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 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.

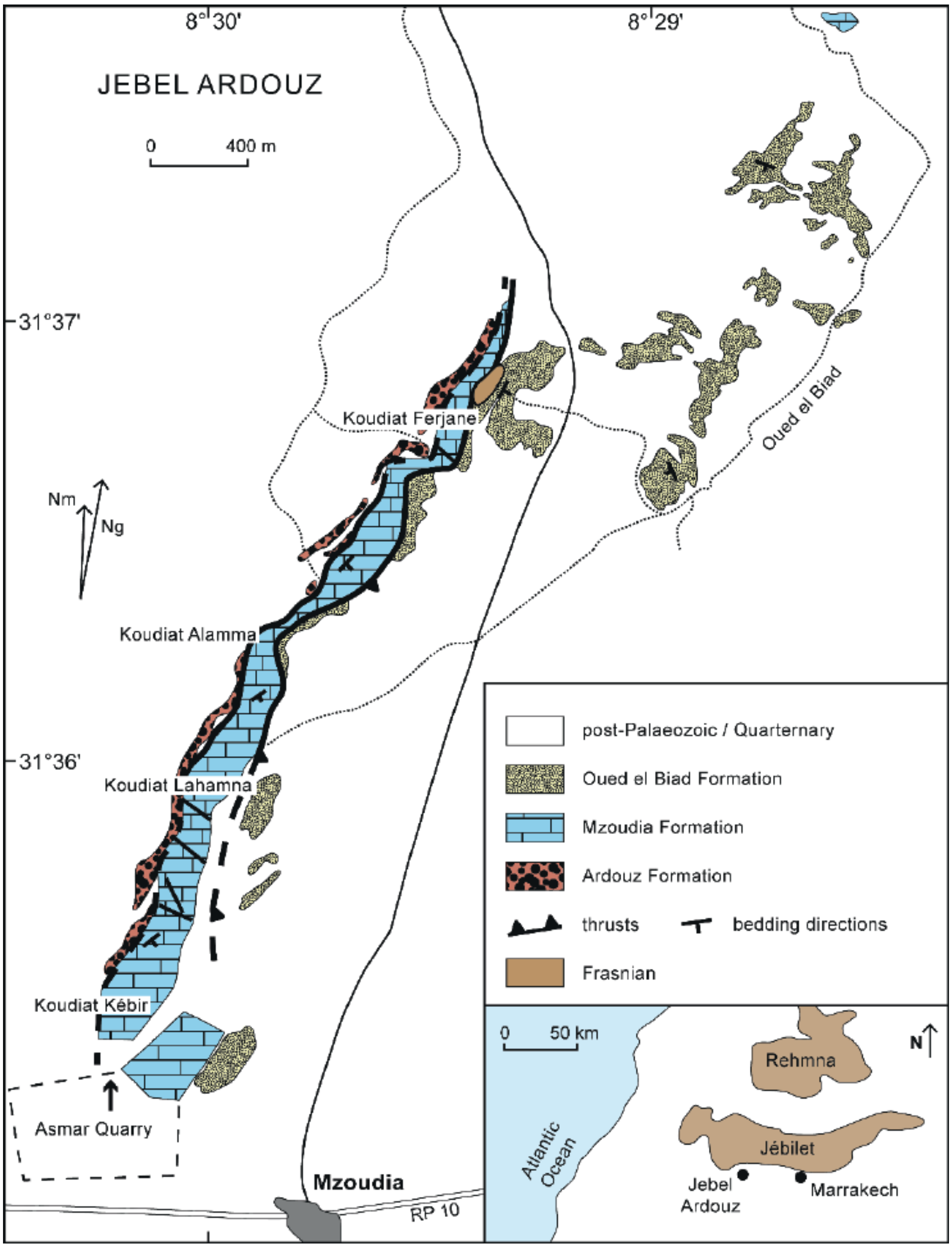

Fig. 2: Geology of the Jebel Ardouz north of Mzoudia, re-drawn from TAHIRI (1983, fig. 1); for the present-day extent of the quarry see BOUARI et al. (2021, fig. 2d).

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.

