub-Meseta Zone forms the transition between the southern Meseta of the main Variscides and the Anti-Atlas realm. The Skoura region at the southern foot of the High Atlas includes a west-east, discontinuous sequence of Devonian and Lower Carboniferous outcrops, from Tizi-n´Tichka East in the NW of Ouarzazate to Asserhmo in the NE. Based on detailed logging, microfacies, conodont and macrofauna sampling, especially at Taliouine and Tizi n-Ouourti, the regional Devonian litho, bio- and event stratigraphy and facies development is revised. The Lochkovian is marked by a change from unfossiliferous black shales (Lower Member of new Tizi-n-Tichka Formation) to condensed, discontinuous, black, detrital Orthocone Limestones (Upper Member, middle Lochkovian) deposited under strong bottom current influence (contourites). Slumps and a subsequent erosional disconformity mark the regional tectonic episode Sk-TP-1a, followed by a distinctive "Antevariscan"

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conglomerate and reworking interval (Sk-TP 1b) that falls in the lower Pragian (Member 1 of new Imi-n-Tazaght Formation). The higher Pragian and lower Emsian are represented by cyclic, coarsening upwards successions of nodular limestones with trilobites and early goniatites (Members 2 and 3). At the top, Member 4 contains a *Mimagoniatites* marker level, partly interbedded within cross-bedded dacryoconarid calcarenites. The global Daleje Event is regionally very pronounced and led to an abrupt change to poorly fossiliferous green silty shales of the new Tizi-n-Ouourti Formation (Lower Member). The anarcestid-rich, nodular Upper Member is only locally well-developed, especially at Tizi-n-Ouourti. It is truncated at the top by the next regional Eovariscan erosion, unconformity, reworking and slumping phase that began in the Eifelian (Sk-TP 2a). The sedimentary record ended locally near the top of the Eifelian (Tizi-n-Ouourti) or a second slumping phase (Sk-TP 2b) began after the top-Eifelian Kačák Event Interval (Member 1 of new Taliouine Formation). The lower Givetian (Member 2) consists of well-bedded to nodular mudstones with some brief reworking episodes (Sk-TP 2c) near the base. The middle Givetian Member 3 includes hypoxic marls with maenioceratid faunas that strongly resemble the succession of the Tata region (Ahrerouch Formation) in the eastern Dra Valley. From the top of the middle to the upper Givetian, a third regional phase of Eovariscan block faulting (Sk-TP 3) caused the intercalation of thick, polymict conglomerate units (Member 4), followed by still poorly known Frasnian strata. Only in the east, the Asserhmo Formation is developed, a thick sequence of polymict conglomerates with reworked Ordovician to upper Famennian pebbles and isolated reef corals. It represents Sk-TP 4 and its origin may correlate with the similar breccia units of the Tinerhir region in the eastern Sub-Meseta Zone. In all of the Skoura region, a significant pre-middle Viséan erosion cut variable into Devonian or even Silurian beds. The oldest Carboniferous beds differ from place to place. At Taliouine, ca. 10 m of very fossiliferous neritic limestones with abundant brachiopods, large euomphalid gastropods, and bryozoans yielded very abundant foraminifers that provide a correlation with the middle Viséan V2a (Cf5α) fauna from Assif n´Tanzouzmine. The Skoura Devonian and Lower Carboniferous records an individual crustal development at the Meseta-Anti-Atlas transition, with lateral facies similarities fluctuating strongly in time, constrained by the repeated synsedimentary tectonic movements.

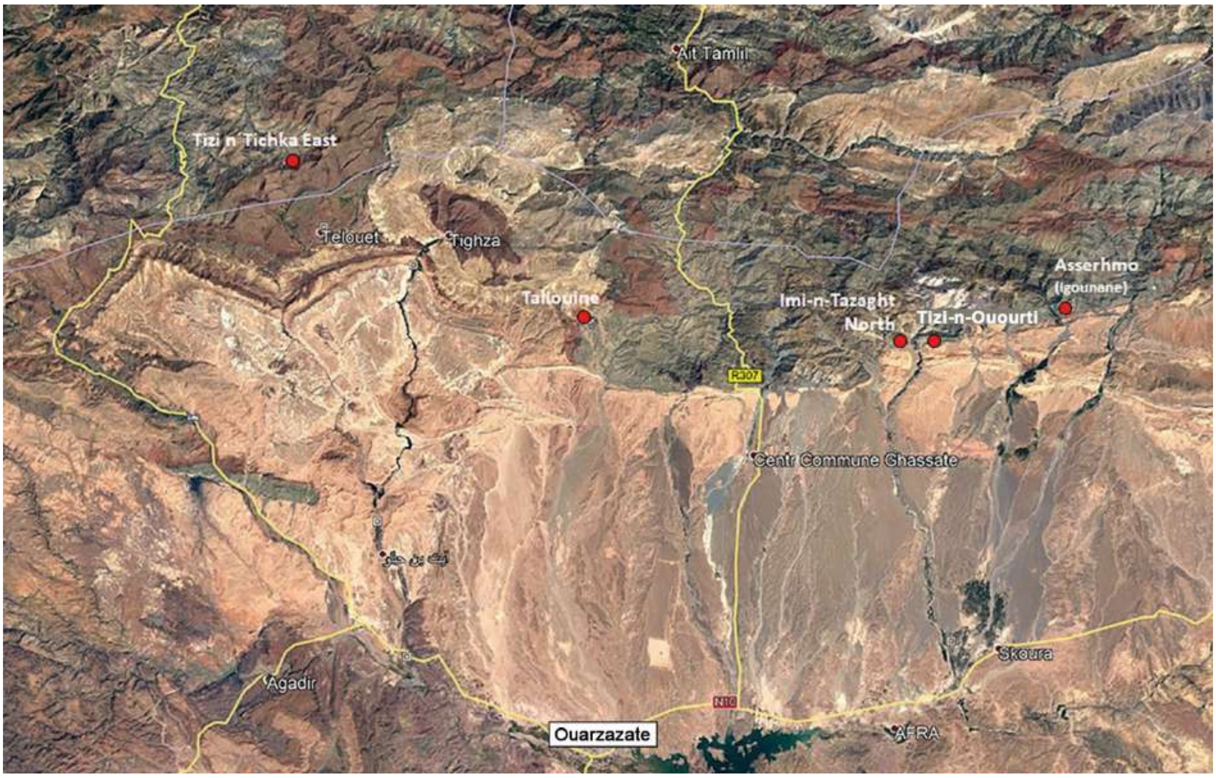

Fig. 2: Google Earth satellite image showing the position of important but each isolated Devonian localities in the wider Skoura region NW to NE of Ouarzazate and at the southern foot of the High Atlas. Separate Devonian and Viséan successions occur at Ait Tamlil in the north (picture width = 100 km).

1. Introduction

The wider Skoura region ("Pays de Skoura") includes from the NW to NE of Ouarzazate a discontinuous series of important Silurian to Lower Carboniferous successions at the southern foot of the High Atlas (Fig. 2), which are well-known since the work by ROCH (1939). They represent an intermediate palaeogeographic position between the Anti-Atlas in the south (eastern Dra Valley) and the southern parts of the western Meseta to the NW, such as the Jebilet. The Palaeozoic basement of the High Atlas, including Devonian and Lower Carboniferous strata, is also exposed to the north around Ait Tamlil (e.g., JENNY & LE MARREC 1980; ES-SADIQ et al. 2014; Fig. 2). Apart from mapping, the Skoura region Devonian remained practically unstudied in terms of modern litho-, bio- and chronostratigraphy in the last 50 years, although the early work documented rich faunas (e.g., TERMIER & TERMIER 1950c). Our new "pioneer work", with the first bed-by-bed logging, and sampling for microfacies, goniatites and conodonts, concentrated on three successions, from Taliouine (= Twiline or Tiliwine) in the west, via Tizi-n-Ouourti in the middle, to Asserhmo at the eastern end. We studied briefly the Devonian just north of Imi-n-Tazaght and paid a brief visit to the Devonian east of the Tizi-n-Tichka pass, which was included in a preliminary conodont study by LAZREQ & OUANAIMI (1998).

Our data enable a new lithostratigraphic subdivision, with six new formations that are partly subdivided into members. In brief, Silurian to Lochkovian black shales and limestones are assigned to the Tizi-n-Tichka Formation (with three members), Pragian to lower Emsian predominant nodular and cyclic limestones make up the Imi-n-Tazaght Formation (type-section at Taliouine, with four members), upper Emsian thick Daleje Shale equivalents (Lower Member) and overlying nodular goniatite limestones (Upper Member) are assigned to the Tizi-n-Ouourti Formation (type-section at Tizi-n-Ouourti), Eifelian to middle Givetian limestones, goniatite marls and overlying conglomerate-marl alternations form the Taliouine Formation (with four members); only locally developed, unsorted, polymict Famennian conglomerates are named as Asserhmo Formation. As previously noted (e.g., ROCH 1939; LAVILLE 1980), there are clear facies and thickness differences from west to east. For all new rock units, conodonts, ammonoids, or foraminifers (in the Viséan) provide precise ages, as a base for correlation with Dra Valley and southern Meseta successions (e.g., of the eastern Jebilet). We did not restudy the poorly known Ait Tamlil Devonian, which appears to be generally similar to the Skoura successions. However, WAFIK et al. (2017) noted from the Tighmart copper mine, slightly to the north, an anticline with mostly shaly-sandy Devonian strata.

2. Regional tectonic setting

The peculiar importance of the Skoura Devonian and Lower Carboniferous lies in its position near the southern margin of the Variscides. In fact, there are similarities with the Anti-Atlas successions and only the eastern sections, especially Asserhmo, are affected by strong deformation, characterizing the "Domaine oriental" east of the oblique Skoura Fault (OUANAIMI & PETIT 1992). Therefore, PIQUE et al. (1993) placed (most of) the Skoura Palaeozoic on the craton, south of the Atlas Palaeozoic Transform Zone (APTZ), which supposedly caused left lateral displacement in relation to the southern Meseta, which included the Ait Tamlil Devonian at the southern margin.

HOEPFFNER et al. (2005) introduced a "Southern Zone" of the Moroccan

Hercynides, running from the Tamelelt Inlier in the east to the Skoura Inlier in the west. An eastern continuation of the South Atlas fault was shown to run through the Skoura Palaeozoic, which would explain the west-east difference of tectonic style described by OUANAIMI & PETIT (1992). The model was refined by HOEPFFNER et al. (2006), who placed the Skoura Palaeozoic between the APTZ in the north and the South Moroccan Variscan Front (SMVF) in the south. The terminology was updated by MICHARD et al. (2008, 2010), who proposed the new Sub-Meseta Zone (SMZ, adopted here) to fall between the South Meseta Fault (SMF) in the north, replacing the APTZ, and the not well-defined South Atlas Fault (SAF), replacing the SMVF, in the south. The SMZ continues eastwards to the Tinerhir and Tinejdad regions, where the Devonian is either strongly tectonized or preserved as olistolites (e.g., MICHARD et al. 1982; FERONI et al. 2010; RYTINA et al. 2013). Recent studies showed that the Neoproterozoic basement of the Skoura Palaeozoic bears similarities with the Anti-Atlas successions (e.g., KARAOUI et al. 2019).

Our new data on stratigraphy and facies evolution document that the Skoura Lochkovian to lower Emsian had strong affinities with the eastern Jebilet, that the main upper Emsian was uniform in the whole region, and that after an Eifelian Eovariscan phase, the lower/middle Givetian was a continuation of the eastern Dra Valley. This facies development was terminated by upper Givetian Eovariscan movements as typical for all of the Meseta. The changing pattern in time emphasizes the intermediate structural position. It supports the view (BAIDDER et al. 2008) that there was no major plate tectonic boundary between the Anti-Atlas and southern Meseta in Devonian time. The local limitation of studied outcrops and complex nappe tectonics (e.g., LAVILLE 1980) reflect the post-Hercynian deformation.

3. Research History

GIGOUT (1937): Unpublished thesis on the High Atlas Palaeozoic.

ROCH (1939): Pioneer study on the Palaeozoic in the High Atlas realm (Ait Tamlil and "Pays des Skoura").

ROCH (1950): Brief summary of previous results.

TERMIER & TERMIER (1950c): First illustration of cephalopods from Taliouine and Tizi-n-Ouourti: *Hercoceras mirum* (coiled early nautiloid), *Mimagoniatites "bohemicus"* (aff. or a new species), *"Latanarcestes noeggerathi"* (auct.), *"Werneroceras ruppachense"* (probably a *Sellanarcestes*), "*Anarcestes* cf. *lateseptatus*" (clearly a *Sellanarcestes*), as well as from the Viséan at Tamzerit (*Prolecanites serpentinus*).

PETTER (1959): Description and illustration of ROCH´s *Mimagoniatites bohemicus* from Tizi-n-Ouourti, including a photo of the specimen illustrated as a drawing in TERMIER & TERMIER 1950c [the second specimen is deposited in the Paris Natural History Museum under MHNH.F.R53278].

AMBROGGI et al. (1952): Reference to ROCH´s upper Emsian anarcestid fauna.

HOLLARD (1967): Summary of the Devonian succession, based on unpublished new data by F. DUFFAUD, with an unusual record of a lower Emsian *Mimosphinctes* and a supposed record of Frasnian goniatite shales with "*Koenenites* cf. *lamellosus*" (= upper Givetian *Mzerrebites* record).

HOLLARD (1974): Occurrence of *Anetoceras* (= *Erbenoceras*) in the Skoura Emsian.

LAVILLE (1980): Monographic study on the tectonics of the "Boutonnière de Skoura", including a separation of western and eastern stratigraphic successions.

Fig. 3: View from the west on the thick Silurian black shales (Tizi-n-Tichka Formation, in the center, partly with reddish cover) overlain by a yellowish-weathering band of lower Emsian nodular limestones (Imi-n-Tazaght Formation) east of Tizi-n-Tichka, western end of Skoura Palaeozoic outcrop belt.

CHLUPÁČ & TUREK (1983): Questioning the *Mimag. bohemicus* identification of ROCH´s and PETTER´s Tizi-n-Ouourti specimens.
IZART et al. (1989): Stratigraphy and palaeogeography of the Skoura Viséan, with a new solitary rugose coral, *Caninophyllum skouraense* (nom. corr.).
LAZREQ & OUANAIMI (1998): Conodont data for the Lower Devonian of Tizi-n-Tichka.
OUANAIMI & LAZREQ (2008): Re-illustration of Tizi-n-Tichka section.
BECKER et al. (2015): Brief reference to „Antevariscan“ synsedimentary tectonics in the Lower Devonian of Taliouine.
KLUG (2017): Reference to HOLLARD´s *Mimosphinctes* record.
BECKER & ABOUSSALAM (2019): Reference to the presence of thick Daleje Shale equivalents above a *Mimagoniatites* marker limestone in the Skoura region.
BECKER et al. (2019): Note on the presence of lower Emsian goniatites at Taliouine.
CÓZAR et al. (2020a): Re-sampling and re-dating of the basal Viséan at Assif N´Tanzouzmine S of Taliouine.
BECKER & EL HASSANI (2020): Outline of conducted work in the Skoura region.

4. Devonian of Tizi-n-Tichka

Silurian and lower Devonian strata crop out east of the Tizi-n-Tichka Pass (Figs. 2-3), GPS N31°19´4.06´´, W7°19´19.72´´. Thick (> 200 m) black shales of the new Tizi-n-Tichka Formation form a wide northern slope and grade upwards into alternations with black limestones, Units a-b of LAZREQ & OUANAIMI (1998). Their Unit c consist of ca. 30 m marl-limestone alternation. A conodont fauna with *Caudicriodus postwoschmidti* and *Caud. eolatericresecens* was reported from the middle. However, *Caud. eolatericrescens* is now regarded as based on juveniles of other early icriodids (see DRYGANT & SZARNIAWSKI 2012). Therefore, it is a pity that the Tizi-n-Tichka specimens were not illustrated. The presence of lower Lochkovian icriodid taxa (MASHKOVA 1970; CORRADINI & CORRIGA 2012) requires confirmation. The massive Unit d represents locally the higher part of the Imi-n-Tazaght Formation (see below). The conodont record of LAZREQ & OUANAIMI (1998), with *Criteriognathus steinhornensis, Caud. sigmoidalis*, and *Eolinguipolygnathus excavatus excavatus*, is in full accord with a position in the ca. middle part of the lower Emsian (see ABOUSSALAM et al. 2015, *steinhornensis* Zone). Distinctive is a local debris flow level (Unit e), followed by ca. 60 m Daleje Shale equivalents (Unit f); the originally reported "Middle Devonian fauna" refers to the upper Emsian, which was widely included in the Eifelian before that stage was refined.

5. Devonian of Taliouine

The Devonian of Taliouine can be seen from the distance as a light-grey band above the mostly Silurian black shales (Fig. 4). The village sits on a solid limestone cliff, the Upper Member of the Imi-n-Tazaght Formation, and on the locally very thick, silty greenish shales of the lower Tizi-n-Ouourti Formation (Figs. 1, 5). We measured and sampled bed-by-bed three sections, the Lochkovian-lower Emsian section in the ravine below the village (Section 1, Figs. 1, 6, GPS N31°15´23.7´´, W6°59´0.89´´), the lower-upper Emsian transition just east of the village, and the Middle Devonian ca. 1.2 km east of village (north of the new 2019 piste leading eastwards).

5.1. Silurian-Lochkovian (new Tizi-n-Tichka Formation)

A thick package (up to 300 m, LAVILLE 1980) of black shale forms the lower part of the slope below Taliouine (Figs. 1, 4), the Tizi-n-Tichka Formation ("Schistes á Graptolites" in ROCH 1939, 1950). The Silurian-Devonian transition must lie within the black shale, followed higher by an "Antevariscan" (BECKER et al. 2015) unconformity. Based on graptolites from eastern sections (WILLEFERT in LAVILLE 1980), the thick main black shales (**Lower Member**) represent the Wenlock-Pridoli.

The Lochkovian to lower Emsian was logged along the western base of the ravine (Fig. 1), with a secondary section in the eastern slope. The **Upper Member** is characterized by an alternation of black shales with laminated, fine-grained, pyritic, partly concretionary limestones, which can be more than 40 cm thick (Bed 4 = G7; Figs. 6, 7.1). Macrofauna is rare apart from a few orthocones. Bed 2 (= G5, Figs. 7.1, 8.2) was sampled without success for conodonts. It is a laminated, dark-grey, argillaceous, microsparitic mudstone with some ostracods, minute calcispheres, very fine shell filaments, dispersed silt grains, and medium-sized, thin mollusk shells, which are embedded convex-up, and which partly cracked due to the overlying sediment load. There is short radiaxial cement growing from shell surfaces. The lamination is caused by variations in dark organic matter and thin, light-grey layers of recrystallized calcisiltite. The microfacies represents a deep, subphotic, anoxic (non-bioturbated), overall hostile shelf basin facies, deposited under mostly calm conditions. The thin calcisiltite bands represent short episodes of increased turbulence and decreased influx and preservation of organic matter.

The top of the member (Beds 6a-8 = G9-10, Figs. 6, 7.2) is characterized by irregularly bedded black limestones with detrital layers and with abundant orthocones (Beds 6b = middle G9 and 8 = upper G10), which filled an erosional relief above black mud-wackestone (Figs. 7.3, 8.3). HOLLARD (1967) noted for his black Lochkovian "Unit a" bivalves (*Panenka, "Lunulicardium"*).

Fig. 4: View on the Taliouine Devonian from the distance in the south, easily marked by the light-grey upper cliff of the lower Emsian Imi-n-Tazaght Formation below intensively red Permo-Triassic beds.

Fig. 5: Thick, poorly fossiliferous, greenish, silty Daleje Shale equivalents (Lower Member of Tizi-n-Ouourti Formation) exposed at the NE end of Taliouine village, locally intersected by Permo-Triassic redbeds.

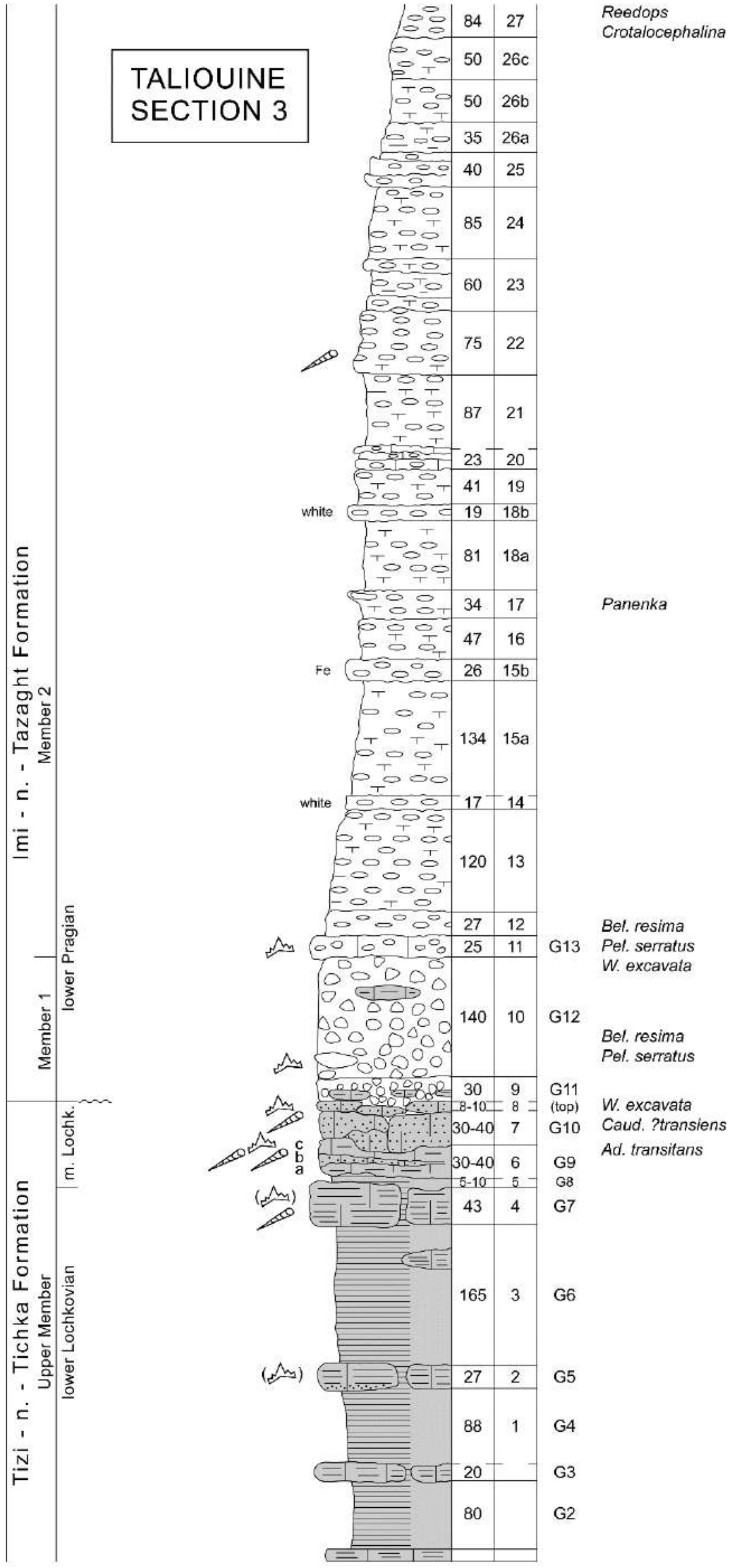

Fig. 6: Lithological succession, position of conodont samples and macrofauna in Taliouine Section 1 (Lochkovian to Pragian part) below Taliouine village (see Fig. 1). G2-13 = independent bed numbering of Greifwald Group.

Fig. 7: Field photos of the Upper Member of the Tizi-n-Tichka Formation at Taliouine, Section 1. **1.** Concretionary black limestones (Beds 0 and 2 = G3 and G5) intercalated between unfossiliferous black shale; white alum salt deriving from pyrite weathering; **2.** Concretion within Bed 3 (= G6) and the condensed, irregularly bedded top of the member (Beds G7-G10); **3.** Detail of Bed G9, showing internally (above the painted numbers) the sharp truncation of dark micrite by a bioclastic layer with abundant orthocones; **4.** Large *Deiroceras* embedded in marl between equivalents of Bed G9 (below, at hammer) and thin, lenticularly bedded bioclastic limestones of Bed G10; **5.** Excavated giant, corroded *Deiroceras* from 4., with an original total length around 1 m, high pyrite content weathered to orange-brown limonite/goethite (on future display in the Geomuseum Münster).

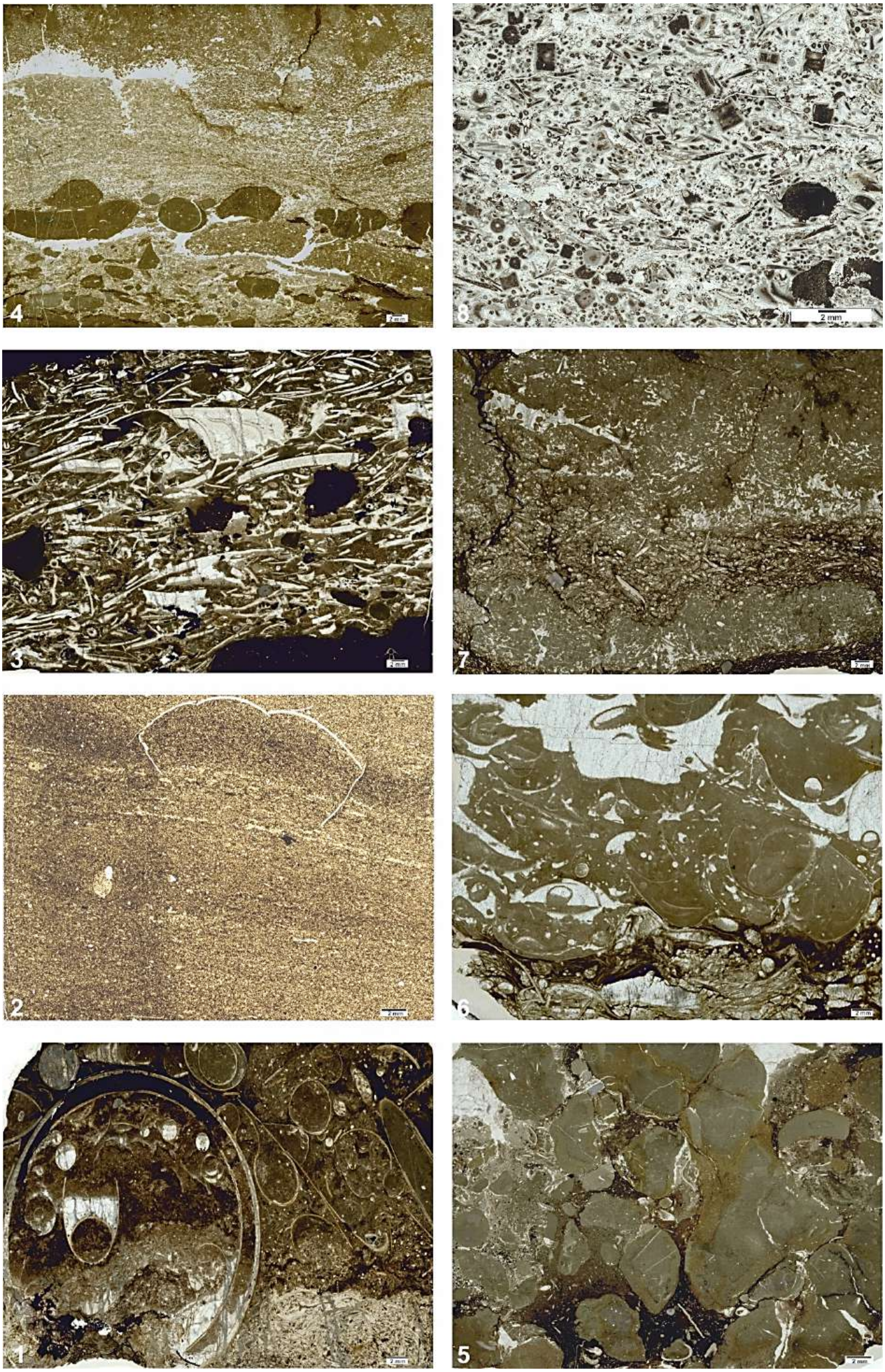
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Fig. 8: Microfacies of Lower Devonian limestones at Taliouine Section 1. **1.** Sparitic rudstone with orthocone and crinoid debris at the base, truncated by an undulating unconformity and overlain by orthocone floatstone with current orientation of variably sized specimens (slightly oblique to the thin-section plane), cone-in-cone stacking, geopetal orthosparite fillings, bivalved ostracods, and a matrix changing from bioclastic pack-grainstone at the base to organic-rich, dark, micritic wackestone at the top, Bed G10 on east slope of the ravine (top Tizi-n-Tichka Formation, Upper Member); **2.** Dark-grey (photo lightened in order to display details), argillaceous, laminated, microsparitic mudstone, with layers variably rich in dark C_{org}, minor dispersed silt content, thin (light) recrystallized calcisiltite layers, and isolated, partly broken (by sediment load), thin-shelled mollusk shells in convex-up position, Bed 2 (= G5), west side of ravine; **3.** Black, organic-rich mudstone (lower right corner) unconformably overlain by cephalopod rudstone, with mostly fractured and planar, current-oriented orthocones, variably sized, angular to torn black mudstone intraclasts reworked from below, small-sized crinoid debris, ostracods, and a dense micrite matrix, Bed 8 (= upper G10), top of Tizi-n-Tichka Formation, west side of ravine; **4.** Poorly sorted, conglomeratic, inversely graded intraclast float-rudstone with subangular to subrounded, partly flat mud-wackestone pebbles at the base, swimming in wacke-packstone matrix with styliolinids and ostracods, overlain by cross-laminated wacke-grainstone, and finally by bioturbated wackestone, Bed 9 = G11, base of Imi-n-Tazaght Formation (Member 1), west side of ravine; **5.** Coarse conglomerate, poorly sorted, non-graded intraclast rudstone with angular to rounded pebbles consisting of bioturbated pelagic mud-wacke-packstone with styliolinids and shell filaments, sitting in a variable matrix of bio-intraclast pack-grainstone with crinoid and trilobite debris, styliolinids, and shell fragments, which was locally washed out or impregnated by dark ferro-manganese minerals; note the concentric weathering of larger pebbles, Bed 10 = G12, Member 1 of Imi-n-Tazaght Formation; **6.** Rudstone with wavy-bedded, mollusk debris sitting in organic-rich wackestone or sparite matrix, overlain by bioturbated mollusk floatstone with ostracodes and dense micrite matrix, with geopetal filling of bioclast interspaces and orthocones by blocky, late diagenetic orthosparite, Bed 27, lower half of Member 2 of Imi-n-Tazaght Formation; **7.** Alternating, flaser-bedded, bioturbated nowakiid wacke- and packstone with minor crinoid debris and micrite matrix that has partly been washed out; the thin packstone layer shows cone-in-cone stacking, current-orientations, and lies above an undulating erosional surface, indicating episodic winnowing and reworking within a contour-current regime, base of Member 3 of Imi-n.-Tazaght Formation; **8.** Styliolinid-crinoid grainstone with ferro-manganese impregnations of clasts and bimodal orientation of the sand-sized cones (from left to right and normal to the thin-section plane), caused by deep-marine bottom currents during peak-flow conditions, Taliouine Section 2, top of Member 4 of Imi-n-Tazaght Formation (see Fig. 17.5).

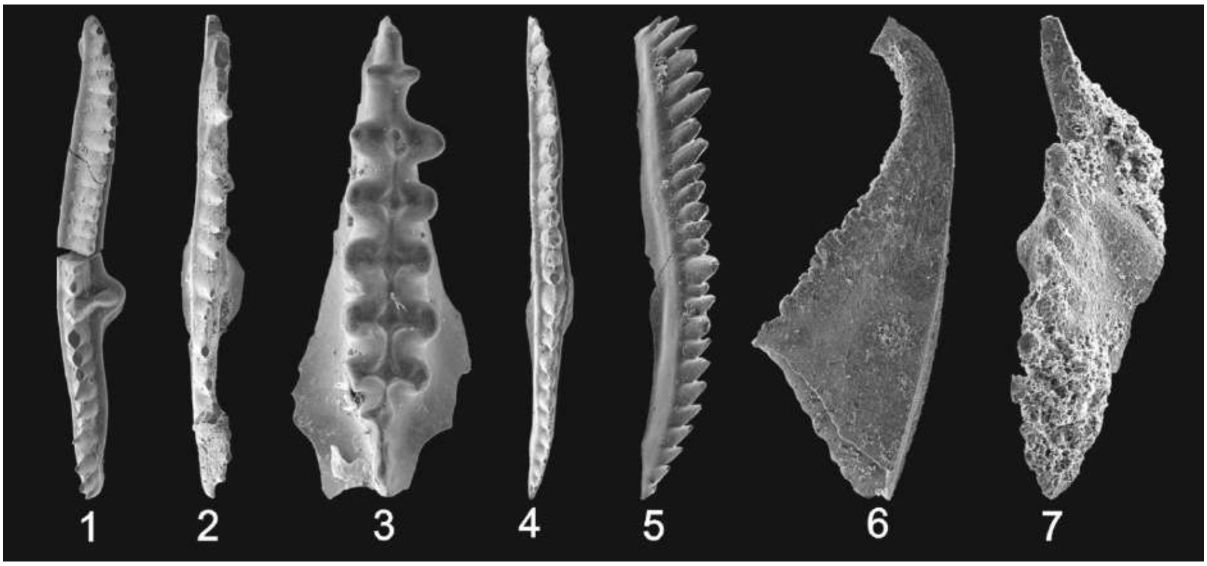


Fig. 9: Lochkovian and Pragian conodonts from Taliouine Section 1; GMM B4C.2.149-154. **1.** *Wurmiella* aff. *wurmi*, with well-defined, small side node, eastern slope, upper Bed G10, x 25; **2.** *Wurmiella wurmi*, eastern slope, upper Bed G10, x 45; **3.** *Caudicriodus ?transiens*, identified due to the number of rows with distinctive nodes and the gently widening basal cavity, posterior part broken off, Bed 8 (= upper G10), x 60; **4-5.** *W. wurmi*, Bed 8 (= upper G10), x 35; **6.** *Belodella resima*, Bed 9 (= G11), x 45; **7**. *Pelekysgnathus serratus*, Bed 9 (= G11), x 65.

