# A new species of *Ivdelinia* Andronov, 1961 from the Moroccan Givetian and its palaeoecological and palaeobiogeographical implications

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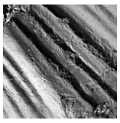

The collection and study of benthic fauna from Middle Devonian carbonate buildups of the Maïder Basin in the eastern Anti-Atlas of Morocco permitted the taxonomic revision of previously described brachiopods from this area. Rhynchonellids dominate the brachiopod fauna. In this work, however, the focus is put on the description of a new gypidulid species, *Ivdelinia pulchra*, which belongs to the family Gypidulidae (subfamily Ivdelininae), found among the brachiopods from the Aferdou el Mrakib reef mound. It represents the youngest *Ivdelinia* species so far described and is compared with other ivdelinids. *Ivdelinia pulchra* occurs as densely packed communities which lived in a carbonate predominant environment during the earlier stage of reef mound growth, suggesting a more or less allochthonous state of these communities. However, this taxon does not properly belong to the reef guild. In addition we discuss the palaeoecology of the new species. • Key words: *Ivdelinia*, Pentamerida, palaeoecology, palaeobiogeography, Maïder, Morocco, Givetian.

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The occurrence of many Devonian mounds in the Tindouf Basin (Dumestre & Illing 1967), in the Sebkha Azzel Matti (Wendt *et al*. 1997), and in the Moroccan eastern Anti-Atlas is well documented in literature, particularly the Anti-Atlas Tafilalt (Choubert *et al*. 1952; Le Maître 1952; Hollard 1963, 1967, 1974, 1981a, 1981b; Massa *et al*. 1965; Michard 1976; Brachert *et al*. 1992; Aitken *et al*. 2002; Klug *et al*. 2009), and Maïder Basin (Wendt 1993; Kaufmann 1995, 1996, 1997, 1998a, b).

The Maïder Basin (Fig. 1) offers one of the most impressive outcrops of Devonian mounds. Hollard (1974) was the first who mentioned the 4 mud mounds at Jebel el Oftal, the solitary mud mound at Guelb el Maharch, and the reef mound named Aferdou el Mrakib in the Maïder Basin (Fig. 2). Because of their shape and lithology, these mounds are very similar to the Kess Kess mounds of Hamar Laghdad (Tafilalt) which are well studied by Brachert *et al*. (1992), Belka (1998), and Aitken *et al*. (2002). Even though they have been studied for decades, the origin of the carbonate buildups of the Maïder Basin is still under debate and detailed descriptions of strategic taxa, *e.g*. brachiopods, could provide new palaeoecological data useful for inferring their genesis.

The aim of this paper is to provide a detailed description of the taxon *Ivdelinia pulchra* sp. nov., which is part of the Aferdou el Mrakib reef guild. The other specimens collected during the field survey in February 2011 belong to the orders Spiriferida, Orthida, and Athyridida. Only a few strophomenids were found in another mound locality. *Ivdelinia pulchra* sp. nov. occurs in various situations: it can be found in monospecific shell beds (see Klug *et al*. 2009), sometimes, associated with abundant specimens of the gypidulid *Devonogypa* (which reaches almost 80 mm shell length) in low diversity associations together with some other brachiopods, and sometimes, it can be found in free association with the variable fauna of the Aferdou el Mrakib reef mound. Andronov (1961) established the genus *Ivdelinia* with the type species *I. ivdelensis* (Khodalevich, 1951) from the Ural Mountains and included 4 European and 32 Russian species, most of which he