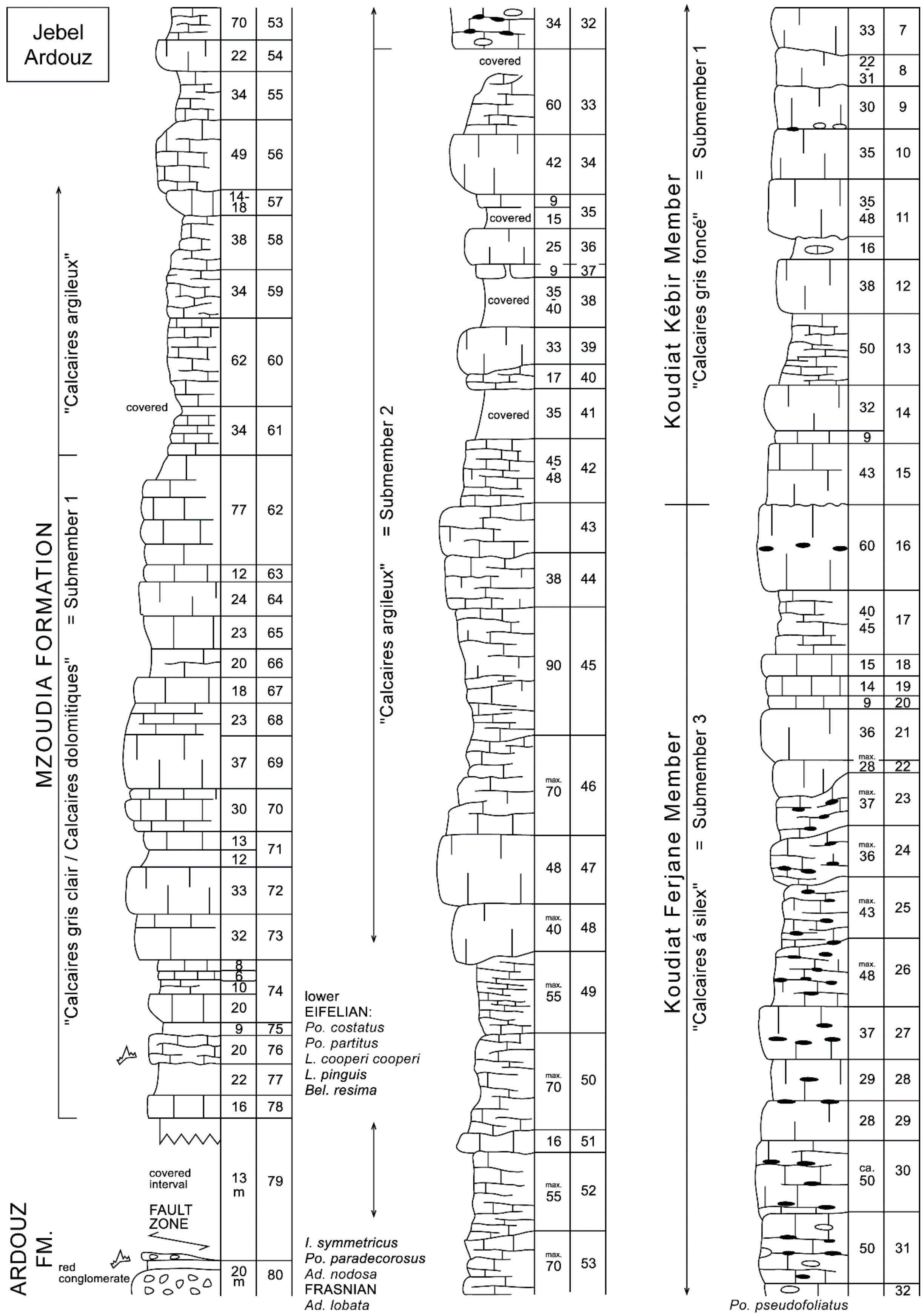

Fig. 4: Section log for the lower part of the (new) Mzoudia Formation at Koudiat Ferjane (northern Jebel Ardouz), showing the position of conodont samples and the lithological units of Tahiri (1983); legend see Fig. 7.

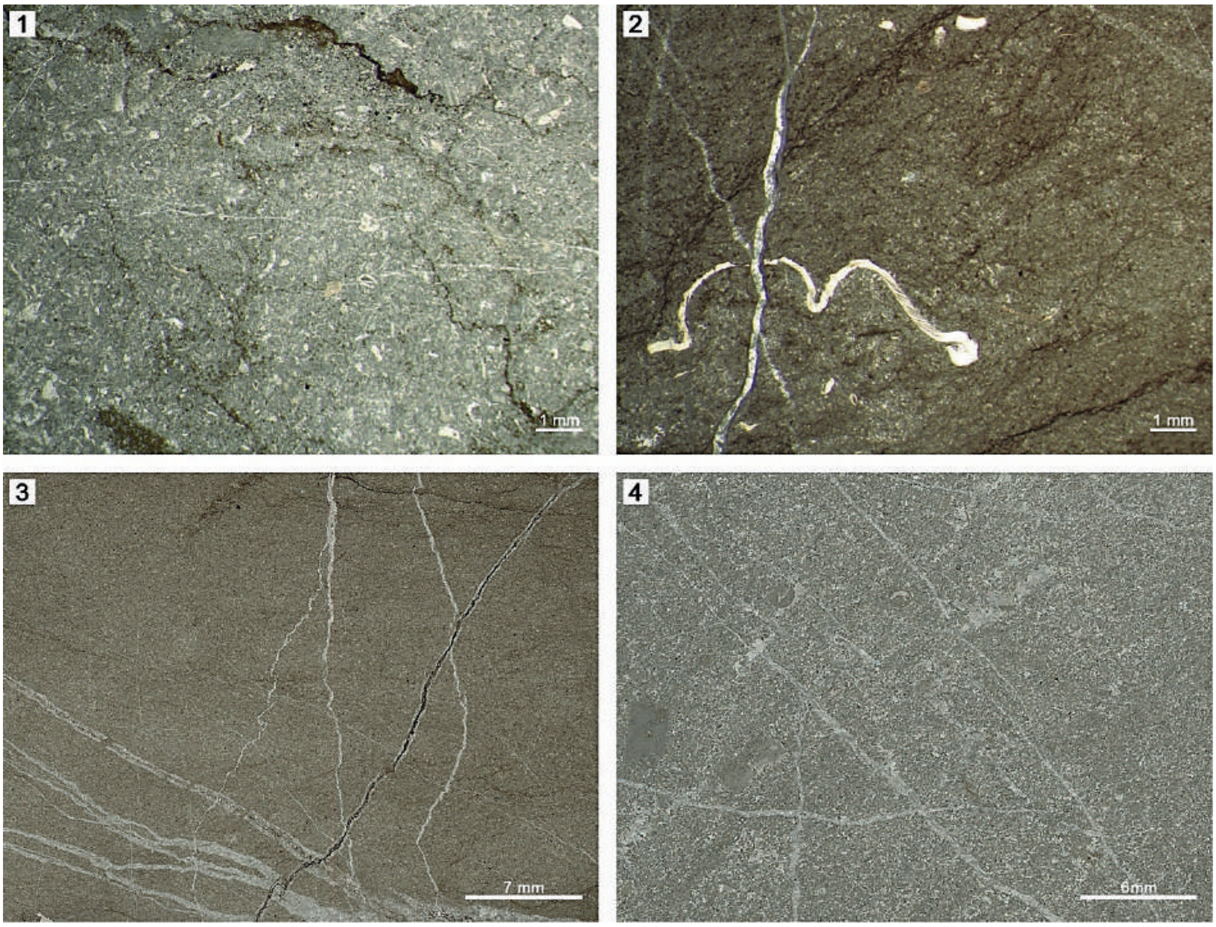

Fig. 5: Microfacies of the Mzoudia Formation at Koudiat Ferjane. **1.** Flaser-bedded, bioturbated, bioclastic wacke-packstone with abundant re-crystallized crinoid pieces and shell-debris, micritic matrix, and pressure solution stylolites, lower Eifelian (basal Koudiat Ferjane Member); **2.** Flaser-bedded, 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).

