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Ordovician stratigraphy and benthic community replacements in the eastern Anti-Atlas, Morocco

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Abstract

The Anti-Atlas contains a thick, volcanic-free Ordovician succession, originally deposited in a passive-margin basin. Three main sedimentary packages are bounded by major unconformities: (i) the Tremadocian–Floian Lower Fezouata and Upper Fezouata formations, which unconformably overlie a palaeorelief of Cambrian rifting volcanosedimentary complexes, and is subsequently overlain by a Dapingian paraconformable gap; (ii) the Darriwilian–Katian Tachilla Formation and First Bani and Ktaoua groups, the latter unconformably overlain by a Hirnantian glaciogenic succession; (iii) subsequently infilled with deposits of the Second Bani Group. Due to the scarcity of carbonate interbeds for etching analyses, leading to rare references of conodonts, the global Ordovician chart is interpolated on the basis of microphytoplancton (acritarchs and chitinozoans), regional graptolites and brachiopods. The Ordovician counter-clockwise rotation of Gondwana led its Moroccan margin from mid- to high-latitude positions, leading to the onset of a siliciclastic, wave- and storm-dominated platform. Flooding surfaces are marked by shelly silty carbonate interbeds that reflect the episodic development of echinoderm-bryozoan meadows during Katian times; in areas protected from siliciclastic input, they reached massive and bedded bioaccumulations (Khabt-el-Hajar Formation). The Hirnantian glaciation controlled the incision of numerous tunnel channels, infilled with both alluvial-to-

fluvial sediments and glaciomarine diacmictites. The Hirnantian palaeorelief was definitively sealed during Silurian times.

Introduction

In the Anti-Atlas Ranges of Morocco, the Ordovician rocks occupy approximately 24,000 km^2 of surface exposures (Fig. 1A–B) and host one of the most productive sedimentary metalliferous deposits in NW Africa (Agard *et al*. 1952; Destombes 1954, 1958, 1959, 1985a; Destombes & Jeanette 1962; Destombes 1970; Destombes *et al*. 1985; Raddi *et al*. 2011). Largely due to their economic importance, these ironstones have ceaselessly been the focus of continuing mapping programs and associated research projects.

About three decades ago, Destombes *et al*. (1985) summarized what was known at that time about the Ordovician stratigraphy (Moroccan Program of Geological Mapping at 1/200,000 scale) and basin evolution history in the Anti-Atlas. Since them, the huge work fostered by the Moroccan Geological Survey has been progressively improved by the subsequent programs of geological mapping at 1/100,000 and 1/50,000 scales. Data acquired during the last decades have provided important information about the Ordovician fossil record and represent the basis for comparisons with neighbouring margins of Gondwana and other continents based on chronostratigraphical, biogeographical, sedimentological and sequence-stratigraphical correlations.

The Ordovician of the eastern Anti-Atlas contains three major gap-bounded, volcanic-free sedimentary packages: (i) the Tremadocian–Floian Lower Fezouata and Upper Fezouata formations, which unconformably overlie a palaeorelief of Cambrian rifting volcanosedimentary complexes, and is subsequently overlain by a Dapingian paraconformable gap; (ii) the Darriwilian–Katian Tachilla Formation and First Bani and Ktaoua groups, the latter unconformably overlain by a Hirnantian glaciogenic succession; and (iii) the Second Bani Group that infills the former glaciogenic palaeorelief.

Due to the virtual lack of igneous rocks and the scarcity of carbonate interbeds, mapping and correlation of the Ordovician have traditionally relied on lithostratigraphical comparisons along a 1,000 km-long transect from Tan-Tan (western edge of the Anti-Atlas) to Erfoud (eastern edge). It seems timely to review the stratigraphical nomenclature established over the past three decades in order to provide a convenient synthesis, from which to develop local and basin-wide correlations. We provide below an overview of the Ordovician strata from the eastern Anti-Atlas and adjacent areas. Major mappable lithostratigraphical units are reviewed and placed in a regional geodynamical and sequence context.