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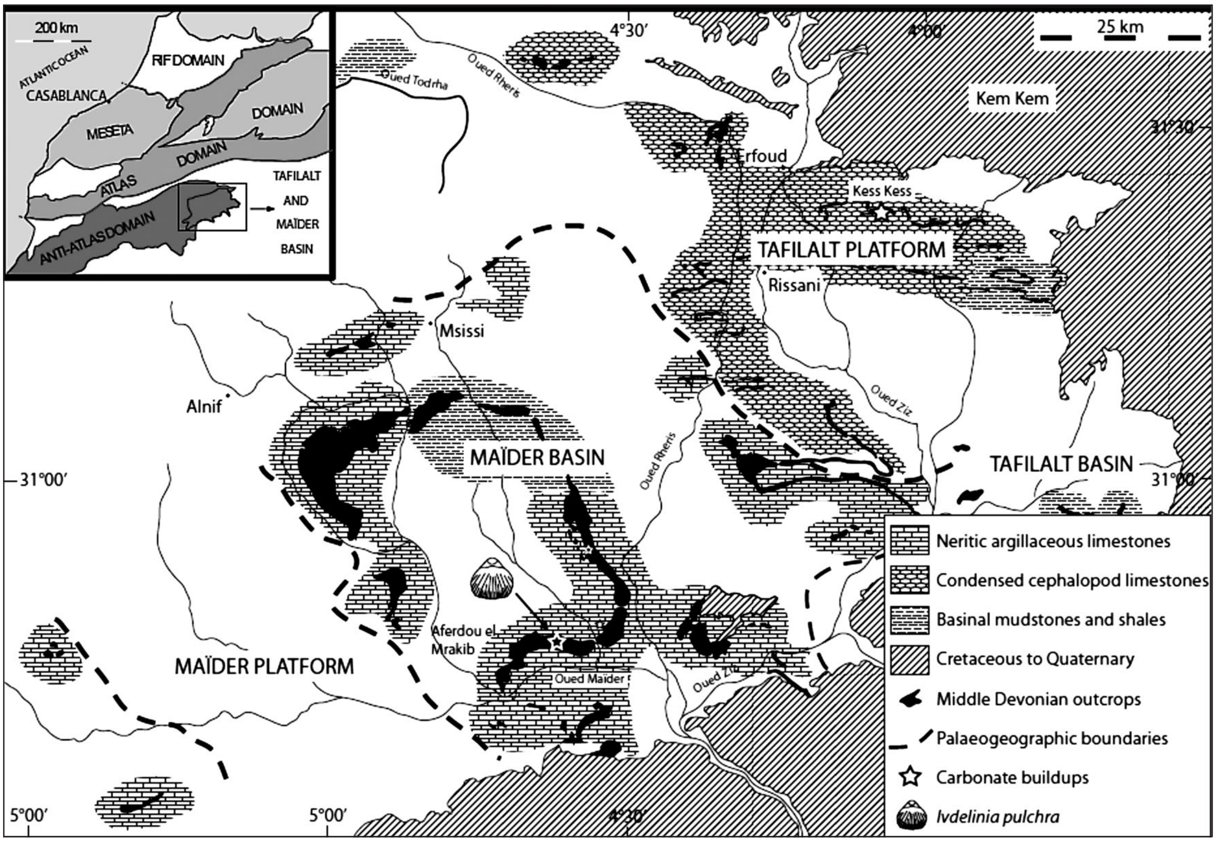

**Figure 1.** Geological schematic map of the eastern Anti-Atlas (modified after Kaufmann 1996). In the box, the tectonic domain is indicated (modified from Michard 1976). The three stars indicate the carbonate buildup localities. Collecting localities of *Ivdelinia pulchra* sp. nov. are indicated by the brachiopod symbol.

established in this monograph. Biernat (1966), however, considered *Ivdelinia* only as a subgenus of *Gypidula* Hall, 1867 and argued that splitting of ribs is not a generic-level character because it is only recognizable in adult specimens. Jux (1969) followed Biernat (1966) in his study of the German Devonian gypidulids and Godefroid (1972) regarded *Ivdelinia* as a genus, redescribed the type species, and figured detailed serial sections. Malygina & Sapelnikov (1973) and Sapelnikov (1985) described further taxa from Lower Devonian and Eifelian strata of the Ural Mountains and Central Asia. Brice (1982) subdivided the genus into two subgenera with material from Arctic Canada based on the presence and absence of a ventral median septum. Blodgett & Boucot (1999) reported the first species from Alaska and proposed its relationship to *Ivdelinia* species from the Urals. Even though a lot of taxonomic work has been done so far on this genus, the systematic description of North African material, which first was mentioned in literature almost two decades ago is still lacking until now.

*Institutional abbreviations.* – MGGC – Museo Geologico Giovanni Capellini, Bologna, Italy.

## Geological setting

The Anti-Atlas is one of the external parts of the Variscan-Appalachian-Ouachita-Mauritanides orogen (Burkhard *et al*. 2006). Palaeozoic deposits in the eastern Anti-Atlas of Morocco are included in a continental shelf sequence developed on the northwestern margin of Gondwana during Late Precambrian to Early Carboniferous time. The closure of the western Paleo-Tethys and consequent clockwise Gondwana rotation during the Devonian resulted in a gradual formation of two main intracratonic non-folded sedimentary basins, the Maïder and Tafilalt basins, which correspond to the Maïder and Tafilalt platforms (Wendt 1985). The Devonian sediments were deposited in these platform-basin systems in a wide epicontinental sea at a paleolatitude of approx. 60° south of the palaeo-equator (Stampfli & Borel 2002). This platform basin system was in place from the early Variscan tensional stress on the passive continental margin of northwest Gondwana (Wendt 1985, 1988). Variscan compression exposed the Palaeozoic rocks in WE and NW-SE trending synclines.

The Maïder region is situated south of Msissi (Fig. 1), where the Devonian strata crop out in a 50 km

**Figure 2.** The carbonate buildups. • A – mound number 2 at the Jebel el Oftal, the largest in this locality, *ca* 40 meters high. • B – Guelb el Maharch solitary mound seen from W, *ca* 40 meters high. C – Aferdou el Mrakib reef mound seen from NE, 100–130 meters high.

wide amphitheater-like structure. The carbonate buildups lie on top of a 200–300 m thick Middle Devonian succession of argillaceous, fossiliferous limestones (Hollard 1974, Wendt 1993). During the Late Devonian, the Maïder Basin was filled by a succession of approx. 800 m of shales and sandstones, which correspond to just some tens of meters of cephalopod limestone in the Maïder Platform (Wendt 1991). Afterwards, Upper Devonian/ Lower Carboniferous marine siliciclastic deposits leveled both the platform and the basin.