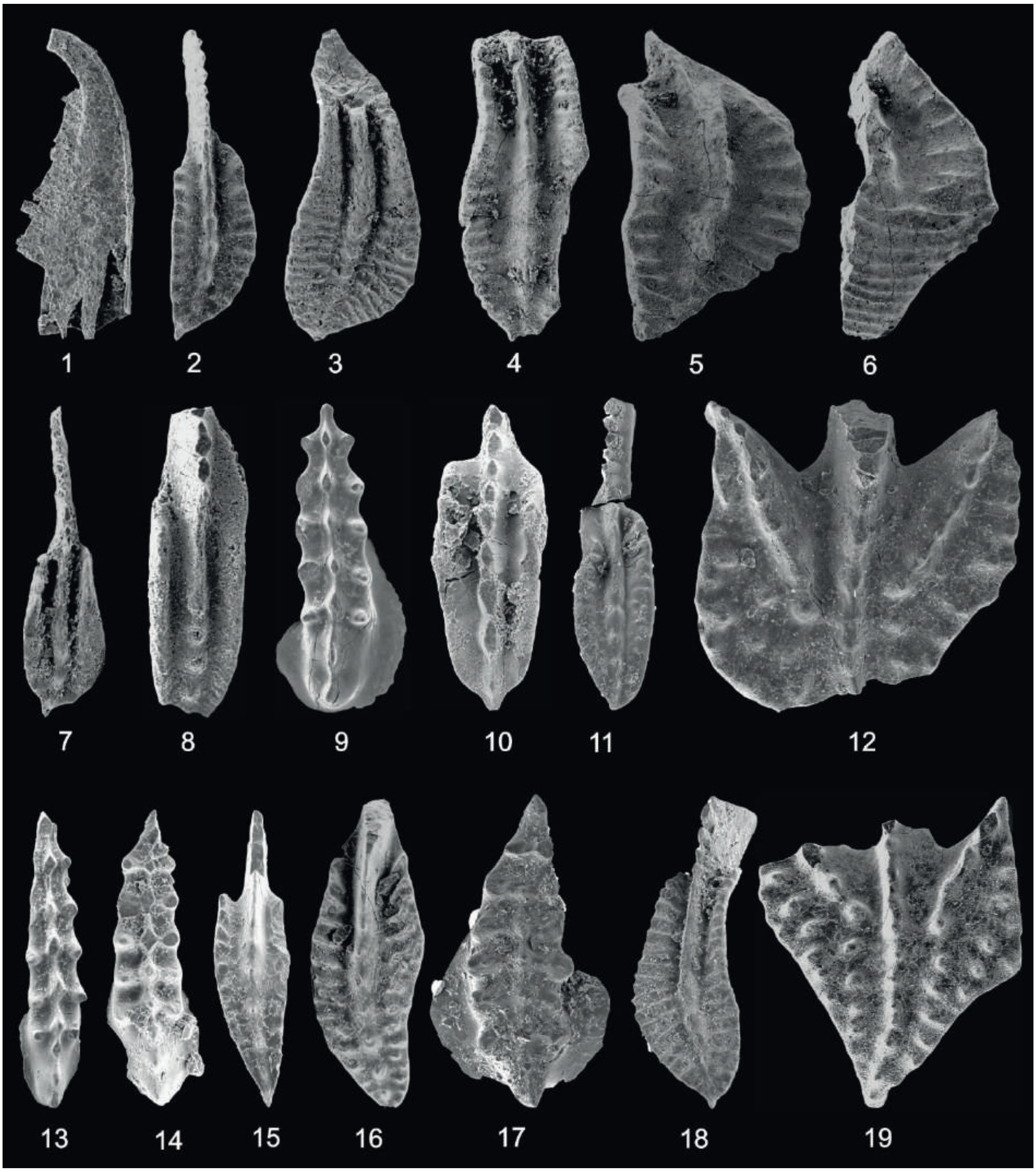

Fig. 6: Eifelian to Frasnian conodonts from Koudiat Ferjane (Jebel Ardouz), 1-6 = lower part of Koudiat Ferjane Member, Bed -76, *costatus* Zone, 7 = lower part of Koudiat Kébir Member (Submember 1, Beds -3/-4), 8-10 = top part of Submember 1 of Koudiat Kébir Member, ca. Beds 64/65, *ansatus* Zone, 11 = 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.

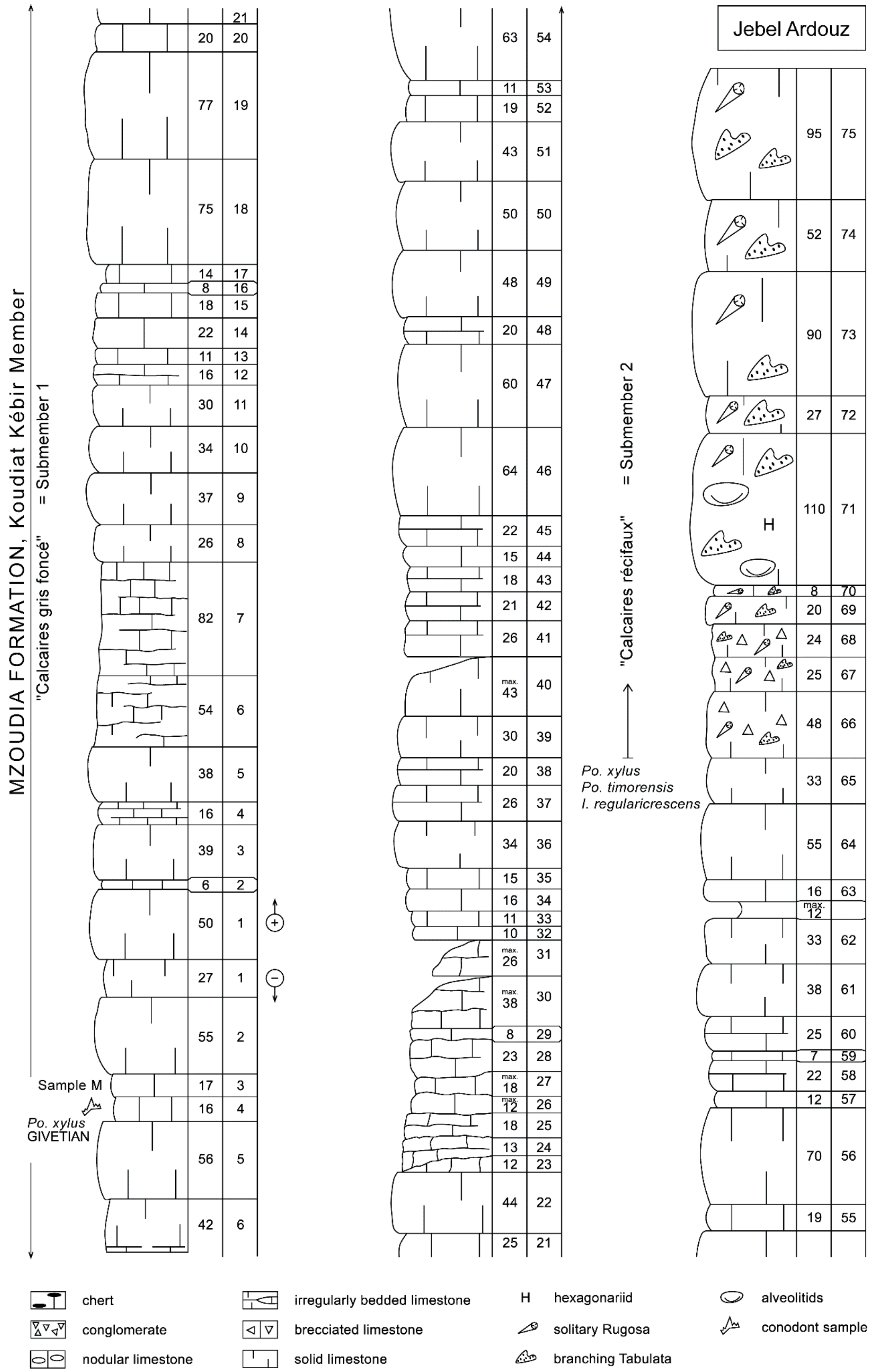

Fig. 7: Upper part of the section log through the Mzoudia Formation (Koudiat Kébir Member), showing the approximate position of conodont samples and the units of TAHIRI (1983).

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.