Geological setting and tectonostratigraphical units

The Proterozoic basement of the Anti-Atlas lies along the northern margin of the West African craton (Ennih & Liégeois 2008). The inliers of the High Atlas and the Anti-Atlas inliers are crosscut by two major fault networks, the so-called South Atlas and Anti-Atlas Major Faults (SAF and AAMF in Fig. 1B): the former crosscuts longitudinally the High Atlas, whereas the latter exemplifies a Neoproterozoic ophiolite-bearing transect, representative of the Pan-African orogenic suture (Michard *et al*. 2008). The end of the Pan-African orogeny was succeeded by the onset of a latest Ediacaran–Cambrian rift, known as the Cambrian Atlas Rift (Álvaro *et al*. 2014a, b; Pouclet *et al*. 2018), which evolved during Ordovician times into a passive-margin basin.

Geographically speaking, the Anti-Atlas is subdivided into the western, central and eastern Anti-Atlas, the latter including the Jbel Saghro, the Jbel Ougnate and the Tafilalt district. In contrast, from a geological point of view, several works suggest distinguishing the eastern Anti-Atlas as westerly bounded by the Anti-Atlas Major Fault, as a result of which, a part of the El Graara massif (including the Bou Azzer-El Graara inlier) would be included in the eastern Anti-Atlas. In this work, we consider the eastern Anti-Atlas as including the Ordovician exposures flanking the Jbel Saghro, the Jbel Ougnate and the scattered outcrops that punctuate the Tafilalt district (1/200,000 maps of Destombes 1985b, d, 1987, 2006a; Raddi *et al*. 2006, 2012; Álvaro *et al*. 2014c, d; Benharref *et al*. 2014a, b, c) (Fig. 1B–C). In the eastern Anti-Atlas, Ordovician rocks are well exposed, easily accessible, fossiliferous and relatively undisturbed by tectonism. These advantageous attributes make this region a key area for the study of the Ordovician stratigraphy and fossil record in Northwest Africa.

A mid-latitude passive-margin basin

After the end of the Pan-African Orogeny, a syn-rift megasequence comprises the Cambrian Taroudant, Tata, Feijas Internes and Tabanite groups. These volcanosedimentary complexes infilled the accommodation space generated during a ca. 55.6 m.y.-rifting episode, known as the Cambrian Atlas Rift. A network of narrow, interconnected rifting branches was episodically generated, bounded by disconnected shoulders that were locally tilted and uplifted during syn-rifting pulses.

The beginning of rift geodynamics is diachronous throughout the Anti-Atlas but extended across the Ediacaran–Cambrian boundary interval. During Cambrian times, the Atlas Rift recorded the onset of (half-)grabens and horsts forming a linear SSW-NNE trending belt, up to 400 km long and interrupted by a series of major en echelon extensional faults (Soulaimani *et al.* 2003; Pouclet *et al*. 2007, 2018; Álvaro & Debrenne 2010). The resulting accommodation space was controlled by extensional rift pulses that led to (i) sharp changes in lithology and facies thickness; (ii) episodic deposition of conglomerates and breccias along rift flanks; (iii) local tilting and uplift along rift shoulders associated with subaerial exposure, development of hydrothermally induced metal ore deposits and local stratigraphic gaps; and (iv) deposition of deeper water facies along the axes of rift branches (Álvaro & Clausen 2007, 2008; Álvaro 2013, 2014; Álvaro *et al*. 2015). Several major unconformities punctuate the Cambrian volcanosedimentary complexes of the Atlas Rift, marking (i) a pre-rift unconformity at the base of the Adoudou Formation; (ii) a syn-rift unconformity marking the top of the Taguedit Bed (Tabia Member, Adoudou Formation), which represents a sharp change from extensive fault-controlled hydrothermal activity, carbonate production and phosphogenesis followed by sealing of the palaeorelief by microbial carbonate-dominated platforms (Tifnout Member, Adoudou Formation); (iii) the hiatal shell accumulations of the Brèche à Micmacca Member (Jbel Wawrmast Formation) overlying a low-angle unconformity locally affected by karstification; and (iv) a Furongian break-up unconformity that marks the rift/drift turnover (Álvaro 2013; Álvaro *et al*. 2014a, b; Álvaro & Vicaïno 2018) (Fig. 2). The Azlag Formation (Tabanite Group) marks the end of Cambrian sedimentation in the Anti-Atlas, excluding a tectonically depressed area of the central Anti-Atlas (El Graara massif), where lies the Jbel Lmgaysmat Formation (Tabanite Group). The latter comprises a 10 cm-thick shelly siltstone that has yielded Furongian trilobites and brachiopods (Destombes *et al*. 1985; Destombes & Feist 1987; Álvaro *et al*. 2007a).