## Carbonate buildups

The long lasting debate on the origin of the carbonate buildups of the Maïder Basin roots in two main problems: their genesis and the control of their stratigraphic position. Kaufmann (1998a) suggested a microbial origin for the carbonates of the Maïder Basin mud mounds, in spite of the microbial structures only being preserved in stromatactis fabrics, and concluded that changes of the physico-chemical parameters of the water would have allowed the microbial communities to fix the $CaCO_3$ in their biofilms (Chafetz & Bucrynski 1992, Monty 1995) consolidating the steep flanks of the carbonates buildups. This hypothesis is also supported by high accumulation rates of the mound facies, greater than in the off-mound facies, purity of mound carbonates (95% $CaCO_3$), and homogeneous calcite mineralogy (Kaufmann 1996), which suggests an authigenic origin.

The scattered occurrence of the carbonate buildups can hardly be explained by the presence of cold seeps and/or hot vents on the sea floor (*e.g.*, Belka 1998). Geochemical data do not support this suggestion unequivocally. Methane seepages are not supported by the $^{13}$C-values of the mound carbonates which suggest normal marine conditions, and the $^{18}$O-values do not indicate a sufficiently elevated temperature to suggest any hydrothermal activity (Kaufmann 1997). Nevertheless, Aferdou el Mrakib and Guelb el Maharch carbonate buildups appear to be aligned with a Precambrian E-W trending strike-slip fault system (Kaufmann 1998a) that could be a preferential way for deep fluids. It cannot be excluded, therefore, that the development of the carbonate buildups was initiated with a low temperature hydrothermal water seepage and subsequent benthic fauna colonization. Mixing with the normal sea-water might also explain the near-normal isotopic values. In the case of the Algerian mud-mounds, the fault alignment is evident (Wendt *et al*. 1993).

### Aferdou el Mrakib

Kaufmann (1996, 1997) established the age of the Maïder carbonate buildups by the study of conodont faunal associations formerly described by Belka *et al*. (1997). The stratigraphical position of the Aferdou el Mrakib mound spans the *hemiansatus* to the early *varcus* conodont zones (Givetian). The Aferdou el Mrakib reef mound with its approx. 900 m diameter and 100–120 m altitude is the largest reef mound of the Anti-Atlas (Fig. 2c). The Aferdou el Mrakib fauna is enriched in macroscopic organismal remains compared to the other Maïder Basin carbonate buildups, Kaufmann (1998b) provided a broad description of the faunal assemblage from this carbonate buildup. The reef rocks are dominated by *in situ* and detrital crinoids, tentaculitids (tentaculites, styliolinids and rare nowakiids), tabulate corals such as auloporids (*Bainbridgia*, *Cladochonus, Remesia, Aulocystis*), striatoporoids (*Pachystriatopora*), thamnoporids (*Thamnopora*), favositids (*Platyaxum*), heliolitids (*Heliolites*, large mamelons up to almost one meter), rugose corals, both solitary (*Heliophyllum, Cystiphylloides, Acanthophyllum, Macgeea*) and colonial (*Hexagonaria*, *Phillipsastrea*). The Aferdou el Mrakib mound also yields one of the most abundant brachiopod guilds of the Maïder Basin which consists of pentamerids (*Ivdelinia*, *Devonogypa*), spiriferids (*Atrypa*, *Desquamatia*, *Planatrypa*, *Carinatina*), orthids (*Schizophoria*), athyrids, and leptaenid strophomenids.

Despite of the abundance of *in situ* frame builders (stromatoporoids, tabulate and rugose corals), framestones and boundstones (as described by Wright 1992) are lacking in this buildup. Several stromatoporoids (*Actinostroma*) only appear to locally bound other bioclasts. According to Fagerstrom's (1991) theory of reef guilds, the Aferdou el Mrakib fauna is compatible with a constructor guild and a baffler guild. The predominance of stromatoporoids and rugose corals as well as the absence of calcareous green algae suggests a moderately shallow environment below the euphotic zone (Kaufmann 1995, 1996).

The entire buildup is made up of stromatactis-bearing wackestones, floatstones, and rudstones. Bioclasts are mainly crinoids, corals and subordinate brachiopods. The concordance between the bottom of the stromatactis structures and the strata dip seem to suggest a synsedimentary origin for these cavities. Neptunian dikes filled by dark to violet micrite and a variety of cements cut across the Aferdou el Mrakib buildup. The topmost southeastern part of the buildup is pervasively dolomitized and fossils and structures, therefore, have been obliterated or at least were overprinted by dolomitization. Whereas at the Aferdou el Mrakib mound the fossil remains are more than in other buildups of the Maïder Basin, the taxonomic composition seems to be the same in all the studied places.