Some of the orthocones reached a length of more than 1 m (Fig. 7.5). A longitudinal section (Fig. 10) of one of the giants proved that it belongs to the actinoceratid *Deiroceras hollardi* KRÖGER, 2008. In the Tafilalt, it characterizes a basal Emsian marker unit, the *Deiroceras* Limestone (see ABOUSSALAM et al. 2015), but the widespread genus is known to have a much lower range, down into the Ordovician. For Tafilalt *Deir. hollardi* sizes > 1.5 or even > 2.5 m have been documented or calculated; but from the lower Emsian, not from the Lochkovian (POHLE & KLUG 2018).

Fig. 10: Longitudinal section through the annuli-cyrtochoanitic siphuncle of the actinoceratid *Deiroceras hollardi* from the top of the Tizi-n-Tichka Formation at Taliouine Section 1, picture width 4 cm; GMM B6C.54.190.

A conodont sample from Bed 6c (= upper G9) yielded a single *Ancyrodelloides transitans* (Fig. 11.1), the index species of the middle Lochkovian *transitans* Zone (e.g., CORRADINI & CORRIGA 2012). The species is known from black orthocone limestones of both the Meseta (Oued Cherrat, BECKER et al. 2020a) and the eastern Dra Valley (LAZREQ & OUANAIMI 1998). Associated are broken *Wurmiella* and a probably new pelekysgnathid provisionally identified as *Pel.* n. sp. aff. *elongatus* (Figs. 11.2-3; see taxonomic appendix). Typical *Pel. elongatus* occur in the middle Lochkovian of Spain (e.g., CARLS & GANDL 1969; GARCÍA-LÓPEZ et al. 2002) and Bohemia (e.g., SLAVÍK et al. 2012), which agrees with the age of our specimens.

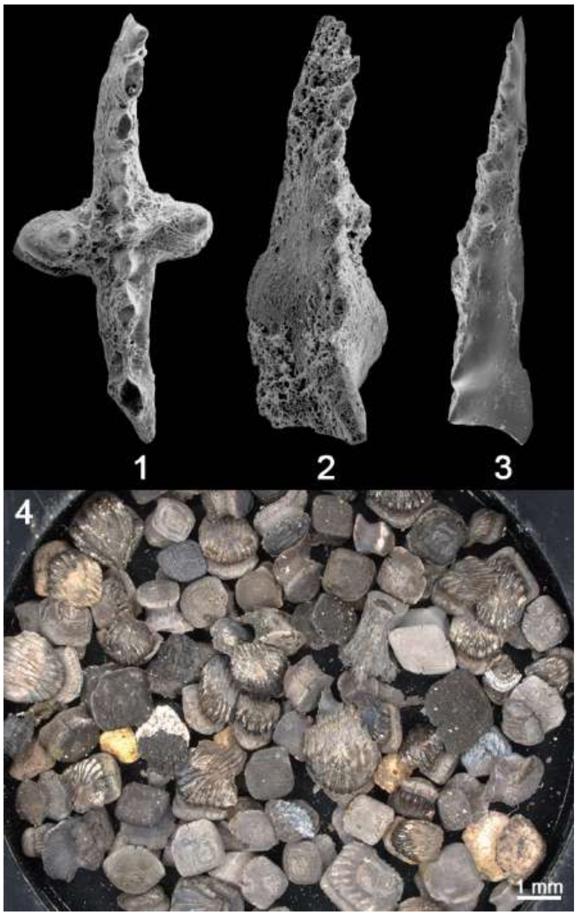


Fig. 11: Conodonts and fish scales from the top Tizi-n-Tichka Formation at Taliouine Section 1. **1.** *Ancyrodelloides transitans*, upper view, Bed 6c (= upper G9), GMM B4C.2.155, x 60; **2-3.** *Pelekysgnathus* n. sp. aff. *elongatus*, two specimens (GMM B4C.2.156-157) with upper and slightly oblique views, Bed 6c (= upper G9), x 60 and x 65; **4.** View on one of five microfossil slides filled with rhombic acanthodian scales (GMM A1C.5.2, Bed 8 (= upper G10).

In Bed 8 (= upper G10), there is a strange, elsewhere unknown (at least in pelagic facies) sudden mass influx of rhombic acanthodian scales (Fig. 11.4). Acanthodian scales are not a normal element of black cephalopod limestones and their scales are even rare in the lower Emsian, where the large-sized *Machaeracanthus* can be common, for example in the Tafilalt (LEHMAN 1976, 1977; KLUG et al. 2008) but also at Tizi-n-Ouourti (see below). The *Machaeracanthus* scales look very different than the ones from Bed 8 but the taxonomic position of that genus is doubtful. Associated conodonts of Bed 8 (upper G10) are *Wurmiella "excavata"* auct. (10 specimens), *W. wurmi* (Figs. 9.4-5), and a *Caudicriodus ?transiens*. (Fig. 9.3). On the eastern side of the ravine, just above the marl with a giant *Deiroceras* (Fig. 7.5), detrital limestones of Bed G10 produced *W.* aff. *wurmi* (Fig. 9.1) and also *W. wurmi* (10 specimens excluding fragments).

Whilst *Caud. transiens* occurs around the lower-middle Lochkovian boundary, *W. wurmi* ranges throughout the middle-upper Lochkovian (e.g., CORRADINI & CORRIGA 2012). The absence of typical upper Lochkovian species in two samples suggests that the top of the Tizi-n-Tichka Formation is not younger than the middle Lochkovian.

The microfacies of Bed 8 = top G10 (Fig. 8.3) is complex. At the base, there is organic-rich, black, pelagic mudstone with minute calcispheres or, laterally, black ostracod wacke-packstone, mostly with single-valved ostracod debris, and with the fragment of a small-sized tabulate coral. This unit is truncated by unsorted and non-graded orthocone float-rudstone with dense, light-grey micrite matrix, deposited during a high-energy depositional event. It transported mostly crushed (Fig. 8.3) and recrystallized orthocone shells of variable size, some with dark micrite, some with orthosparite filling, small-sized crinoid ossicles, ostracods, trilobite fragments, dacryoconarids, the acanthodian scales, and intraclasts. The latter are black mudstones or middle-grey microsparitic limestones derived from below. There is finely dispersed pyrite that sometimes impregnated shells.

The top of Bed G10 on the other side of the ravine has a similar, complex microfacies (Fig. 8.1) but the orthocones are partly better preserved. A high current regime led to cone-in-cone stacking and parallel orientations. At the base, there is a rudstone composed of orthocone debris, with ostracods, crinoid ossicles, rare trilobite fragments, and largely washed out micrite matrix. Above an undulating unconformity, an orthocone floatstone follows. Right above the erosional surface, the matrix is bioturbated, organic-rich ostracod-shell debris packstone with partly preserved micrite matrix. The latter persisted in the middle part, grading upwards into black, very organic-rich wackestone with ostracods, crinoids, and calcispheres. The filling of the orthocones is also variable, ranging from geopetal orthosparite filling to middle-grey wackestone with ostracods and abundant fine pyrite dispersed in dense micrite matrix, microsparitic wackestone, to bioturbated wackestone with styliolinids. This variability suggests that cephalopods were washed together from different sources.

The erosive unconformities within the beds, erosion of unconsolidated intraclasts and fossils from variable underlying units, planar to wavy deposition of coarse shell debris without removing the micrite matrix, and the lack of sorting or grading point to reworking followed by gravity-induced rapid sedimentation from turbulent density flows. This is supported by the irregular bedding and slumping (Fig. 13.3), as evidence for syndepositional seismic activity ("Antevarican" phase, BECKER et al. 2015).

5.2. Pragian to lower Emsian (new Imi-n-Tazaght Formation)

Pragian to lower Emsian nodular limestones are assigned to the new Imi-n-

Tazaght Formation, which is subdivided into four members. The name stems from the village in the upper, eastern reaches of the Oued Tagraga, between localities Imi-n-Tazaght North and Tizi-n-Ouourti (Fig. 2), which both have good outcrops of the formation. However, we select Taliouine as the type locality, where we have logged bed-by-bed the complete formation and where Member 1 at the base is best developed. The main part of the formation is bioturbated (nodular to flaser-bedded) and strongly cyclic (Figs. 6, 13), representing perhaps Milankovitch cyclicity controlled alternations of carbonate versus clay/marl deposition. Faunas are shallow pelagic, with benthos consisting of trace fossils, various trilobites and *Panenka* bivalves, with often large orthocones and rare goniatites as nekton, and abundant dacryoconarids as calcareous plankton. Despite this, the conodont record is extremely sparse. Coarsening upwards is indicated by a trend towards thicker interbeds of pack- and grainstone within the cyclic-bedded limestones.

5.2.1. Conglomeratic Member 1

Member 1 of the Imi-n-Tazaght Formation consists of two beds (Beds 9-10 = G11-12, 1.7 m, Fig. 6) of yellowish to light grey weathering, poorly sorted, non-graded conglomerate (Figs. 8.1, 12, 13.1). Pebbles are a few mm to ca. 10 cm large, subangular to subrounded, partly flat (Fig. 8.4). Bed 9 (= G11) shows a complete grading upwards from sudden intraclast redeposition to background "pelagic rain" accumulation (Fig. 12). In the lower third, up to 4 cm large pebbles of mud-wackestone with styliolinids, shell filaments, and some ostracods float in a fine matrix of wacke-packstone with ostracods, styliolinids, subordinate crinoid debris and shell filaments, interrupted by sparite fenestrae that also fill large interspaces between pebbles. In the upper part of the conglomeratic interval, the micrite has been washed out more strongly and there is debris from trilobites, crinoids, mollusks, ostracods, as well as fine intraclasts. A single small clast consists of *Rectangulina*, a small-sized algal colony of uncertain affinities that is typical for pelagic limestones (e.g., HOUSE et al. 2000; BECKER et al. 2016).

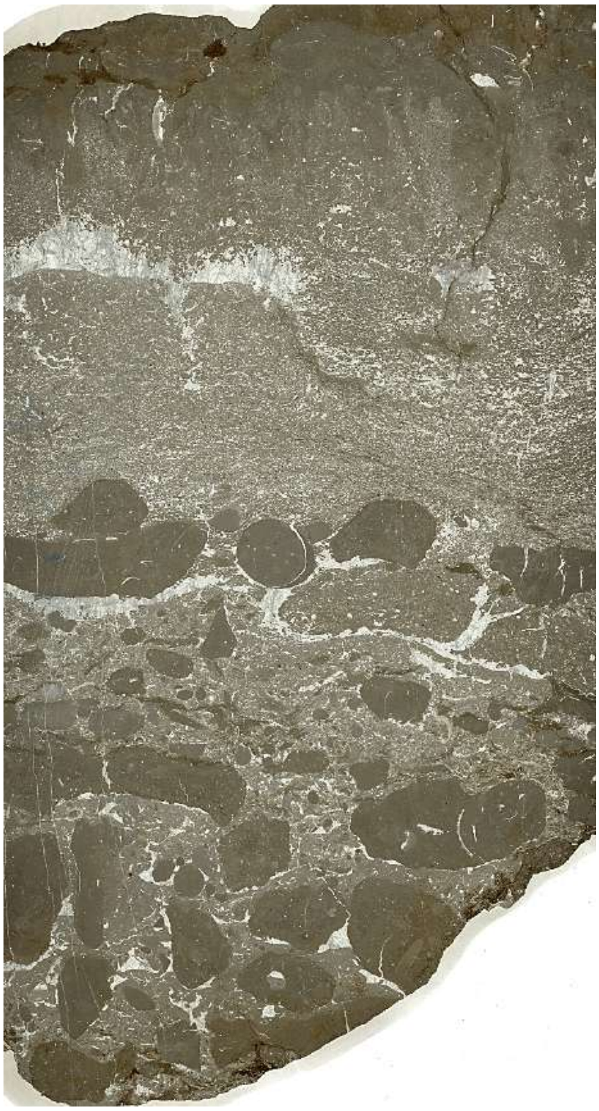


Fig. 12: Complete thin-section and depositional sequence of the lower conglomerate (Bed 9 = G11) at the base of the Imi-n-Tazaght Formation (Member 1) at Taliouine Section 1. Unsorted and non-graded conglomerate (intraclast floatstone) with dacryoconarid mud-wackestone pebbles, increasing washing out of the micrite matrix and sparite replacement, overlain by wavy-laminated styliolinid grainstone with *Stromatactis*, grading into styliolinid wackestone and bioturbated mudstone at the top, the normal pelagic background sediment; picture width 6 cm.

The conglomeratic interval is overlain by wavy-laminated, fine-grained peloid-styliolinid grainstone indicating decreasing but persisting bottom current energy. Intercalated typical *Stromatactis* near the top indicate interruption phases. Above these, there is a gradual transition into wacke- to mudstones with decreasing amounts of styliolinids, ostracods, shell filaments, and increasing bioturbation and flaser-bedding at the top. Along diagenetic dissolution seams microsparitization proceeded.

The conglomerate microfacies of Bed 10 (= G12) is different (Fig. 8.5). Subrounded to subangular, rarely well-rounded pebbles show no sorting or grading. The clasts consist mostly (ca. 80 %) of poorly-preserved, middle-grey, bioturbated styliolinid wacke-packstone with shell filaments and rare ostracods. Subordinate are middle-grey mud-floatstones with few styliolinids and rare orthocones or large mollusk fragments. Rather peculiar are concentric seams of very fine pyrite, a diagenetic feature that obviously postdated early lithification and pre-dated the redeposition. The matrix is rather heterogeneous, ranging from blocky orthosparite to light-/middle-grey bio-/intraclast packstone with debris of crinoids, styliolinids, trilobites, and mollusks. As diagenetic features, there are abundant idiomorphic pyrites and microsparitization. In some parts with dacryoconarids and calcispheres, there is a massive impregnation by ferro-manganese minerals.

In both beds there are subordinate reworked black mudstone clasts of variable size from the underlying upper Tizi-n-Tichka Formation (Fig. 13.2). The dominant clasts made of light- to middle-grey mud- to packstone pebbles prove that the organic-rich, hypoxic Tizi-n-Tichka facies was originally overlain by oxic pelagic facies. Conodonts date them as lower Pragian, based on rare *Pelekysgnathus serratus* (Fig. 8.7) and *Belodella resima* (Fig. 8.6) from the base of Bed 10 (= base G12). The first is the index species of the *serratus* Zone recognized in the lower Pragian of Bohemia (SLAVÍK 2004). It is possible that the marked facies change was caused by the global regression at the Lochkovian-Pragian boundary (e.g., TALENT et al. 1993; WALLISER 1996; BECKER et al. 2020a). However, it seems that the upper Lochkovian is missing in the Skoura region. Since we do not know whether our *Pel. serratus* came from pebbles or the conglomerate matrix, the reworking and re-sedimentation occurred either low or ca. in the middle of the Pragian. The lack of sorting, strong size contrast between pebble size and fine matrix, and the polymict pebble composition suggest deposition from two submarine density flow events. They reflect a re-activation of the fault zone that previously caused the top middle Lochkovian slumping. Block faulting of Pragian age is not common in the Meseta or Anti-Atlas.

5.2.2. Nodular Member 2

Member 2 consists of 47.5 m, cyclic, yellowish to light-grey, marly nodular shales and limestone with abundant orthocones (especially in the lower part, Fig. 13.4), pelagic bivalves (mostly *Panenka*, Fig. 15.2), trilobites (Fig. 14), and pyritic intervals marked by white sulfate weathering minerals (Figs. 6, 13.1). ROCH (1939, 1950) misleadingly called the unit “Calcaires du Ludlow”. HOLLARD (1967) recognized it as Unit b (“marno-calcaires grumeleux à tentaculites”, with phacopids), and LAVILLE (1980) used the term “marno-calcaires beige”. A basal more solid nodular limestone (Bed 11 = G13; Fig. 6) yielded four *Pel. serratus*, associated with *Wurmiella “excavata”* auct. (12 specimens), and *Belodella resima* (two specimens). This suggests that the member begins higher in the lower Pragian, probably directly after the conglomerate deposition.

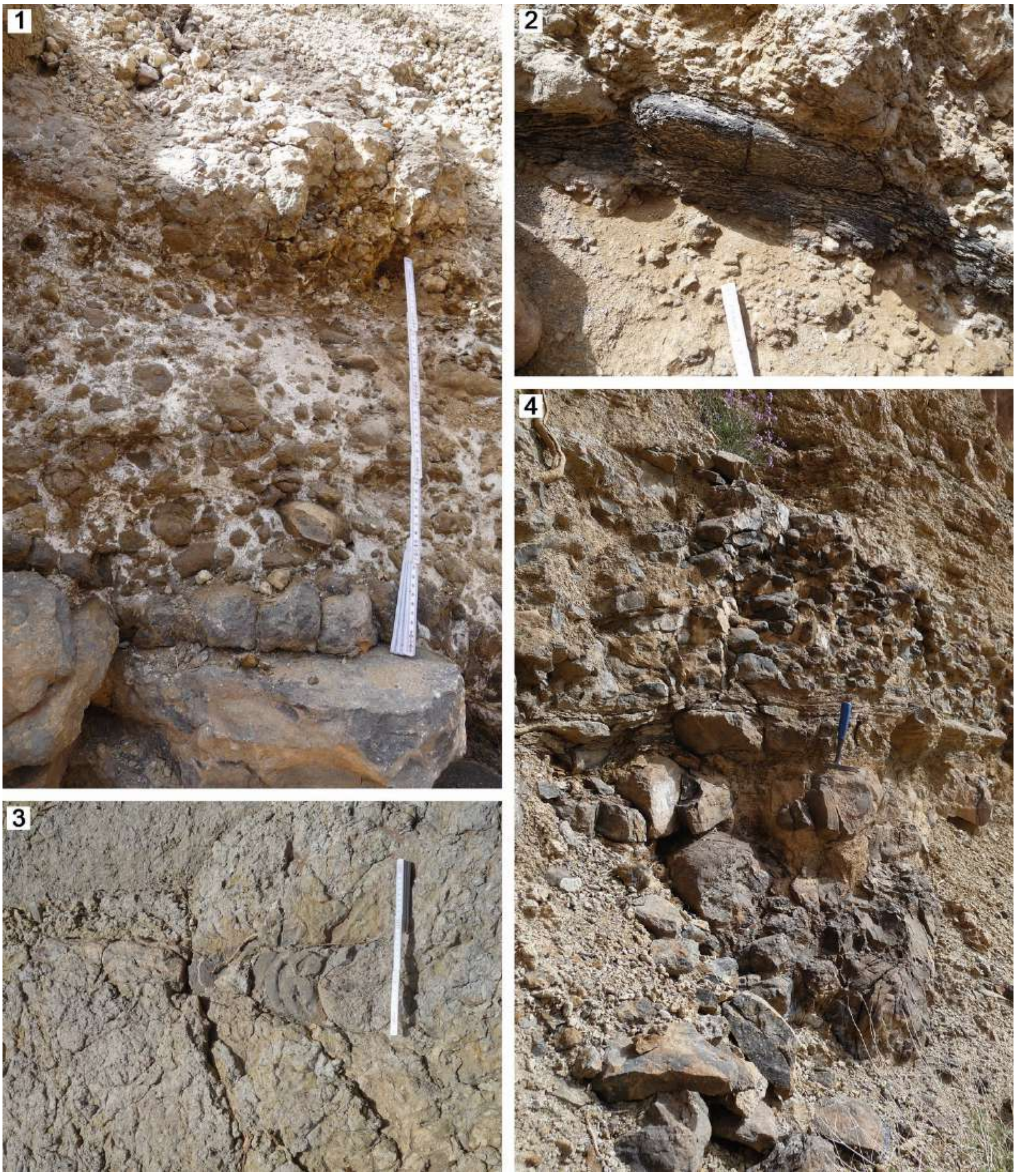


Fig. 13: Field photos of the Lochkovian-Pragian transition at Taliouine Section 1. **1.** Truncation of the top of the Tizi-n-Tichka Formation by the coarse-grained Eovariscan conglomerate at the base of the Imi-n-Tazaght Formation (Member 1), main section, west side of the ravine; **2.** Large slab of black limestone within the conglomerate, reworked from the top Tizi-n-Tichka Formation; **3.** Poorly preserved giant orthocone with moderately dense septal spacing and large apical angle (unlike as in *Deiroceras*) from upper Pragian nodular limestones (lower part of Member 2 of Imi-n-Tazaght Formation); **4.** Eastern slope of the ravine, showing slumping of the Upper Member of the Tizi-n-Tichka Formation, followed by the layer of large *Deiroceras* (of Fig. 5.4) and subsequent, thin- to wavy-bedded black limestones (Bed G10) that are sharply overlain by the coarse Pragian conglomerate (Member 1 of Tizi-n-Tazaght Formation).

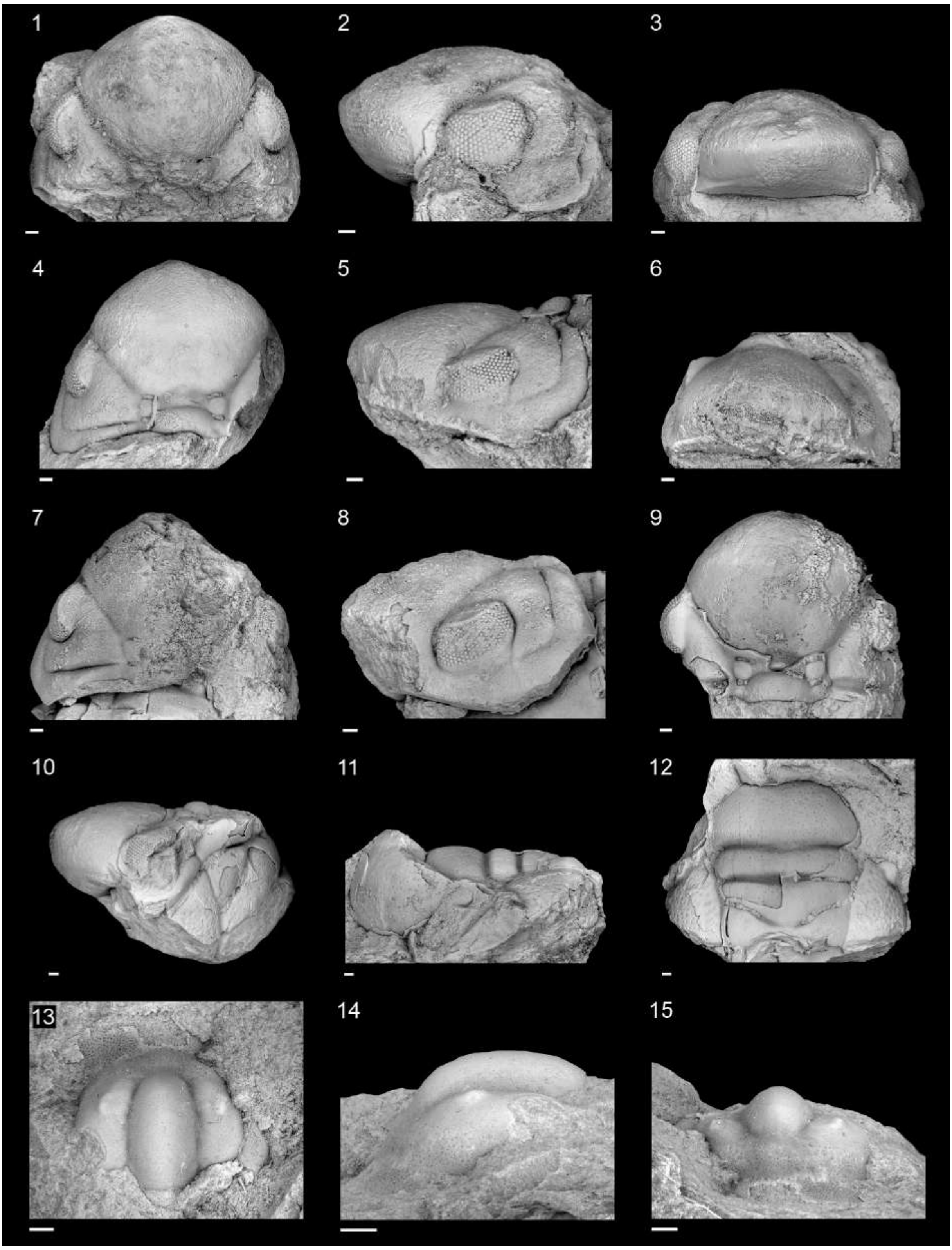


Fig. 14: Trilobites from the Pragian (loose from the higher part of Member 2 of Imi-n-Tazaght Formation, Section at Taliouine; scale bar = 1 mm. **1-3.** *Reedops* cf. *cephalotes hamlagdadianus* ALBERTI, 1983, GMM B7A.12.1; **4-6.** *Reedops* n. sp., GMM B7A.12.2; **7-8.** *R.* cf. *maurulus* ALBERTI, 1970, GMM B7A.12.3; **9-10.** Nodule with *R.* cf. *cephalotes hamlagdadianus* (GMM B7A.12.4) and *Cheirurus (Crotalocephalina)* sp. aff. *gibbus auster* ALBERTI, 1970 (GMM B7A.12.5); **11-12.** *Cheirurus (Crotalocephalina)*? sp., GMM B7A.12.6; **13-15.** *Harpes* sp., GMM B7A.12.7.

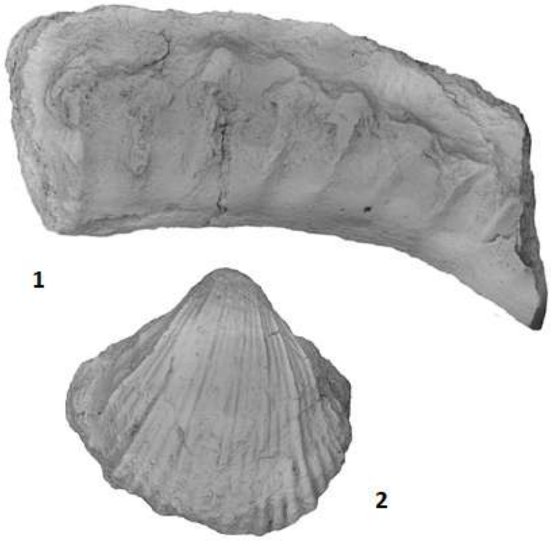


Fig. 15: Mollusk molds from the Imi-n-Tazaght Formation at Taliouine Section 1. **1.** Fragment of last gyroconic whorl of an *Erbenoceras advolvens*, Bed G177, leg.O. MAYER, lower Emsian, lower part of Member 3, GMM B6C54.191. **2.** Small-sized *Panenka* sp. with uneven sharp ribbing, Member 2, Bed 40, upper Pragian, GMM B6A.37.2.

The interval from Beds 27 to 42 yielded various trilobites. There are three species of phacopids, *Reedops* cf. *cephalotes hamlagdadianus* (Figs. 14.1-3, 9-10), *Reedops* n. sp. (Figs. 14.4-6), and *R.* cf. *maurulus* (Figs. 14.7-8). The first is a typical Pragian form of the Tafilalt (ALBERTI 1983), the third a Pragian species of the Rabat-Tiflet Zone (ALBERTI 1970). Cheirurids, such as *Ch. (Crotalocephalina) gibbus*, are typically associated (ALBERTI 1970); the subspecies identification of the Taliouine representative (Figs. 14.9-12) is not clear. The incomplete *Harpes* (Figs. 14.13-15) is an interesting record because the Pragian Harpetida of Morocco are still insufficiently known. In terms of lithology and trilobite assemblages, there are similarities of the Taliouine trilobite levels with the Pragian *Reedops* Limestone of Hassi Nebech in the eastern Tafilalt (BECKER & ABOUSSALAM 2015, p. 114).

The loose teicherticeratid collected from around Bed 27 is much younger and was probably derived from above. *Teicherticeras* is rare in Morocco but has been recorded from LD III-C (DE BAETS et al. 2010; ABOUSSALAM et al. 2015). The position of the Pragian/Emsian boundary is currently placed roughly at the top of Member 2.

Fig. 16: Strongly cyclic Imi-n-Tazaght Formation in the northern end of the ravine of Taliouine Section 1, with Lahssen BAIDDER and Ahmed EL HASSANI for scale, the latter sitting on beds with large orthocones.

Fig. 17: Bimodal current orientation of large orthocones at the top of Member 3 of the Imi-n-Tazeght Formation just east of Taliouine village.

The microfacies of Bed 27 shows that long episodes of calm pelagic sedimentation were occasionally interrupted by periods with weak bottom-currents (contourites). High-energy conditions resulted in the fragmentation of mollusks, forming rudstones of recrystallized shells, and with subordinate trilobite debris. The matrix is organic-rich micrite with calcispheres or sparite. The overlying mollusk floatstone (Fig. 8.6) is characterized by abundant geopetal orthosparite fillings of shells or interspaces and a dense micrite matrix with ribbed nowakiids, fine shell filaments, ostracods, and trilobites.

5.2.3. Cyclic Member 3

This unit was called in ROCH (1939, 1950) as "Calcaires eifeliens", in HOLLARD (1967) as "calcaires bleus á entroques et polypiers, terminus par des calcaires à *Panenka*, and marnes et marno-calcaires à tentaculites avec un banc lie-de-vin" (Units c-d), and in LAVILLE (1980) as "calcaire à entroques – Emsien". The thickness is in the range of 20-25 m (Figs. 1, 16). Typical are light-grey, strongly cyclic, flaser-bedded, bioturbated bioclastic limestones that are poor in macrofauna in the main cliff. Well-exposed bedding planes covered by bimodally oriented large orthocones (Fig. 17) or *Panenka* are typical at the top, just east of the village. The cyclicity is caused by subtle variations in the carbonate mud/skeletal grain ratio.

A conodont sample from the member base yielded *Caudicriodus celtibericus*, which ranges from the upper Pragian into upper parts of the lower Emsian (*inversus* Zone, ABOUSSALAM et al. 2015). The whorl fragment of a subadult *Erbenoceras advolvens* was collected in-situ in Bed G177 (Fig. 15.1), laterally to the main ravine, from a nodular interval in the lower part of Member 3. The species ranges in the lower Emsian from LD III-B to C (e.g., KLUG 2001; DE BAETS et al. 2010; BECKER et al. 2019).

The microfacies of the basal bed (Fig. 8.7) shows nowakiid wackestone with shell filaments, interrupted by sharply bounded layers of nowakiid packstone with cone-in-cone stacking, bimodal current alignments, and a minor amount of crinoid debris. The dense, middle-grey micrite matrix has partly been washed out, creating small sparite fenestrae. In comparison to Bed 27 (mollusk rudstone), the cyclic occurrence of nowakiid packstone layers, which show a systematic thickening upwards, indicate increasing bottom-current intensity. The increase of bottom currents prevented the settling of clay and coincides with a regressive phase, which is in accord with the eustatic trend high in the lower Emsian (e.g., BECKER et al. 2020a).

5.2.4. Member 4

The ca. 5 m thick Member 4 was not separated by ROCH (1939, 1950) from Member 3 but recognized as Unit e ("calcaires à *Panenka*") by HOLLARD (1967). It includes two subunits. A lower nodular limestone exposed in Section 2 (Fig. 18.1) contains abundant *Mimagoniatites* (Fig. 18.2), orthocones, *Pananeka* mass occurrences (Figs. 18.3), and current-related shell hash beds with cladochonid tabulate corals, small orthids, crinoid debris, styliolinids, and striatostyliolinids. The microfacies of Bed A (Fig. 19) is a flaser-bedded, strongly bioturbated/intercalated mixture of dark dacryoconarid (mostly nowakiids) and light-grey mollusk debris wacke-packstone with rare gastropods.

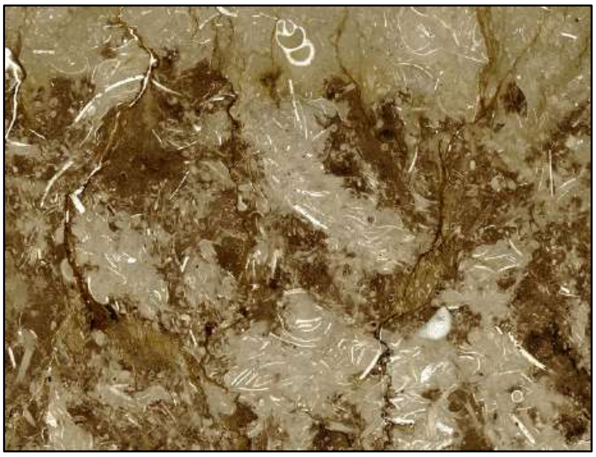


Fig. 19: Microfacies of the lower part of Section Taliouine 2, Bed A (lower subunit of Member 4 of Tizi-n-Ouourti Formation): strongly bioturbated (mixed) wacke-packstone, variably with abundant dacryoconarids and high C_{org}, or shell filaments and a gastropod (picture width = 32 mm).