Throughout the Anti-Atlas, the Cambrian/Ordovician or Tabanite/Fezouata contact is represented by both paraconformities and angular discordances. The Tremadocian Lower Fezouata Formation occurs unconformably overlying either the Jbel Afraou, Bailiella, Azlag or Jbel Lmgaysmat formations of the Tabanite Group. As a result, the erosive gap involved at this break-up unconformity varies throughout the region from part of the Furongian to the Drumian–Guzhangian–Furongian time span. The rift/drift unconformity is marked in the Anti-Atlas by generalized uplift, tilting, subaerial exposure and erosion, which led to the sedimentation of the breccias and conglomerates that characterize the lower member of the Lower Fezouata Formation (Álvaro & Vizcaïno 2018) (Fig. 2). The latter may represent a lag interval of latest Furongian alluvial-to-fluvial deposition (Destombes *et al*. 1985; Destombes 2006b) before final drowning of the entire Atlas Rift and the onset of the Anti-Atlas passive-margin basin.

The Cambrian evolution of the Atlas Rift recorded an episodic volcanism, which ranged from rift tholeiites to subsidiary sub-alkaline and alkaline magmatism that ended during Guzhangian times. The Atlas Rift was somewhat geodynamically connected to the Ossa-Morena Rift, which recorded a common (although diachronous) late Ediacaran–Terreneuvian arc-rift transition and a late Furongian rift-drift shift (Álvaro *et al*. 2014b; Pouclet *et al*. 2018).

During Ordovician times, a SW-NE-trending depositional trough developed in the Anti-Atlas that experienced enhanced axial subsidence in a depocentre located close to the Zagora-

Foum Zguid area (central Anti-Atlas). Although the Ordovician history of the Anti-Atlas is characterized by relative tectonic quiescence, by comparison with the Cambrian rifting history, the Ordovician succession is punctuated by two major, laterally extensive gaps, marking a Dapingian hiatus and a Hirnantian glaciogenic gap. The Ordovician represents over 41.2 m.y. of continuous sedimentation, (i) regionally preceded by major episodes of tilting and shoulder uplift of a graben-to-halfgraben framework recording the dynamic geological history from the initial (rift-to-drift) breakup unconformity; (ii) punctuated by the Dapingian hiatus related to non-deposition and/or erosion; and (iii) the final post-glacial Silurian sealing of an inherited glaciogenic palaeorelief (Fig. 2).