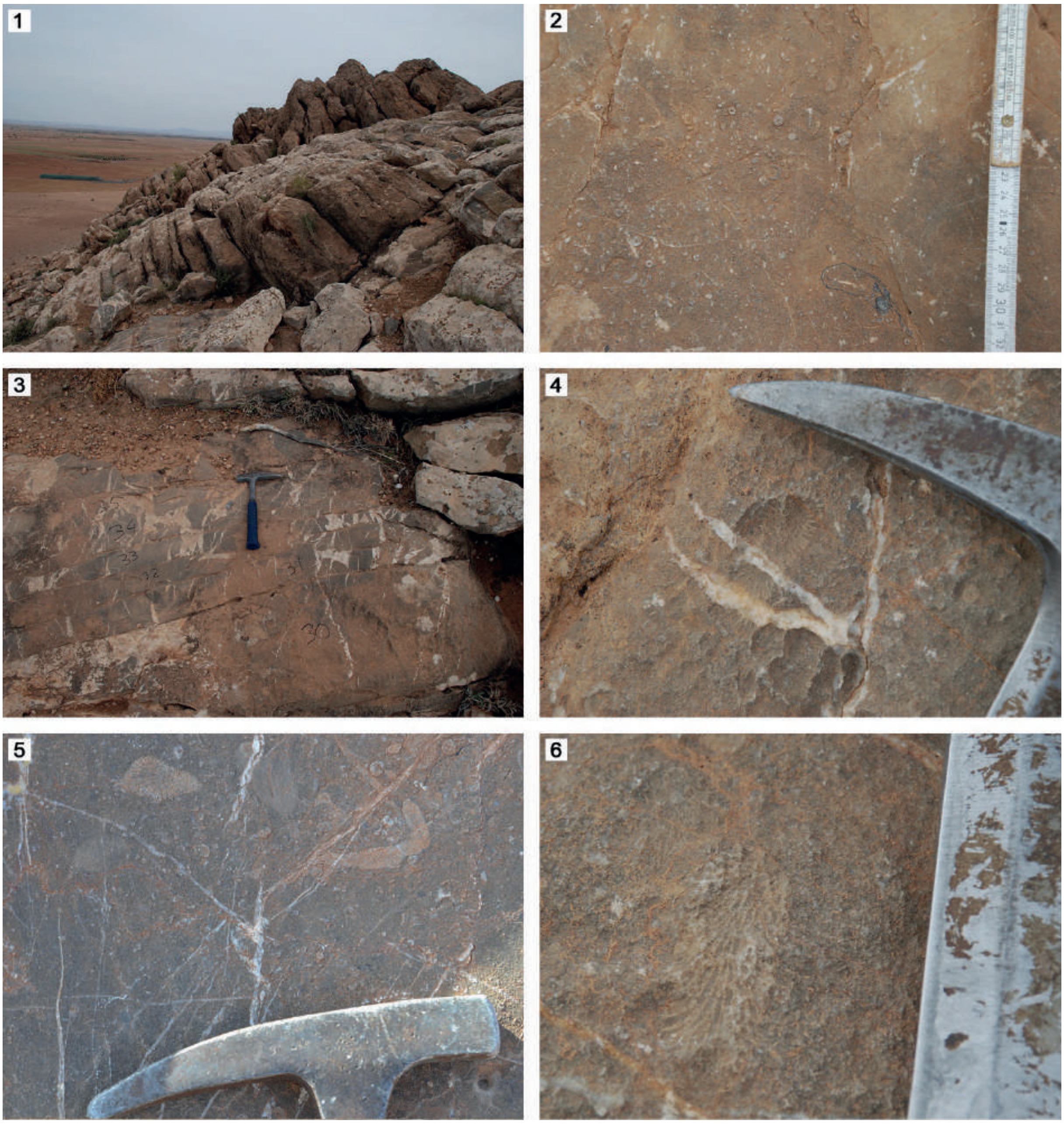

Fig. 9: Field photos of the Koudiat Kébir Member of the Mzoudia Formation. **1.** The medium- to thick-bedded, poorly fossiliferous Submember 1 forming the upper part of the western cliff at the northern end of Koudiat Ferjane; **2.** Crinoidal, light-grey limestone with a poorly preserved, dark-shelled 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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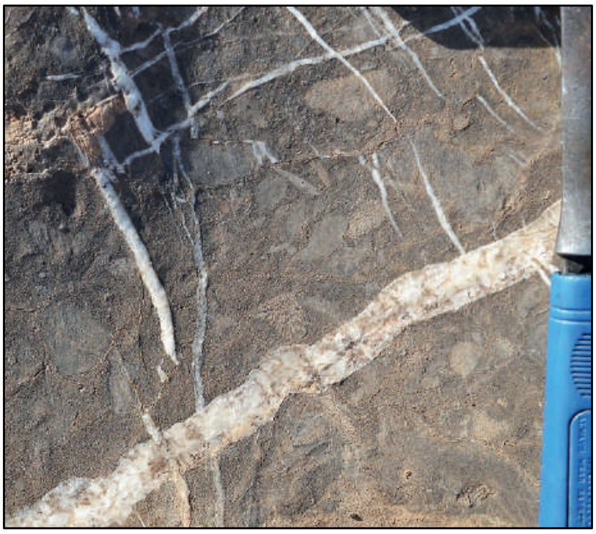

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Fig. 10: Outcrop photos of the reefal Submember 2 of the Koudiat Kébir Member at the northern end (eastern slope) of Koudiat Ferjane. **1.** Thick-bedded, measured section (see section log), showing the probably fault-related sharp upper end, where 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.

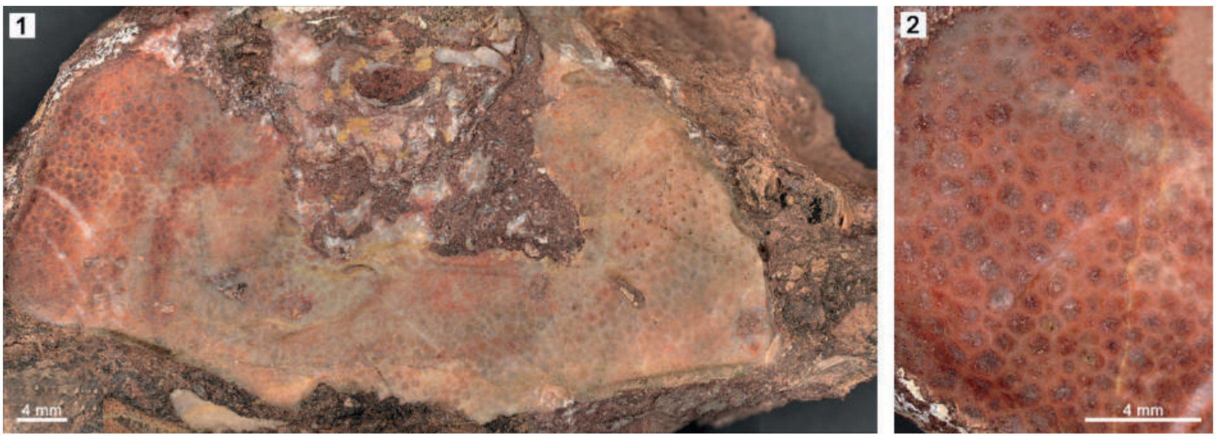

Fig. 11: Flat, 7.5 cm large colony of a favositid (possibly *Squameofavosites* sp., det. A: MAY) with concave margin, encrusted on and by hematitic, sandy limestone, upper "red conglomerate" (upper Ardouz Formation), GMM B2C.57.3.