## Materials and methods

All studied brachiopods were collected by FF and CK in February and March 2011 from the Aferdou el Mrakib reef mound along the Maïder Basin (Fig. 1). Further information on the localities are provided by Wendt (1993) and Kaufmann (1995, 1996, 1997, 1998a, b).

The specimens described here are deposited at the Museo Geologico Giovanni Capellini of the University of Bologna (Bologna, Italy) with the serial numbers MGGC 21835–21844.

Petrographic and palaeontological investigations of the samples collected during the field survey are currently under investigation by FF. Specimens are preserved as shell material and coated with magnesium oxide prior to photographing. In the present paper the brachiopod taxonomy systematics follows the revised *Treatise on Invertebrate Paleontology* (Blodgett *et al*. 2002).

## Systematic palaeontology

Order Pentamerida Schuchert & Cooper, 1931
Suborder Pentameridina Schuchert & Cooper, 1931
Superfamily Gypiduloidea Schuchert & LeVene, 1929
Family Gypidulidae Schuchert & LeVene, 1929
Subfamily Ivdeliniinae Sapelnikov, 1985

**Genus *Ivdelinia* Andronov, 1961**
**Subgenus *Ivdelinia* (*Ivdelinia*) Andronov, 1961**

*Type species*. – *Gypidula ivdelensis* Khodalevich, 1951, p. 22.

*Diagnosis.* – *Ivdelinia* with strongly raised costae or plicae and with median septum. [After Blodgett *et al.* (2002), p. 1014.]

*Stratigraphic and geographic occurrence.* – Lochkovian to Givetian (lower Lower to upper Middle Devonian); Ural Mountains, Central Asia, Siberia, Uzbekistan, Alaska (USA), Arctic Canada, Europe (Germany, Belgium, Czech Republic), North Africa.

***Ivdelinia pulchra* sp. nov.**
Figure 3

1998b *Ivdelinia* sp. Kaufmann, pl. 13, fig. 11.

*Derivation of name.* – From the Latin word *pulcher, pulchra, pulchrum* = beautiful.

*Holotype.* – Articulated, but broken, specimen showing the spondylium stored in the Museo Geologico Giovanni Capellini, Bologna, Italy, under the inventory number MGGC 21842a.

*Type horizon and locality.* – Lens of gray to dark gray crinoidal wackestone to floatstone with abundant organic matter. Lower Givetian, northeastern flank of Aferdou el Mrakib reef mound, Maïder Basin, Anti-Atlas, Morocco.

*Material.* – 2 articulated specimens, 8 external ventral valves, 1 fragment of internal ventral valve (MGGC 21835–21844).

*Stratigraphic and geographic distribution.* – Lower Givetian (probably *hemiansatus* conodont zone); Maïder Basin, Morocco.

*Diagnosis.* – Large *Ivdelinia* with 3 to 5 plications on fold which show furrows in the anterior third of valve. Fold bordering plications almost parallel and higher than fold. Sulcus tongue clearly developed with straight anterior margin.

*Description.* – Shells medium to large-size, strongly ventribiconvex to planoventriconvex. Hinge line strophic. Almost entire shell covered by plications which are diminishing on flanks toward the lateral ends. Plications split by furrows in the anterior third of valve. Sulcus moderately broad, sulcus bordering plications coarser than plications of fold and sulcus and usually higher elevated than fold. Fold flat to U-shaped in cross-section. Sulcus tongue clearly developed, box-like in anterior view, and with straight anterior margin. Dorsal valve always wider than long. Ventral median septum clearly developed, high, and long, reaching to at least half of shell length. Spondylium gypiduloid (see Blodgett *et al.* 2002, fig. 621.12). Microornamentation not preserved.