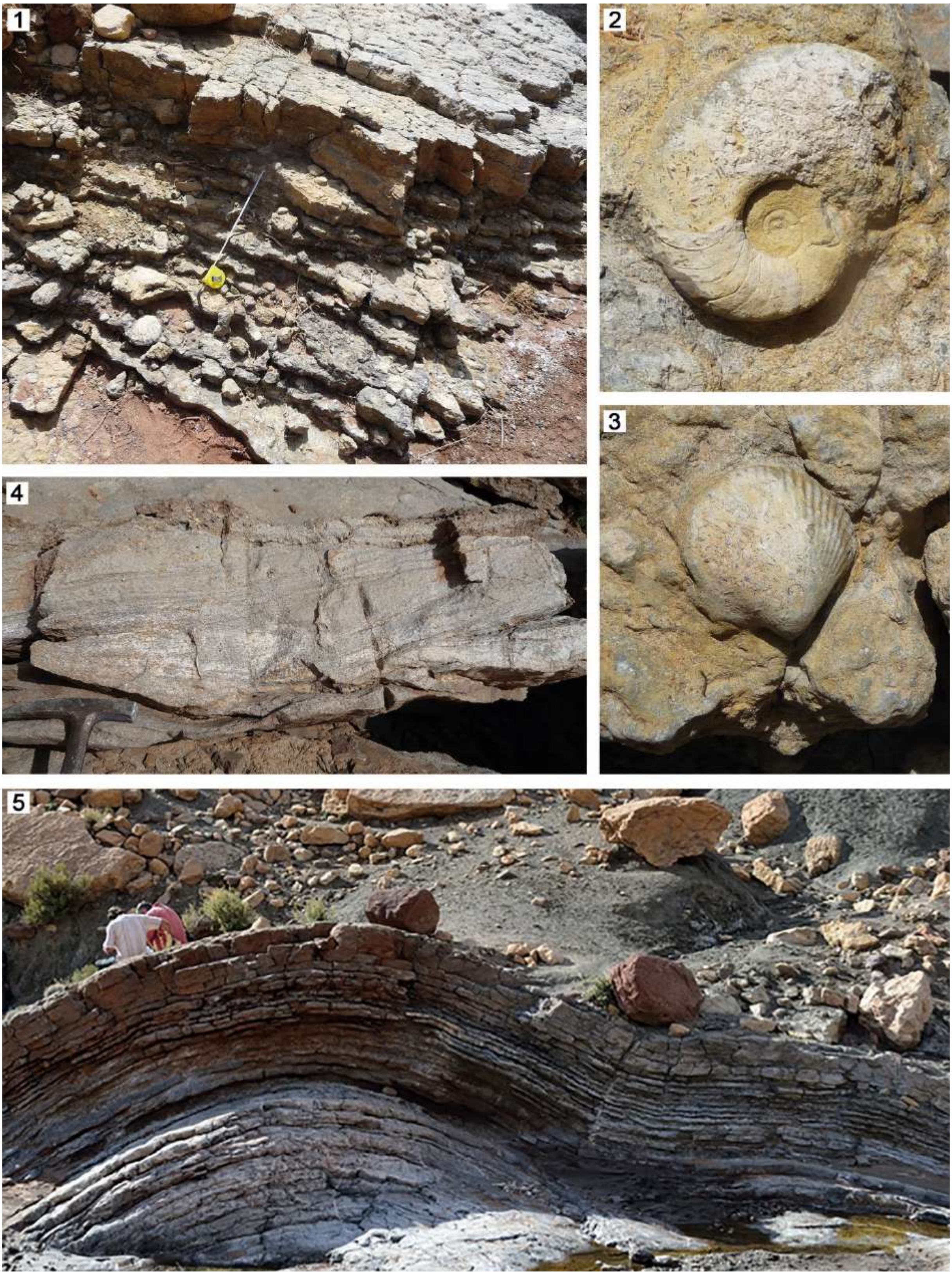


Fig. 18: Field photos of Member 4 of the Imi-n-Tazaght Formation. **1.** Thin-bedded, very fossiliferous nodular limestones of Section 2, lower subunit with goniatites; **2.** *Mimagoniatites* sp., strongly compressed species, in-situ from thin Bed E, ca. at the end of the measuring stick in 1., 4 cm diameter, GMM B6C.54.192; **3.** Locally abundant finely ribbed species of *Panenka* from the same bed, length = 3 cm, GMM B6A.37.2; **4.** Cross-bedded styliolinid grainstone (contourite) from the upper subunit east of Section 2; **5.** "Folding" of the top part of the Imi-n-Tazaght Formation and Member 4 normal to the overall Variscan folding, perhaps caused by buckling adjacent to normal faults and against the soft overlying shales of the basal Tizi-n-Ouourti Formation.

The *Mimagoniatites* was assigned by Hollard (1967) to *Mim*. cf. *zorgensis* but our specimens suggest that it is a different, strongly compressed species, not *Mim. fecundus*, the valid senior synonym of *Mim. zorgensis* (Chlupác & Turek 1983). *Mimagoniatites* defines genozone LD III-D near the top of the lower Emsian (Becker & House 1994). In the Anti-Atlas, a late lower Emsian epibole of the genus can be found from the Tafilalt Platform to the eastern (Jansen et al. 2004a) and western Dra Valley (Becker et al. 2008; Becker & Aboussalam 2011; Aboussalam et al. 2015). Within Member 4, F. Duffaud found the first North African *Mimosphinctes* (recorded by Hollard 1967) but the specimen has never been figured or described (see Klug 2017), and its whereabouts are unknown. *Mimosphinctes* is the index genus of LD III-E (Becker & House 2000d). Therefore, Member 4 comprises the complete LD III-D/E interval, as the *Mimagoniatites* Limestone of the eastern Anti-Atlas (Becker et al. 2019). Despite the pelagic facies, a conodont sample was barren, which fits the poor Tafilalt conodont record of the same interval (Aboussalam et al. 2015). The top bed of the short Section 2 shows again numerous large, current-oriented orthocones.

Following the beds on strike to the east, to the small oued that feeds the ravine of Section 1, there are good exposures of the top of the formation and member (upper subunit). It is characterized by cross-bedded dacryoconarid grainstones (Fig. 18.4), which represent calcarenitic contourite deposits formed at conditions of vigorous bottom currents. A conodont sample from the top limestones of Fig. 18.5 was, again, barren. The microfacies shows a nowakiid grainstone with a minor amount of crinoid, mollusks, and trilobite debris (Fig. 9.8). There is fine syntaxial cement growth around nowakiid cross-sections while crinoid pieces are surrounded by rim cements. Deep impregnation or coating by ferro-manganese minerals is very common. The main matrix is late diagenetic blocky orthosparite.

Towards the east, normal faults cause an upslope repetition of the succession. The upper subunit forms wide gentle "folds" (Fig. 18.5) with axes normal to the direction of the regional Variscan folds. These are interpreted to have resulted from buckling associated with the normal faulting. The overlying green shales provided no rheological resistance to the seismic energy; the folds, but not the faults, continue in the shale unit.

5.3. Upper Emsian (new **Tizi-n-Ouourti Formation)**

All upper Emsian strata are assigned to the Tizi-n-Ouourti Formation, which is well exposed at the name-giving type locality (see below). At Taliouine, the thickness is considerably higher but the upper part is incomplete and strongly affected by Eovariscan synsedimentary movements and slumping.

5.3.1. Lower Member (greenish shale)

The limestones of the Imi-n-Tazaght Formation are sharply overlain by dark-grey to greenish-grey, silty, poorly fossiliferous, resistant shales (Figs. 18.5, 20), the Lower Member of the Tizi-n-Ouourti Formation. It forms rather steep slopes and can be seen from the distance as a lithostratigraphic marker (Fig. 1). Rare fossils are preserved as siderite nodules, which suggest eutrophic and hypoxic conditions. There are incomplete orthocones and a solitary rugose coral (deep-water type), which do not provide a biostratigraphic age. According to the sketch in Laville (1980), a thickness in the scale of 300 m can be assumed (see the same value given for Unit g of Hollard 1967). Roch (1939, 1950) noted the lack of fossils but called the unit "Schistes eifeliens". It has to be recalled that upper

Emsian strata where still included in the Eifelian at his time. Based on the faunas from right below and above, there is no doubt that the Lower Member is an equivalent of the Bohemian Daleje Shales and especially of the lithologically similar lower member of the Amerboh Formation of the Tafilalt (e.g., BECKER et al. 2013, 2018a: Unit K).

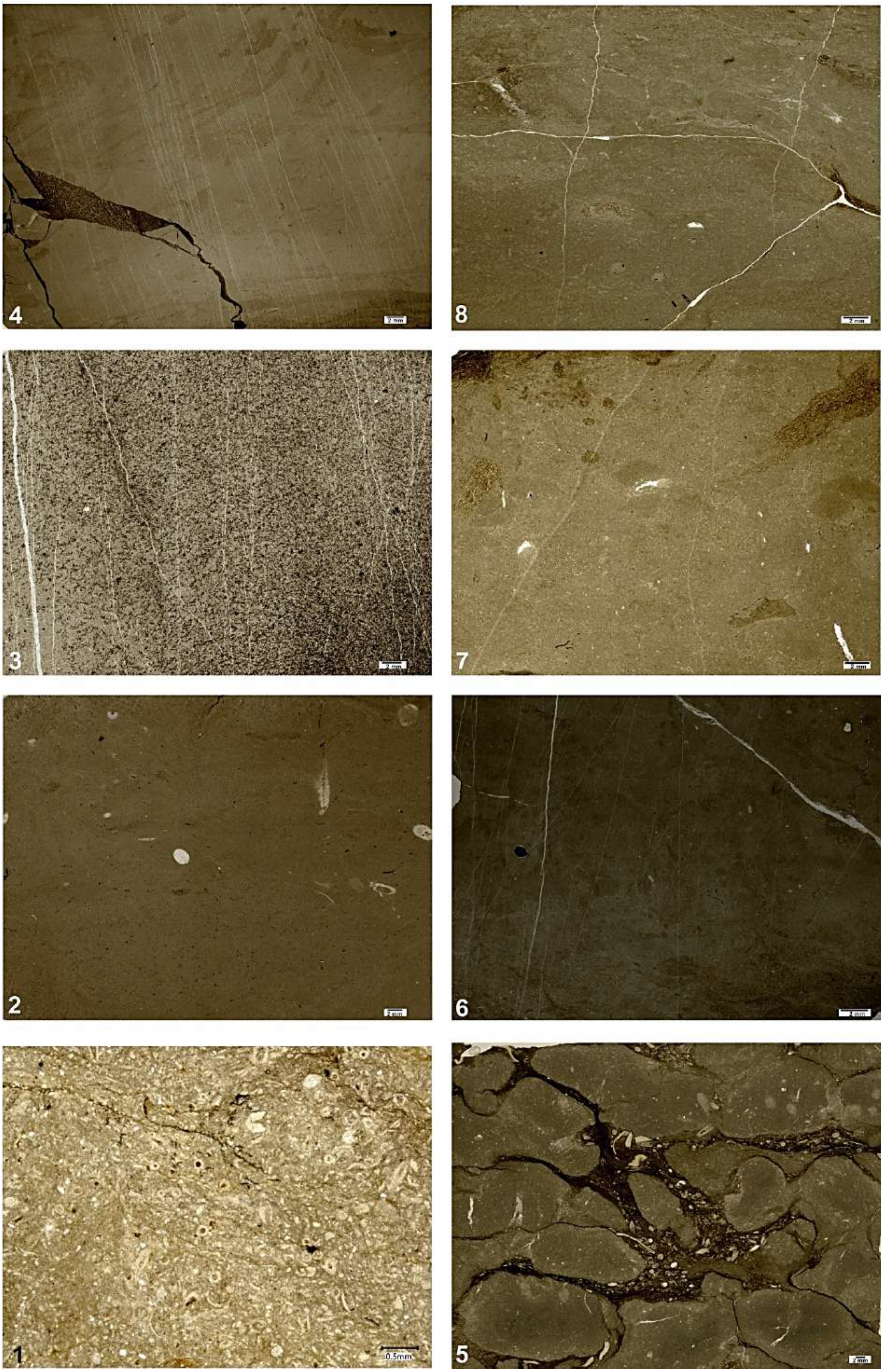
Fig. 20: Thick succession of almost unfossiliferous green, silty shales forming the Lower Member of the Tizi-n-Ouourti Formation ca. 600 m east of Taliouine.

5.3.2. Upper Member (Anarcestid Limestone olistolites)

The shales of the Lower Member become gradually dark-grey. Our Section 3 lies in a narrow ravine starting from the new piste to the east, ca. 1.2 km northeast from the last houses of Taliouine village (at N31°16′00.64′′, W6°58′41.89′′). On the northeastern ravine side, numerous small blocks of light- or dark-grey limestone and isolated fossils (olistolites) lie without any orientation in the upper part of the Tizi-n-Ouourti Formation and form a slump unit, the Upper Member. In the middle part of the steep southwestern slope, there is a large, internally bedded glide block of upper Emsian limestone. A conodont sample from its middle part yielded ten specimens of *Linguipolygnathus bultyncki*, an alternative index species of the *serotinus* Zone, which is also more frequent than the nominal zonal species in the eastern Anti-Atlas (ABOUSSALAM et al. 2015). The suite of loosely collected macrofossils adds to the similarity with the *Anarcestes* Limestone of the Tafilalt and *Sellanarcestes*-rich limestones (LD IV-D_1, *An. crassus* Subzone) of the Dra Valley (BECKER et al. 2004c, 2004d; EBBIGHAUSEN et al. 2004, 2011):

"Latanarcestes noeggerathi" auct. (Figs. 20.5-6; see TERMIER & TERMIER 1950c, pl. 145, figs. 4-6; possibly = *An*. cf. *subnautilinus* in ROCH 1939)
Sellanarcestes wenkenbachi
Sellanarcestes applanatus (Figs. 20.1-2; probably = *An.* cf. *lateseptatus* and *An.* cf. *crispus* in ROCH 1939, = *Werneroceras ruppachense* in TERMIER & TERMIER 1950c, pl. 145, figs. 15-16, = *An.* cf. *lateseptatus* on pl. 146, fig. 1)
Anarcestes simulans
Anarcestes crassus
Achguigites tafilaltensis
Panenka div. sp. (Fig. 20.7)
large orthocones (Figs. 20.3-4, *Temperoceras*)
solitary Rugosa
phacopid trilobites (poorly preserved)

Fig. 21: Representative macrofauna from the upper Emsian of Taliouine, Section 3, all figures in natural size. **1-2.** Mature *Sellanarcestes applanatus*, lateral and adoral views, body chamber occupying the full last whorl, leg. A. EL HASSANI, GMM B6C.54.193; **3.** Large orthocone with central siphuncle, lateral view GMM B6C.54.194; **4.** Septal view of a very similar second fragment, GMM B6C.54.195; **5-6** "*Latanarcestes noeggerathi*" auct., lateral and ventral views, GMM B6C.54.196; **7.** Large *Panenka* sp., GMM B6A.37.4.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8
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Fig. 22: Microfacies of carbonates from Taliouine Section 3, partly enlightened in order to display details. **1.** Bioturbated, recrystallized dacryoconarid wacke-packstone with shell filaments and thickly encrusted nowakiids, upper Emsian glide block in the SE slope of Taliouine Section 3 (enlightened); **2.** Pelagic mudstone with rare shell filaments, crinoid ossicle, and a sparite-filled orthocone, Bed 4; **3.** Strongly recrystallized (microsparitic) and organic-rich mudstone, almost without fossils, Bed 5 (enlightened); **4.** Mudstone with discrete burrows filled by darker carbonate mud, Bed 9 (enlightened); **5.** Nodular "conglomerate" (intraclast rudstone formed by in-situ brecciation), with subrounded mudstone pebbles and interspaces invaded by coarser-grained wacke-packstone matrix with ostracods and other bioclasts, impregnated by ferro-manganese minerals, Bed 17; **6.** Dark brownish-grey, organic-rich, bioturbated mudstone, Bed 28a (enlightened); **7.** Light-grey bioturbated mudstone with distinctive burrows in the upper part, filled by darker, more organic-rich mud, Bed 39b; **8.** Middle-grey, bioturbated, partly flaser-bedded mudstone, Bed 44c.

Taliouine Section 3																
conodont zones	*serot.*	*hemiansatus*			*timorensis*								*rhen./varcus to ansatus*			
Bed and sample no.	**U. Ems**	**4**	**7**	**9**	**15**	**17**	**28a**	**39b**	**44a**	**46**	**55**	**67**	**71**	**81**	**kgl1**	**kgl2**
L. bultyncki	10															
L. linguiformis		1			13	6			0.5			4	2	3		4
L. weddigei		1														
Po. hemiansatus		1			4											
Linguipolygnathus sp.			0.5							0.5						
Po. pseudofoliatus				3	11											
I. cf. *difficilis*					4											
I. obliquimarginatus						3	1	1?								
Po. parawebbi									0.5			1			1	
Po. timorensis												2	1			1
I. regularicrescens												1?			2	
Po. varcus															1	2
Po. rhenanus															1	
I. difficilis															2	
Bel. resima															2	
Oz. plana																1
total conodonts	**10**	**3**	**1**	**3**	**32**	**9**	**1**	**1**	**1**	**1**	**0**	**8**	**3**	**3**	**9**	**9**

Tab. 1: Conodont ranges in the upper Emsian to middle Givetian at Taliouine Section 3.

ROCH (1939) added a pleurotomariid gastropod and the early nautiloid *Hercoceras mirum*, which is better known from the upper Emsian of Bohemia (TUREK 2007). The microfacies of the middle part of the large glide block is a dark-grey, bioturbated dacryoconarid wacke-packstone with some mollusk filaments, crinoid debris, and rare bryozoan fragments (Fig. 21.1). Recrystallization led to a poor preservation of many bioclasts. Ribbed nowakiids are encrusted by thick cement and show no current orientation. The environment was a eutrophic, calm, pelagic carbonate ramp.

5.4. Eifelian/Givetian (new Taliouine Formation)

The unfossiliferous black alum shales at the base of Section 3 are thought to represent the global Kačak Event Interval since the directly overlying limestones defining the base of the Taliouine Formation yielded *Polygnathus hemiansatus*, the basal Givetian index species. It enters just above the main event interval in the Jebel Mech Irdane GSSP of the Tafilalt (e.g., WALLISER et al. 1995; WALLISER & BULTYNCK 2011).

5.4.1 Member 1 (black limestones)

Member 1 is the lower part of Unit h of HOLLARD (1967). It is characterized by medium-bedded, partly chaotically arranged (slumped, with angular unconformities, Fig 23), argillaceous, black limestones (Beds 2-9, Fig. 26). The reworking of middle upper Emsian anarcestid limestones and the subsequent absence (by erosion or non-deposition) of top-Emsian to lower Eifelian limestones suggests that a local third interval of Eovariscan seismic activity occurred in the higher Eifelian. This is supported by evidence from Tizi-n-Ouourti (see below). The next regional block faulting phase causing the slumping began just above the Eifelian-Givetian boundary. Accordingly, the slumped and lenticular Bed 4 yielded *Po. hemiansatus* (Fig. 27.3) in association with *Linguipolygnathus* (e.g., *L. weddigei,* Fig. 27.3). Bed 4 is a poorly fossiliferous mudstone (Fig. 22.2) with only a few small crinoid ossicles, rare ostracods, and a sparite-filled small orthocone. It is increasingly microsparitic (recrystallized) in the upper part. A few dacryoconarids show syntaxial fine cement growths into the organic-rich matrix.

In the overlying Bed 5, the recrystallization is even stronger and the fossil content even poorer (Fig. 22.3). The lack of lamination is distinctive. Bed 7 yielded only a fragmentary linguipolygnathid, Bed 9 *Po. pseudofoliatus*, a species that ranges in the Anti-Atlas from the middle Eifelian into the Givetian (BELKA et al. 1987). While the base of Bed 9 is laminated, the main part shows irregular evidence of burrowing, with darker mud filling of feeding traces (Fig. 22.4).

5.4.2 Member 2 (oxic pelagic mudstones)

Member 2 (upper Unit h of HOLLARD 1967) starts with Bed 13 (Fig. 26) and is defined by light-grey limestones that are partly argillaceous (especially in the upper part) and that alternate with levels of nodular shale (e.g., Beds 29, 37, 40, 42-43) and, near the top, shale/marl (Beds 56, 61). Macrofauna is poor, with the exception of reworked shells, including trilobites, at the top of Bed 17. The total thickness is 11.2 m.

Fig. 23: Irregular bedding indicative of strong slumping of detrital basal Givetian limestones embedded in black alum shale at the base of Section Taliouine 3 (base Taliouine Formation); white color from weathered pyrite.

A limestone from ca. 1.5 m above the section base, collected during reconnaissance a year before the bed-by-bed logging (ca. Bed 15), yielded the name-giving marker species (Fig. 27.8), *Po. pseudofoliatus* (Figs. 27.9-10), *L. linguiformis* (Fig. 27.7), and an icriodid that is close to *I. difficilis* (Fig. 27.6). True *difficilis* indicate a younger, middle Givetian position (BULTYNCK 1987; GOUWY & BULTYNCK 2002). The microfacies of the bed is complex (Fig. 24, enlightened), with evidence for reworking and synsedimentary tectonics. From base to top the following subunits are recognizable:

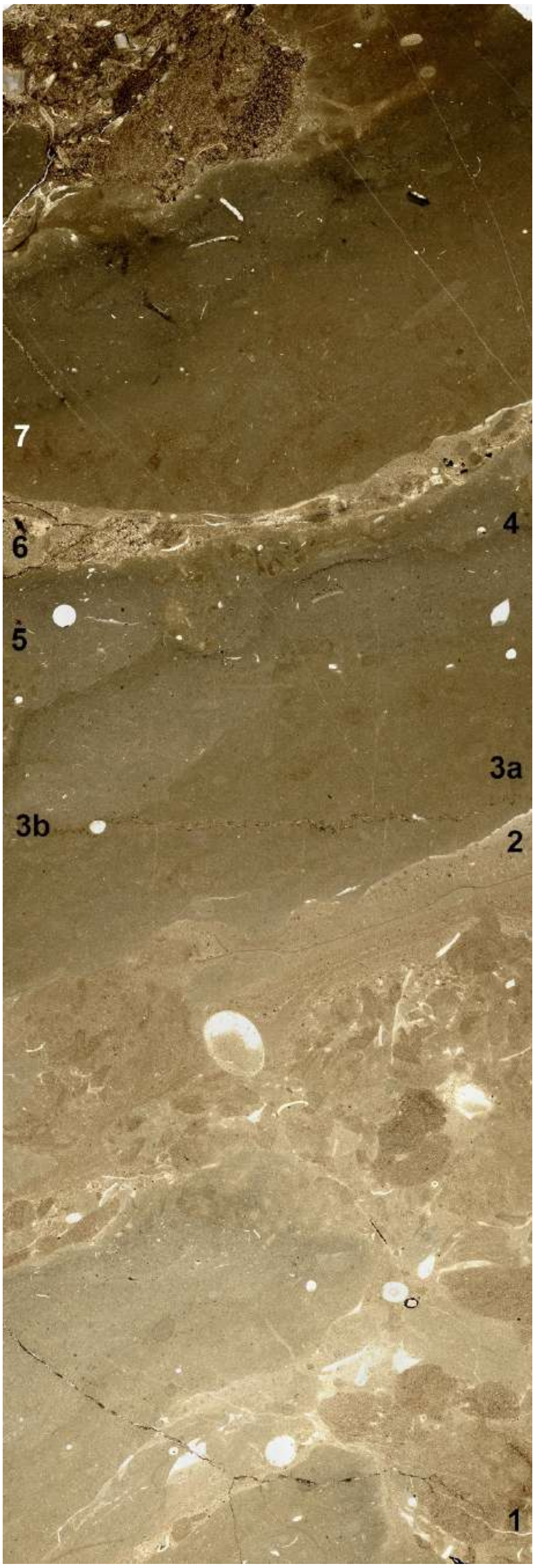

Fig. 24: Complex microfacies of Bed 15, ca. 1.5 m above the base of Member 2 of the Taliouine Section 3.

1. Ca. 10 cm conglomerate with unsorted, non-graded, partly flat pebbles reaching 5 cm or more, consisting variably of middle-grey mudstone with a few shell filaments or some orthocones, or slightly darker but smaller, subrounded pebbles consisting of microsparitic mudstone. The matrix ranges from lighter-grey microsparitic mudstone to floatstone with crinoid ossicles, dacryoconarids (showing syntaxial, radially growing cements), and sparite-filled orthocones. The top is formed by a laminated, slightly peloidal mudstone.
2. Undulating, sharp discontinuity surface marked by a laterally fading sparite seam.
3. Ca. 2 cm non-laminated mudstone with single bivalved ostracods (3a) and a minor discontinuity (3b) within.
4. Third undulating discontinuity surface marked by a seam of fine, dispersed pyrite/hematite.
5. Ca. 0.5-1 cm slightly coarser and peloidal mudstone with shell filaments, orthocones and burrows coming partly from the top.
6. Crack filled above an undulating discontinuity by strongly recrystallized bio-intraclast wacke-packstone with debris from mollusks, trilobites, crinoids, and some dacryoconarids.
7. Ca. 7 cm large pebble of mudstone with burrows (Fig. 25).
8. Erosional truncation, followed by recrystallized bioclastic wacke-packstone similar as in 4. The trilobite debris is rather thin-shelled.

The strongly polyphase deposition suggests the interruption of generally calm, deep shelf mudstone facies by four different high-energy events. The first originated from a debris flow and formed the unsorted and polymict mudclast conglomerate (Fig. 25.1). The weaker second event led to scouring on the seafloor and a sedimentary break marked by the sparite seam (Fig. 24). The third also caused scouring, but during increasingly anoxic conditions, causing an alignment by minute pyrite aggregates. The fourth was caused by a stronger bottom current moving and embedding a large, bioturbated mudclast in a coarse-grained, detrital layer.

2

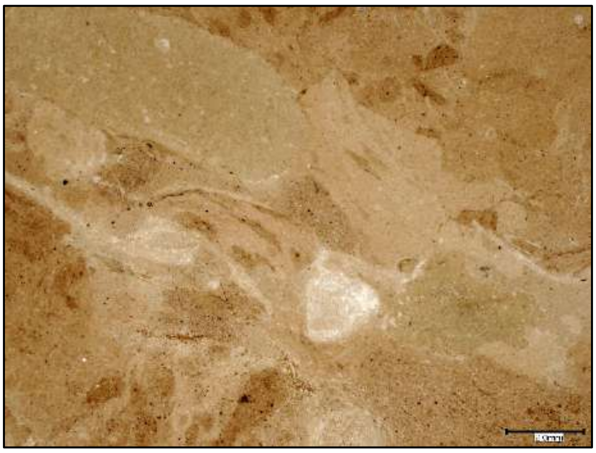

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Fig. 25: Microfacies details of Fig. 24. **1.** Partly flat mudstone pebbles in the lower part of the conglomeratic debris flow Unit 1; **2.** Details of the abundant trace fossils (burrows) below and above unconformities 4 and 5/6 (both photos enlightened).

Bed 17 represents superficially a second, nodular weathering "conglomerate" (Fig. 22.5). A sparse conodont fauna with *Icriodus obliquimarginatus* (Figs. 27.11-12), an alternative basal Givetian marker species, and *L. linguiformis* suggests a position just slightly higher in the *hemiansatus* Zone. At the base, there is a layer of wavy-laminated microsparitic mudstone. Above, the thin-section suggests an in-situ brecciated pelagic mudstone with rare shell filaments, ostracods, and nowakiids. Interspaces between the 1 to 20 mm large, subrounded clasts were invaded by a much coarser wacke-packstone matrix with abundant ostracods, dacryoconarids, trilobite and crinoid debris. During diagenesis, there was recrystallization, impregnation by ferro-manganese minerals, and the forming of dissolution seams at clast contacts. The lithology of Bed 17 is explained by synsedimentary seismic activity triggering brecciation and resedimentation that brought in bioclastic calcareous sand, which invaded opened interspaces and which also formed the locally unique, fossiliferous, bioclastic bed top.

The main part of Member 2 consists of mudstones that are very unfossiliferous, apart from burrows, even in thin-section (Bed 28a, Fig. 22.6, Bed 39b, Fig. 22.7, Bed 44c, Fig. 22.8; Bed 51, Fig. 29.1, Bed 60). There are very rare dacryoconarids and shell filaments. Flaser-bedding is caused by different degrees of microsparitization and the diagenetic overprinting of bioturbation (Bed 60). Well-defined burrows are filled by darker, organic-rich microsparite (Bed 39b, Fig. 22.7). Some beds are silty (Bed 60). In Bed 67, a nodular, bioturbated mudstone with very fine shell filaments, including a thin trilobite piece, is under- and overlain by wavy-laminated, flaser-bedded silty mudstones with rare crinoid debris and dacryoconarids. This succession indicates fluctuating currents, either distal turbidites or contourites. The general setting was the same as before, a subphotic pelagic ramp below the main habitat of ammonoids, trilobites, and other deeper-water benthic fauna.

Conodont faunas are sparse (Tab. 1) and include *I. obliquimarginatus* from Bed 39 (Fig. 27.13), *Po. parawebbi*, a species ranging from the upper Eifelian to the lower Givetian (Belka et al. 1987), and *L. linguiformis* from Bed 44c (Fig. 27.14). A slightly richer fauna comes from the top of Member 2 (Bed 67), with *Po. parawebbi* (Fig. 27.16), *Po. timorensis* (Fig. 27.17), marker of the lower Givetian *timorensis* Zone, and *I. regularicrescens* (Fig. 27.15).

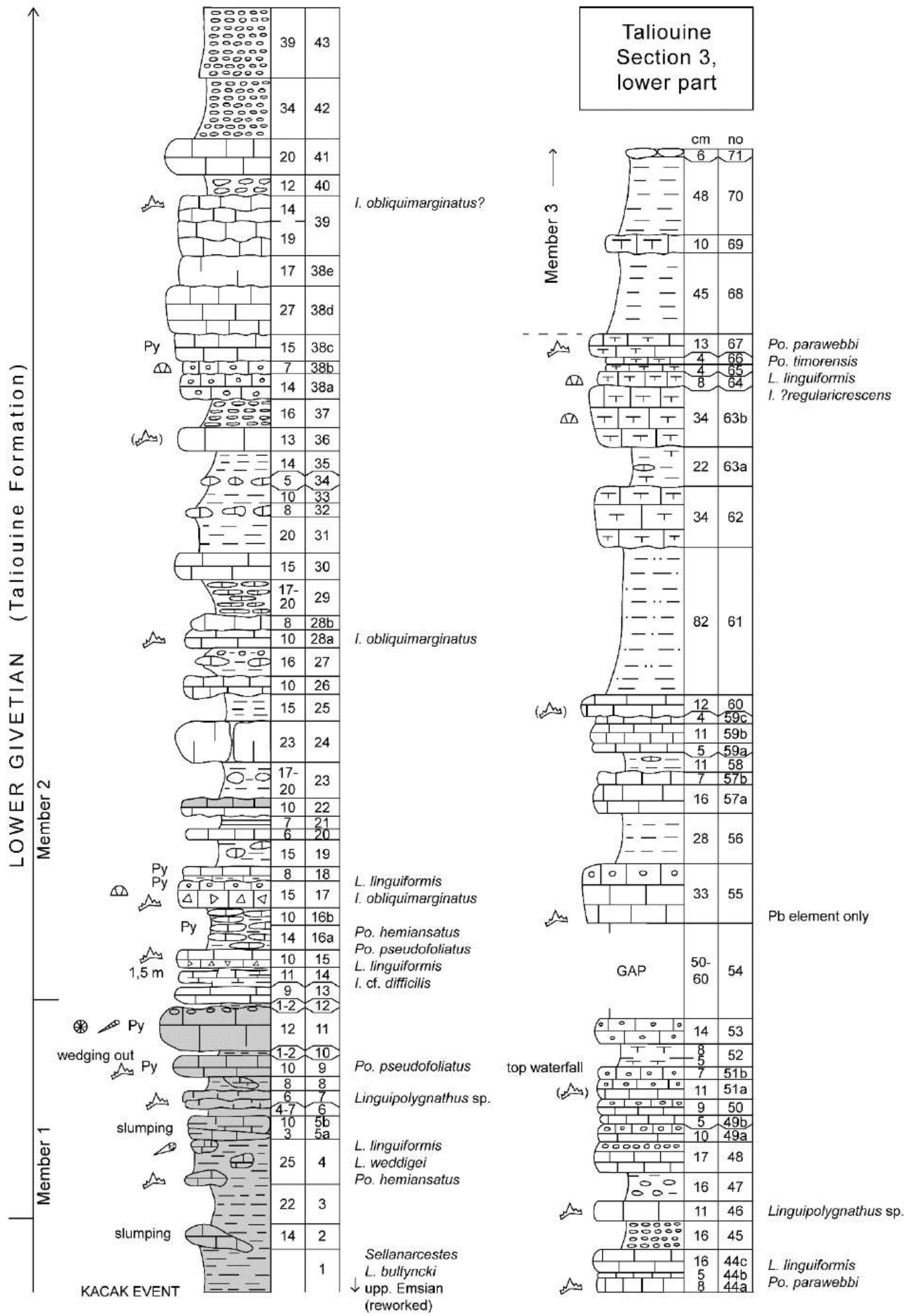

Fig. 26: Lithological and faunal succession of upper Eifelian to lower Givetian part of Taliouine Section 3, showing the position of conodont samples (see Tab. 1); Py = pyrite.