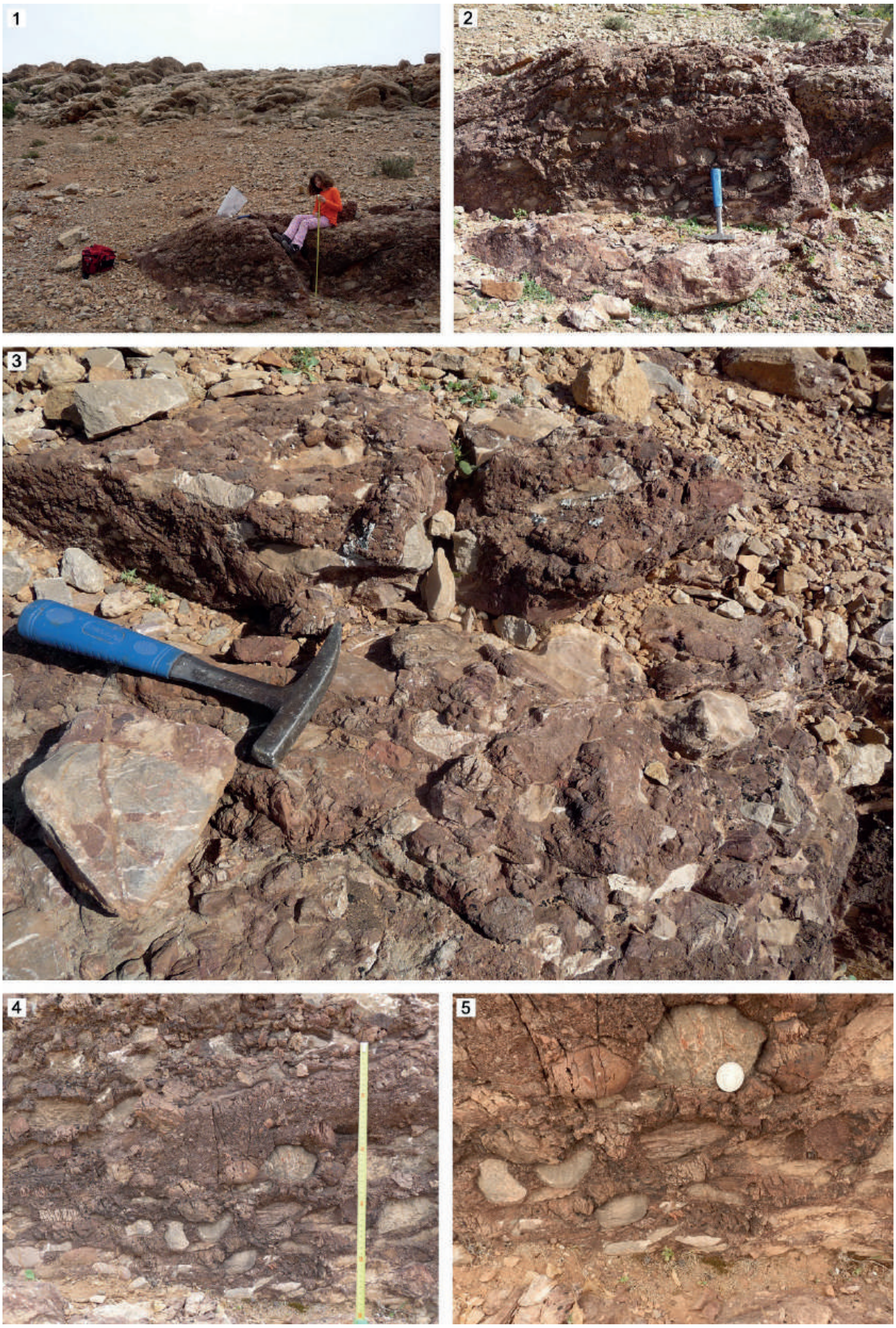

Fig. 12: Field photos of the "red conglomerate" (upper Ardouz Formation) at the base of the western slope of Koudiat Ferjane. **1.** Overview (photo from April 2012, with Lea Amira BECKER for scale) showing the "red conglomerate", the > 10 m outcrop gap above, followed by the basal Mzoudia Formation 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).