*Discussion.* – A vast number of taxa of *Ivdelinia* are described, especially from the Ural Mountains (Russia), some of which can probably be rejected as already stated by Biernat (1966). It is beyond the scope of this work, to revise all species of *Ivdelinia*, especially because we could not study the type or topotype material of these taxa. Therefore, we discuss the new species only from literature data and external morphology of illustrated specimens. If no other indication is provided, the compared taxa are from Lower Devonian–Eifelian strata of the Ural Mountains. *Ivdelinia pulchra* sp. nov. differs from *I. ivdelensis* (Khodalevich, 1951) in wider forms, and fewer and broader ribs on flanks. *Ivdelinia acutolobata* (Sandberger & Sandberger, 1850–1856) including its cf.-forms from the Ural Mountains, the Holy Cross Mountains (Poland), and Germany has smooth flanks or flanks covered with one or two weak plications and only one plication in the sulcus and only 2 plications on the fold, which also represent its bordering plications. *Ivdelinia* sp. cf. *I. multiplicata* (Roemer, 1854) figured by Biernat (1966, pl. 2, figs 2–4) has many more and finer plications than *I. pulchra*, while the specimens of *I. multiplicata* figured by Andronov (1961, pl. 3, figs 11–17) show a smaller sulcus tongue and only very short furrows in the anterior part of the plications. *Ivdelinia pseudoivdelensis* (Khodalevich, 1951) is probably a juvenile form of another *Ivdelinia* species, but the specimen figured in Andronov (1961, pl. 4, figs 24–27) shows very short furrows in the plications and coarser sulcus bordering plications than *I. pulchra*. *Ivdelinia geniculatis* Andronov, 1961 is wider, smaller, and has more plications on the fold than our new species. *Ivdelinia menneri* Andronov, 1961 has many more and finer plications, *I. archangalskii* Andronov, 1961 also has finer plications and a more transverse outline than *I. pulchra*. *Ivdelinia krestovnikovi* Andronov, 1961 has fewer and coarser ribs than *I. pulchra* and broader fold and sulcus bordering plications. *Ivdelinia milradowitchi* Andronov, 1961 has a posteriorly smooth shell, its fold is almost inconspicuous, but shows a coarse median furrow, whereas the complete external surface in *I. pulchra* is covered by plications with furrows of equal size. *Ivdelinia uralensis* Andronov, 1961 has in general plications of the same size as *I. pulchra*, however, the median costa of the sulcus is remarkably coarse, but specimens are smaller than in the new species. Flanks in *I. egorovi* Andronov, 1961 are smooth and its fold is not U-shaped in cross-section. Furthermore, specimens are smaller than in *I. pulchra*. *Ivdelinia savtschencoi* Andronov, 1961 differs from the new species in having smaller and more transverse specimens with fewer plications. The representatives of *I. petropavlowskiensis* Andronov, 1961 show coarser plications on the fold and larger furrows on the plications than in *I. pulchra*. *Ivdelinia* *antiqua* Andronov, 1961 has smaller forms with a less distinct sulcus tongue and coarser plications than the new species. *Ivdelinia motovilichaensis* Andronov, 1961 has a higher elevated fold and higher plications than *I. pulchra*. *Ivdelinia intima* Andronov, 1961 and *I. pulchra* show plications of the same size. Nevertheless, *I. intima* has a subcircular, rather than transverse outline and larger furrows on its plications than the new species. *Ivdelinia planosella* Andronov, 1961 is questionably regarded as a species of *Ivdelinia* because the furrows on the plications are not visible on the figured specimen (Andronov 1961, pl. 7, figs 16–18). This taxon has finer plications than *I. pulchra*. *Ivdelinia apera* Andronov, 1961 has coarser plications than the new species and an inconspicuous fold. The dorsal valves of *I. planosella* and *I. aspera* are not illustrated. The plications of *I. crassicosta* Andronov, 1961 are more distinct and coarser than in *I. pulchra*. *Ivdelinia rossica* Andronov, 1961 differs from *I. pulchra* in having finer costae and a more transverse and smaller specimens. In contrast to *I. pulchra*, *I. moldawanzewi* Andronov, 1961 is smaller with a thinner fold and fewer plications on the flanks. *Ivdelinia moldawanzewi* form alpha Khodalevich & Breivel, 1959, differs from the new species also in smaller intercalated plications on the fold and in the sulcus. The plications in *I. soswaensis* Andronov, 1961 are sharper and specimens of this taxon are smaller and show a broader sulcus than *I. pulchra*. Representatives of *I. trivialis* Andronov, 1961, *I. pulchellis* Andronov, 1961, and *I. kelleri* Andronov, 1961 are very similar to each other and all are forms smaller than *I. pulchra*, with fewer plications on the fold and mostly possess a very pronounced median plication in the sulcus. *Ivdelinia sarytchevi* Andronov, 1961 is smaller and has a broader sulcus and a broader fold than *I. pulchra*. *Ivdelinia ataevi* Andronov, 1961 is quite similar to *I. pulchra*, but differs from the new species in being smaller, having a deeper sulcus, and larger furrows on the plications. *Ivdelinia sphaerica* Andronov, 1961 is subcircular instead of transverse, smaller, and shows a less elevated fold, and larger furrows on the plications than *I. pulchra*. *Ivdelinia simplex* Andronov, 1961, *I. maslovi* Andronov, 1961, and *I. karjavini* Andronov, 1961 are all smaller and have coarser plications with no or shorter furrows than *I. pulchra*. *Ivdelinia procerula* (Barrande, 1879) from the Barrandian region (Czech Republic) and the Holy Cross Mountains is much smaller, has a circular outline, and fewer but overall coarser costae with clearly preserved furrows. The flanks are smooth or covered anteriorly by very weak and broad costae with fine, short, but well developed furrows. *Ivdelinia madmonica* Sapelnikov & Kartaschova, 2003 is more compact and with more ribs in the sulcus, furthermore, the furrows on the ribs are shorter than in *I. pulchra*. *Ivdelinia praeivdelensis* Sapelnikov *in* Sapelnikov & Mizens, 2005 shows smaller and more compact forms with a coarser median furrow on the fold than the new species. *Ivdelinia lahuseni* (Tschernyschew, 1885) shows smaller forms with higher and angular plications than in *I. pulchra*. *Ivdelinia dissecta* Malygina & Sapelnikov, 1973, has a smooth fold with an angular and deep median furrow, a high and angular median plication in the fold and finer plications on its flanks than the bordering plications of the fold and sulcus, whereas in *I. pulchra*, the fold and sulcus show numerous plications, which are less deep and elevated. Furthermore, the plications on the fold, sulcus, and flanks are of equal size. Brice (1982) described *I. grennellensis* Brice, 1982 from the Arctic Canadian Islands. This species has a shorter ventral median septum, a more compact form, and 4 ribs on the fold. The furrows on the costae are almost invisible in her monograph, and the illustrated representatives of Li & Jones (2002) show more costae on flanks, a shorter sulcus tongue, and weaker furrows on the costae. *Ivdelinia pseudoivdelensis* (Khodaievich, 1951) has smaller and more transverse shells with costae of unequal size, whereas *I. pulchra* has less transverse shells, larger specimens, and costae of equal size. The subspecies *I. rectangularis quadruplicata* (Torley, 1934) from Germany shows most similarities to *I. pulchra*, but this subspecies is smaller and has a more strongly transverse ornament than the new species. Besides the morphological differences described herein, no taxon of *Ivdelinia* has been reported from Givetian strata so far.