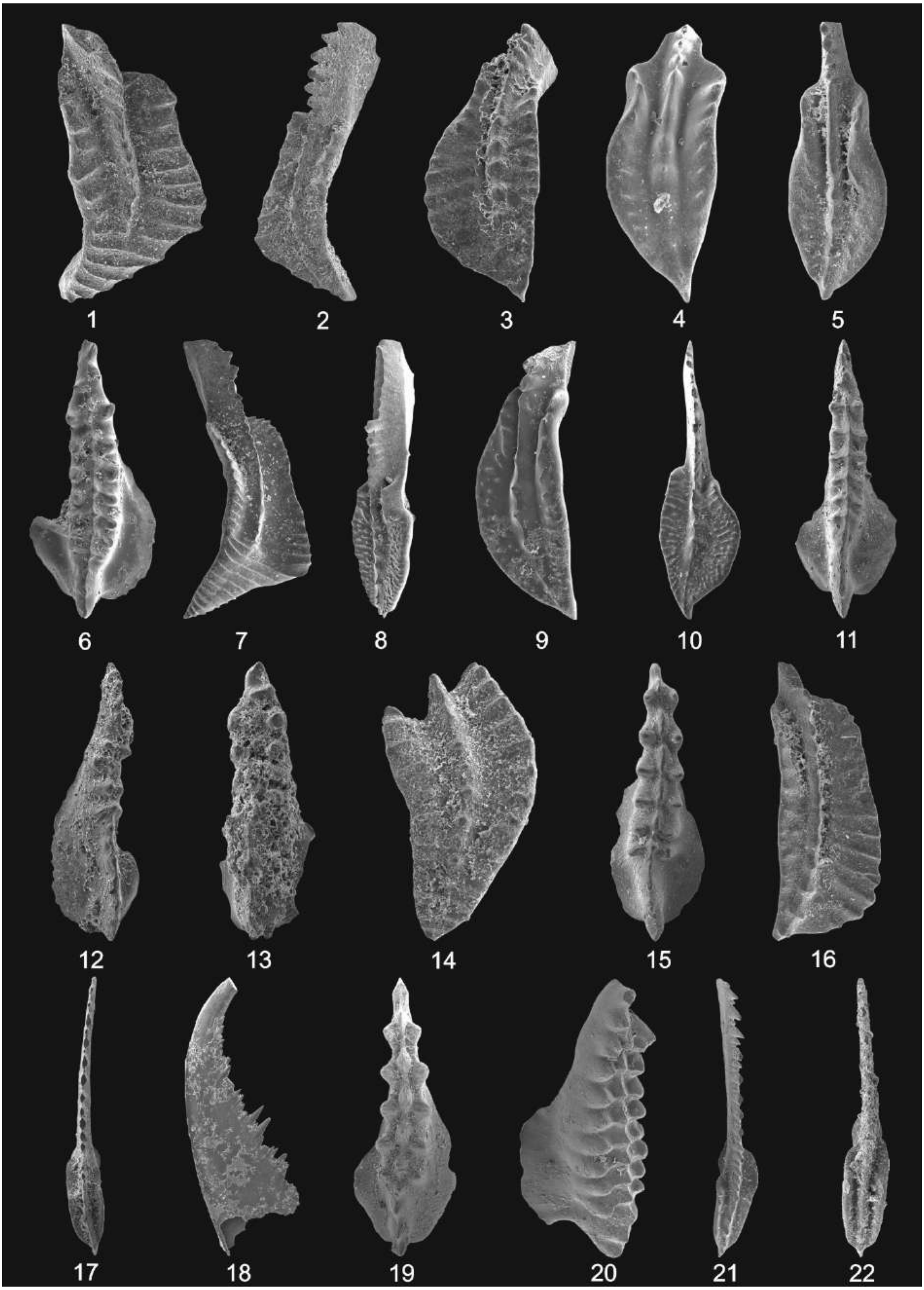

Fig. 27: Conodonts from Taliouine Section 3; GMM B4C.2.158-179. **1-2.** *Linguipolygnathus bultyncki*, upper part of upper Emsian glide block on the SW slope of the ravine, x 60 and x 55; **3.** *L. weddigei*, Bed 4, x 60; **4.** *Polygnathus hemiansatus*, Bed 4, x 80; **5.** *Po. pseudofoliatus*, Bed 9, x 70; **6.** *Icriodus* cf. *difficilis*, Bed 15, x 40; **7.** *L. linguiformis*, Bed 15, x 30; **8.** *Po. hemiansatus*, Bed 15, x 25; **9-10.** *Po. pseudofoliatus*, Bed 15, x 55 and x 25; **11-12.** *I. obliquimarginatus*, Bed 17, x 35; **13.** *I. obliquimarginatus*, Bed 39, x 60; **14.** *Po. parawebbi*, Bed 44c,

x 55; **15.** *I. regularicrescens*, Bed 67, x 65; **16.** *Po. parawebbi*, Bed 67, x 80; **17.** *Po. timorensis*, Bed 67, x 30; **18.** *Belodella resima*, Conglomerate 1, x 40; **19.** *I. difficilis*, Conglomerate 1, x 65; **20.** *I. regularicrescens*, Conglomerate 1, x 35; **21.** *Po. rhenanus*, Conglomerate 1, x 40; **22.** *Po. varcus*, Conglomerate 1, x 60.

5.4.3. Member 3 (goniatite shale/marl)

Member 3 is defined by the dominance of marls and hypoxic goniatite shales above the last compact sequence of limestone beds. It was recognized by HOLLARD (1967) as 70 m thick Unit i: "schistes à *Koenenites* cf. *lamellosus* puis calcaires à "Orthoceres" et tentaculites". A supposed Frasnian age is probably based on the mid-identification of the homoeomorphic upper Givetian genus *Mzerrebites* as lower Frasnian *Koenenites*. Intercalated argillaceous mudstones are very conodont-poor, with *L. linguiformis* and *Po. timorensis* in Bed 71. The first was also found in Bed 83; both species occur widely in the middle Givetian (e.g., ABOUSSALAM 2003; ABOUSSALAM & BECKER 2011). In the Givetian conodont biofacies model of NARKIEWICZ et al. (2016), *Linguipolygnathus* is especially abundant in outer shelf settings and pelagic platforms. More precise ages are provided by the ammonoid succession. The total thickness is in the scale of 60-70 m but the significant amount of scree from above enabled bed-by-bed logging only in lower ca. 38 m (Fig. 28). We attempted to trace Bed 70 laterally, but doubt that Bed 71 in the two partial sections (Figs. 26, 28) is the same bed. However, the correlation error appears to be small. In the upper lateral section (Fig. 28), Bed 71 is rather peculiar because of its internal, marked angular unconformity between burrowed laminated, silty mudstone (Fig. 29.2). This was either caused by slumping or we are dealing with the cross-section of structures of a large trace fossil, such as *Zoophycos*.

The microfacies of the subordinate higher limestone beds strongly resembles that in higher parts of Member 2 (see Bed 81, Fig. 29.3 in comparison to Fig. 29.1). The macrofauna is diverse but not abundant, often small-sized, and requires a tedious sampling effort. There is a remarkable admixture of pelagic (goniatites, orthocones, deeper-water solitary Rugosa) and neritic fauna (large-eyed phacopids, reefal corals, bryozoans, spiriferids), as it has been described from the Tata region of the eastern Dra Valley (BECKER et al. 2004b; EBBIGHAUSEN et al. 2007; SCHWERMANN 2011). This suggests a shallower setting than for Member 2 despite the higher amount of shale/marl. Fauna is either preserved as goethitic moulds (many mollusks), indicating hypoxic conditions, or in light-grey pelagic limestone, where all mollusks lack their shell. The currently known complete fauna is as follows:

*Agoniatites meridionalis** (Figs. 30.9-10)
*Agoniatites costulatus**
Sellagoniatites waldschmidti (Figs. 30.1-2)
*Sobolewia virginiana** (Figs. 30.11-12)
Maenioceras sp. indet.*
*Afromaenioceras crassum**
Afromaenioceras n. sp. A (more involute than *Afro. crassum*, close to *Afromaenioceras* n. sp. sensu BECKER et al. 2004b)*
Afromaenioceras n. sp. B (umbilicus wide, pachyconic, with more advanced sutures than in *Afro. crassum*; Figs. 30.13-14)
Afromaenioceras n. sp. C* (= *Bensaidites* n. sp. of KORN & KLUG 2002 and *Maenioceras* n. sp. II of BECKER et al. 2004b)
Wedekindella n. sp.* (sensu BECKER et al. 2004b, with concave umbilical wall; Figs. 30.7-8)
*"Trevoneites" assessi** (Figs. 30.3-4)
"Phoenixites" n. sp. 1* (sensu BECKER et al. 2004a and ABOUSSALAM & BECKER 2011; strongly compressed at very small size and with punctiform umbilicus, Figs. 30.5-6)
?*Lobobactrites* sp.* (compressed fragment)
?Bactrites declivis
orthocones indet*
Naticopsis sp.*

?Goniphilus sp. (species without ribbing)
other gastropods*
“Palaeonucula” sp.
?sponge
Dig. (Digonophyllum.) sp. (Fig. 32.7)
Laccophyllum sp.
Argutastrea (Argutastrea) hullensis hullensis (flat, 13 cm large colony, Bed 86, Figs. 32.1-2)
Heliolites intermedius* (Fig. 32.4)
Thamnopora irregularis* (Bed 82, Fig. 32.8)
Favosites sp. (Fig. 32.3)
tabulate coral colony with square cross-section
Thomasaria (Mzerrebiella) bultyncki (see García-Alcalde & El Hassani 2020)*
?Adolfia sp. (Fig. 30.21)
terebratulid brachiopods
fenestellid and other bryozoans
crinoid stem pieces*
Geesops? sp. (Figs. 31.1-3)
Chotecops? sp. 1 (Fig. 31.7)
Chotecops? sp. 2 (Figs. 31.8-9)
Gerastos sp. aff. *izius* (Figs. 31.4-5)
proetid pygidium (Fig. 31.6)
wood pieces

All taxa/faunal groups marked by an * occur in contemporaneous beds of the Tata region (Bensaîd 1974; Becker et al. 2004a, Aboussalam et al. 2004; Aboussalam & Becker 2004). The faunal similarity is very large, both in the goniatites and benthic assemblages. However, there is one distinctive difference, which gives an important relationship with the Tafilalt: the entry of *Sellagoniatites* in Beds 70-72. The genus is missing in the Dra Valley and enters in the Tafilalt in the Lower/Middle *Sellagoniatites* Beds, which encompass the Upper *pumilio* Event beds at the base of the *ansatus* Zone (ca. in the middle of the middle Givetian; Becker et al. 2004b; Aboussalam & Becker 2011). The *Sell. waldschmidti* Zone forms the upper part of MD II-C. Equivalent strata are overlain in the Tata region by the *Agoniatites* Beds with *Agon. meridionalis*, which also characterizes Beds 70-79 at Taliouine Section 3. It is remarkable that the two widespread *pumilio* Event beds (e.g., Lottmann 1990) do not occur locally.

Heliolites intermedius was first described by Le Maître (1947) from lower Givetian reef limestone of Morocco. It was found jointly with *Thamnopora* in the lower middle Givetian Upper *Maenioceras* Beds of Oued Mzerreb (Schwermannn 2011). *Heliolites* and *Thamnopora* are both known as pioneer reefal-type corals, ranging in low numbers into muddy and dysphotic settings, for example at the base of Givetian biostromes of the northern Maïder (Stichling 2013). Another “pelagic occurrence” of Givetian *Thamnopora* is in the marly facies of the Lower Marker Bed of the Tafilalt Basin at Hassi Nebech (Bockwinkel et al. 2013). *Thamnopora irregularis* is a long-ranging Emsian to Givetian species (May 1993b). Heliolitids were in principle tolerant to a high detrital influx, which caused growth interruptions, but relied on sediment removal by episodic currents (Król et al. 2021). The possibly new tabulate coral occurs abundantly in a single Givetian locality of the southern Tafilalt (Amessoui Syncline).

Argutastrea (Arg.) hullensis hullensis was described by Hill (1954) from the lower Frasnian of the far distant Canning Basin, Western Australia (see revision by Brownlaw & Jell 2008). However, very similar forms, e.g., *Arg. tenuiseptata* Coen-Aubert & Lütte, 1990, are known from the Givetian of Europe, which were re-assigned as a subspecies to *Arg. (Arg.) hullensis* by May (1993a). The unusual presence of *Argutastrea* in middle Givetian pelagic goniatite facies was first noted by Aboussalam (2003, fig.15; identification by S. Schröder) in the Tafilalt Basin at Hassi Nebech. There is a middle Frasnian equivalent of colonial rugose corals in deep, subphotic facies, the *Hexagonaria* Bed of Oued Mzerreb, (Becker et al. 2004b), which yielded *Hex. buxutiensis*, a species from the Frasnian of the Ardennes.

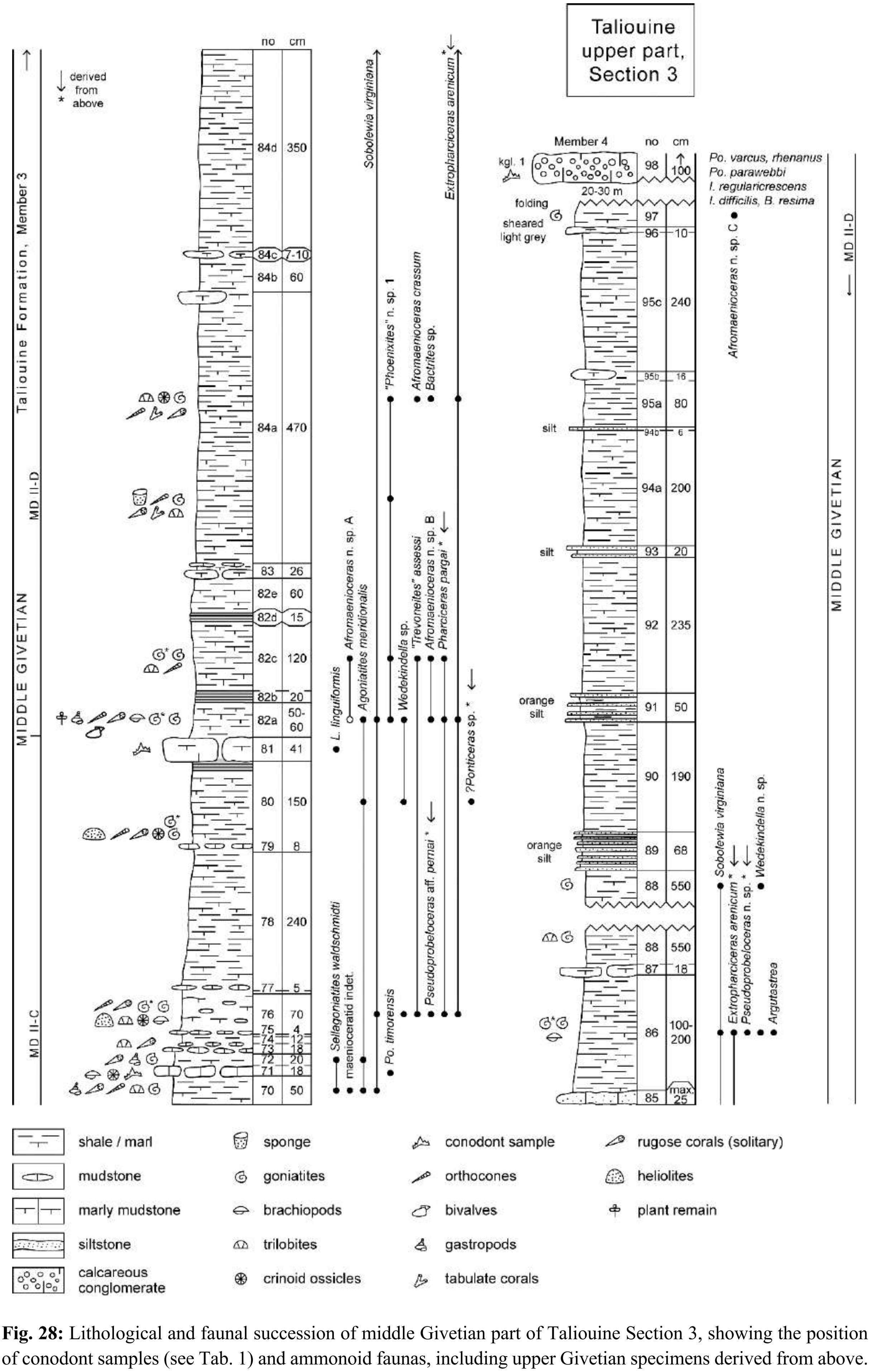

Fig. 28: Lithological and faunal succession of middle Givetian part of Taliouine Section 3, showing the position of conodont samples (see Tab. 1) and ammonoid faunas, including upper Givetian specimens derived from above.

Afromaenioceras, the index genus of MD II-D, enters in Bed 82a (Fig. 28). We correlate the thick sequence of Beds 75 to 88 with the pre-Taghanic *Maenioceras* Marl of the Tafilalt (ABOUSSALAM & BECKER 2011), which shares the presence of "*Phoenixites*" (strongly compressed tornoceratids with slightly open umbilicus and weak traces of ventrolateral furrows), *Wedekindella, Sobolewia, Agoniatites,* and of the *"Trevoneites" assessi* Group. The latter represents a new genus of the Parodiceratinae that closes the umbilicus at maturity, unlike as in true *Trevoneites*. The figured *Sobolewia* displays some randomly distributed "Housean Pits" on the flanks (Fig. 30.11). They are of unusually variable size (the largest occur at the last two septa) and do not conform with the even larger few pits illustrated by DE BAETS et al. (2011, fig. 5) on the surface of Algerian sobolewiids. In our specimen, there are intermediates between Types 1 and 2 sensu DE BAETS et al. (2011).

Five Beds (76, 82a, 82c, 84a, 86) yielded loose upper Givetian goniatites that are in complete disagreement with the rest of the fauna; they must have been washed down from above. We found three taxa, *Pharciceras pargai* juv. (Figs. 30.15-16), *Extropharciceras* cf. *arenicum* (nine fragments), and *Pseudoprobeloceras* aff. *pernai* (Figs. 30.17-18, more strongly ribbed than *pernai* and with weak ventrolateral double furrows, unlike as in *Ps. costulatum*). While *Ph. pargai* is typical for MD III-C (BOCKWINKEL et al. 2009), *Pseudoprobeloceras* is an index genus of MD III-D (BECKER & HOUSE 1994b, 2000a, 2000d). Since we did not observe any upper Givetian goniatites in the upper 20-30 m of Member 3 (Fig. 28), we assume that they derive from Member 4, from marls between the conglomerates higher up in the steep slope.

The local position of the Taghanic Crisis interval at the middle/upper Givetian boundary is currently unclear. The orange-weathering siltstones in the upper part of Member 3 (Beds 89, 91, 93, 94b; Fig. 28) indicate a polyphase shallowing trend but above, we could not locate the top middle Givetian (Upper Tully level) *Mzerrebites juvenocostatus-Atlantoceras* fauna (MD III-A), which is so characteristic for the Tata region (BENSAID 1974; BECKER et al. 2004b; ABOUSSALAM et al. 2004). However, HOLLARD (1967) probably recorded *Mzerrebites* as the homoeomorphic, lower Frasnian genus *Koenenites*.

Rather low in the succession, in Bed 70, we collected each a small and a median-sized, incomplete spiriferid with a single rib within the narrow sulcus, ribs right at each sulcus margin, undivided lateral ribs, and poorly preserved traces of undulating growth lamellae (Fig. 30.21). We preliminarily identify it as *?Adolfia* (wr. comm. U. JANSEN, April 2021), which previously has been questionably recorded from the Givetian of the Western Sahara (SCHEMM-GREGORY 2011, p. 10). The top-Emsian *?Adolfia* described by GOURVENNEC (2018) from the Algerian part of the Tindouf Basin has much coarser ribs. In general, the genus had a global distribution. For a reliable identification, the shell ornament of our specimens is too poorly preserved. There are some morphological similarities with *Vandercammenina*, which is not known from the Givetian. GOURVENNEC (2018) suggested that the *Vandercammenina-Cyrtospirifer* transition took place from the Eifelian to the Givetian and one may suspect that our specimens are part of this lineage.

The trilobite fauna includes a relative of the proetid *Gerastos izius*, which was described from the lower Givetian of the northern Maïder (GIBB & CHATTERTON 2010). The proetid pygidium may have belonged to the same form. The three phacopids are not well preserved but appear to represent taxa that have not yet been documented from Morocco. The two forms with smooth cephala agree with the genus *Chotecops*, which ranges from the upper Emsian to upper Givetian. In the Tafilalt, it is so far only known from the lower Eifelian of Hamar Laghdad (ALBERTI 1983) and the top-Eifelian of Jebel Mech Irdane (FEIST & ORTH 2000). The species with strongly ornamented cephalon is difficult to place generically. There are similarities with the Emsian *Morocops*. Among described Givetian genera, *Geesops* is closest.

5.4.4. Conglomeratic Member 4

Member 4 includes three main conglomerate beds separated by poorly exposed marls that are mostly covered by Carboniferous limestone scree from above. Conglomerate 1 (Figs. 29.4, 33.1) consists of unsorted, non-graded subangular to subrounded clasts with stylolithic and partly ferromanganese-stained compaction contacts, and a peloidal mudstone in the interspaces that has widely been washed out and replaced by sparite. There are four types of clasts:

1. Middle-grey, slightly bioturbated mudstones with a few dacryoconarids and shell filaments.
2. Slightly lighter middle-grey mudstones with calcispheres.
3. Partly laminated, brownish peloidal mudstones.
4. Isolated crinoid ossicles, rugose (*Thamnophyllum*, Fig. 32.5), and tabulate corals (*Platyaxum*, Figs. 32.6).

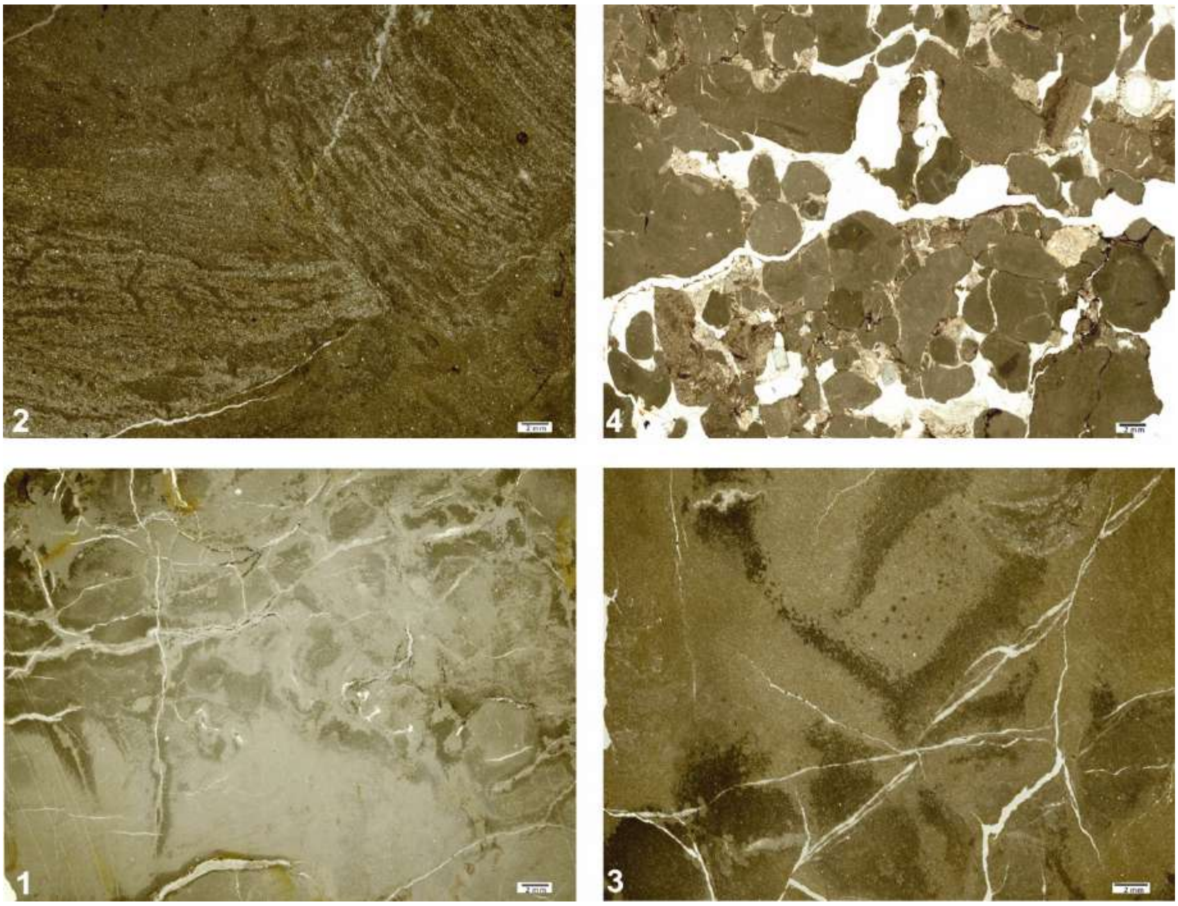

Fig. 29: Microfacies of limestones in Member 3 and 4 of the Taliouine Formation, Taliouine Section 3. **1.** Almost unfossiliferous mudstone, with numerous calcite veins and associated variable late diagenetic microsparitization causing a strongly patchy-cloudy pattern, Bed 51; **2.** Internal angular unconformity (55°) between laminated and burrowed, silty mudstone, within Bed 71 (enlightened), possibly structures of a large trace fossil, such as *Zoophycos*; **3.** Almost unfossiliferous mudstone overprinted by patchy diagenetic recrystallization, Bed 81; **4.** Conglomerate 1 of Member 4, an unsorted and non-graded extraclast rudstone with subangular to subrounded mud-wackestone pebbles, often in stylolithic contact, including isolated corals, and with a matrix of unsorted fine clasts or white sparite.

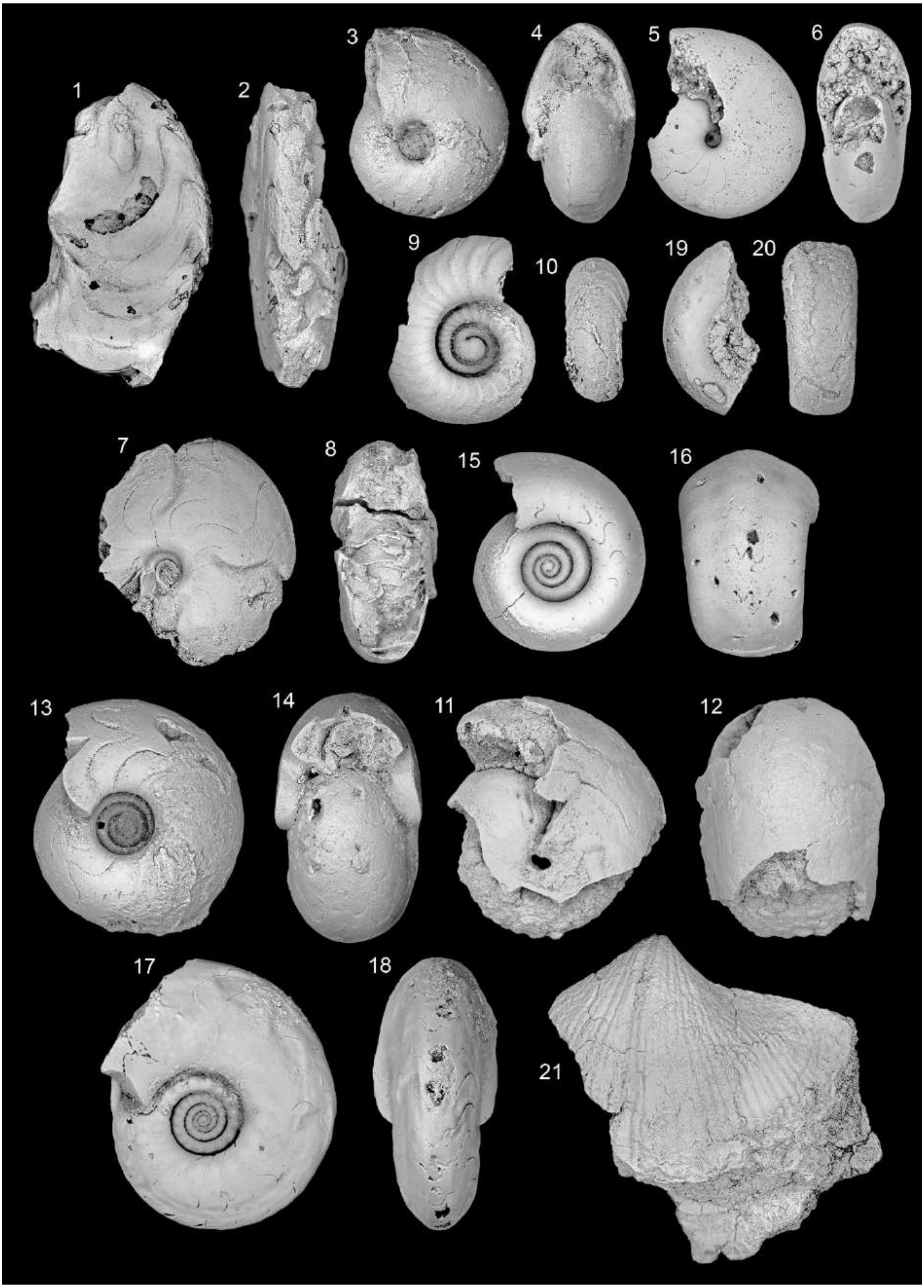

Fig. 30: Goniatites (GMM B6C.54.197-206) and a brachiopod from the middle/upper Givetian of Taliouine Section 3. **1-2.** *Sellagoniatites waldschmidti*, whorl fragment with typical sutures, Bed 72, x 1.5; **3-4.** *"Trevoneites" assessi*, Bed 76, x 5; **5-6.** *"Phoenixites"* n. sp. 1, showing the open umbilicus, juvenile shell compression, and incipient ventrolateral furrows, Bed 82c, x 5; **7-8.** *Wedekindella* n. sp. sensu BECKER et al. (2004b), incomplete specimen showing the typical, furrowed, concave umbilical wall, Bed 88, x 3; **9-10.**

Agoniatites meridionalis juv., Bed 82a, x 5; **11-12.** *Sobolewia virginiana*, incomplete, with a few small, lateral Housean pits, Bed 88, x 3; **13-14.** *Afromaenioceras* n. sp. B, with wide umbilicus, advanced sutures, and ventral Housean pits, Bed 82c, x 3; **15-16.** *Pharciceras pargai* juv., with incipient broad ventral keel, collected loose from Bed 76, x 5; **17-18.** *Pseudoprobeloceras* aff. *pernai*, collected by S. STICHLING loose from Bed 76, x 4; 19-20. *?Ponticeras* sp., whorl fragment with gephuroceratid ventral sutures, collected loose from Bed 80, x 5; **21.** *?Adolfia* sp., Bed 70, SMF 102136, x 2.5.

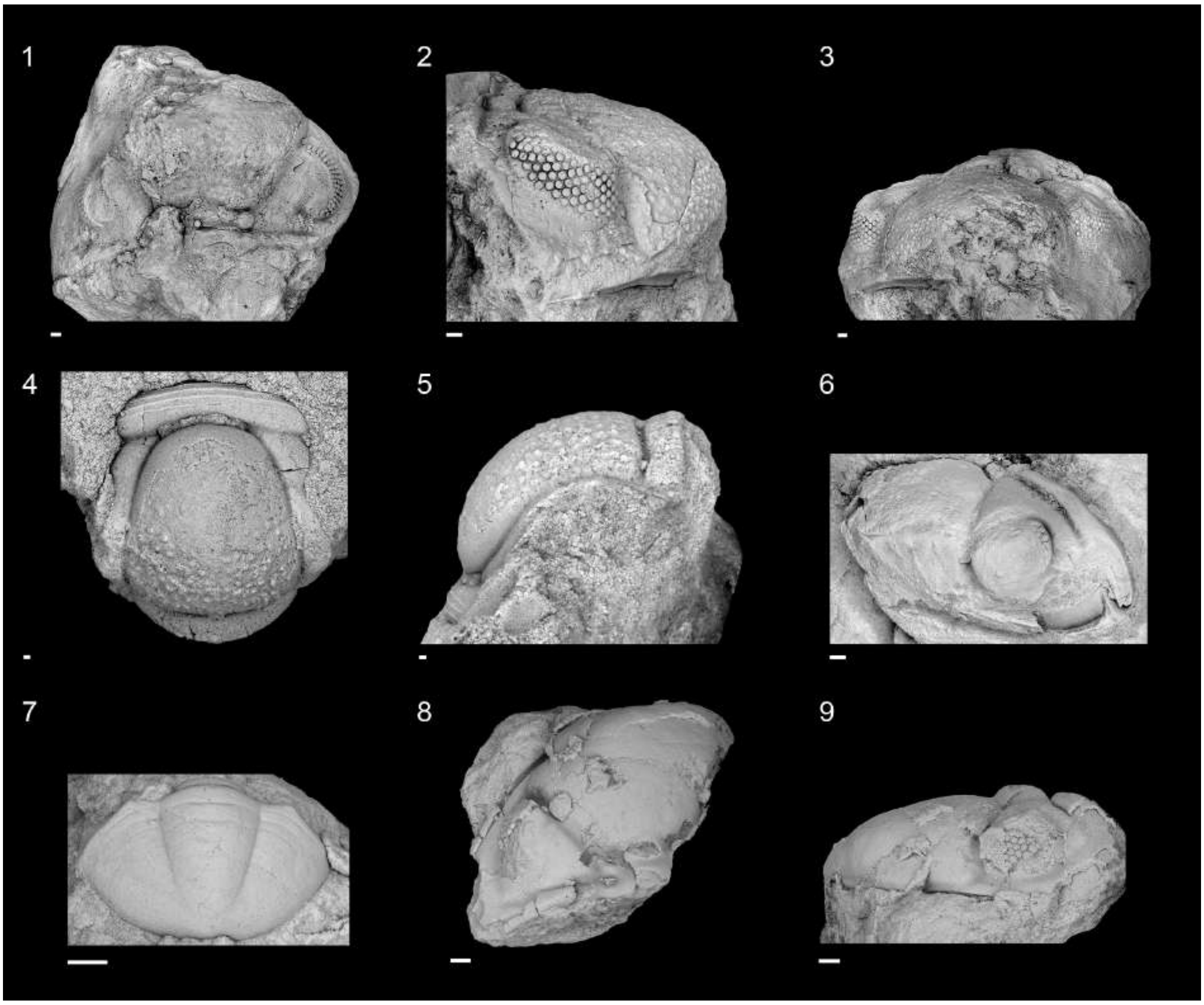

Fig. 31: Trilobites from the middle Givetian Member 3 of the Taliouine Formation, Taliouine Section 3; scale bar = 1mm. **1-3.** *Geesops*? sp., Bed 82, GMM B7A.12.8; **4-5.** *Gerastos* sp. aff. *izius* GIBB & CHATTERTON, 2010, Bed 84, GMM B7A.12.9; **6.** *Chotecops?* sp. 1, loose, GMM B7A.12.10; **7.** Proetid pygidium, Bed 82, GMM B7A.12.11; **8-9.** *Chotecops?* sp. 2, ca. Bed 88, GMM B7A.12.12.