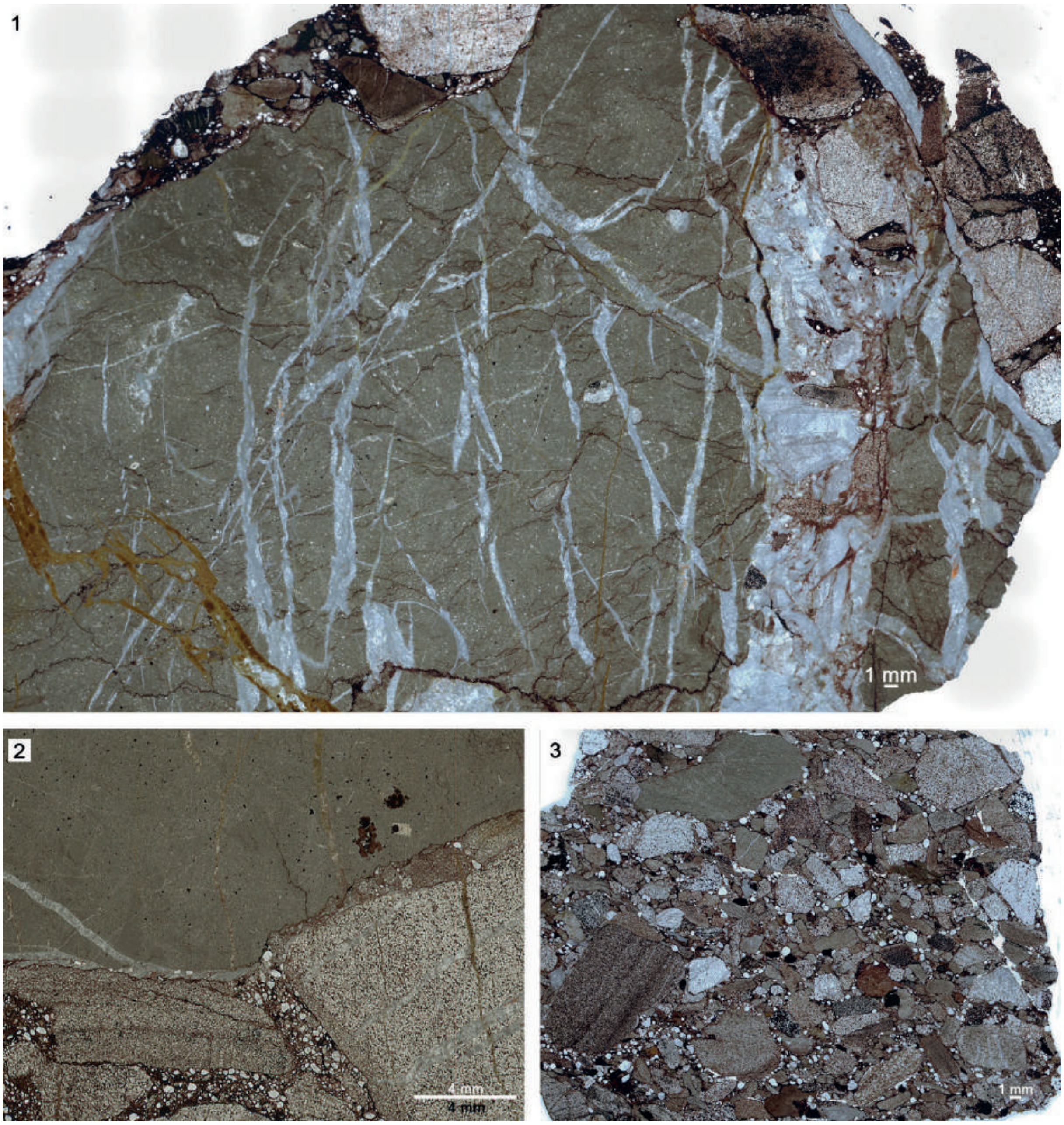

Fig. 13: Microfazies of the "red conglomerate" (upper Ardouz Formation). **1.** Strongly unsorted conglomerate with large limestone clast consisting of flaser-bedded, peloidal, slightly silty mudstone with rare large mollusk shell (lower left center) and three directions of thin to thick calcite veins 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.

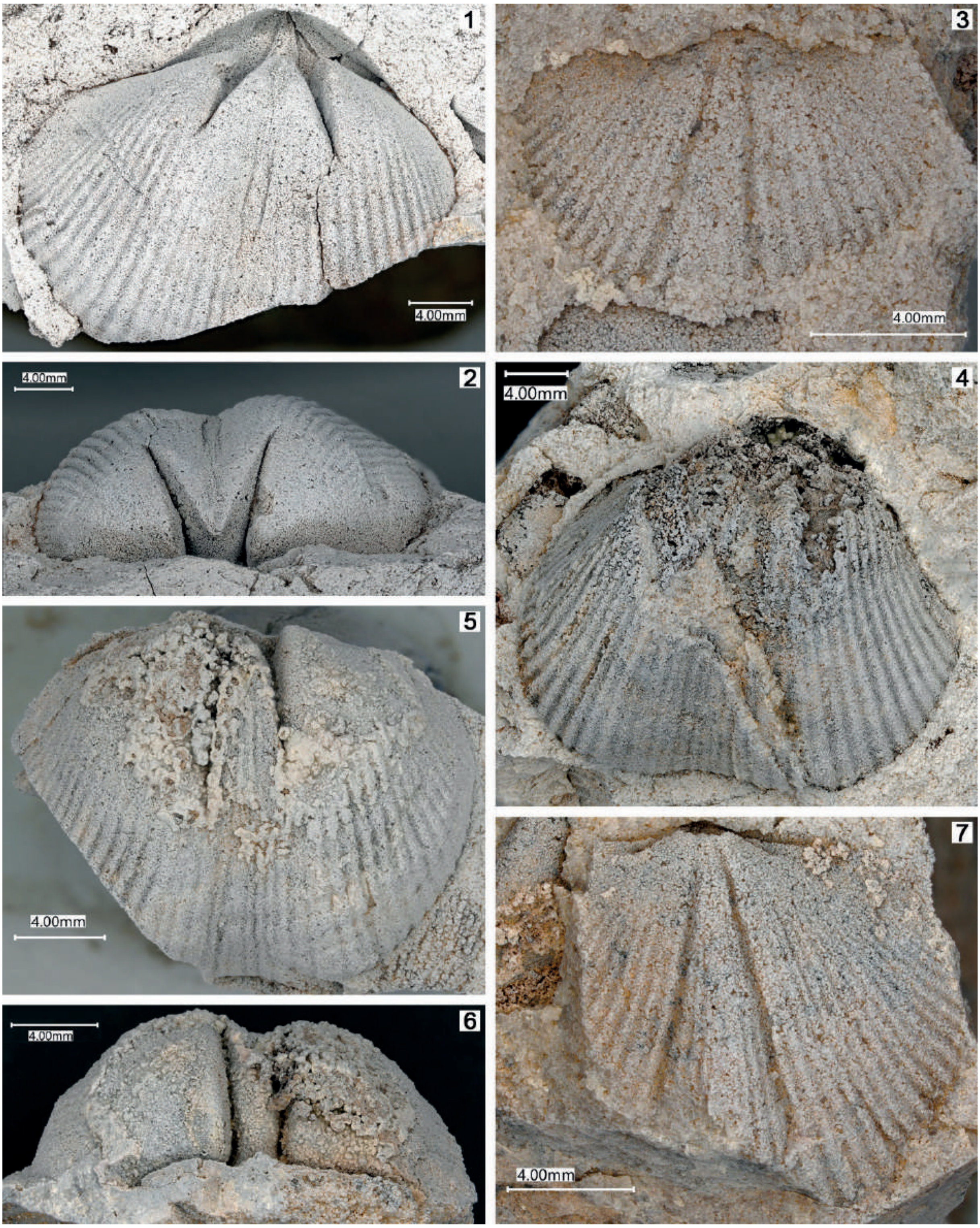

Fig. 15: Spiriferid brachiopods from the lower part of the Oued el Biad Formation; GMM B5B.16.9-13. **1-4.** Cyrtospriferinae gen. indet.; **5-6.** Cyrtiopsinae gen indet., **7.** Cyrtospiriferidae indet.

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.

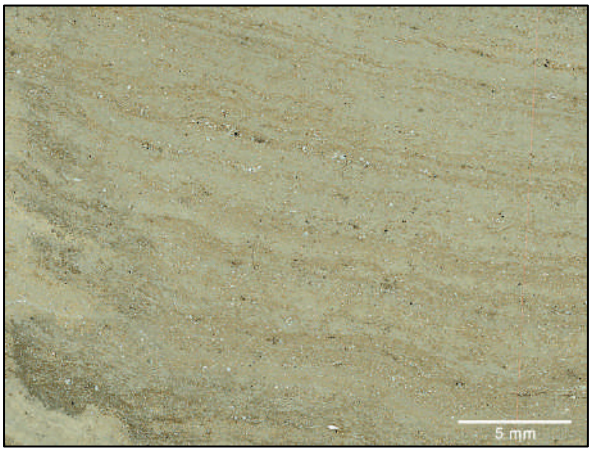

Fig. 16: Thin-section of yellowish, wavy-laminated calcrete to dolocrete with embedded silt grains from the plain immediately west of Koudiat Ferjane.