## Palaeobiogeographical and palaeoecological implications

The origin of *Ivdelinia* lies without doubt in the Ural Mountains, where their highest diversity has been described from Eifelian strata. Outside Central Asia and the Ural Mountains, the first *Ivdelinia* appeared during the Emsian, and this agrees with a step-by-step loss of the Early Devonian endemism with a faunal migration pathways from Asia to Central Europe and North Africa (*e.g.*, Schemm-Gregory & Jansen 2008; Schemm-Gregory 2009a, b). Within the phylogenetic relationships of taxa of *Ivdelinia* shown by morphological similarities of the *Ivdelinia* faunas, a geographical relationship between Europe and North Africa can be confirmed. Additionally, as already proposed by Blodgett & Boucot (1999) and Blodgett *et al.* (2002), a closer relationship of SW Alaska to the Urals than to the Canadian Arctic Islands appears plausible. Even though a single species of *Ivdelinia* occurs in the Canadian Arctic Islands and suggesting a faunal migration, the subgenus *Ivdelinella* Brice, 1982 seems to be endemic for this region. The species *Ivdelinia* (*Ivdelinella*) *salairica* Gratsianova, 1998 would be the first taxon within this subgenus from Emsian strata; due to the lack of plications or only faint plications on the dorsal valve and the lack of the median