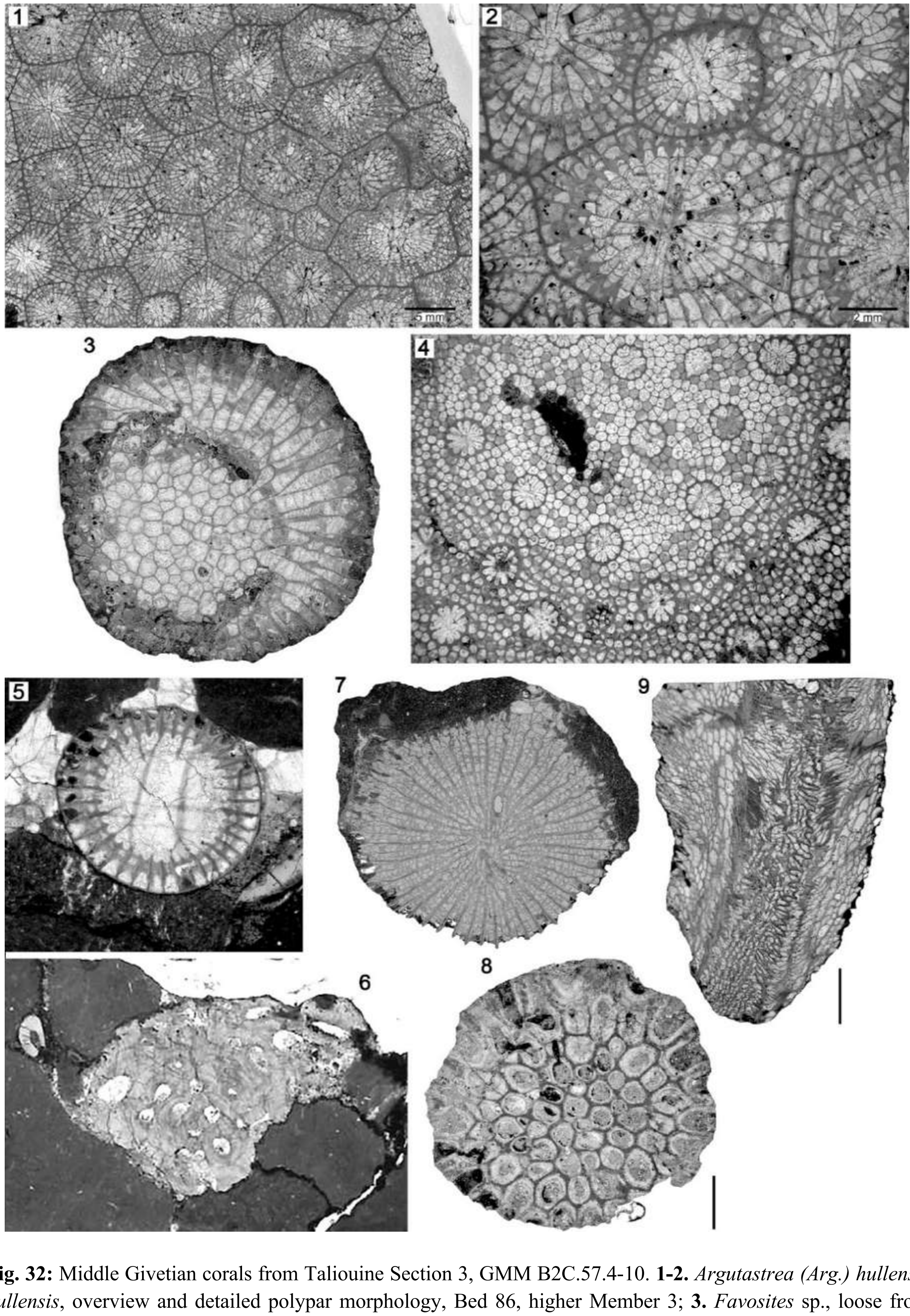

Fig. 32: Middle Givetian corals from Taliouine Section 3, GMM B2C.57.4-10. **1-2.** *Argutastrea (Arg.) hullensis hullensis*, overview and detailed polypar morphology, Bed 86, higher Member 3; **3.** *Favosites* sp., loose from Member 3, 27 mm colony diameter; **4.** *Heliolites intermedius*, loose from Member 3, picture width 14 mm; **5.** *Thamnophyllum* sp., Conglomerate 1, Member 4, 5.3 mm diameter; **6.** *Platyaxum* sp., oblique section; Conglomerate 1, Member 4, oblique colony length 6.8 mm; **7, 9.** *Digonophyllum (Digonophyllum)* sp., cross-section, 26 mm diameter, and longitudinal section, scale bar = 5 mm, Member 3, loose specimen (normally a shallow-water form, not one of the German species); **8.** *Thamnopora irregularis*, cross-section, Member 3, Bed 82, scale bar = 2 mm.

1

2

Fig. 33. The conglomeratic Member 4 at Taliouine Section 3. **1.** Details of Conglomerate 1, with mostly angular and small-sized pebbles in close, partly stylolithic contact; **2.** Overview of massive Conglomerate 2, with large-sized subrounded pebbles in the scale of 10-40 cm diameter.

The limestone clasts were probably all derived from Member 2, which must have been uplifted and eroded after lithification at a near-by fault scarp. Support for post-lithification reworking comes from sparite-filled veins that end at clast margins. The crinoids and corals lived just before or at the time of redeposition since they form isolated bioclasts and were reworked without surrounding sediment. There are only lower/middle Givetian conodonts, such as *Po. parawebbi, Po. varcus* (Fig. 27.22), *Po. rhenanus* (Fig. 27.21), *I. difficilis* (Fig. 27.19), and *I. regularicrescens* (Fig. 27.20). Consequently, we assign Conglomerate 1 to the first main Eovariscan episode that affected all the Meseta, starting high in the middle Givetian (BECKER et al. 2015). Deposition occurred by rockfall at an active fault scarp.

Conglomerate 2 follows after ca. 8 m of light-grey marl, is up to 5 m thick, and forms a steep cliff in the slope (Fig. 33.2). It is also a rockfall deposit but with much larger clasts. Again, it yielded only lower/middle Givetian conodonts: *Po. varcus, Po. timorensis*, *L. linguiformis*, and *"Ozarkodina" plana* (Tab. 1). Conglomerate 3 is ca. 3.5 m thick and follows after another ca. 8-10 m thick, poorly exposed interval. It has not been sampled for conodonts but is believed to belong to the same synsedimentary tectonic episode; by fault uplift the youngest strata are eroded first and, therefore, should be found in the first reworking unit (Conglomerate 1).

Conglomerate 3 is overlain by ca. 20 m of poorly exposed bioclastic and marly limestone alternating with marls. There is indirect evidence for a Frasnian succession: From Bed 80 we collected a small-sized, loose, goniatite fragment (Figs. 30.23-24) that combines a widely evolute, depressed conch with a manticoceratid suture. It is probably a juvenile ponticeratid, which indicates the local presence of an upper Frasnian goniatite shale interval (see Boudouda goniatite chapter, this volume). In addition, we collected a middle grey, coarse crinoidal limestone block with fragmented auloporid corals and an atrypid, a brachiopod group that died out with the top-Frasnian Upper Kellwasser Event. This record fits the recognition of a Frasnian detrital limestone in the section log of LAVILLE (1980) and the discovery of reworked Frasnian brachiopod limestone at Asserhmo (see below). Further studies are in progress.

Fig. 34: View on the thick Silurian to strongly cyclic lower Emsian succession at Tizi-n-Ouourti from just north of Imi-n-Tazaght. Access to the section is from the south along the valley behind the mountain on the right.

6. Devonian at Imi-n-Tazaght North

The Lower Devonian crops out on the hill just west of the piste that winds (after a sharp left turn) from Imi-n-Tazaght (= Imi n´Tarzat) to the north (Fig. 2). As noted by ROCH (1939), there are Silurian black and greenish-grey shales (Tizi-n-Tichka Formation) but just at the road we did not observe embedded limestones with orthocones, bivalves, or gastropods mentioned by him. To the west, the succession is cut off by a normal fault. The Lochkovian-Pragian boundary is locally marked by an unconformity and sedimentary gap spanning ca. the middle Lochkovian to middle Pragian. Member 1 of the Imi-n-Tazaght Formation is characterized by two solid marker limestones that dip steeply to the south. The first, brownish weathering, bioclastic marker bed is characterized by large *stromatactis* filled by white orthosparite or (in the middle part) by invading, strongly recrystallized dacryoconarid wackestone grading into shell filament packstone. The *Stromatactis* are underlain by poorly fossiliferous, non-bioturbated mudstone layers. The main microfacies (Fig. 35.1) is a flaser-bedded, bioturbated wacke-packstone with abundant crinoids, mollusk debris of very variable size, ostracods, gastropods (pleurotomariaceans), and orthocones, partly with geopetal filling. The matrix is micritic but there are thin packstone layers with small-sized shell debris, caused by winnowing due to the periodic influence of bottom currents. The environment was a moderately shallow carbonate ramp with episodic microbial growth. We assume that the calcimicrobes grew in a dysphotic environment since there is no evidence for euphotic organisms. However, the setting was shallower than at Taliouine. Iron-manganese impregnations of some shells and dissolution seams are diagenetic features.

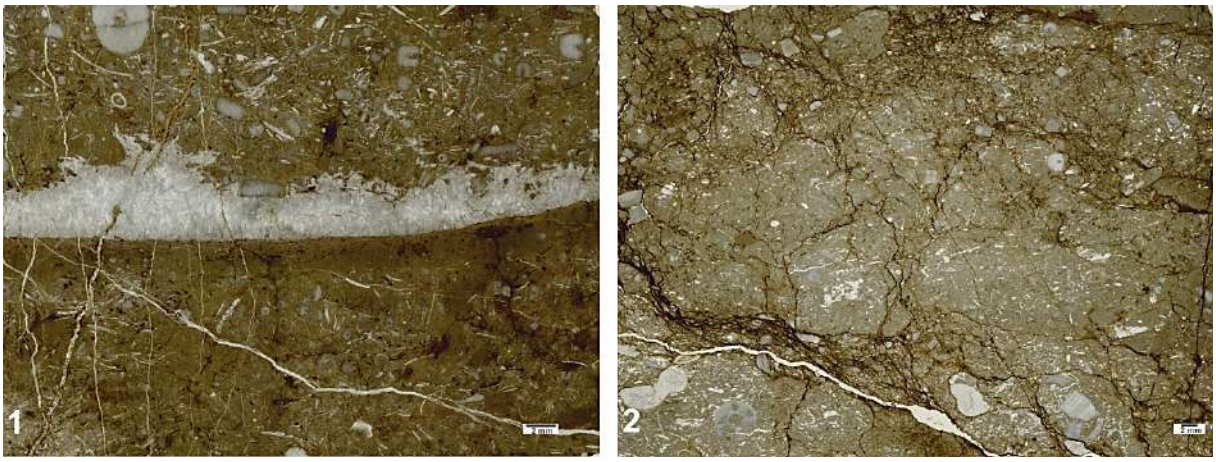

Fig. 35: Microfacies of Pragian/Emsian limestones from Imi-n-Tazaght North. **1.** Bioclastic, microbial, bioturbated packstone with abundant shell filaments, crinoid ossicles/debris, ostracods, and large, sparite-filled *Stromatactis*, underlain by micritic mudstone layers, upper part of *Stromatactis* Bed, base of the Lower Member of Imi-n-Tazaght Formation; **2.** Flaser-bedded, bioclastic, bioturbated wacke-packstone with abundant crinoid remains, shell filaments, dacryoconarids (mostly nowakiids), and many pressure solution seams, Member 3 of Imi-n-Tazaght Formation.

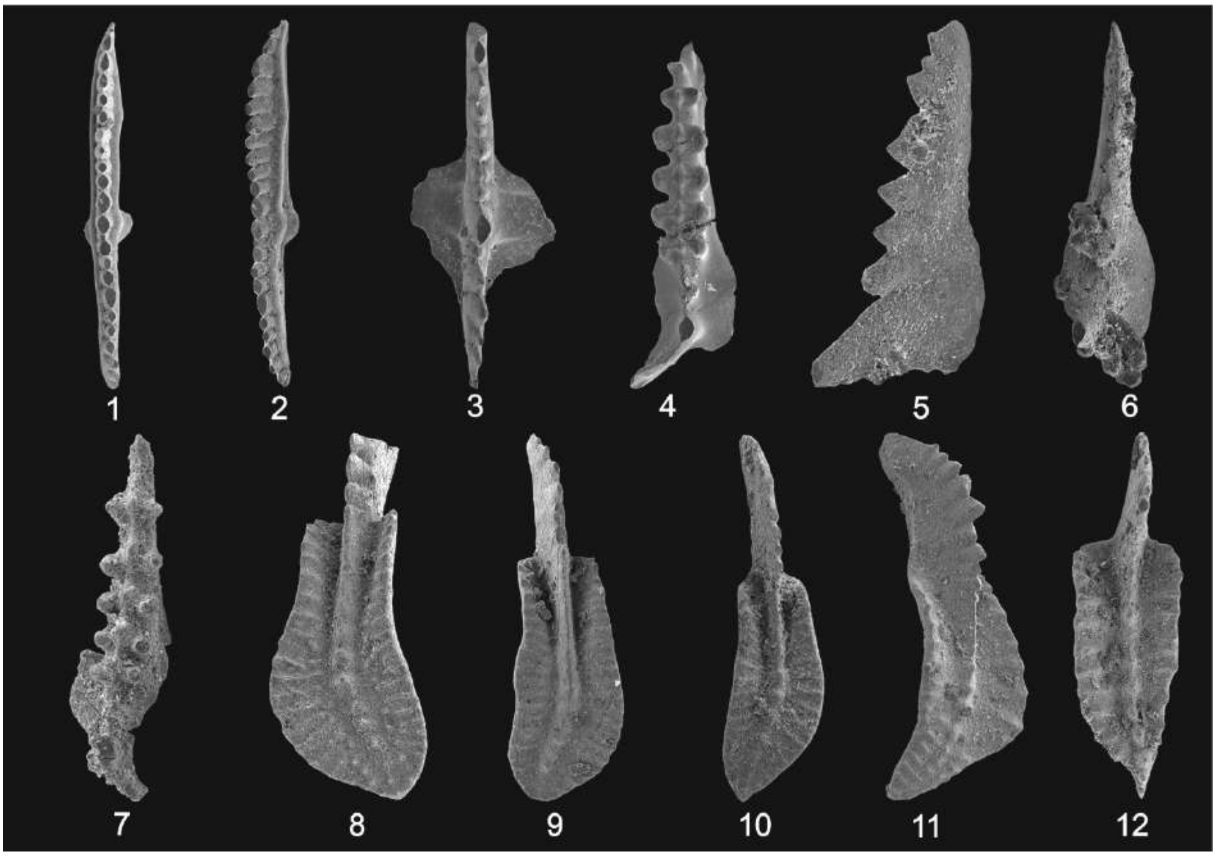

Fig. 36: Conodonts from the Lower Devonian of Imi-n-Tazaght North (1-6 from basal *Stromatactis* Bed of Imi-n-Tazaght Formation, 7 from Member 3 of that formation) and the upper Eifelian of Tizi-n-Ouourti (Bed G50a, kockeli Zone); GMM B4C.2.180-189. **1-2.** *Wurmiella wurmi*, x 35; **3.** *Criteriognathus miae*, x 80; **4.** *Caudicriodus celtibericus*, x 60; **5-6.** *Pelekysgnathus serratus*, x 95; **7.** *Caud. curvicauda*, x 95; **8.** *Polygnathus amphora*, x 50; **9.** *Po. costatus*, x 40; **10.** *Po. parawebbi*, x 45; **11.** *Linguipolygnathus pinguis*, x 35; **12.** *Po. praetrigonicus*, x 50.

The dominance of spathognathodids is in accord with a moderately deep setting. We found *Wurmiella wurmi* (14 specimens, Figs. 36.1-2), a single *Criteriognathus miae* (Fig. 36.3), two *Caudicriodus celtibericus* (Fig. 36.4), and a *Pelekysgnathus serratus* (Figs. 36.5-6). In Bohemia, *Caud. celtibericus* and the oldest *Crit. miae* overlap for a brief interval early in the upper Pragian with the youngest *Pel. serratus*, for example at Mramorka (SLAVÍK 2004). In our opinion, the FAD of *celtibericus* should define the *celtibericus* Zone, not the LAD of *Pel. serratus*. *Wurmiella wurmi* is known to range into the lower Pragian (e.g., SLAVÍK & HLADIL 2004) but has not been recorded from upper Pragian levels with *Caud. celtibericus*. However, this may be based on taxonomic problems. *Wurmiella wurmi* cannot be confused with the Pa element that is widely but incorrectly included in the highly problematical (see MURPHY et al. 2004) multi-element species *W. excavata*. This un-named form has fewer denticles on its shorter blade (see ROOPNARINE et al. 2004) but is not identical with *"Ozarkodina" simplex*, the assumed Pa element of the Silurian *W. excavata* s. str. (see REXROAD & CRAIG 1971). MAWSON & TALENT (1994) illustrated as *W. excavata* a specimen from Victoria, Australia, jointly with *Crit. miae*, that has only a few denticles less than our specimens. Since we have no evidence for extreme condensation in the *Stromatactis* Bed, we accept a range extension of *W. wurmi* into early parts of the upper Pragian, where the morphology and variability of specimens called *W. excavata* (e.g., 1400 specimens mentioned by SLAVÍK 2004) requires documentation.

The second prominent bed is a solid, grey, oxygenated Orthocone Limestone, which has not been sampled for conodonts. It is overlain by a mostly covered interval of light-grey nodular limestone, the basal part of Member 2 of the Imi-n-Tazaght Formation.

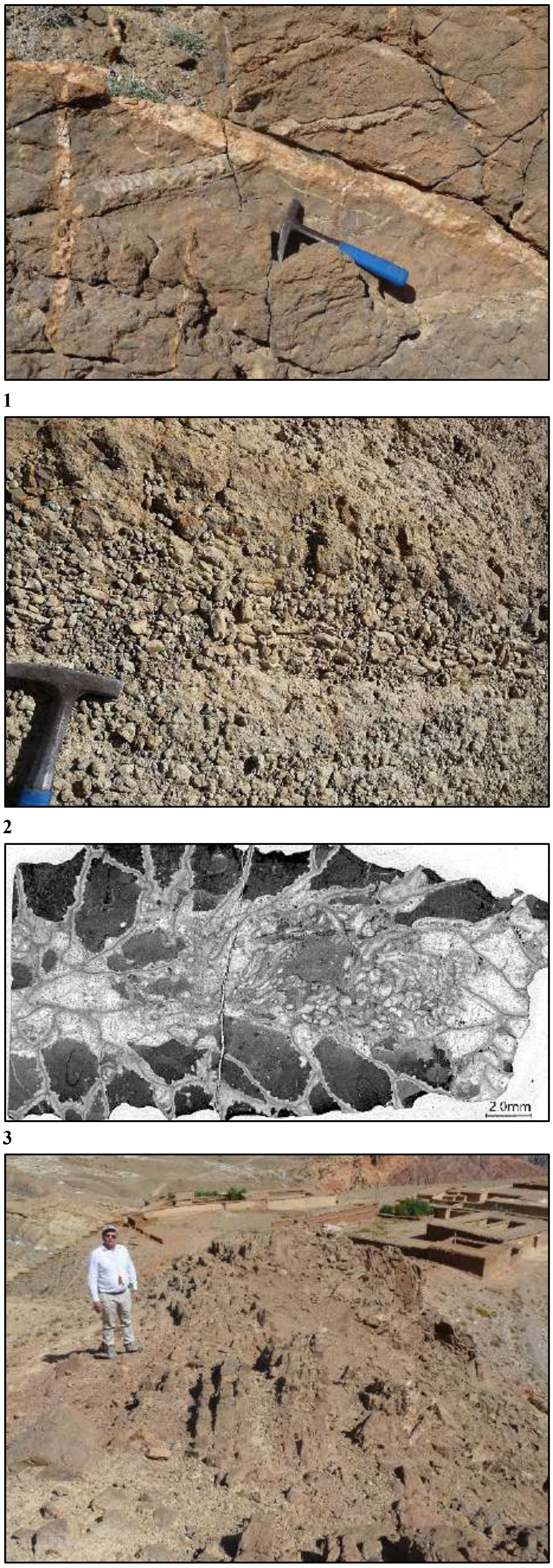

Fig. 37: Pragian and lower Emsian at Imi-n-Tazaght North. **1.** Very large-sized and slender orthocone (?*Deiroceras*) cut and displaced by a later calcite vein, Orthocone Limestone, lower part of Member 2 of Imi-n-Tazaght Formation; **2.** Vertically bedded nodular

Member 2 with mass occurrences of small orthocones; **3.** Longitudinal section through a *Michelinia* sp., Member 2, GMM B2C, 57.11; **4.** Thin- to medium-bedded, slightly overturned, solid, crinoidal limestones of Member 3 at the top of the section, with L. BAIDDER for scale and the northern houses of Imi-n-Tazaght in the background.

A local special feature is a second prominent Orthocone Limestone with straight nautiloids reaching originally almost a meter in length (Fig. 37.1). The main part of the nodular Member 2 contains 10-15 cm thick layers that are extremely rich in smaller-sized orthocones (Fig. 37.2). Associated are a few trilobites, such as the Pragian *Cheirurus* (*Crotalocephalina*). *Panenka* is locally rare while there are common crinoid stem pieces. Rare branches of tabulate corals (*Michelinia* sp., Fig. 37.3) suggest a slightly shallower ramp setting than at Taliouine. *Michelinia* (including its likely synonym *Praemichelinia*, MAY 2006) is not common but globally widespread in the Lower Devonian. For example, it is known from the Pragian of the Armorican Massif (e.g., LAFUSTE & PLUSQUELLEC 1980), from the basal Emsian of the Dra Valley (PLUSQUELLEC in DE BAETS et al. 2010), the upper Emsian of Spain (MAY 2006; FERNÁNDEZ-MARTÍNEZ & PLUSQUELLEC 2006), and southern Algeria (e.g., LE MAÎTRE 1952; BOUMENDJEL et al. 1996).

The prominent, ca. 1.5 m thick, thin- to medium-bedded, light-grey crinoidal limestones of Member 3 (Fig. 37.4) begin above a sharp base. In the middle, we found a nodule of more than 10 cm diameter surrounded almost completely by a branching auloporid coral. A conodont sample from the base of Member 3 yielded two specimens of *Caud. curvicauda* (Fig. 36.7). The species ranges in the Tafilalt from the upper Pragian into the basal Emsian. Therefore, the base of the member is taken as the approximate Emsian base. Dissolution in acetic acid produced also fragments of *Machaeracanthus* spines. This somewhat problematical acanthodian is common in the basal Emsian of the Anti-Atlas (e.g., KLUG et al. 2008; BECKER et al. 2018a).

The microfacies of the conodont sample block fluctuates between bioturbated nowakiid-crinoid packstone with many shell filaments and dense micrite matrix, somewhat coarser, more crinoid-rich packstone with partly washed out matrix, and nowakiid wackestone. There are geopetal fillings and cone-in-cone stacking of some dacryoconarids. This indicates small variations of bottom current strength on the upper parts of a pelagic ramp. The dominant crinoid debris, lack of cephalopods, and presence of tabulate corals suggests the proximity of a shallower environment with crinoid forests. Fe-M-mineralizations follow dissolution seams that produce flaser-bedding. The top of Member 3 is slightly overturned (Fig. 37.3) and ends at a steep cliff, which follows a fault. Higher strata are lacking at Imi-n-Tazaght North (ROCH 1939).

7. Devonian of Tizi-n-Ouourti

The Tizi-n-Ouourti section was called by ROCH (1939) the most distinctive section of the Skoura Devonian. He gave a faunal list for the "Eifelian", which in fact refers to the locally very fossiliferous upper Emsian strata (see LAVILLE 1980). The section can be reached from the piste leading from Toundout in the east to Imi-n-Tazaght in the west, much closer to the latter (Fig. 34). It requires a short walk along the northwards leading oued filled with Silurian black shale debris, which is, therefore, easy to recognize. Our measured section lies at N31°17'21.99", W6°39'43.74".

7.1. Lochkovian to lower Emsian

The Silurian black shales (Tizi-n-Tichka Formation, Field Unit A) are well exposed in the lower slope of the section (Figs. 34, 38.1). There are unfossiliferous siderite (Fig. 38.3) and partly large black limestone concretions (Fig. 38.2), as in the Upper Member of Taliouine. The environment was anoxic. We did not note orthocone-rich limestones but the bedding is also irregular, suggesting slumping (Fig. 38.4). At the top there is a conglomerate/slump bed, which represents Member 1 of the Imi-n-Tazaght Formation. A conodont sample was unfortunately barren.

Member 2 (Field Unit B, 1° in ROCH 1939, fig. 21) is a ca. 15 m thick succession of cyclic and variably resistant (Figs. 34, 38.4), yellowish weathering marly, nodular limestone with orthocones, *Panenka*, phacopids, and dacryoconarids. The thickness is higher than at Imi-n-Tazaght to the west. We have not yet logged or sampled it locally.

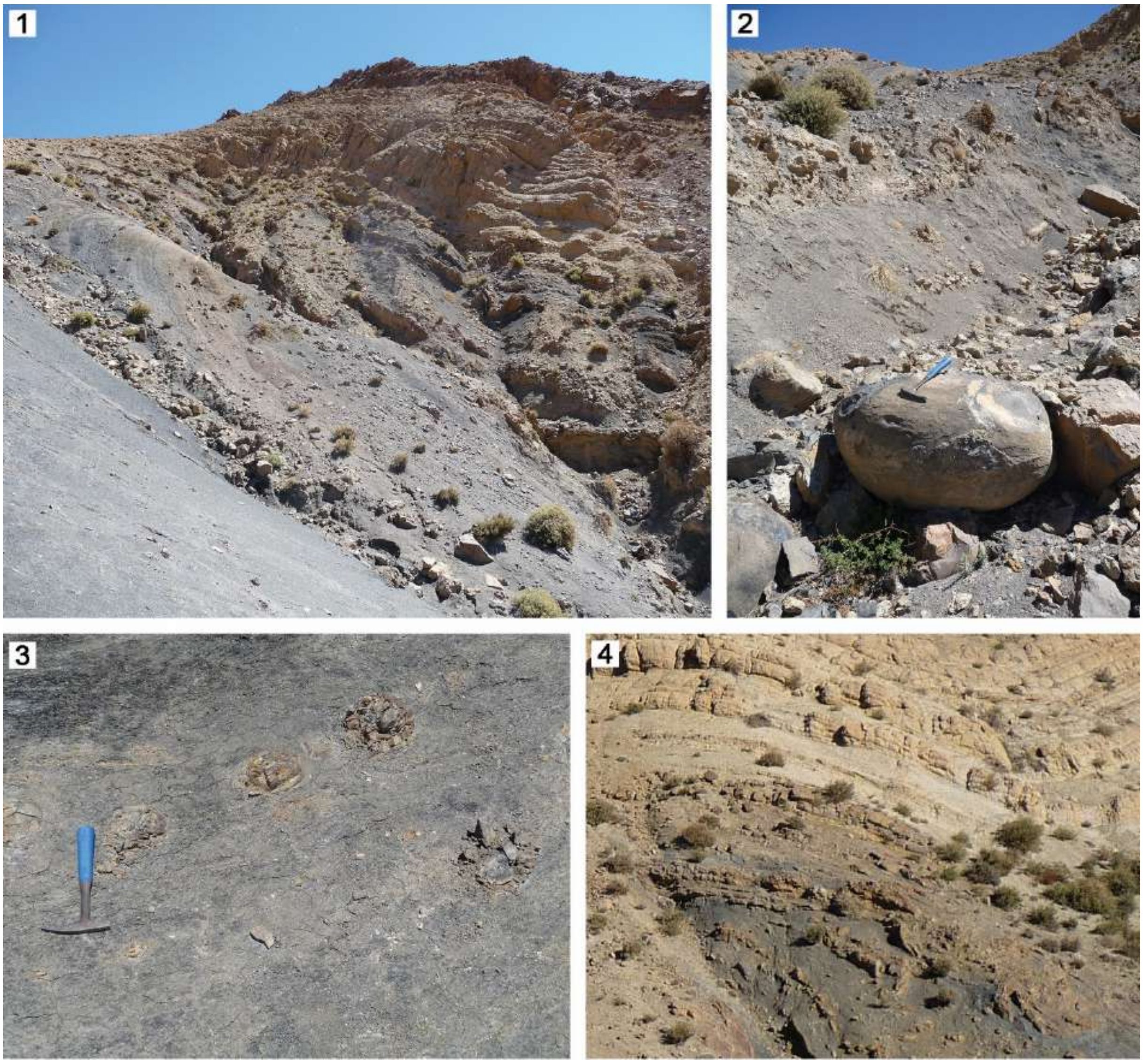

Fig. 38: Field photos of the Lochkovian to lower Emsian at Tizi-n-Ouourti. **1.** Overview of succession from the Silurian black shales (Tizi-n-Tichka Formation, Lower Member) to the thick cliff-forming, lower Emsian limestones of the Imi-n-Tazaght Formation; **2.** Large limestone concretion in the Lower Member; **3.** Isolated large siderite concretions in the Lower Member of the Tizi-n-Tichka Formation; **4.** Slumped, irregular bedding of the Upper Member, followed by a conglomerate/slump bed at the top, and then by the yellowish-grey weathering, well-bedded and cyclic nodular limestones of Member 2 of the Imi-n-Tazaght Formation.

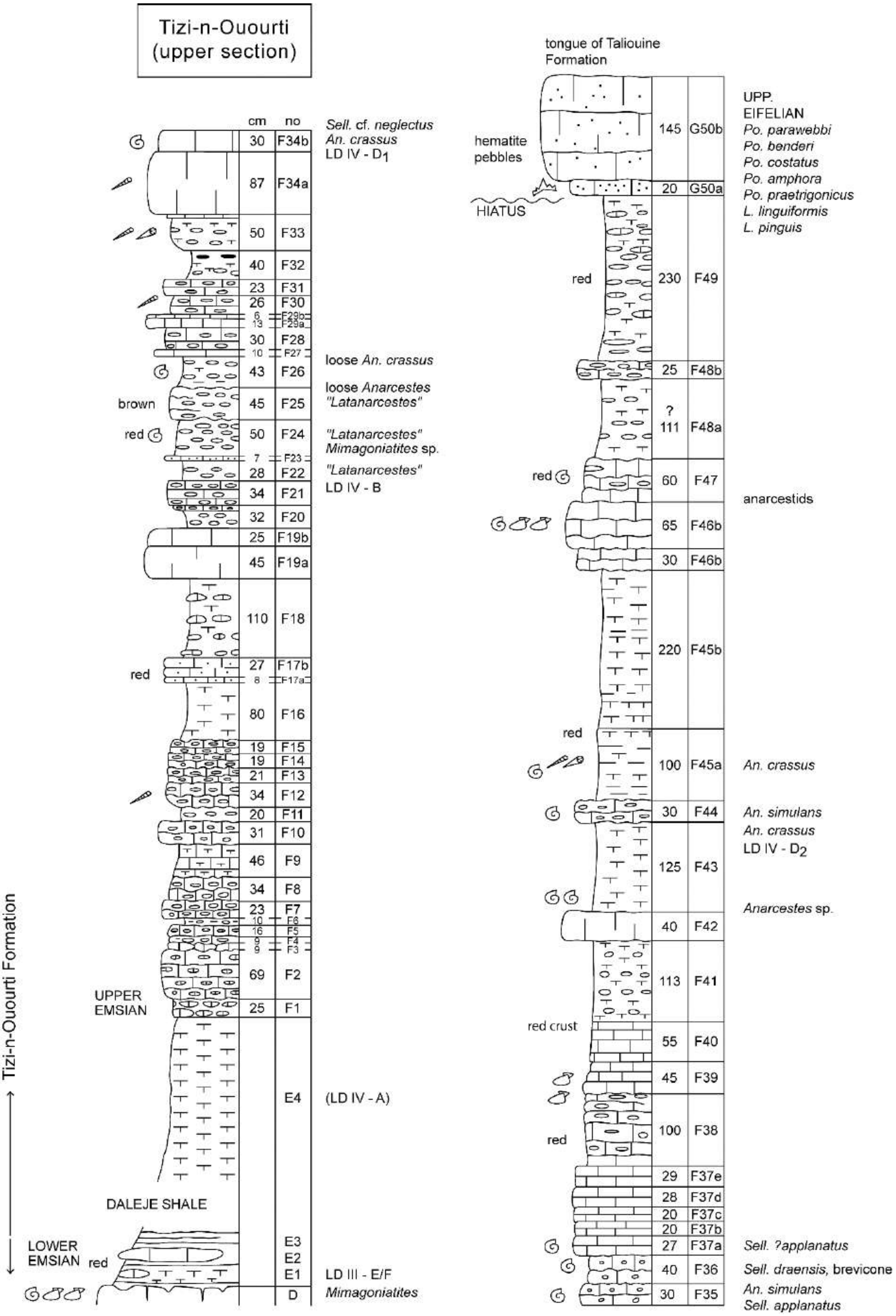

Fig. 39: Sedimentary and faunal sequence of the upper Emsian (Tizi-n-Ouourti Formation) to Eifelian (tongue of lower Taliouine Formation) at Tizi-n-Ouourti.

Fig. 40: Backside (southern flank of mountain) of the lower cliff at Tizi-n-Ouourti with the top of the lower Emsian on the left (Member 4 of Imi-n-Tazaght Formation), locally moderately thick Daleje Shale equivalents (Lower Member of type Tizi-n-Ouourti Formation), and cyclic, nodular anarcestid limestones (Upper Member), erosionally capped by a thin upper Eifelian limestone unit (tongue of Talioune Formation) on the right.

Member 3 (Field Unit C, blue limestone with crinoids and corals in ROCH 1939 = lower 2°) forms the main lower cliff (Fig. 34) composed of brownish-grey weathering bioclastic limestones. It has been logged in detail by the Greifswald Group but results are still forthcoming. Member 4 (Unit D) forms a sequence of very fossiliferous limestones with masses of *Panenka* and *Mimagoniatites* sp. (Fig. 41) on the steep dipping, southern backside (Fig. 40). At least some larger *Mimagoniatites* have wider whorls than at Taliouine.