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.

References

ABOUSSALAM, Z. S. (2003): Das « Taghanic-Event » im höheren Mittel-Devon von West-Europa und Marokko. – Münstersche Forschungen zur Geologie und Paläontologie, **97**: 1-332.

ABOUSSALAM, Z. S., BECKER, R. T. & EICHHOLT, S. (2012): Conodont dating of reefs and carbonate platforms in the Middle and Upper Devonian of the Moroccan Meseta. – Terra Nostra, **2012** (3): 27-28.

ABOUSSALAM, Z. S., BECKER, R. T., EL HASSANI, A., EICHHOLT, S. & BAIDDER, L. (2017): Late Early Carboniferous conodonts from a supposed Middle Devonian reef limestone of the Marrakech region (Morocco). – Stratigraphy, **14** (1/4): 7-14.

BAIDDER, L., RADDI, Y., TAHIRI, M. & MICHARD, A. (2008): Devonian extension of the Pan-African crust north of the West African craton, and its bearing on the Variscan foreland deformation: evidence from eastern Anti-Atlas (Morocco). – In: ENNIH, N. & LIÉGEOIS, J.-P. (Eds.), The Boundaries of the West African Craton. Geological Society, London, Special Publications, **297**: 453-465.

BECKER, R. T. & EL HASSANI, A. (2020): Devonian to Lower Carboniferous stratigraphy and facies of the Moroccan Meseta. Implications for palaeogeography and structural interpretation – a project outline. – Frontiers in Science and Engineering, Earth, Water and Oceans, Environmental Sciences, **10** (1): 9-25.

BECKER, R. T., ABOUSSALAM, Z. S., EL HASSANI, A., HARTENFELS, S. & BAIDDER, L. (2015): The timing of Eovariscan block faulting, reworking and re-deposition in the Moroccan Meseta. – Strata, Série 1, **16**: 14-15.

BECKER, R. T., HARTENFELS, S., ABOUSSALAM, Z. S., HELLING, S. and the Münster Group (2017): Membership News. – SDS Newsletter **32**: 40-47.

BECKER, R. T., ABOUSSALAM, Z. S., EL HASSANI, A., EICHHOLT, S. & HELLING, S. (2020a). The Devonian of the Oued Cherrat Zone (Western Meseta) – review and new data. – Frontiers in Science and Engineering, Earth, Water and Oceans, Environmental Sciences, **10** (1): 87-126.

BELKA, Z., KAUFMANN, B. & BULTYNCK, P. (1987): Conodont-based quantitative biostratigraphy for the Eifelian of the eastern Anti-Atlas. – Geological Society of America, Bulletin, **109** (6): 643-651.

BEN BOUZIANE, A. (1995): Évolution sédimentologique et diagenétique des carbonates du Dévonien de la Meseta marocaine occidentale (Oulad Abbou, Mechra Ben Abbou et Doukkala). – Thèse Université Hassan II, Casablanca, 245 pp.

BEUN, N., HUVELIN, P., BRICE, D., BULTYNCK, P., DESTOMBES, J., MERGL, M. & MORZADEC, P. (1992): Le Paléozoïque de Khemis-n'Ga: Discordance du Silurien Supérieur sur l'Arenig (Région de Safi, Maroc). – Annales de la Société Géologique du Nord, 2ème série, **1**: 171-177.

BIRENHEIDE, R. (1985): Chaetetida und tabulate Korallen des Devon. – Leitfossilien, **3**: 249 pp.; Berlin, Stuttgart (Borntraeger)

BOUARI, A., LAZREQ, N., SOULAIMANI, A., TAHIRI, A. & ABOU EL FARAJ, A. (2021 in press): The Heritage interest of Koudiat Ferjane Outcrops of Jbel Ardouz in the Mzoudia region and their Protection. – Geoheritage, **13**.

BRICE, D. (1988). Brachiopodes du Dévonien de Ferques (Boulonnais – France). - Biostratigraphie du Paléozoïque, **7**: 323–395.

BULTYNCK, P. (1987): Pelagic and neritic conodont successions from the Givetian of pre-Sahara Morocco and the Ardennes. – Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre, **57**: 149-181.

BULTYNCK, P. & SARMIENTO, G. N. (2003): Reworked Ordovician and autochthonous Siluro-Devonian conodonts from Khemis-n'Ga (Moroccan Meseta) – Depositional, environmental, and palaeogeographic implications. – Courier Forschungsinstitut Senckenberg, **242**: 257-283.

CORNÉE, J.-J., DESTOMBES, J. & WILLEFERT, S. (1987): Stratigraphie du Paléozoïque de l'extrémité nord-ouest du Haut-Atlas occidental (Maroc hercynien); interprétation du cadre sédimentaire du Maroc occidental. – Bulletin de la Société géologique de France, série 8, **III** (2): 327-335.

EICHHOLT, S. & BECKER, R. T. (2016): Middle Devonian reef facies and development in the Oued Cherrat Zone and adjacent regions (Moroccan Meseta). - Facies, **62** (7): 29 pp.

EL HASSANI, A. & BENFRIKA, M. EL (1995): Biostratigraphy and correlations of the Devonian of the Moroccan Meseta: a synopsis. – Bulletin de l'Institut Scientifique, Rabat, **19**: 29-44.

EL HASSANI, A. & BENFRIKA, M. EL (2000): The Devonian of the Moroccan Meseta: biostratigraphy and correlations. – Courier Forschungsinstitut Senckenberg, Frankfurt, **225**: 195-209.

EL KAMEL, F. (2004): Études géologiques du Paléozoique de Mechra Ben Abbou et d'Oulad Abbou, Meseta occidentale, Maroc. – Notes et Mémoires du Service géologique Maroc, **462,** 187pp.

El Kamel, F. & Muller, J. (1987): Sédimentation et tectonique dans le bassin molassique permo-carbonifère de Mechra ben Abbou (Rehamna). – Bulletin de l'Institut Scientifique, Rabat, **11**: 69-78.

El Kamel, F., El Hassani, A. & Dafir, J. E. (1992): Présence d´une tectonique synsédimentaire dans le Dévonien inférieur des Rehamna septentrionaux (Meseta marocaine occidentale). Bulletin Institut Scientifique, Rabat, **16**: 37-43.

Fahraeus, L. E., Slatt, R. M. & Nowlan, G. S. (1974): Origin of carbonate pseudopellets. – Journal of Sedimentary Research, **44** (1): 27-29.

Gaillet, J.-L. (1986): La tectonique du Dévono-Dinantien du Haouz occidental et l´hypothèse d´une transformante varisque au sud de la Meseta marocaine. – Sciences Géologiques Bulletin, **39**: 361-370.