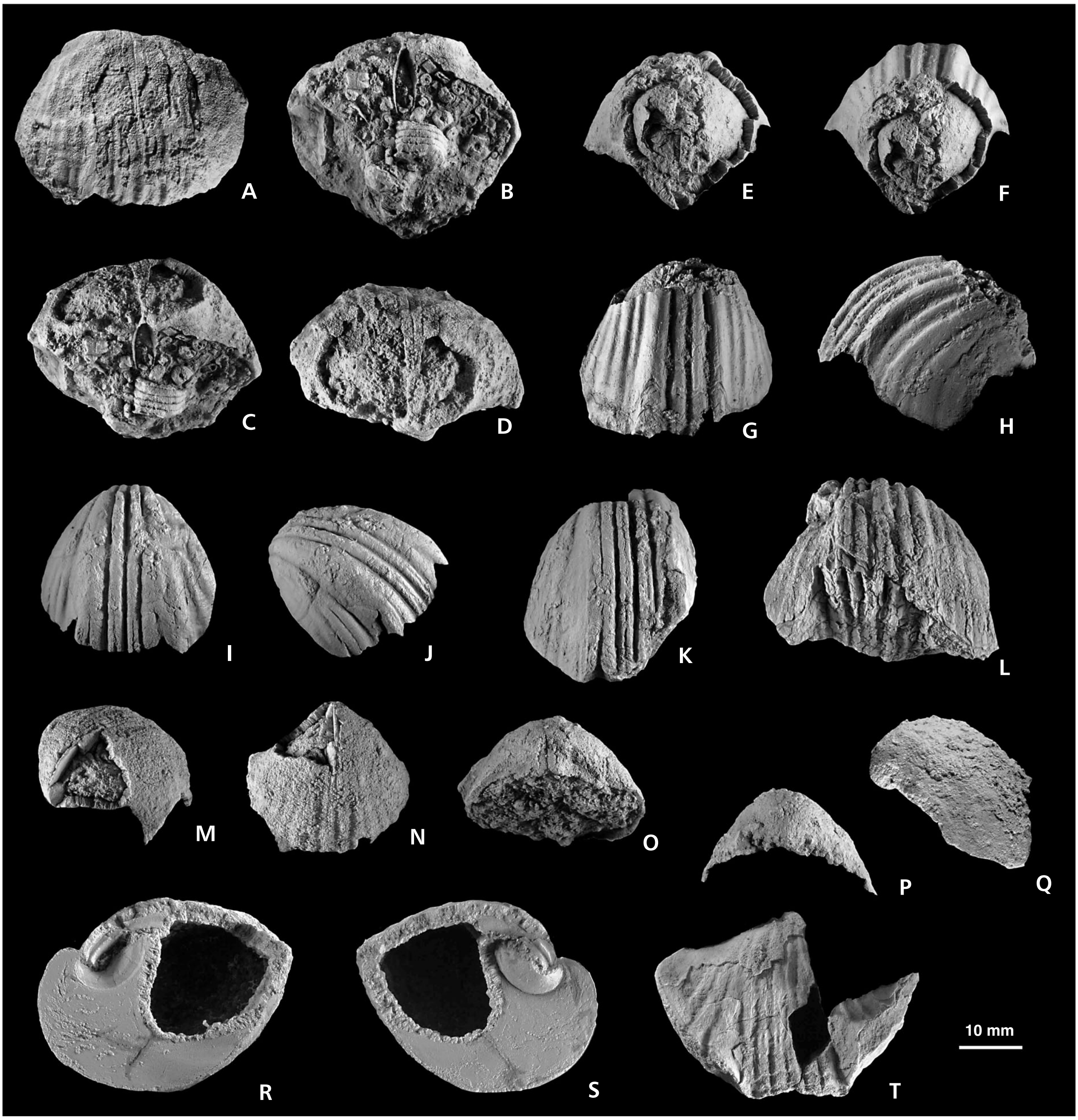

**Figure 3.** *Ivdelinia pulchra* sp. nov. • A–D – MGGC 21837. Ventral (A), dorsal (B), oblique posterodorsal (C), and oblique posterior (D) views of ventral valve; note the spondylium (B) and the ventral median septum (C). • E–H – MGGC 21838. Posterior (E), oblique posterior (F), ventral (G), and oblique anterolateral (H) views of ventral external valve. • I, J – MGGC 21843. Ventral (I) and oblique anterolateral (F) views of ventral external valve. • K – MGGC 21839. Ventral view of ventral external valve; note furrows on ribs. • L – MGGC 28144. Anterior view of articulated shell; note furrows on ribs and margin of sulcus tongue. • M, N – MGGC 21840. Oblique posterolateral (M) and ventral (N) views of ventral external valve; note ventral median septum. • O – MGGC 21835. Oblique posterior view of ventral external valve. • P, Q – MGGC 21836. Posterior (P) and lateral (Q) views of ventral external valve. • R–T – MGGC 21842a, b. Holotype. Lateral (R, S) and dorsal views of articulated specimen; note spondylium, ventral median septum, and outline of dorsal valve. A–Q from Aferdou el Mrakib, north-eastern flank, southern Maïder Basin, Anti-Atlas, Morocco, leg. F. Franchi, February 2011. R–T from Aferdou El Mrakib, northwestern flank, southern Maïder, Anti-Atlas, Morocco, leg. C. Klug, March 2011. All specimens are Early Givetian age and original size (1.0×).

septum we attribute this taxon to *Carinagypa* Johnson & Ludvigsen (1972) (personal communication R.B. Blodgett, 2011).

Gypidulid brachiopods are restricted to distinct environmental palaeohabitats. Jux (1969) reported that gypidulids are abundant in the turbiditic and fine grained sandstone and