7.2. Upper Emsian (Tizi-n-Ouourti Formation)

The *Panenka-Mimagoniatites* marker bed at the top of the Imi-n-Tazaght Formation ends with an upper discontinuity surface formed during an interval of current-induced sediment starvation and non-deposition. It is followed by the type succession of the Tizi-n-Ouourti Formation.

Fig. 41: Squashed *Mimagoniatites* sp. from the top of Member 4 at Tizi-n-Ouourti, GMM B6C.54.207.

Unit E, the ca. 10 m thick Lower Member (3° in Roch 1939), begins with dacryoconarid-rich marls with limestone concretions (Bed E1, Fig. 39), followed by a red shale (Bed E2) and large, flat, up to 15 cm thick, unfossiliferous concretions (Bed E3). The main part (Bed E4) consist of greenish-grey to whitish weathering shales and marls without macrofauna. The ca. 30 m thick Upper Member (4° in Roch 1939) begins with 6 m of light-grey to brownish weathering, thin-bedded nodular limestone and nodular shale (Beds F1-18) with poor macrofauna (rare orthocones). The ca. 35 cm thick, prominent Bed 17 is a detrital wacke-grainstone with dacryoconarids deposited under the episodic influence of bottom currents. The next marker unit is the ca. 70 cm thick Bed 19 (Fig. 39).

The first goniatite faunas enter in the nodular package of Beds F22 to F26 (base of 5° in Roch 1939). Bed F23 is a thin bioclastic bed (dacryoconarid packstone). Bed F24 is distinctive due to its red to violet nodules. Apart from one large *Mimagoniatites* (Figs. 42.11-12) all goniatites collected in-situ belong to "*Latanarcestes noeggerathi*" auct., which defines in the northern Maïder (Stichling 2013) and Dra Valley (Becker et al. 2004d; Ebbighausen et al. 2011) the first anarcestid zone (LD IV-B) of the upper Emsian (see also Becker & House 1994b). In the Dra Valley, the "*noeggerathi*" Zone correlates with higher parts of the *Icriodus fusiformis* Zone (Weddige in Jansen et al. 2004b; Aboussalam et al. 2015).

The preservation of all Tizi-n-Ouourti goniatites is moderate at best (Fig. 42). Shells have been dissolved, corrosion by diagenetic dissolution is common, and many moulds show elliptical deformation, which prevent precise shell parameter measurements. Large orthocones and solitary rugose occur in Beds F30-33 and in the massive, almost 1.2 m thick marker bed F34 that forms a second cliff top. In its upper part, there are in-situ *Sellanarcestes* and *Anarcestes*, which prove that zone LD IV-D_1 (sensu Becker & House 1994b) has been reached. In the Anti-Atlas conodont succession, this is the level of the *Linguipolygnathus bultyncki* Zone, which correlates internationally with the *serotinus* Zone (Aboussalam et al. 2015). Abundant *Anarcestes-Sellanarcestes* assemblages continue in overlying nodular beds (Beds F35-37, Fig. 39). Bed F38 is another reddish unit with large *Panenka*. The top of the limestone-dominated part of the member ends with a red crust at the top of Bed F40, an indicator of a short-termed interval of non-deposition. Above, thick marl and nodular marl units dominate on the (southern) back slope. In the lower part, the 40 cm thick Bed 42 is a good marker for orientation. Beds F43 to F47 yielded only *Anarcestes*, associated with orthocones, solitary Rugosa, and *Panenka*. The disappearance of *Sellanarcestes* defines the base of MD IV-D_2 (Becker & House 1994b), which falls in the Tafilalt in the middle of the *L. cooperi* Subzone (Aboussalam et al. 2015). There are three reddish intervals in the upper part of the Tizi-n-Ouourti Formation, a red marl at the top of Bed F45a, reddish nodules with *Anarcestes* of Bed F47, and red nodules in the middle of Bed F49. Since the red intervals do not follow changes from marl to nodular and solid limestone, and since they are laterally not consistent, they represent a superimposed feature, perhaps the circulation of iron-enriched pore water coming from the overlying post-Variscan redbeds.

The upper Emsian fauna of Tizi-n-Ouourti is as follows (bivalve identifications by M. G. Waterlot in Roch (1939):

"*Latanarcestes noeggerathi*" auct. (Figs. 42.1-2)
Sellanarcestes draensis (Figs. 42.3-4)
Sellanarcestes applanatus (Figs. 42.13-14)
Sellanarcestes cf. *neglectus*
Sellanarcestes aff. *neglectus* (Figs. 42.5-6)

Anarcestes simulans (Figs. 42.7-8)
Anarcestes crassus (Figs. 42.9-10)
Mimagoniatites bohemicus (see TERMIER & TERMIER 1950c)
Mimagoniatites sp. (Figs. 42.11-12)
?Pseudendoplectoceras tazaghtense n. sp. (Fig. 55.1), Bed F36
?Pseud. rochi n. sp. (Fig. 55.2), Bed F26
various orthocones
Panenka erosa
Panenka obtusa
Panenka pulchra
Panenka cf. *subtilis*
Panenka cf. *intermittens*
styliolinids and nowakiids
crinoid stems and ossicles
Favosites sp.
Cladochonus sp. (growing on goniatites)
solitary Rugosa (at least two species)
Linguipolygnathus bultyncki
Linguipolygnathus cooperi cooperi
Linguipolygnathus mawsonae

As in the Dra Valley and Tafilalt, non-corroded anarcestids show the wide-spread "Housean Pits" (Type 1, Figs. 42.3-4) resulting from endoparasitism (e.g., DE BAETS et al. 2011). *Sellanarcestes draensis* underlines the faunal similarity with the Tata region (EBBIGHAUSEN et al. 2011), where *An. crassus* is also a common form.

7.3. Eifelian (Taliouine Formation)

The Emsian/Eifelian boundary at Tizi-n-Ouourti is marked by a disconformity and long hiatus, ranging from the top-Emsian to the middle part of the upper Eifelian. There is a 20 cm thick, brownish weathering crinoidal limestone with sharp base (Bed G50a, Fig. 39), followed by a 145 cm thick, massive bed (Bed G50b) with abundant hematite nodules. Both represent a short tongue of the Taliouine Formation, but in very different facies. The lower unit yielded various Eifelian conodonts: *Polygnathus parawebbi* (Fig. 36.10, 2 specimens), *Po. benderi* (two specimens), *Po. amphora* (Fig. 36.8, 15 specimens), *Po. costatus* (Fig. 36.9, nine specimens), *Po. praetrigonicus* (Fig. 36.12, four specimens), *Linguipolygnathus linguiformis* (nine specimens), and a single *L. pinguis* (Fig. 36.11). *Polygnathus parawebbi* enters in the upper part of the *pseudofoliatus* Subzone (of the *costatus* Zone, "middle" Eifelian) but is more typical from the upper Eifelian *kockelianus* Zone on (BELKA et al. 1997; GOUWY & BULTYNCK 2002). The upper part of the latter zone is the type-level of *Po. amphora* (WALLISER & BULTYNCK 2011), the locally dominant species. Normally, it should not overlap with some of the other taxa: *L. pinguis* and *Po. praetrigonicus* range typically within the lower Eifelian from the *partitus* Zone through most of the *costatus* Zone. Based on graphic correlation, GOUWY & BULTYNCK (2002) suggested that *Po. costatus* may overlap with *Tortodus kockelianus*, but not with *Po. amphora* (see WALLISER & BULTYNCK 2011). *Polygnathus benderi* was so far not known from Morocco; in Germany it occurs from the "upper part of the *costatus* Zone" (*pseudofoliatus* Subzone) to the *australis* Zone (WEDDIGE 1977). As a consequence, the fauna from Bed G50a represents a mixed assemblage, with lower (*costatus* Zone) and top-Eifelian species. The local pure polygnathid biofacies indicates deep neritic to shallow pelagic deposition. It is peculiar since *Tortodus* (s.str.) is normally a common genus in the Moroccan upper Eifelian. The hiatus, reworking and faunal mixing occurred during the same regionally distinctive Eovariscan tectonic interval that caused the slumping and shedding of upper Emsian glide blocks and small olistolites at Taliouine. The Tizi-n-Ouourti section belonged to a more stable upper part of the carbonate ramp, where deposition became very episodic and incomplete. ROCH (1939, fig. 21) assigned overlying strata to the Cretaceous, overthrusted by Liassic limestones.

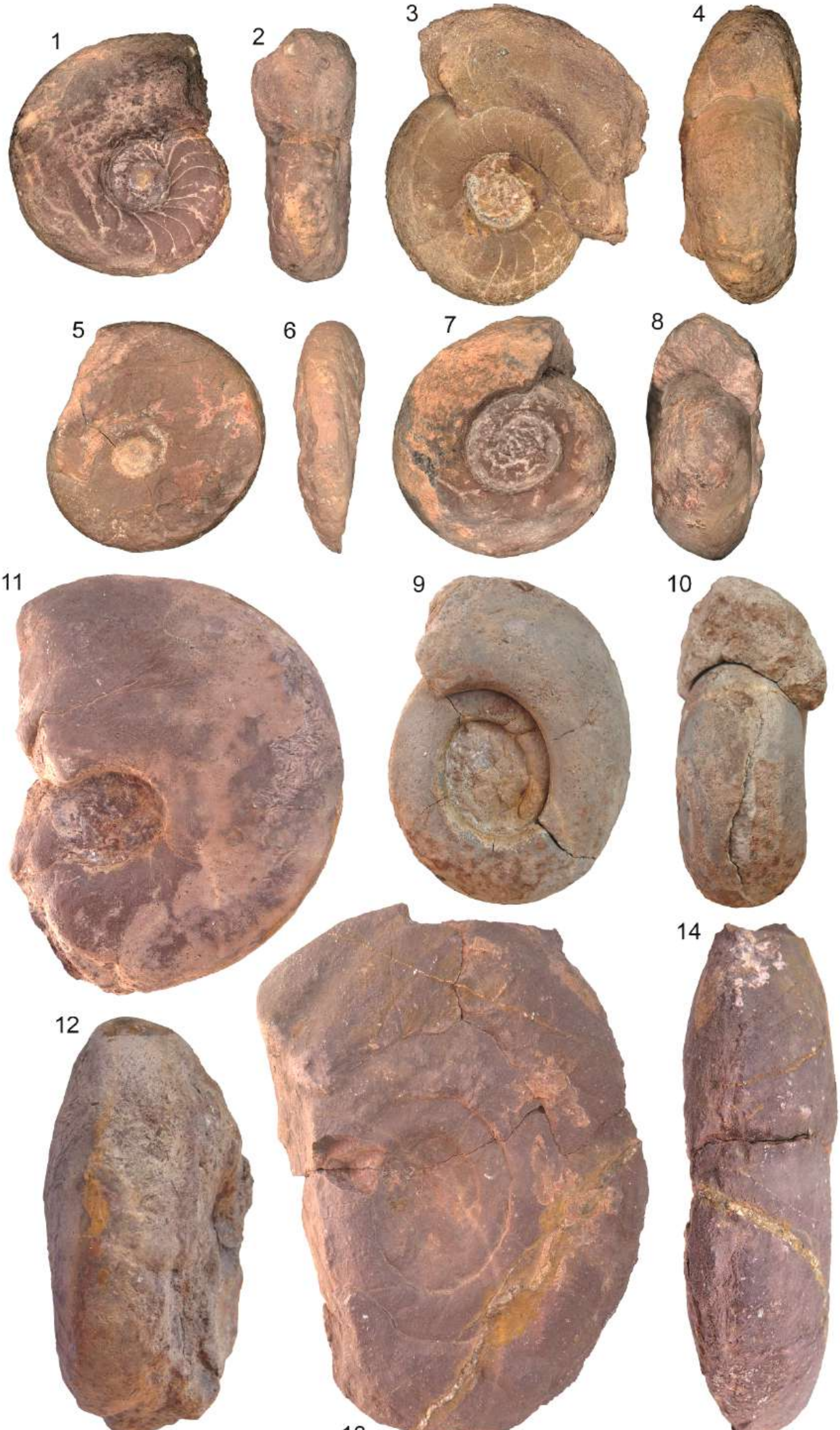
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Fig. 42: Goniatites from the Upper Member of the Tizi-n-Ouourti Formation (upper Emsian) in the type section; GMM B6C.54.208-214. **1-2.** "*Latanarcestes noeggerathi*" auct., lateral and adoral views, Bed F24, x 1; **3-4.** *Sellanarcestes draensis*, showing the typical, rather narrow umbilicus of median stages, and a ventrolateral row of elongated Housean Pits, lateral and adoral views, Bed F36, x 1.3; **5-6.** *Sell*. aff. *neglectus*, too involute and compressed for typical *neglectus*, lateral and ventral views, loose, x 1.5; **7-8.** *Anarcestes simulans*, lateral and adoral views, Bed F45, x 1; **9-10.** *An. crassus*, lateral and adoral views, Bed F44, x 1; **11-12.** *Mimagoniatites* sp., with relatively low whorl expansion rate, possibly caused by distortion, Bed F24, x 1; **13-14.** *Sell. applanatus*, lateral and ventral views, Bed F42, loose, x 1.

Fig. 43: View from the water reservoir on the two lateral Lower Devonian sections Asserhmo West (in the background) and Asserhmo East, at the foot of the foreground slope, with the cliff-building solid limestones of Members 3/4 of the Imi-n-Tazaght Formation for orientation. The winding dirt road runs in the Silurian black shales of the Tizi-n-Tichka Formation.

8. Devonian at Asserhmo

The Devonian of Asserhmo can be reached by following the winding road from Toundout to the NE and taking a piste to the left after crossing a major oued filled by shale. The piste joins after ca. one km the oued, then branches, where the right oued leading to the north should be used. After less than a km, a winding piste branches off to the left (west), leading uphill and, after passing some houses, eventually reaches the hill with the local water reservoir on the top. Fig. 43 shows the view from there onto the two adjacent Lower Devonian sections below, to the west. Note that the piste ends within the settlement (background of Fig. 43) and cannot be used for a circuit.

8.1. Silurian/Lower Devonian

The Silurian to lower Emsian succession follows closely the general lithostratigraphy of the Skoura Palaeozoic but thicknesses are much reduced (only ca. 15 m for the complete Pragian/lower Emsian, 10-20 m according to Laville 1980, p. 98). This suggests either a more proximal platform/ramp setting at Asserhmo and/or the influence of different subsidence. Significant for the regional tectonic model is the locally strong, cleavage-type, dense fracturing, which even affected rather massive limestones (Figs. 45.2-3). OUANAIMI & PETIT (1992) drew attention to this different tectonic style and postulated an oblique Skoura Fault, which delimited an "Domaine oriental" (with Asserhmo) from the much less deformed "Domaine central" (Tizi-n-Tichka to Tizi-n-Ouourti). The fact that different Variscan tectonic styles cross a uniform Lower Devonian sedimentary basin shows that the regional deformation types do not characterize different original terrains. The contrasting tectonics of the Skoura region is consistent with the model that the Meseta and Anti-Atlas were lying close to each other in the Devonian (e.g., BAIDDER et al. 2008), with a rather variable overprint during the later main Variscan orogeny.

8.1.1. Asserhmo West

The western small Lower Devonian cliff of Asserhmo (N31°19'46.35", W6°33'24.18") was logged bed-by-bed in two parts (Fig. 44). The Pragian Member 2 of the Imi-n-Tazaght Formation (low hill at the piste, left column) consists of ca. 11 m exposed cyclic nodular shales and limestones with abundant orthocones, *Panenka*, and dacryoconarids. Unlike as in the western sections, no trilobites were observed. Member 3 begins with thin- to medium bedded solid limestones (main cliff, right column), followed by detrital limestone, and a massive, 3.6 m thick limestone unit (Beds 6-7), which is possibly cut off in the south by a fault. Bed 5 (right column) is a flaser-bedded, slightly reddish, bioturbated bioclastic packstone with many dacryoconarids (styliolinids and subordinate nowakiids), ostracods, crinoid ossicles and fragments, some orthocones, abundant small shell filaments, and micrite matrix that was partly washed out (Fig. 46.1). It represents a shallow pelagic ramp below the storm wave base but under the influence of bottom currents. As typical for the strong regional tectonic overprint, there are many cracks filled with sparite and secondary black iron minerals. The conodont fauna is sparse (Tab. 2), with *Criteriognathus miae* (Fig. 47.1) and *Latericriodus bilatericrescens*. The latter species confirms a basal Emsian age (*bilatericrescens* Zone, see ABOUSSALAM et al. 2015). In the plain at its southern base, follow black shales, which may represent the Daleje Shale equivalents (Lower Member of Tizi-n-Ouourti Formation).

8.1.2. Asserhmo East

Below the eastern cliff (Fig. 43), the Silurian to basal Devonian black shales of the Tizi-n-Tichka Formation crop out in the small valley but the transition to the nodular marls of the lower Imi-n-Tazaght Formation (Member 2) is covered; based on changing bedding directions, a minor fault cannot be excluded. Member 3 is equally massive as at the adjacent western section and Member 4 is easily accessible on the southern side of the cliff (Fig. 45). It consists of densely fractured, solid bioclastic limestone with masses of *Panenka* shells covering in convex-up position the top surface. Since there are no bivalved shells, these were not preserved in living position but were transported by bottom-currents. The microfacies (Fig. 46.2) shows within the bed a flaser-bedded alternation of styliolinid wackestone and styliolinid-bivalve packstone with few crinoid ossicles, thick *Panenka* fragments, poor orientation but very frequent cone-in-cone stacking of the dacryoconarids, and very fine, light-grey micrite matrix. The diagenesis introduced iron mineralizations and microsparitization at pressure solution seams. There are several *Mimagoniatites* sp. (the compressed form known from Taliouine) on the top surface, indicating LD III-D high in the lower Emsian. The monospecific conodont fauna consists of abundant *Crit. steinhornensis* (Tab. 2, *steinhornensis* Zone). The complete absence of polygnathids resembles the Anti-Atlas *Mimagoniatites* Beds (ABOUSSALAM et al. 2015) and suggests a shallow pelagic setting.

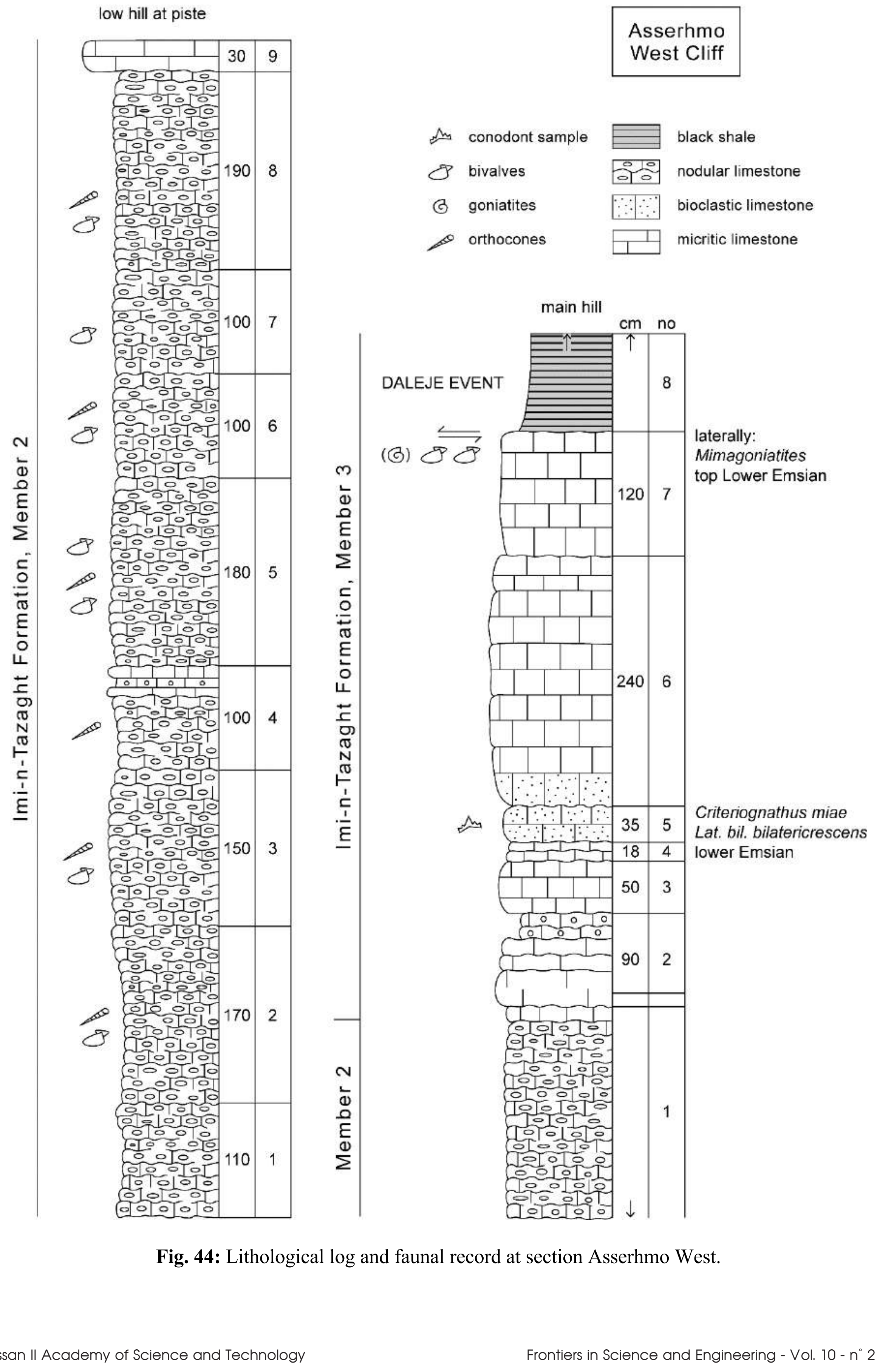

Fig. 44: Lithological log and faunal record at section Asserhmo West.

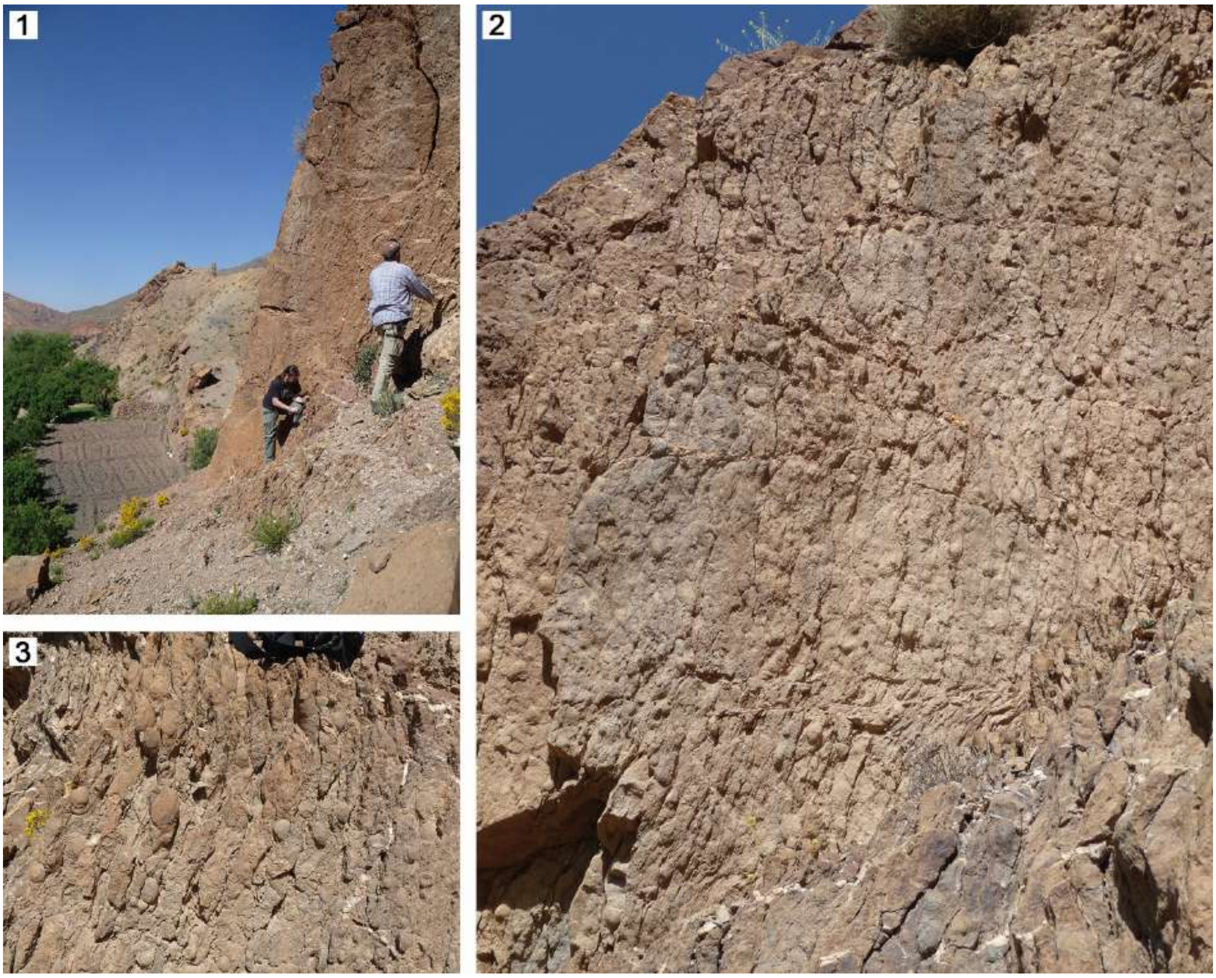

Fig. 45: Top of Imi-n-Tazaght Formation (top Member 4) at Asserhmo East. **1.** Overview of the steep cliff, with S. HELLING and H. HÜNEKE for scale, and with Asserhmo West in the background; **2-3.** *Panenka* mass occurrence and strong, undulating, cleavage-type, dense fracturing of the solid limestones.

On the adjacent hill to the east, below the water reservoir, the ca. 60 m thick Daleje Shale equivalents (Lower Member of Tizi-n-Ouourti Formation) seem to lie directly on the Silurian black shales but the poor outcrop situation does not rule out a fault contact.

8.2. Asserhmo Formation

The new formation is defined as a succession of conglomerates, silt- and sandstones, and subordinate fine, detrital limestones. The upper part of the hill below and at the water reservoir is formed by a 3-5 m thick conglomerate unit (**Lower Member**) (Fig. 48.1), followed on the eastern backside by up to 50 m fine-grained siliciclastics (**Upper Member**; compare description in LAVILLE 1980).

8.2.1. Lower Member

At the base, there is a 25 cm thick interval with two beds of solid, fine detrital, dark-grey limestone. The upper, platy bed is a completely unfossiliferous, slightly wavy laminated, microsparitic and dolomitic mudstone with thin, oblique calcite veins (Fig. 46.3). Conodont sampling was not successful. It represents the distal part of a hostile pelagic shelf basin receiving very fine-grained carbonate detritus. Separated by a dark shale interval, a 8-10 cm thick first conglomerate follow, marked by macroscopically distinctive, flat but well-rounded, black pebbles reaching ca. 2 cm maximum size. It yielded no conodonts. In thin-section (Fig. 46.4), it is a rudstone with abundant, rounded black ferromanganese, brownish, goethized or limonitized, and smaller, red hematite pebbles. The majority of the diverse limestone pebbles is also rounded, strongly affected by variable recrystallization, dolomitization, iron mineral impregnation at the margins or along fractures, and pressure solution contacts. As far as the original microfacies is preserved, there are light- and dark-grey mudstones, light-grey nowakiid packstones, black dacryoconarid-orthocone wackestones, and black orthocone-gastropod floatstones with micritic matrix and poorly preserved dacryoconarids. Subordinate are fine sand- and siltstones. There is almost no matrix in the clast interspaces. We suggest distal rockfall deposition at the lower slope of a fault scarp, where uplifted Lower Paleozoic to Middle Devonian strata were subject to a long interval of erosion and reworking in an agitated coastal setting before sediment overload at the upper slope and/or seismic activity triggered a small avalanche.

The timing of events can be better deduced from the higher, more fossiliferous conglomerates, which follow above 33 cm of laminated black shale, the background facies of a normally quiet basin. The ca. 1.2 m thick lower unit of the main conglomerate begins with a second layer of small-sized (1-3 cm) pebbles, which shows an irregular, erosive base. There is inverse grading towards the middle part (clast size increasing up to 20 cm), reverting into normal grading at the top. Well-rounded Ordovician quartz pebbles are very common (Fig. 48.2). In the subsequent 60 cm, there are subrounded to subangular, yellowish to reddish weathering limestone clasts (Fig. 48.3).

Asserhmo conodont samples							
age	**low. Emsian**	***steinhorn* . Zone**	**m. Lochk.**	**MN 10/11**	**Givet.**	**upp. Fam.**	
bed and sample no.	**West - Bed 5**	**East - top Mbr. 4**	**Orth. Lst.**	**brach lst.**	**coral lst.**	**cgl. 1**	**cgl. 2**
Bi. spinulicostatus M1						2	
Bi. aculeatus aculeatus						1	
Bi. costatus M2						1	
Neo. communis cf. *yazikovi*						3	
Neo. communis communis						6	
Pseud. primus primus						1	
Lat. claudiae?						1	
Crit. miae	2						
Crit. steinhornensis		27					
Lat. bilatericrescens	1						
Ancyrodelloides transitans			3				
Pa. hassi				5			
Po. ?webbi				1			
Po. aff. *paradecorosus*				1?			
Avign. decorosus				1			
L. linguiformis					1?		
L. zieglerianus							1
Br. ampla							2
Bi. stabilis stabilis							1
Sc. velifer leptus					1		1
total conodonts identified	**3**	**27**	**1**	**8**	**2**	**15**	**5**

Tab. 2: Conodonts from the Lower Devonian, from individual clasts, and conglomerate bulk samples at Asserhmo.

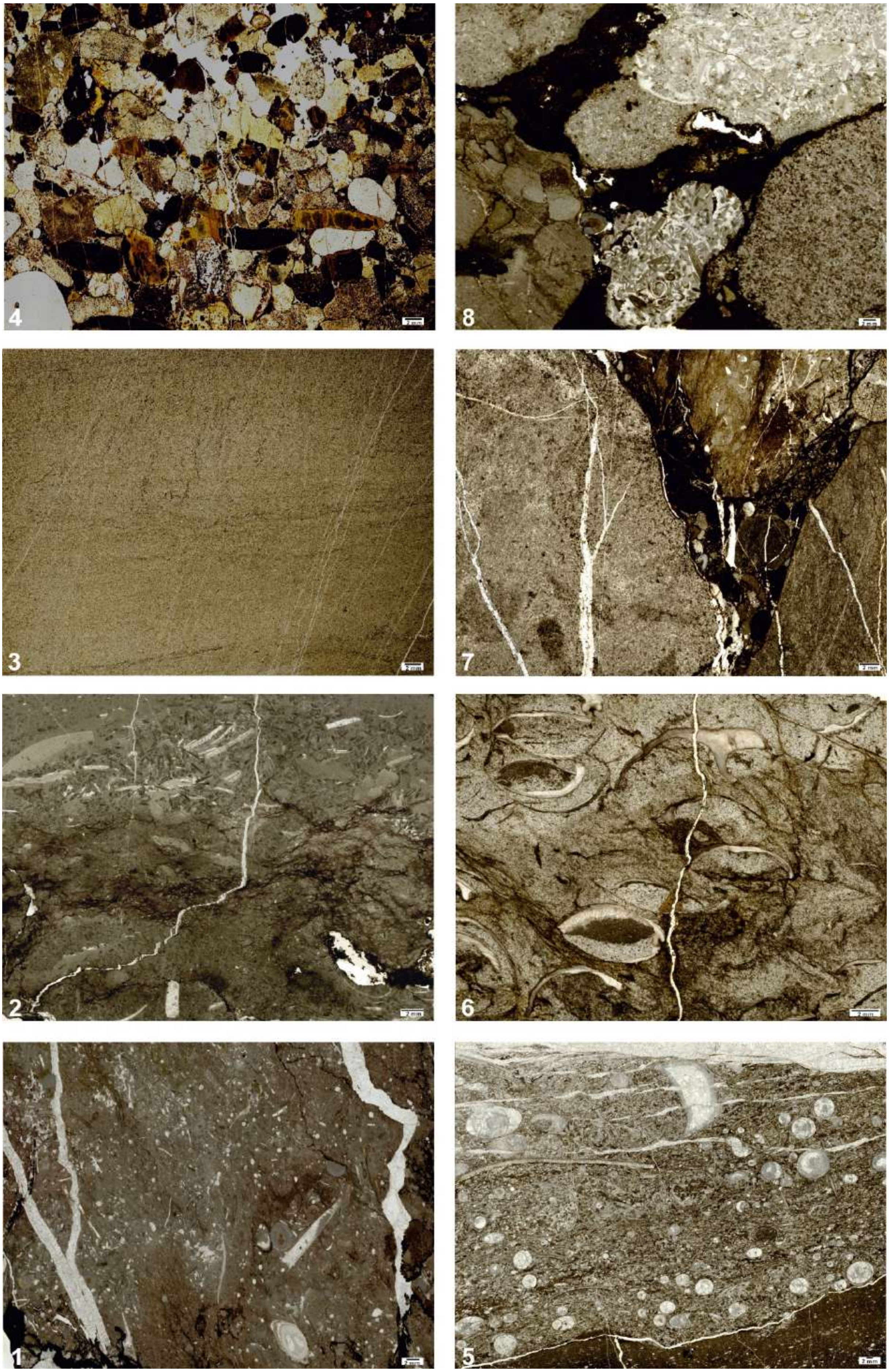
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Fig. 46: Microfacies of thin-sections from Asserhmo. **1.** Bioturbated wacke-packstone with abundant dacryoconarids, ostracods, orthocones, fine mollusk filaments, and crinoid debris, embedded in fine micritic matrix that is locally washed out, Asserhmo-West, Bed 5, basal Member 3 of Imi-n-Tazaght Formation (right column in Fig. 43); **2.** Alternation of dacryoconarid wackestone, bivalve-dacryoconarid packstone with rare crinoid ossicles, and recrystallized flaser-bedded intervals with diagenetic iron mineralizations, top of Imi-Tazaght Formation (Member 4, *Panenka* Bed with *Mimagoniatites*); **3.** Dark, unfossiliferous, microsparitic and dolomitic, laminated mudstone, base of the Lower Member of the Asserhmo Formation; **4.** Fine-grained conglomerate low in the Asserhmo Formation, a poorly sorted, strongly polymict extraclast rudstone with often well-rounded pebbles of black ferromanganese mineralization, brownish goethite/limonite, and whitish to brownish recrystallized and dolomitized, variable pelagic limestones; **5.** Black, laminated, organic-rich dacryoconarid wackestone with abundant ostracods (at the base), disconformably overlain (above the thin, diagenetic sparite seam) by an unsorted, non-graded, partly laminated, organic-rich orthocone floatstone with sparite-filled, current-orientated (almost normal to the thin-section plain) longi-orthocones, large mollusk filaments, and a bioclastic, peloidal grain-packstone matrix; at the top with a sparite-filled crack, large pebble from main conglomerate, middle Lochkovian; **6.** Recrystallized (pseudosparitic), flaser-bedded, bioturbated brachiopod floatstone with ferromanganese coating of some shells and bivalved or convex-up, current-controlled brachiopod embedding; shell filling partly by matrix, partly geopetal, pebble in main conglomerate, middle Frasnian; **7.** Unsorted extraclast rudstone with angular to subrounded larger pebbles of dolomitized, middle- to dark-grey, peloidal, bioturbated mudstone with several generations of calcite veins, dolomitic, originally light-grey, bioclastic wacke-packstone with dacryoconarids, abundant mollusk debris (upper right), and small-sized, iron-mineralized finer clasts including black ferromanganese pebbles, microsparitic mudstone, and isolated crinoid ossicles, coral-bearing main conglomerate; **8.** Extraclast rudstone with subrounded to subangular clasts of light-grey nowakiid grainstone with cone-in-cone stacking (lower center), middle- to dark-grey dolomitized mudstone (lower right, center, and upper left), light-grey, poorly sorted crinoid grainstone with ostracods (upper right), and brecciated mudstone (lower left), surrounded by iron-mineralized matrix that coated the clasts, upper part of main conglomerate.