Gendrot, C. (1973): Environnements du Dévonien récifal au Maroc. – Notes du Service géologique du Maroc, **34**: 55-86.

Gendrot, C., Kergomard, D. & Rabaté, J. (1969): Étude des formations récifale du dévonien de la meseta occidentale. – Vol. I: 68 pp. Rapport interne BRPM (Rabat).

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

Hollard, H. (1967): Le Dévonien du Maroc et du Sahara nord-occidentale. – In: Oswald, D. H. (Ed.), International Symposium on the Devonian System, Calgary, 1967, **I**: 203-244; Alberta Society of Petroleum Geologists (Calgary).

Hollard, H., Michard, A., Jenny, P., Hoepffner, C. & Willefert, S. (1982): Stratigraphie du Primaire de Mechra-Ben-Abbou, Rehamna. – In: Michard, A. (Ed.), Le massif Paléozoïque des Rehamna (Maroc), Stratigraphie, Tectonique et Pétrogenèse d´un segment de la Chaine Varisque. Notes et Mémoires du Service géologique, **303**: 13-34.

Huvelin, P. (1977): Étude géologique et gitologique du massif hercynien des Jébilet (Maroc occidental). Notes et Mémoires du Service Géologique, **232bis**: 1-307.

Kergomard, D. (1970): Contribution à l'étude du Siluro-Dévonien de la Meseta occidentale. – Unpublished Report B.R.P.M., Rabat.

Keyserling, A., von (1846): Geognostische Beobachtungen. – In: Krusenstern, P. & von & Keyserling, A. (Eds.), Wissenschaftliche Beobachtungen auf einer Reise in das Petschora-Land: 151–406; Carl Kray (St. Petersburg).

Klapper, G. (1989): The Montagne Noire Frasnian (Upper Devonian) conodont succession. – In: McMillan, N. J., Embry, A. F. & Glass, D. J. (Eds.), Devonian of the World, Proceedings of the Second International Symposium on the Devonian System, Calgary, Canada. Canadian Society of Petroleum Geologists, Memoir, **14** (III): 449-468 [imprint 1988].

Koning, G. de (1956): Géologie des Ida ou Zal (Maroc). – Leidse Geologische Mededelingen, **23**: 1-209.

Launay, L. de (1903): Les richesses minérales de l´Afrique. – Ch. Béranger (Paris and Liège).

Lazreq, N. (2017): A propos de l'existence du Famennien au sud des Jébilet Centrales et altération des conodontes: cas de Koudiat Laabid (Jbel Guéliz, Marrakech, Maroc). – Bulletin de l´Institut Scientifique, Rabat, Section Sciences de la Terre, **39**: 79-86.

Lazreq, N., Königshof, P., Essaifi, A., Bouari, A. & Outigua (2021): A Devonian age for the Sarhlef Formation (Jebilet Massif, Morocco) – evidence from new biostratigraphic data based on metamorphosed conodonts. – Palaeogeography, Palaeoclimatology, Palaeoecology, **572**: 110395, 13 pp.

Mayol, S. (1987): Géologie de la partie occidentale de la boutonnière paléozoïque des Jébilet, Maroc: un exemple d´évolution structural hercynienne de bassins intercontinentaux cambrien et carbonifère. – Travaux de Laboratoire de Science de la Terre, Saint Jérôme, Marseille, B, **27**: 241 pp.

Moret, L. (1931): Recherches géologiques dans l´Atlas de Marrakech. – Notes et Mémoires du Service des Mines et de la Carte Géologique du Maroc, **1931**: 1-255.

Nowiński, A. (1976): Tabulata and Chaetetida from the Devonian and Carboniferous of southern Poland. – Palaeontologia Polonica, **35**: 1-125, 27 pls.

Pisarzowska, A., Becker, R. T., Aboussalam, Z. S., Szczerba, M., Sobien, K., Kremer, B., Owocki, K. & Racki, G. (2020): Middlesex/*punctata* Event in the Rhenish Basin (Padberg section, Sauerland, Germany) – multidisciplinary clues to the early-middle Frasnian global biogeochemical perturbation. – Global and Planetary Change, **191**: 103211, 14 pp.

Pohler, S. (2002): Favositidae (Tabulata) from Emsian to Middle Devonian limestones of the Tamworth Group (N.S.W., Australia). – Paläontologische Zeitschrift, **76** (1): 1-19.

Rigaux, E. (1908): Le Dévonien de Ferques et ses brachiopodes. - 33 pp.; Deligny (Boulogne-sur-Mer).

ROCH, E. (1930): Études géologiques dans la région méridionale du Maroc occidental. – Notes et Mémoires du Service des Mines et Carte géologique du Maroc, **9**: 542 pp. [Ph. D. Thesis of Paris university]

TAHIRI, A. (1980a): Présence d'une mylonite à la base de la série calcaire dévonienne du Jebel Ardouz, Jébilet, Maroc hercynien. – 8è Réunion annuaire des Sciences de la Terre, Marseille: 334.

TAHIRI, A. (1980b): Étude lithostratigraphique et structural de la boutonnière allochtone du Jebel Ardouz. Les mylonites de base, Maroc hercynien. - Rapport de mission Oct-Déc 1979. - Travaux du Laboratoire des Sciences de la Terre, St. Jérôme, Marseille, série X: 38 pp.

TAHIRI, A. (1982). Lithostratigraphie, structure et métamorphisme de la partie Sud des Jébilet occidentales autochtones et allochtones – contribution à la connaissance de la chaine hercynienne en Meseta marocaine. – Thèse 3ème cycle, Université Aix-Marseille III, St. Jérôme, 171 pp.

TAHIRI, A. (1983): Lithostratigraphie et structure du Jebel Ardouz – Maroc hercynien. – Bulletin de l´Institut Scientifique, Rabat, **7**: 1-16.

TAHIRI, A. (1984): Les unités structurales des Skhirat et d'Abda dans les Jébilet occidentales, région sud du Jebel Bou Gader (Maroc hercynien). – Bulletin de l´Institut Scientifique, Rabat, **8**: 1-37.

TERMIER, H. (1936): Études géologiques sur le Maroc central et le Moyen-Atlas septentrional. Tome III. Paléontologie, Pétrographie. – Notes et Mémoires, Service des Mines et Carte géologique du Maroc, **33**: 1-1566.

VODRÁŽKOVÁ, S. & SUTTNER, T. J. (2020): Middle Devonian (Eifelian, *australis-ensensis* zones) conodonts from the Jirásek quarry near Koněprusy (Barrandian aream Czech Republic) with special emphasis on the *Polygnathus psaeudofoliatus* Group and notes on environmental changes related to the Kačák Episode. – Bulletin of Geosciences, **95** (1): 81-125.

WENDT, J. & BELKA, Z. (1991): Age and Depositional Environment of Upper Devonian (Early Frasnian to Early Famennian) Black Shales and Limestones (Kellwasser Facies) in the Eastern Anti-Atlas, Morocco. - Facies, **25**: 51-90.