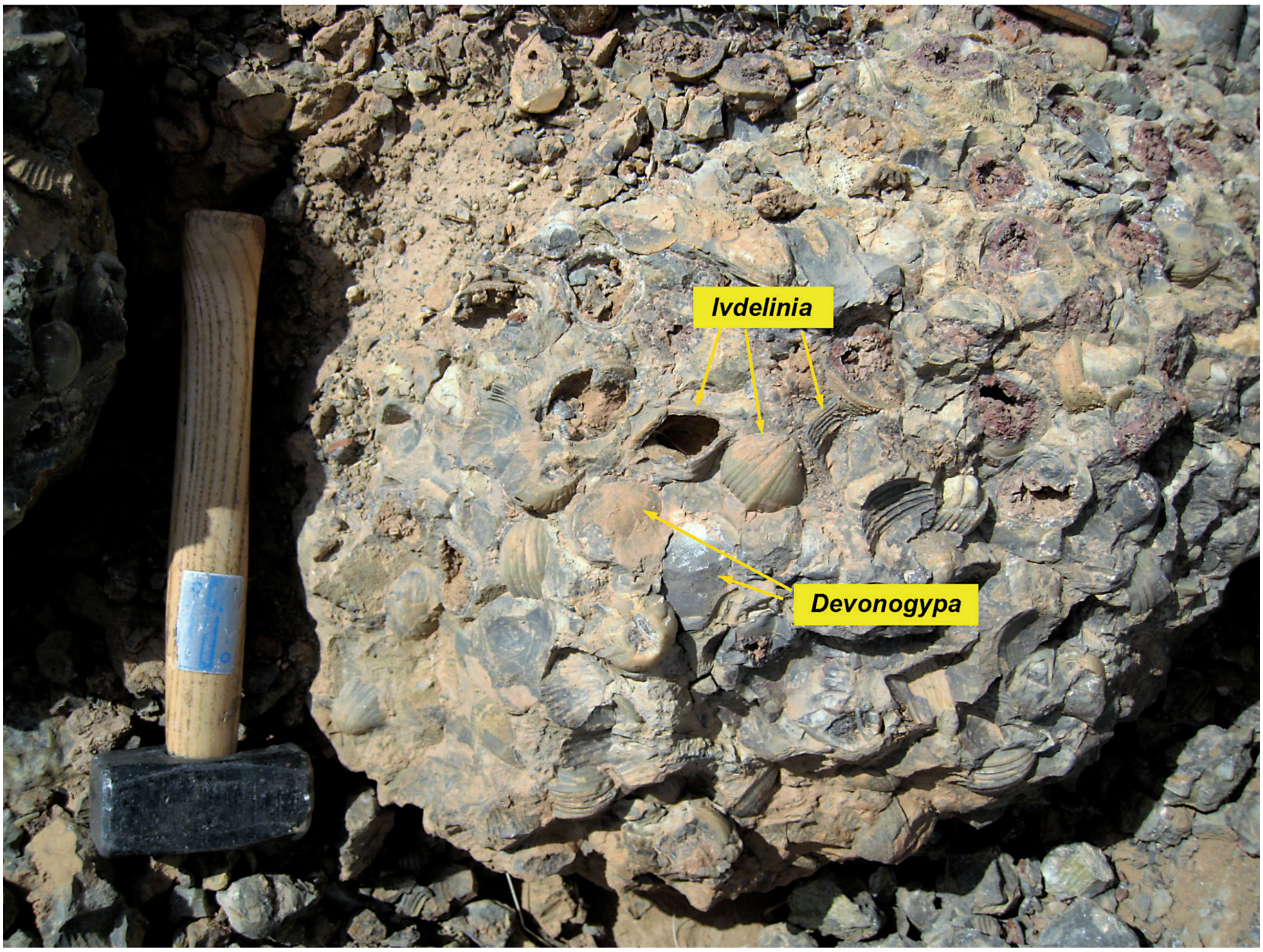

**Figure 4.** Mass-occurrence of *Ivdelinia pulchra* sp. nov. and *Devonogypa* sp. on Aferdou el Mrakib, northeastern flank.

marly limestone facies, gypidulid coquinas were also found in near shore plattenkalk facies. With a faunal assemblage made up of tabulate and rugose corals, atrypids, and rhynchonellids, the studied mud mounds of the Maïder Basin seem to represent a suitable palaeoenvironment for *Ivdelinia*. During ontogeny, ivdelinids probably reduced their pedicle and were dependent on a fine-grained substrate in which they were partly imbedded umbonally in a stable position. Furthermore, living in clusters also guarantees shelter from being transported by currents.

On Aferdou el Mrakib, mass-occurrences are remarkable (Fig. 4), where they co-occur with large *Devonogypa*, which apparently shared the same palaeoecological requirements. The patchy distribution across the bottom strata of Aferdou el Mrakib indicates a more or less allochthonous state of these occurrences. Apparently, they formed little forest-like or colony-like aggregations during the early stage of the reef growth. These brachiopods mass-occurrences, as well as the crinoid remains, acted as a substrate for the colonization by the reef builder communities. The abundance of bioclastic remains, specially crinoids, within the embedding dark rock, was already described elsewhere in the shallow platform facies in Tafilalt Basin and Maïder Basin, suggesting that the colonies bloomed in a quite turbulent environment (compatible with Gypidulid ecology) characterized by currents and not properly in the reef buildups. On the opposite in the other Anti-Atlas analogue basins, where no reef buildups were described, *I. pulchra* does not occur, which shows that this taxon is strongly related with the reef development.

Furthermore, we must consider that during Givetian age the Maïder Basin was situated at middle-high latitude (Stampfli & Borel 2002) and water temperature must have been lower than in present day tropical platforms. Anyway the high latitude is comparable with the Urals latitudes throughout the Devonian, where *Ivdelinia* first occurred.

## Conclusion

The new early Givetian ivdelinid species, *Ivdelinia pulchra*, represents the youngest *Ivdelinia* species described to date. It exhibits a characteristic morphology of fold and sulcus, as well as number of ribs enables an easy identification and, therefore, it might be a useful stratigraphic tool for the lower Givetian deposits of the Maïder Basin. *Ivdelinia pulchra* is suggested to have migrated near the Eifelian/Givetian boundary interval from today's Central Asia to Europe and North Africa.

Further at least mono specific assemblage of *Devonogypa* sp. and *Ivdelinia pulchra* is related to particular adaption to an environment characterized by high nutrient supply, turbid water and low temperatures in an high latitude intracratonic shallow sea during the early stage of reef development.

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