The subsequent conglomerate at the terrace of the building is coarse, extremely polymict (Fig. 48.5), without any sorting or grading, and with isolated corals sitting between quartzite or limestone pebbles (Fig. 48.4). It represents the deposits at a higher part of the palaeoslope, originating from a sequence of rockfall events caused probably by repeated seismic activity. The strong mixing of clasts of very different age and provenance requires a common source, probably from a larger high-energy, coastal environment prior to their gravitational downslope transport. Since there is a difference between the rounding of older siliciclastic (Cambro-Ordovician) and younger (Devonian) limestone clasts (e.g., Figs. 48.2 and 48.4), recycling of the first is likely. The exposure and reworking time of the lithified Devonian limestones was much shorter than for the resistant quartzite pebbles. A survey of the clasts spectrum, their faunas and ages, adopting notes by LAVILLE (1980), gave the following results:

1. Well-rounded, mostly brownish to dark-grey, thin-bedded Ordovician quartzites (Figs. 46.4, 48.1 and 48.4).
2. Well-rounded, small-sized, flat, black ferromanganese pebbles (Figs. 46.4, 6 and 46.7, 48.4; probably Lower Paleozoic in age).
3. Red hematite clasts (Fig. 46.4).
4. Completely recrystallized, light-grey to brownish, variably dolomitic or goethitic limestones.
5. Unfossiliferous silt- and fine sandstone.
6. Dark-grey, laminated limestone poor in macrofauna: organic-rich mudstone or wackestone with dacryoconarids and partly dominant ostracods, sometimes with orthocones, with micritic or microsparitic matrix (Fig. 46.5; reworked from the upper Tizi-n-Tichka Formation).
7. Dolomitized or microsparitic, bioturbated, sometimes peloidal grey mudstone with sparite-filled veins ending at the clast margins, as evidence for full lithification and tectonic overprint (healing of fractures) before reworking and redeposition (Figs. 46.7-8).

8. Black Orthocone Limestone (Fig. 46.5): Unsorted, non-graded, partly laminated, organic-rich orthocone float-rudstone with mostly sparite-filled, rarely geopetal, current-orientated orthocones, large mollusk fragments, and a bioclastic (fine shell debris, abundant ostracodes, subordinate dacryoconarids), peloidal grain-packstone matrix. Matrix partly micritic, partly sparitic (washed out). Conodonts include the middle Lochkovian index species *Ancyrodelloides transitans* (Fig. 47.3; see VALENZUELA-RÍOS et al. 2015), possible *Wurmiella* fragments, and many ramiforms. Early stages of the orthocones are longiconic, with very low apical angles, and with hemisphaeric protoconch, as in Sphaerorthoceratidae (Orthoceratida, Neocephalopoda) (reworked from the top Tizi-n-Tichka Formation).
9. Dark-grey, bioturbated orthocone-gastropod floatstone with micritic matrix and poorly preserved dacryoconarids (?Lochkovian).
10. Flaser-bedded to nodular, light- to middle-grey limestone poor in macrofauna: bioturbated dacryoconarid wacke- or packstone with mollusk debris (Figs. 46.6-7) or grainstone with current-controlled washing out of the micritic matrix and nowakiid cone-in-cone stacking (Fig. 46.8). Such clasts are probably the source of rare Pragian conodonts, such as *Latericriodus ?claudiae* (Tab. 2; reworked from the Imi-n-Tazaght Formation).
11. Light- to middle-grey, unfossiliferous bioturbated mudstone, often recrystallized or dolomitic (probably reworked from Givetian Taliouine Formation).
12. Crinoidal limestone with *Panenka* (reworked from top Imi-n-Tazaght Formation).
13. Light- or middle-grey, fine detrital/crinoidal limestone: poorly sorted crinoidal packstone with ostracods and mostly washed out micrite matrix (Fig. 46.8), partly darker due to secondary iron impregnations (possibly reworked from Middle Devonian Taliouine Formation that, however, has no local outcrop).
14. Encrinite: coarse crinoid rudstone with ossicles and stem pieces (probable provenance as 13.).
15. Brecciated mudstone (Fig. 46.8), indication for seismic activity before the exhumation.
16. Flaser-bedded brachiopod limestone (Fig. 46.6): Recrystallized (pseudosparitic), bioturbated brachiopod floatstone with ferromanganese coating of some shells and bivalved or convex-up, current-controlled embedding. Complete shells are filled by a mixture of matrix and geopetal sparite. Conodonts include an encrusted *Avignathus decorosus* (Fig. 47.4), incomplete probable *Polygnathus webbi* (Fig. 47.6), *Po.* aff. *paradecorosus* (Fig. 47.5) with unusually wide platform, and five *Palmatolepis hassi* (Fig. 47.7). The first species enters at the top of the middle Frasnian (e.g., KLAPPER 1997), where it was found in griotte facies of the Tata region (BECKER et al. 2004a, 2004b). The palmatolepid dominance is not typical for brachiopod limestone and suggests a deep neritic setting, near the storm wave base. The top middle/upper Frasnian brachiopod limestone probably correlates with the atrypid block collected at Taliouine. It proves that a Frasnian carbonate ramp existed once, but in the Asserhmo region this was completely destroyed by Eovariscan uplift and erosion.
17. Isolated crinoid ossicles (Fig. 47.7) and corals, such as *Parastriatopora* (Figs. 49.1-2), *Alveolites* (Figs. 49.3-4), *Heliolites*, and phillipsastreids. *Parastriatopora* is a widely distributed genus in the Silurian to Emsian (e.g., MAY 2005). Its presence as isolated clast is unusual since we did not observe corals in the Pragian/lower Emsian at Asserhmo West and East. This suggests a more distant source, where the coral must have been freed from marl, not from lithified limestone. The partly large alveolitid colonies are unlikely to have been derived from the Lower Devonian. The group is characteristic for neritic to biostromal facies, which does not occur in the Skoura Lower Devonian. Based on an associated Middle Devonian linguipolygnathid (Tab. 2, coral limestone sample), the alveolitids probably derived from a local reefal facies of the Givetian Taliouine Formation. This is supported by the phillipsastreids (see *Prismatophyllum* of LAVILLE 1980), which occur in the Givetian/Frasnian, while *Heliolites* is not known above the Givetian.

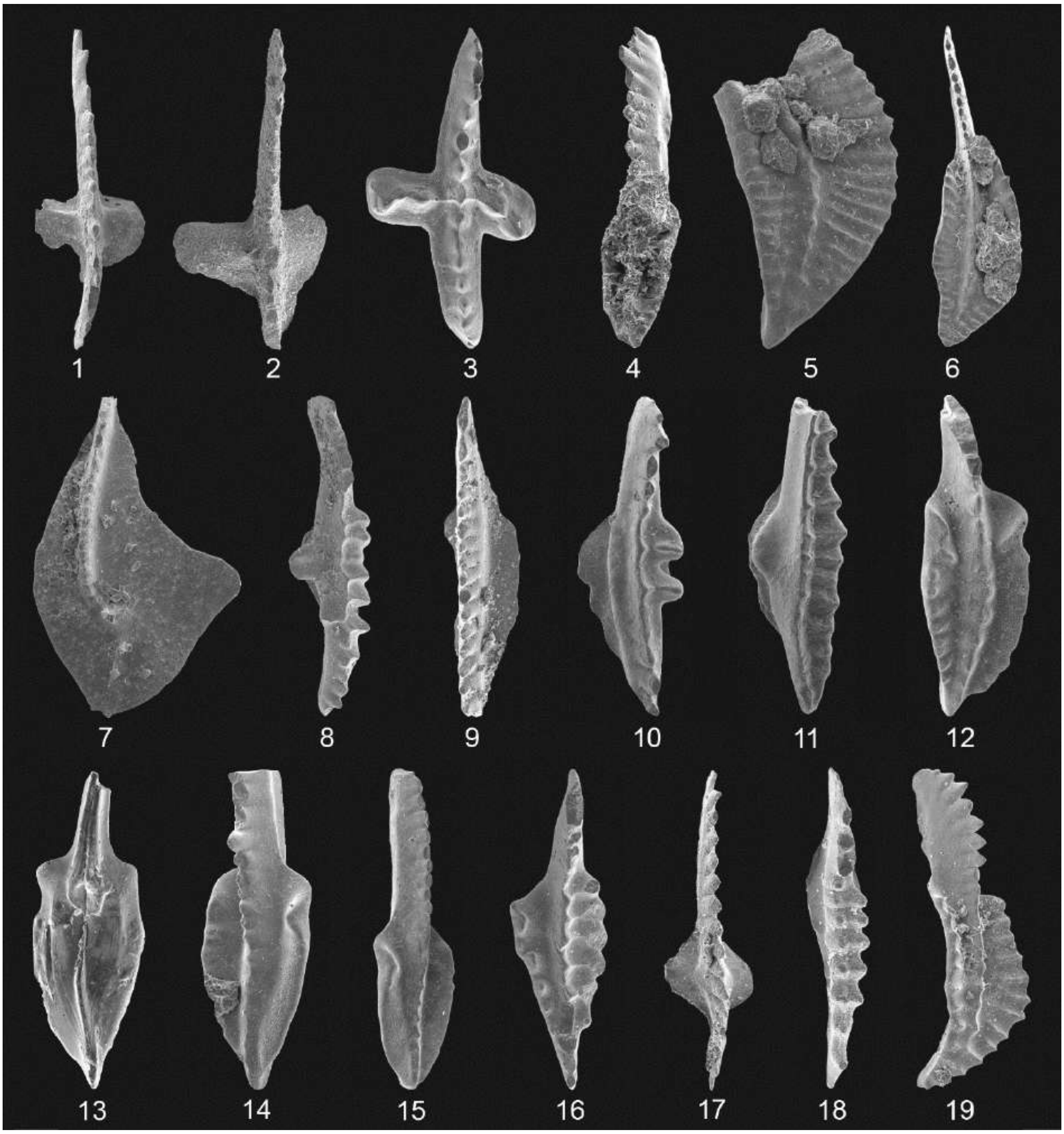

Fig. 47: Conodonts from the Lower Devonian, from individual clasts and conglomerate bulk samples at Asserhmo; GMM B4C.2.190-207. **1.** *Criteriognathus miae*, Asserhmo West, Bed 5, x 65; **2.** *Crit. steinhornensis* (early form), Asserhmo East, top of Imi-n-Tazaght Formation, x 60; **3.** *Ancyrodelloides transitans*, unusual morphotype with downlapping side lobe, pebble of black Orthocone Limestone, middle part of main conglomerate, x 40; **4.** *Avignathus decorosus*, encrusted, brachiopod limestone pebble, x 65; **5.** *Polygnathus* ?*webbi*, incomplete, brachiopod limestone pebble, x 45; **6.** *Po*. aff. *paradecorosus*, with atypically wide platform, brachiopod limestone pebble, x 55; **7.** *Palmatolepis hassi*, brachiopod limestone pebble, x 60; **8.** *Bispathodus spinulicostatus* M1, with side node on a left platform extension, as in the type material (ZIEGLER et al. 1974), conglomerate bulk sample 1, x 35; **9.** *Bi. stabilis stabilis*, conglomerate bulk sample 2, x 65; **10.** *Bi. aculeatus aculeatus*, transitional from *Bi. bispathodus*, with posterior extended basal cavity, conglomerate bulk sample 1, x 60; **11.** *Bi. costatus* M2, conglomerate bulk sample 1, x 60, **12-14.** *Neopolygnathus communis* cf. *yazikovi*, 12-13 = strongly ribbed morphotype, x 65, 14 = variant with ribbing on one side only, x 60, both from conglomerate bulk sample 1; **15.** *Neo. communis communis*, with distinctive collar, conglomerate bulk sample 1, x 45; **16.** *Pseudopolygnathus primus primus* M3, conglomerate bulk sample 1, x 50; **17.** *Branmehla ampla*, conglomerate bulk sample 2, x 65; **18.** *Scaphignathus velifer leptus*, conglomerate bulk sample 2, x 65; **19.** *Linguipolygnathus zieglerianus*, conglomerate bulk sample 2, x 50.

Fig. 48: Field photos of the conglomeratic Asserhmo Formation. **1.** Section overview, with the small water reservoir building (2 m high) at the top; **2.** Details of lower part of main conglomerate dominated by well-rounded Ordovician quartzite pebbles; **3.** Middle part of main conglomerate dominated by subangular clasts of yellowish to reddish-weathering limestone; **4.** Details of upper part of conglomerate, showing the embedding of a tabulate coral between unsorted, polymict, rounded to angular clasts; **5.** Large subrounded pebble of orthocone limestone in unsorted upper part of Asserhmo Formatio, with almost no matrix between the polymict clasts (coin = 24 mm).

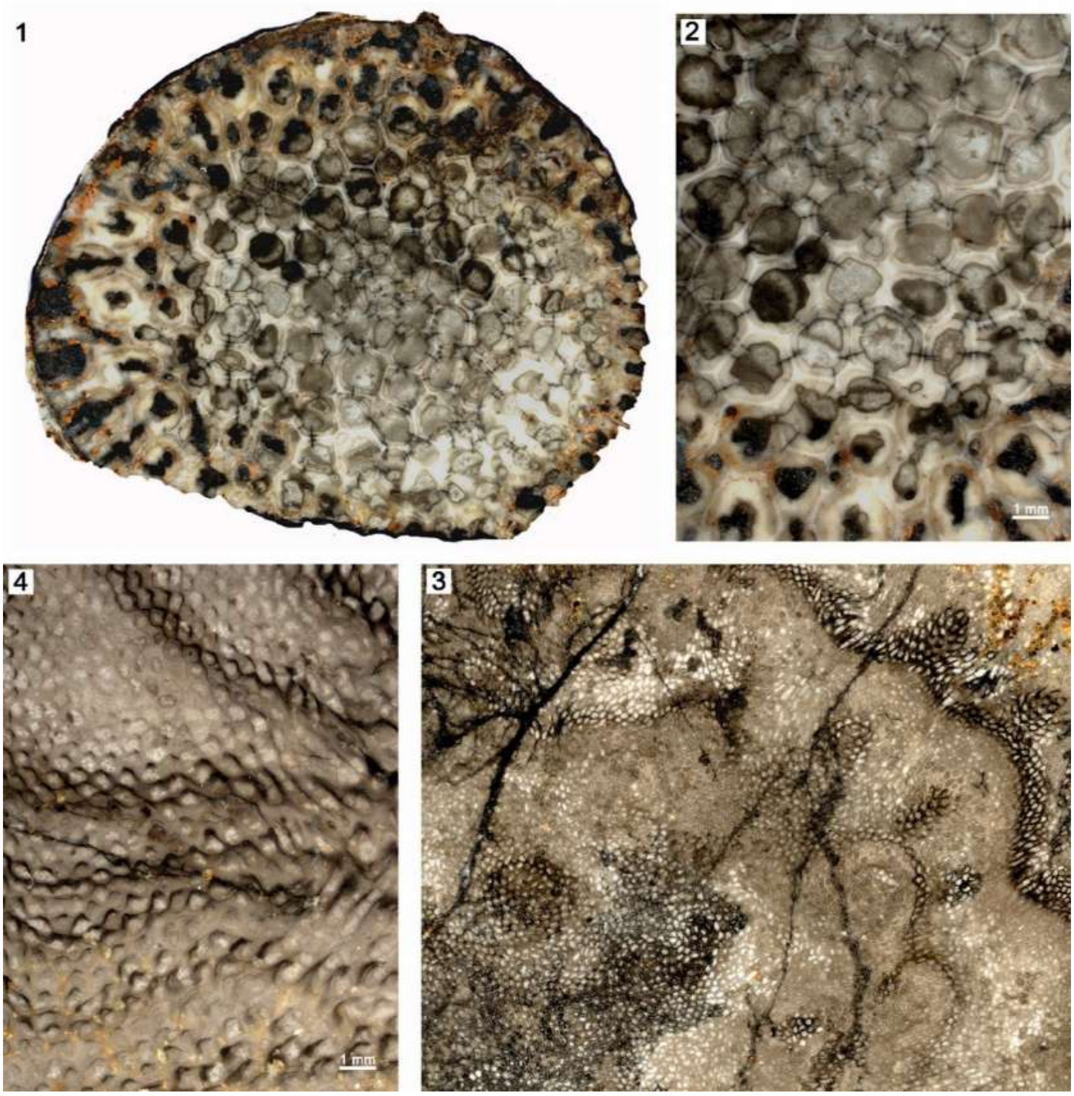

Fig. 49: Isolated tabulate corals from the upper part of the Lower Member of the Asserhmo Formation (scale = 1 mm). **1-2.** *Parastriatopora* sp., colony diameter 2.5 cm, GMM B2C.57.12; 3-4. *Alveolites* sp., picture width of 3. = 4.5 cm, GMM B2C.57.13.

19. Abundant dark-grey mudstone with rare crinoid debris and fine detrital limestone, resembling the two beds at the base of the Lower Member. This is perhaps the origin of relatively diverse middle/upper Famennian conodonts collected from two conglomerate bulk samples (Tab. 2). Sample "Conglomerate 1" from the base of the main part yielded *Bispathodus spinulicostatus* M1 (Fig. 47.8), *Bi. costatus* M2 (Fig. 47.11), *Bi. aculeatus aculeatus* (Fig. 47.10, transitional from *Bi. bispathodus* due to its long basal cavity), *Pseudopolygnathus primus primus* M3 (Fig. 47.16), *Neopolygnathus communis communis* (Fig. 47.15), and *Neo*. *communis* cf. *yazikovi*. (Figs. 47.12-14; see taxonomic paragraph). *Bispathodus costatus* defines the upper Famennian (higher UD V) *costatus* Subzone of HARTENFELS (2011) or *costatus* Zone sensu SPALLETTA et al. (2017). All other species could come from the same interval (for *Ps. primus primus* M3 see HARTENFELS & BECKER 2016b) but a Pragian clast (see Tab. 2) was part of the same block. The "Conglomerate 2" sample produced *Bi. stabilis stabilis* (Fig. 47.9), *Branmehla ampla* (Fig.47.10), and *Scaphignathus velifer leptus* (Fig. 47.17). The first defines in the scheme of HARTENFELS (2011) a zone that is equivalent to the (Lower) *expansa* Zone of the palmatolepid succession, high in UD IV. The second ranges from the middle Famennian *utahensis* Zone (former

Upper *marginifera* Zone) to the basal *aculeatus aculeatus* Zone (basal UD V; HARTERNFELS 2011). *Scaphignathus velifer leptus* is known from the *utahensis* to the *styriacus* Zones (UD III to middle UD IV). Therefore, the Famennian assemblage is mixed (middle/upper part of UD IV, possibly also UD III) and older than the one from upper Famennian clasts of "Conglomerate 1". Clasts in the sample with alveolitids yielded a second *Sc. velifer leptus*. A pebble within "Conglomerate 2" yielded the basal Eifelian (e.g., BELKA et al. 1987) *Linguipolygnathus zieglerianus* (Fig. 47.18) and a poorly preserved scolecodont. None of the Skoura outcrops yielded so far any in-situ conodonts of the *partitus* Zone.

The conglomerate clast spectrum and conodonts prove that not only the typical Skoura Lower and Middle Devonian known from the outcrops was subject to uplift and reworking, but also a Givetian to Frasnian neritic ramp/platform and ?middle to upper Famennian pelagic limestones. The latter are completely unknown from the studied Skoura localities. The conglomerates, therefore, provide unique windows into the whole Upper Devonian facies development of the region. It is likely that the current lack of lower and undoubted middle Famennian conodonts reflects only the so far limited sampling. Alternatively, there was an upper Famennian transgression, ca. at the level of the *Annulata* Events (see HARTENFELS 2011 and HARTENFELS & BECKER 2016a). There is currently no local evidence for uppermost Famennian and lower/middle Tournaisian strata.

8.2.2. Upper Member

The Upper Member of the Asserhmo Formation occupies the eastern slope of the water reservoir hill. It consists of brownish weathering, fresh dark-grey, silty slates and platy, laminated, micaceous, well-sorted fine sandstones without fossils. There is potential for future palynomorph dating, which could prove a supposed (upper) Tournaisian age. LAVILLE (1980) included the Upper Member in the Devonian, below an Upper Viséan unconformity, but his interpretation was not based on any faunal data.

1

2

Fig. 50: Field photos of the Viséan at Taliouine Section 3. **1.** Steep upper slope, showing a thick package of greenish-grey shale partly covered and overlain at the top by resistant, very fossiliferous bioclastic limestone; **2.** Loose slab of crinoidal limestone with one of the locally very characteristic, large euomphalid gastropods (67 mm max. diameter).

9. Viséan at Taliouine

Previous authors described the laterally rather variable lithology of transgressive Viséan beds in the Skoura region (ROCH 1939, 1950; LAVILLE 1980; IZART et al. 1989). We examined only the succession in the upper slope of Taliouine Section 3 and collected spot samples.

As discussed above, the ca. 20 m thick alternation of shale, marl, and bioclastic limestones overlying the conglomeratic Member 4 of the Taliouine Formation has been assigned by LAVILLE (1980) to the Frasnian. It is followed by ca. 30 m of greenish-grey, poorly fossiliferous shale (Fig. 50.1) of currently unknown age. The top of the steep hill is formed by a ca. 10 m thick cliff of Lower Carboniferous, very fossiliferous limestones with solitary Rugosa (Fig. 52), abundant brachiopods (spiriferids, Fig. 51, strophomenids, productids), large bryozoan colonies (partly > 10 cm), and, locally especially distinctive, large euomphalid gastropods (Fig. 50.2). This is the "Calcaires viséens" of ROCH (1939, 1950) and the "calcaire jaunes et lumachelle calcaire" of LAVILLE (1980), which was also briefly described by IZART et al. (1989, p. 68).

Thin-sections revealed an abundance (thousands of specimens) of foraminifera (Fig. 53). Assemblages are predominantly composed of typical taxa of the upper part of the early Viséan, including *Archaediscus* ex gr. *stilus*, *A. koktjubensis*, *Archaediscus* spp. at *involutus* stage, *Archaediscus* spp. transitional forms between the *involutus* and *concavus* stages, *Endothyra* spp., *Eoparastaffella florigena*, *E. macdermoti*, *Eotextularia diversa*, *Glomodiscus oblongus*, *G. rigens*, *Nodosarchaediscus* spp., *Plectogyranopsis ampla*, *P. moraviae*, *Pseudotaxis eominima*, *Omphalotis frequentata*, *O. chariessa*, *Tetrataxis* spp., *Uralodiscus rotundus*, and *U. elongatus*. However, rarely, *Archaediscus* at *concavus* stage (*A. krestovnikovi* and *A. moelleri*), *Endothyranopsis compressa,* and *Omphalotis minima* also occur.

The latter species indicate Cfm2 (upper Cf5α) in the middle part of the middle Viséan (top-Arundian; e.g., CÓZAR et al. 2020a, fig. 1). Associated are "algospongia", such as *Kamaena*, and the problematical dasycladacean *Koninckopora inflata*. The environment was a storm-ridden, euphotic carbonate ramp. There are close similarities with the microfossil assemblage from Assif n´Tanzouzmine ca. 4 km to the SSE (IZART et al. 1989; CÓZAR et al. 2020a). The combined evidence of both sections suggests for the west-central Skoura region a hiatus that spans the Famennian to lower Viséan. At Asserhmo in the east (see above), it was shorter, including possibly only the top Tournaisian and lower Viséan. At Taliouine, the middle Viséan limestones are overlain on the northern backside of the hill by a thick package of greenish-grey silty shales. Based on goniatites mentioned by ROCH (1939), they are of upper Viséan age and indicate transgression, as typical for the Meseta.

Fig. 51: Spiriferid with exfoliated upper shell (preventing generic identification) from the middle Viséan bioclastic limestone at Taliouine, Section 3, GMM B5B.16.14.

10. Regional comparisons of facies and tectonic developments

The regional palaeogeography and reconstruction of synsedimentary structural history of the Skoura Devonian requires stratigraphically tuned comparisons with the allochthonous eastern Jebilet to the NW (see Jebilet chapter), the eastern Dra Valley in the S/SW (e.g., HOLLARD 1978; BECKER et al. 2004a, 2004b; JANSEN et al. 2004), and the

Tinerhir region in the east (e.g., HINDERMEYER 1954, 1955; SCHIAVO et al. 2007; RYTINA et al. 2013), which also belonged to the Sub-Meseta Zone (SMZ, MICHARD et al. 2008, 2010). Figure 54 correlates the principle Devonian successions of Taliouine, Tizi-n-Ouourti and Asserhmo with the Jaidet and Tata successions. For the Foum Zguid region, knowledge of the Middle/Upper Devonian is currently too incomplete; the Lower Devonian resembles the Tata region. The Ait Tamlil Devonian of the High Atlas (JENNY & MARREC 1980) seems to include similarities with the Skoura region, but lacks modern biostratigraphic and microfacies data.

Fig. 52: Representative thin-section of the middle Viséan limestones at Taliouine Section 3, a non-sorted and non-graded brachiopod-crinoid-coral floatstone with well-sorted bioclastic pack-grainstone matrix, representing a current-swept, neritic carbonate platform setting.

Fig. 53: Representative foraminifer-rich thin-section of the middle Viséan limestone (bioclastic grainstone) at the top of Taliouine Section 3.

10.1. Lower Devonian

The Silurian-Devonian transition of the Skoura region belongs to a deep and anoxic (hemi)pelagic shale basin. The Lower Member of the Tizi-n-Tichka Formation correlates with the main part of the Jebel Smaha Formation at Jaïdet and black shales of Ait Tamlil (Unit 8). The whole region is characterized by the lack of *Scyphocrinites* limestones, which are so characteristic for the eastern Anti-Atlas (e.g., HAUDE et al. 2014) and many Meseta regions (e.g., RÉGNAULT 1985). In the western Dra Valley, there was a very different, neritic, mixed siliciclastic-carbonatic facies (Lmhaifid Formation), characteristic for the cratonic shallow NW Gondwana shelf.

The slumped and strongly current-influenced middle Lochkovian Orthocone Limestones of the Skoura region (Upper Member of Tizi-n-Tichka Formation) has no equivalent in the Jebilet or Anti-Atlas. But interestingly, an only slightly older orthocone rudstone with *Ancyrodelloides carlsi* was found as reworked clast in the Taourirt n´Khellil breccia of the eastern Sub-Meseta Zone (RYTINA et al. 2013). The middle Lochkovian first "Skoura synsedimentary tectonic phase" (Sk-TP 1a), culminating in the upper Lochkovian to lower Pragian hiatus, seems to be a characteristic tectono-sedimentary feature of that zone.

Regionally, the "Antevariscan" movements continued ca. to the "middle" Pragian (conglomeratic Member 1 of Imi-n-Tazaght Formation at Taliouine, Sk-TP 1b). Probably as a consequence of the global Lochkovian-Pragian boundary regression, the anoxic and organic-rich facies had disappeared throughout the region and gave way to oxic pelagic mud-wackestones. These were then eroded and redeposited by seismically induced debris flows, together with reworked lower/middle Lochkovian black limestone clasts. Locally (Imi-n-Tazaght North), the higher Pragian began with a unique, condensed, microbial (*stromatactis*), deep neritic or shallow pelagic (dysphotic) limestone. There was a trend of reduced accumulation rates and more shallow ramp settings from west to east. But in the upper Pragian, the Skoura region shows a uniform oxic, nodular, shallow pelagic facies with bioclastic contourites, partly giant orthocones, and abundant *Panenka* bivalves. This Member 2 of the Imi-n-Tazaght Formation corresponds closely to the griotte of the Middle Member of the Jaïdet Formation, and of Units 10/11 at Ait Tamlil (JENNY & MARREC 1980). The Pragian sedimentary history of the eastern Dra Valley differed fundamentally, being characterized by the neritic Rich 1 and 2 cycles (Oued-el-Mdâouer and Merzâ-Akhsai Formations; e.g., HOLLARD 1978; BECKER et al. 2004a; JANSEN et al. 2004).

The Pragian-Emsian transition of the Skoura region correlates roughly with the boundary of Members 2 and 3 of the Imi-n-Tazaght Formation. There was a regional regressive trend towards less argillaceous, more current-influenced limestones. The overall setting remained shallow pelagic but we cannot recognize the transgressive pulse of the basal Emsian *atopus* Event, which is so characteristic in the Tafilalt (*Devonobactrites* Shale with F1 fauna, e.g., KLUG et al. 2008; ABOUSSALAM et al. 2015) and in the Foum Zguid region (DE BAETS et al. 2010: F1 fauna from the base of the Mdâouer-el-Kbír Formation). In this respect, the Skoura and Jaïdet successions are similar.

Our new *Erbenoceras* record from Taliouine may represent the next younger Chebbi Event level, which is marked in the Tafilalt by the rapid deepening of the *Metabactrites-Erbenoceras* Shale (e.g., ABOUSSALAM et al. 2015; F2 level of KLUG et al. 2008). Based on dacryoconarid dating, *Erbenoceras* occurs at the same time in the northern Maïder (Jebel Issimour, PLODOWSKI et al. 2000). In the eastern Dra Valley, it appears in the middle part of the Lower Member of the Mdâouer-el-Kbír Formation; (HOLLARD 1963a, 1978; BULTYNCK & HOLLARD 1980: conodont Fauna II, *bilatericrescens* Zone). At Jaïdet, a more nodular griotte facies without early goniatites but with common iron mineralizations (Middle Member of Jaïdet Formation) continued in the lower Emsian. By contrast, the possibly correlative Unit 12 of Ait Tamlil is siliciclastic.

The lower Emsian of the eastern Dra Valley terminates the shallowing upwards Rich 3 cycle (Mdâouer-e-Kbír Formation). At its top, a *Mimagoniatites* level was found (JANSEN et al. 2004, 2007). It provides a precise correlation with the top-lower Emsian *Mimagoniatites* Limestone of the Tafilalt (e.g., WALLISER 1991; BULTYNCK & WALLISER 2000; BECKER & ABOUSSALAM 2011), Maïder (top of Bou Tiskaouine Formation, BULTYNCK 1991), and the *Mimagoniatites* level in Member 4 of the Imi-n-Tazaght Formation. The southern Moroccan *Mimagoniatites* bloom and spread has been correlated by BECKER & ABOUSSALAM (2011) with the global Upper Zlíchov Event sensu GARCÍA-ALCALDE (1997). In the Devonian of Ait Tamlil, the detrital, prominent Tassawt Limestone (Units 13/14, JENNY & MARREC 1980) may be a time-equivalent, which needs to be corroborated by biostratigraphical data.

Throughout the Skoura Devonian, the basal upper Emsian Daleje Event is sharp and marked by a fundamental sedimentary change, from fossiliferous, oxic, current-controlled bioclastic limestone to hypoxic silty, hostile shale. The facies break is very similar as in the eastern Anti-Atlas (northern Maïder: base Er Remlia Formation, BULTYNCK 1985; Tafilalt: Unit K, base Amerboh Formation, e.g., BECKER & HOUSE 1994b; BULTYNCK & HOLLARD 2000; BECKER et al. 2018a). However, it is very indistinctive in the eastern Dra Valley succession (ABOUSSALAM et al. 2015) and has not been found in the eastern Jebilet. At Ait Tamlil, greenish to black siltstones (Unit 15) overlying the Tassawt Limestone may represent Daleje Shale equivalents.

The rather uniform development of nodular to flaser-bedded, upper Emsian anarcestid limestones throughout the southern Meseta (eastern Jebilet: Upper Member of Jaïdet Formation)), Sub-Meseta (Skoura: Upper Member of Tizi-n-Ouourti Formation), and Anti-Atlas regions (western Dra Valley to Tafilalt) is intriguing. It suggests a long interval (*bultyncki/serotinus* to *patulus* Zones) of calm, condensed, oligotrophic, pelagic facies with almost identical faunas and without much seismic activity.

10.2. Middle Devonian

The upper Emsian “goniatite garden” episode was abruptly terminated in the lower Eifelian by Eovariscan block tectonics (Sk-TP 2) causing uplift, reworking of the upper Emsian, slumping, and unconformities on the Skoura side (Taliouine, Tizi-n-Ouorti). On the Jebilet side (Lower Member of El Kahla Formation), it led to sudden subsidence and the formation of a siliciclastic and eutrophic basin. A coincident gradual deepening initiated in the Foum Zguid and Tata regions (eastern Dra Valley) a change from condensed limestones to basinal marls with lower Eifelian goniatites (Upper Member of Timrhanrhart Formation, BECKER et al. 2004a). Pyritic (secondarily goethitic) faunas and blooms of minute brachiopods occurred during maximum flooding, the level of the global Choteč Event (BECKER et al. 2004a, 2004b; EBBIGHAUSEN et al. 2011).

Due to the very incomplete, episodic record of Eifelian sediment and conodonts, the Choteč Event cannot be recognized in the Skoura region. Currently, a single reworked conodont from Asserhmo (*Linguipolygnathus zieglerianus*) testifies that deeper-water sedimentation continued at least locally in the basal Eifelian. At Taliouine, black shales between slumped upper Emsian olistolites and glide blocks (Sk-TP 2a) and slumped basal Givetian limestones (Sk-TP 2b) are taken as a regional expression of the top-Eifelian Kačák Event. At Tizi-n-Ouourti, the sedimentary record ends earlier (with the *kockelianus* Zone), after uplift first caused a long, top-Emsian-"middle" Eifelian hiatus, followed by a regionally unique, shallow, crinoidal-conglomeratic facies. In the Tata region, the Middle Devonian sedimentation was continuous, with cephalopod limestones ("*vanuxemi* Beds" of the Ahrerich Member occurring at the Eifelian-Givetian transition.

The Eifelian tectonic interval of the Skoura region lasted with interruptions into the basal Givetian (Member 1 and basal Member 2 of Taliouine Formation; Sk-TP 2c). Evidence are polymict mudclast conglomerates and in-situ-brecciation of mudstones triggered by seismic events. There are no facies similarities any more with the Jaïdet succession (Upper Member of El Kahla Formation), nor with the lower Givetian of the Tata region (goniatite marls of the upper Ahrerich and lower Oued Mzerreb Members of the Ahrerouch Formation, BECKER et al. 2004a). The reworked Givetian of the Tinerhir region (RYTINA et al. 2013) and northern Maïder (e.g., KAZMIERCZAK & SCHRÖDER 1999; FRÖHLICH 2003, STICHLING 2013) was biostromal. Surprisingly, close faunal and facies ties with the Tata succession were re-established in the seismically quiet lower part of the middle Givetian. Member 3 of the Taliouine Formation resembles the upper Oued Mzerreb and Tiguisselt Members of the Ahrerouch Formation, especially concerning the admixture of dominant goniatite and subordinate neritic faunas. In detail, the marker units of Oued Mzerreb (BECKER et al. 2004b) are not developed and the absence of the *pumilio* Events (LOTTMANN 1990) at Taliouine is distinctive. Apart from the presence of *Sellagoniatites*, the faunas and strata of the Tafilalt Platform and Maïder Basin are not similar. However, far in the SE, the middle Givetian of the Tafilalt Basin (Hassi Nebech) shows some identical faunas in goniatite marls (e.g., *Argutastrea, Afromaenioceras*, and other goniatites; ABOUSSALAM 2003).

The next major block faulting, uplift, reworking and redeposition episode (Sk-TP 3) manifested in the massive and polymict conglomerates of Member 4 of the Taliouine Formation. This development severely interrupted the eastern Dra Valley link. The Taliouine conglomerates represent the first major Eovarican phase in the middle/upper Givetian that characterizes most of the Meseta (BECKER et al. 2015). It is also well-developed (as flat pebble breccias) in an allochthonous Devonian block between Tinerhir and Tinejdad (Section Bou Tisdafine Southeast, TALIH et al. in prep.), in the eastern continuation of the Sub-Meseta Zone. The same seismic events caused megaslumps, breccias, biostrome extinctions, and eventually the top middle Givetian unconformity of the northern Maider (e.g., KAZMIERCZAK & SCHRÖDER 1999; FRÖHLICH 2003; STICHLING 2013). Therefore, there was a pattern of upper Givetian synsedimentary tectonic movements ranging from the Meseta through the Sub-Meseta Zone into the cratonic Anti-Atlas, but, somehow, sparing the Dra Valley.

In the Skoura region, the upper Givetian seismic events were sedimentologically distinctive but episodic, and interrupted a persisting outer shelf, hypoxic goniatite shale facies. Interestingly, the faunas with pharciceratids and pseudoprobeloceratids have no equivalent in the Tata region, where there is a gap of goniatite faunas between the top-middle Givetian (*Juvenocostatus* Beds, Tiguisselt Member) and higher middle Frasnian (*Naplesites* Beds, Lower Member of Anoû Smaira Formation, BECKER et al. 2004a, 2004b). The closest similar, but much richer assemblages are from the NW Maïder (BOCKWINKEL et al. 2015).

10.3. Upper Devonian

It should be re-emphasized that the supposed Skoura Frasnian with *Koenenites* in HOLLARD (1967) represents most likely top-middle Givetian goniatite shale with *Mzerrebites* as in the Tata region (*Juvenocostatus* Beds). The true Upper Devonian sedimentary and faunal record of the Skoura region is currently very scarce and incomplete, and mostly based on isolated and reworked blocks. This hampers regional comparisons but the data available are sufficient to state that there was a rather unique facies development.

The middle/upper Frasnian neritic brachiopod limestones of Taliouine and Asserhmo have no pendant in all of the southern or eastern Meseta, nor in the eastern Sub-Meseta Zone or Dra Valley (pelagic goniatite beds of higher Anoû Smaira Formation). The next closest occurrences are poorly studied Frasnian brachiopod limestones from the northern Maïder (DROT & HOLLARD 1967; new collection from the Bou Dib area). In the Taourirt n´Khellil breccia east of Tinerhir, the Frasnian is only represented by Kellwasser Limestone clasts (new record).

The upper Famennian pelagic conodont faunas of the main Asserhmo conglomerate have also no pendant in the southern Meseta (Rehamna, Jebilet) or Dra Valley (siliciclastic Lemgairinat Formation). Again, the next closest occurrence is in the northern Maïder, more specifically around the Jebel Rheris (FRÖHLICH 2004 and new data). However, lower/middle Famennian pelagic conodonts were found very recently in the central Jebilet (Sarhlef Formation, LAZREQ et al. 2021) and it is likely that a mostly siliciclastic Jebilet Basin persisted throughout the Famennian.

The Asserhmo Formation shows overall similarities with the Taourirt n´Khellil Formation (RYTINA et al. 2013; HARTENFELS et al. 2013). It is possible that both originated by seismically triggered rockfall along active fault scarps during the same Eovariscan episode (Sk-TP 4). In the Tinerhir region, the breccia units lie at the base of thick greenish shales and siltstones (Ait Yalla Formation, SCHIAVO et al. 2007), which yielded HINDERMEYER (1954) some upper Tournaisian goniatites. The timing of Sk-TP-4 is constrained below its base by our reworked clasts of the *costatus* Zone (Famennian V). This leaves the uppermost Famennian (UD VI) to middle Tournaisian interval. The latter is known for strong seismic activity in the eastern Anti-Atlas (e.g., KAISER et al. 2011, 2013; TAHIRI et al. 2013).

10.4. Summary

In summary, the Skoura Devonian records distinctive crustal developments at the Meseta-Anti-Atlas transition, with variable facies similarities fluctuating in time, and constrained by four regional phases of synsedimentary tectonics (middle Lochkovian to lower Pragian, Eifelian to basal Givetian, upper Givetian, top-Famennian or middle Tournaisian). It was followed by a fifth episode, resulting in a regional unconformity below a middle Viséan shallow shelf succession.

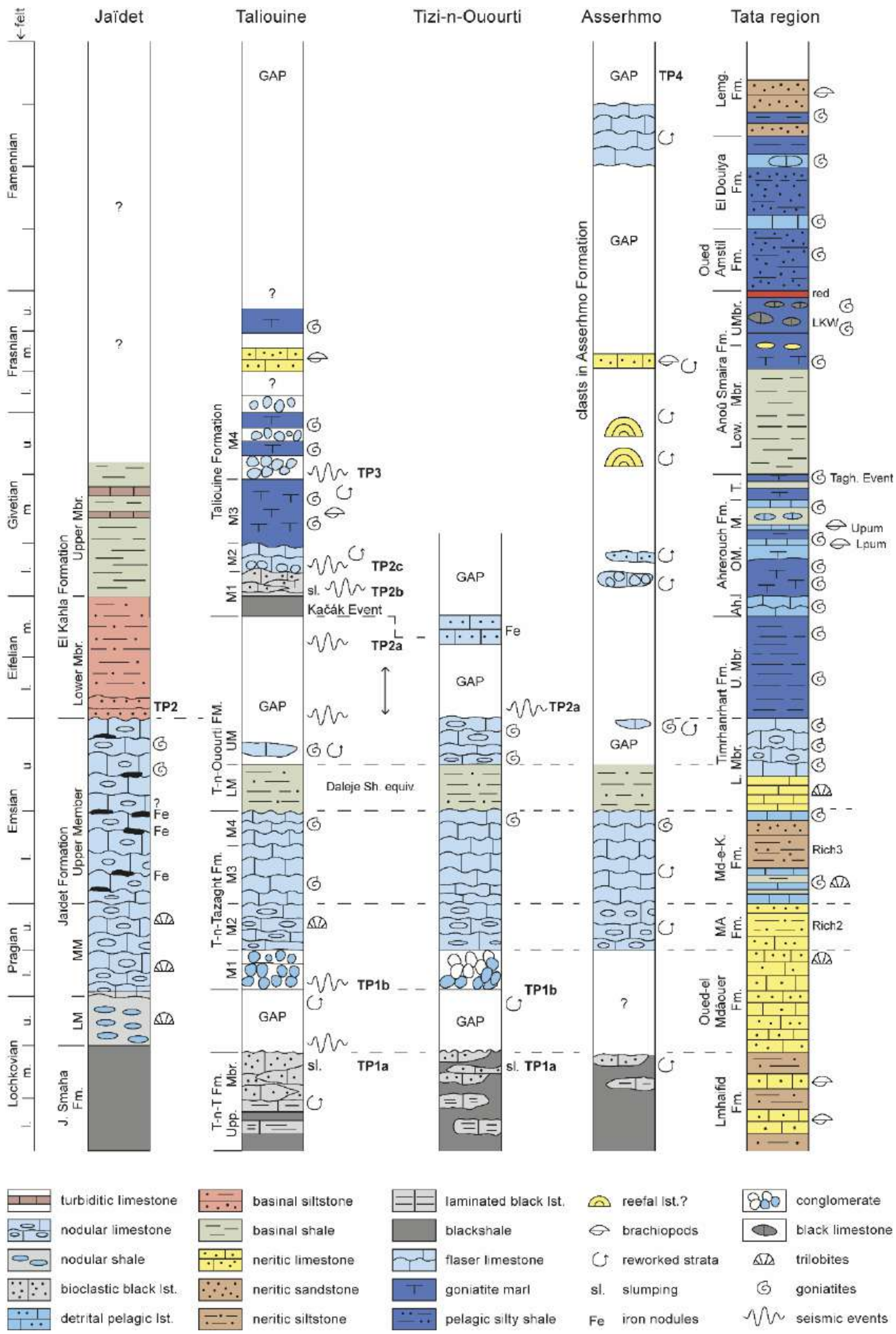

Fig. 54: Correlation of Devonian facies developments in the eastern Jebilet (Jaïdet), Skoura region (Taliouine, Tizi-n-Ouorti, Asserhmo), and eastern Dra Valley (Tata region, BECKER et al. 2004a, 2004b; JANSEN et al. 2004); l. = lower, m. = middle, u. = upper (informal substages); LM = Low. Mbr. = Lower Member, MM = Middle Member, UM = Upp. Mbr. = Upper Member, M1-M4 = Members 1-4, T-n-T Fm. = Tizi-n-Tichka Formation, MA Fm. = Merzâ Akhsai Formation, Md-e-K. Fm. = Mdâouer-el-Kbír Formation, A. = Arherich Member, OMz. M. = Oued Mzerreb Member, T. = Tiguisselt Member, Lemg. Fm. = Lemgairinat Formation, TP 1-4 = tectonic phases of Skoura region, Lpum/U pum = Lower and Upper pumilio Events, LKW = Lower Kellwasser Limestone.

11. Taxonomic notes

11.1. Cephalopods (LA & RTB)

Order Discosorida FLOWER in FLOWER und KUMMEL, 1950
Family Phragmoceratidae MILLER, 1877
Genus *?Pseudendoplectoceras*

***?Pseudendoplectoceras tazaghtense* AFHÜPPE & BECKER n. sp.**
Fig. 55.1a-e

Derivation of name: After the village Imi-n-Tazaght just west of the type locality.

Holotype: GMM B6C.54.155, Geomuseum Münster.

Type locality and level: Tizi-n-Ouourti, Bed F36, upper Emsian, *Anarcestes simulans* Zone, LD IV-D_1.

Diagnosis: Short, small, endogastric, cyrtoconic brevicone with a compressed cross-section. Longitudinal profile ventrally slightly concave, convex in living chamber, dorsally convex, laterally slightly convex. Sutures apparently straight. Siphuncle marginal, with adnation area at adoral ends on dorsal side. Septal necks dorsally cyrtochoanitic and without bullettes. Connecting rings slightly thickened. Chamber deposits with trigonal cross-section on dorsal side of the siphuncle between siphuncular segments and septa.

Description: The specimen consists of part of the living chamber and the last six chambers of the phragmocone. The aperture is not preserved. The shell is weathered, creating some inaccuracies of measurements. The preserved shell is ca. 3.2 cm long, with a maximum diameter of ca. 3.3 cm located 0.5 cm from the last septum within the living chamber. The cross-section at the adapical end is slightly compressed and becomes more distinctly compressed towards the adoral end (ovality = 0.82 – 0.88). The body chamber is short cyrto-breviconic, without evidence of torticonic coiling. The longitudinal conch profile of the ventral side is first slightly concave (Fig. 55.1a) and eventually becomes convex in the living chamber. On the dorsal side, the profile is always convex, laterally it is slightly convex. Due to the surface weathering, sutures are somewhat difficult to discern, but appear to be straight. The chambers are between 3.4 and 3.8 mm long (length/diameter ratio = 0.10 – 0.13) and expand with an angle of 41° (vertically) and 42° (horizontally). The siphuncle is marginal on the internal side of the curvature (siphuncle diameter/chamber diameter = 0.11 – 0.17); therefore, the coiling is endogastric. The siphuncular segments are not particularly inflated, but have an adnation area at their adoral ends on the outer dorsal side. The septal necks are cyrtochoanitic and very short on the dorsal side but not preserved on the ventral (inner) side, where they must have been positioned very close to the dissolved shell wall. The connecting rings are slightly thickened; bullettes are not visible. On the dorsal side of the siphuncle, deposits have been formed within the chamber in the area between the connecting ring and the septum, which have a trigonal cross-section.

Discussion: The knowledge of Lower Devonian Discosorida of Morocco is very restricted and with every new record, the discovery of new taxa can be expected, especially from regions and strata that have never or hardly been sampled for nautiloids. The new species, which is a rare form, resembles *Pseudendoplectoceras lahcani* KRÖGER, 2008 from the Pragian of the southern Tafilalt, the type-species of the genus, in the shape of the siphuncular segments and the chamber deposits as well as in the thickened connecting rings. Both the endogastric coiling and the thickened connecting rings are typical for the Discosorida. Our form differs in the lack of slight torticonic (trochoceroid) coiling, absence of visible bullettes, which questions the generic affinity, and the more compressed cross-section of the shell. Also, *?Ps. tazaghtense* has short cyrtochoanitic septal necks on the dorsal side of the siphuncle, which are thought to be recumbent in *Ps. lahcani*. The much older (middle Silurian) *Endoplectoceras* FOERSTE, 1926 and *Protophragmoceras* HYATT in ZITTEL, 1900 have more evenly inflated siphuncular segments and more strongly curved shells. *Phragmoceras* BRODERIP in SOWERBY in MURCHINSON, 1839 generally contains much larger species with a relatively large siphuncle, lateral lobes, and thickened connecting rings. Since only the imperfectly preserved holotype is available, we refrain from placing the undoubtedly new species in a new genus.

?*Pseudendoplectoceras rochi* AFHÜPPE & BECKER n. sp.

Fig. 55.2a-e

Derivation of name: In honor of the French geologist Eduard ROCH, who first explored the Devonian geology of the Skoura region.

Holotype: GMM B6C.54.156, Geomuseum Münster.

Type locality and level: Tizi-n-Ouourti, Bed F26, upper Emsian, "*Latanarcestes noeggerathi*" Zone, UD IV-B.

Diagnosis: Small, endogastric, cyrtoconic brevicone with (sub) circular cross-section. Ventral longitudinal profile first concave, convex in the living chamber, dorsal profile convex throughout ontogeny, lateral profiles straight, convex in the living chamber. Sutures straight. Siphuncle strictly marginal on inner side of shell curvature. Siphuncular segments with adnation area at their adoral ends, but not at the adapical end. Septal necks on dorsal side short, cyrtochoanitic, with bullettes, adventrally ortho- or (sub-)orthochoanitic. Chamber deposits with trigonal cross-section on dorsal side of siphuncle between siphuncular segments and septa.

Description: The specimen consists of a partially preserved living chamber and the last seven chambers of the phragmocone. The aperture is not preserved. The preserved shell is 4 cm in length, with a maximum diameter of about 2.5 cm located 0.4 cm from the last septum within the living chamber. The cross-section is circular to very weakly compressed at the adapical and adoral ends. The shell is short cyrto-breviconic and endogastrically curved, obviously not torticonic. The longitudinal profile of the ventral side is concave and becomes convex from the third chamber before the living chamber. The dorsal side is convex in profile throughout. The lateral sides are straight and convex from the third chamber before the living chamber. As far as the weathered surface allows to say, the sutures are straight. Phragmocone chambers are 2.5 - 3.5 mm long (length/diameter ratio = 0.10 – 0.16); the shell expands in the phragmocone with about 43° (vertically) and 31° (horizontally). The siphuncle lies strictly marginal on the internal side (siphuncle diameter/chamber diameter = 0.11 – 0.17). The siphuncular segments are more inflated on their dorsal (outer) side towards the aperture than towards the apex, forming an adnation area at their adoral end. The inner ventral side of the siphuncle and the septal necks are not well preserved. On the dorsal side, the latter seem to be short and cyrtochoanitic, on the ventral side ortho- or suborthochoanitic. On the dorsal side, bullettes are not particularly pronounced. Within the chamber, in the area between the connecting ring and the septum, deposits with a trigonal cross-section were formed.

Discussion: ?*Pseudendoplectoceras rochi* n. sp. resembles the older *Ps. lahcani* in the shape of the siphuncular segments, the bullettes, the chamber deposits, and the cross-section of the shell. However, there is a difference in the non-thickened connecting rings and in the cyrto- or (sub-)orthochoanitic septal necks, which are supposed to be recumbent in *P. lahcani*. However, they appear to be rather strongly cyrtochoanitic in the illustrations in KRÖGER (2008, pl. 16). Furthermore, a trochoceroid curling is not visible in ?*P. rochi*, but the shell is not complete. The conch curvature is stronger and the expansion angle smaller in *P. lahcani*. For the differences to related genera see under *?Ps. tazaghtense* n. sp. This slightly younger species does not display the bullettes of *?Ps. rochi* n. sp. and is markedly compressed.

11.2. Conodonts (RTB & ZSA)

***Wurmiella* aff. *wurmi* (BISCHOFF & SANNEMANN, 1958)**

Fig. 9.1

Description: Blade of GMM B4C.2.149 very long and elongate, slightly sinuous, bordered along the entire length by a well-defined margin, with 15 low, dense standing anterior teeth, a central larger tooth above the small and asymmetric basal cavity, and eight low posterior teeth that become more free-standing towards the end. Basal cavity extension on the right side bears a single denticle connected with the central tooth.

Discussion: The blade-type, denticulation, and asymmetric small cavity agree closely with the type material of *W. wurmi* from Franconia, Germany. However, the side denticle sitting on the asymmetric cavity extension is distinctive. It does not seem to be a pathological feature. Similar side nodes are known from much older (top-Silurian) specimens assigned to *"Ozarkodina" eosteinhornensis* (e.g., CORRADINI & CORRIGA 2012), which type material, however, does not show such a feature (see WALLISER 1964). The *eosteinhornensis* Group differs anyway in much shorter blades with much fewer denticles.

There is no documentation of a similar specimen from the middle Lochkovian but ROOPNARINE et al. (2004) mentioned an "alpha morphotype with a denticle developed on the blade shoulder" from the contemporaneous Windmill Limestone of Nevada. Since there is currently only one specimen from Taliouine, we keep it in open nomenclature.

***Pelekysgnathus* n. sp. aff. *elongatus* CARLS & GANDL, 1969**

Figs. 10.2-3

Description: Two pelekysgnathids (GMM B7A.12.156-157) from the top of the Tizi-n-Tichka Formation on the eastern of the ravine below Taliouine differ from all named species of the genus. Only one is well-preserved, the second is encrusted. The blade is narrow and elongate, widening slightly and gradually posteriorly. The lower margin is straight, bending sharply downwards under the most posterior tooth. From the anterior end, eight to nine triangular denticles gain very slightly in height, followed by two much larger, upright, also triangular teeth. There is no platform, only rounded shoulders around the two posterior teeth. The basal cavity is very narrow and deep, widening gradually towards the posterior end.

Discussion: The only named similar Lower Devonian pelekysgnathid is *Pel. elongatus*, which has a wider posterior cavity and denticles of alternating size before the posterior main teeth. Our new form is not identical with *Pel.* aff. *elongatus* from the Lochkovian of Jaidet (see eastern Jebilet chapter, this volume). With respect to the limited and incomplete material available, and since the variability of Lochkovian *Pelekysgnathus* is not sufficiently known, we apply open nomenclature until further sampling.

Occurrence: Restricted to the middle Lochkovian *transitans* Zone of Taliouine.

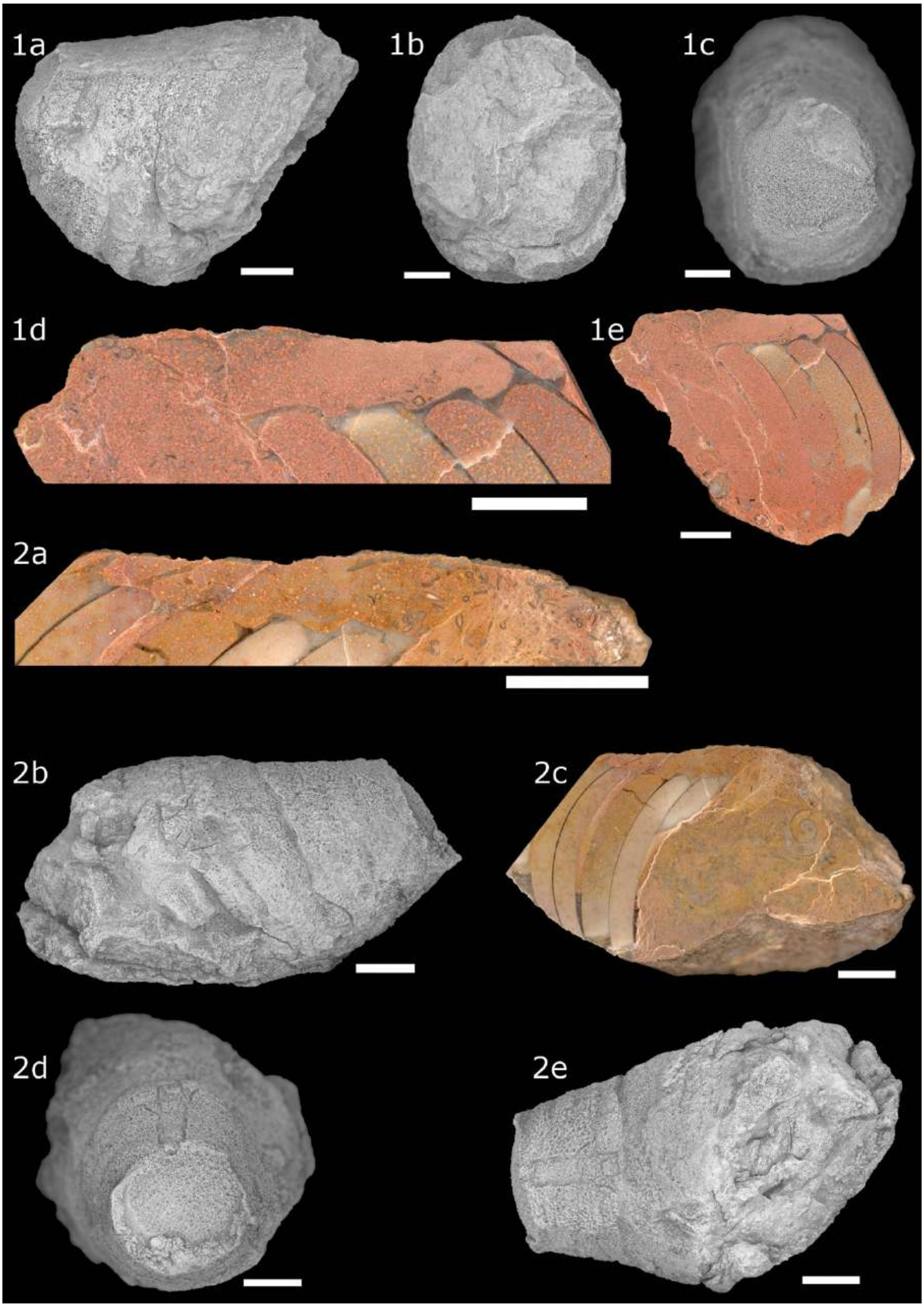

Fig. 55: New Discosorida from the upper Emsian of Tizi-n-Ouourti; scale bars = 5 mm, venter always at the top (apart from 2e). **1.** ?*Pseudendoplectoceras tazaghtense* n. sp., GMM B6C.54.155, a = lateral view, b = apertural view showing compressed cross-section, c = apical view, d = longitudinal section of siphuncle (aperture to the left), e = complete longitudinal section; **2.** *?Pseud. rochi* n. sp., GMM B6C.54.156, a = longitudinal cross-section of siphuncle (aperture to the right), b = lateral view, c = complete longitudinal section, 2 = apical view showing circular cross-section, e = dorsal view with strictly marginal (internal) siphuncle.

***Neopolygnathus communis* cf. *yazikovi* IZOKH in IZOKH & YAZIKOV, 2017**
Figs. 47.12-15

1959 e.p. *Polygnathus communis* HASS: pl. 49, fig. 11 [only]
2017 cf. *Neopolygnathus communis yazikovi* IZOKH (in IZOKH & YAZIKOV): 229, pl. 1, figs. 5-14
2020 *Neopolygnathus* cf. *communis communis* PARZIVI et al.: pl. 2, figs. 24a-b

Description: Free blade with more than 10 low denticles standing in close contact, almost as long as the slightly curved or subsymmetric, subtriangular platform (Fig. 47.15), which is widest near the anterior end. The variably slightly curved or near-straight carina consists of strongly molten denticles that extend slightly beyond the posterior platform end. The anterior platform is always smooth, with a short collar formed on both sides by distinctive margin folds, followed posteriorly by distinctive, slightly irregular (Fig. 47.12) ribbing, often only on one side (Fig. 47.14). The adcarinal troughs are deep and wide. The aboral side displays a small, shallow pit under anterior platform, followed by a shallow depression (Fig. 47.13).

Discussion: In upper Famennian *Neo. communis communis*, the platform is always completely smooth (see Fig. 47.15), mostly curved, and an anterior collar is variably present on one or both sides. The posterior carina extends variably shortly beyond the platform or it may end earlier (see types of BRANSON & MEHL 1934 or the illustrated population of KONONOVA & WEYER 2013, pl. 10). Not in the syntypes (no lectotype has been selected!), but in many other supposedly conspecific specimens, the adcarinal troughs may be narrow and bordered by upturned, sometimes bolstered, smooth margins (e.g., DRUCE 1969; HARTENFELS 2011; HARTENFELS & BECKER 2016a). Clearly, there are several morphotypes within the subspecies (see JI & ZIEGLER 1993; VORONTZOVA 1996), including the invalid *Neo. communis quadratus* WANG, 1989 (a homonym, see BECKER 2012), and *Neo. klapperianus* (ASHOURI, 2006: based on a juvenile); but none agrees with our specimens. “Morphotype 1” sensu JI & ZIEGLER (1993) and GHOLAMALIAN (2005) does not belong to *Neo. communis* but is closely related to the lower Famennian *Neo. osbakensis, Neo. vorontzovae* and *Neo. huijunae* (see WEDDIGE 1984, KUZ´MIN 1996, and WANG et al. 2016); the short free blade is distinctive for the group.

Our specimens do not agree with any named Famennian neopolygnathid. In the curved *Neo. communis dentatus* (DRUCE, 1969), the anterior platform margin is raised and ribbed, especially on the inner side, and, therefore, the rather fine carina sits much lower than the margins. In the Australian *Neo. collinsoni* (DRUCE, 1969), a marked, anterior rostrum with nodes is delimited by a constriction from the main platform, and the aboral depression is narrow and much deeper. There are slight similarities of our material with *Neo. communis lectus* KONONOVA in BUSHMINA & KONONOVA (1981), in which, however, the posterior carina is distinctively short, consisting of a fining row of nodes. *Neopolygnathus communis renatae* CORRADINI, BARCA & SPALETTA, 2003 is characterized by single nodes and short ridges on both sides of anterior platform margin. The platform tends to be constricted, a feature that is extreme in *Neo. margaretae* KONONOVA & WEYER (2013). In *Neo. depressus* (METZGER, 1989), the aboral depression is very deep, and the holotype shows on the left anterior side a row of strong nodes pointing outwards. *Neopolygnathus mugodzharicus* GAGIEV, KONONOVA & PAZUKHIN, 1987 is characterized by high, trigonal margins with some nodes.

Neopolygnathus seminudus (KUZ´MIN, 1992), originally described from Kazachstan, is characterized by marginal ribs that are restricted to the posterior platform. *Neopolygnathus mutabilis* (KHALYMBADZHA, SHINKARYOV & GATOVSKY, 1991), also from the Famennian of Kazakhstan, can be distinguished because of its stronger curvature, finer carina, and different anterior platform, which is variably smooth or serrated, but without a collar. In the lower Famennian *Polygnathus tichonovitchi* KUZ´MIN & MELNIKOVA, 1991, a possible *Neopolygnathus*, the curvature and the ribbing are stronger and there are no anterior margin folds forming a collar, but spine-like protrusions of ribs. All three *communis* subspecies named by SAVAGE (2013) from NW Thailand are different and characterized by flat platforms. Only *Neo. communis namdipensis* is ribbed, but along the wide median and posterior platform margins.

Other Famennian species, such as *Neo. fibula* HARTENFELS & BECKER, 2016a, display nodes and transverse ridges on the inner parts of the anterior platform. The species belongs to the group around *Neo. carina*, which radiates and is most common in the Tournaisian (e.g., LIPNJAGOW in KOZITSKAYA et al. 1978: *Neo. communis stylensis*; NI 1984: *Neo. communis porcatus*; NIGMADZHANOV 1986: *Neo. tschatkalicus*; QIN et al. 1988: *Neo. shangmiaobeiensis*; MATYJA et al. 2001: *Neo. discurrocostatus*; XIA & CHEN 2004: *Neo. communis gancaohuensis*; QIE et al. 2014: *Neo. communis longanensis*; PLOTITSYN & ZHURAVLEV 2017: *Neo. crucesignatis*). The *communis* Group continued in parallel, leading to forms with very deep "second pit", as in *Neo. burtensis* (DRUCE, 1969).

A neopolygnathid that resembles the Asserhmo form has been described by IZOKH (in IZOKH & YAZIKOV 2013) from the upper Tournaisian of northern Siberia (lower reaches of Lena River) as *Neo. communis yazikovi*. It shares with the Asserhmo specimens the anterior platform collar, rather variable ribbing, and a rather weak aboral depression. In most specimens, the free blade is broken off but it may be shorter than in our material. Another minor difference is that the carina tends to have better defined denticles. A probably conspecific specimen has been figured long ago as *Po. communis* by HASS (1959) from the lower Tournaisian of Texas. PARVIZI et al. (2020) figured recently another similar specimen from the upper Famennian *costatus* Zone of the Alborz Mountain in northern Iran, which is likely the same level as our material. The Carboniferous *Neo. talassicus* NIGMADZHANOV, 1986 is much more strongly ribbed, with merged nodes forming a longitudinal ridge on both sides of the anterior platform, not at its margin; there is no collar. In the lower Tournaisian *Neo. nodosarius*, ribs are also very strong, at least on one side, producing a denticulate outer margin. Specimens from the top-middle Tournaisian of Missouri, identified by CHAUFFE & GUZMAN (1997) as *Po.* aff. *collinsoni*, possess a collar, but have wider, asymmetric platforms with variable, partly very strong ribbing, especially in the posterior half, and additional nodes of the inner platform, along the adcarinal troughs. The Tournaisian *Neo. adola* (COOPER, 1939), placed in synonymy with *Neo. communis* by CHAUFFE & GUZMAN (1997), is characterized by a nodose collar, the lack of posterior ribs, and deeper and narrower adcarinal troughs than in our Asserhmo form.

There are two possibilities: either there are homoemorphic ribbed neopolygnathids with anterior platform collar in the upper Famennian and lower to upper Tournaisian, or there was a long-ranging but only episodically occurring subspecies that survived the global Hangenberg Crisis at the Devonian-Carboniferous Boundary. Since our material from reworked pebbles is not suitable to solve this question, we assign it with a cf. to the Tournaisian *Neo. communis yazikovi.*

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