Palaeomagnetic (Smith 1997; Evans 2003) and palaeoenvironmental (e.g., Destombes 1968a, b, 1981, 1987, 2006a, b; Destombes *et al*. 1985; Destombes & Willefert 1988; Ouanaimi 1998; Hamoumi 1999; Álvaro *et al*. 2000, 2004, 2014c, d, 2016a; Sutcliffe *et al.* 2001; Ghienne *et al*. 2007a; Le Heron 2007; Le Heron *et al*. 2007, 2008; Le Heron & Craig 2008; Loi *et al*. 2010; Videt *et al*. 2010; Clerc *et al.* 2013; Benharref *et al*. 2014a, b, c; Ravier *et al.* 2014) evidence indicates for the Anti-Atlas a counter-clockwise drift towards South Polar positions from a latest Ediacaran–Cambrian Epoch 2 arid subtropical (10–30º) setting to a Late Ordovician (50–70º) subpolar palaeolatitude.

Lithostratigraphical chart

The Ordovician lithostratigraphical units erected by Destombes (1962a, 1963a, b, 1971) and Destombes *et al*. (1985) in the vicinity of Zagora (Jbel Bani, central Anti-Atlas) are recognisable in the Tafilalt district. Some differences are remarkable, such as the relative thickness increase in the Middle–Upper Ordovician sandstone and quartzite interbeds, reflecting a palaeogeographical transect from deeper (depocentre in the Zagora-Foum Zguid area) to shallower (Ougnate and Tafilalt) settings of the passive-margin basin. Thus the Ordovician is comparable formation-by-formation from Zagora to Erfoud. The only significant (at formation scale) lateral facies change is the sudden increase in Katian carbonate production (Khabt-el-Hajar Formation) recorded in the vicinity of Erfoud, by comparison with the coeval shale-dominant Upper Ktaoua Formation (Destombes 1987; Álvaro *et al*. 2007; Jiménez-Sánchez *et al*., 2015; Villas & Colmenar, this vol.).

Four major, laterally extensive, sandstone/quartzite packages can be traced for about 400 km (Fig. 2). These are the Darriwilian Tachilla Formation (a major marker bed for mapping due to its dark reddish colour), the Darriwilian-Sandbian First Bani Group (subdivided in the central Anti-Atlas into five formations), the Upper Tiouririne Formation and the Amouktir Member (Upper Formation of the Second Bani Group). Between them, shale-dominated landscapes form the plains and jbel flanks of the Anti-Atlas orography. The absence of

Ordovician fan-shaped aprons and megadebris-flow deposits in the Anti-Atlas led to the identification of its exposures as representative of a marine platform with no significant break slopes and slope-related deposits, which are incompletely recognized in the High Atlas (Destombes *et al*. 1985; Ouanaimi *et al*. 2006).

Feijas Externes Group (Choubert & Termier 1947)

In the Anti-Atlas, a shale-dominated unit is sandwiched between the weathering-resistant, sandstone/quartzite packages of the Cambrian Tabanite and Middle–Ordovician First Bani groups. The Feijas Externes Group forms the plains and flanks of jbels between Akka and Alnif, and mainly consists of monotonous shales with sandy intercalations exhibiting locally glauconitic and ironstone interbeds. The total thickness ranges from a few tens of metres in the northern Jbel Ougnate to about 1100 m in the Zagora-Foum Zguid depocentre. Destombes (1962a, b, 1963a, b, 1971) and Destombes *et al*. (1985) subdivided the group into four units, named Lower Fezouata and Upper Fezouata (grouped in a single formation by Gutiérrez Marco & Martin 2016 and Martin *et al*. 2016a, b in the depocentre, due to their homogeneous lithological features, but still used as distinct mappable formations in the geological maps of the Tafilalt district by Álvaro *et al*. 2014c, d and Benharref *et al*. 2014a, b, c), Zini (recognized in the surroundings of Zagora and in the vicinity of its homonymous jbel, southwestern Anti-Atlas) and Tachilla formations.

Lower Fezouata Formation. This unit is a shale-dominated succession, blue-green in colour, with sandy and glauconitic interbeds in its upper part. As stated above, it unconformably overlies either the Jbel Afraou, Bailiella, Azlag or Jbel Lmgaysmat formations, and ranges in thickness from zero (Jbels Tachilla and Ouarzemine in the northwestern Anti-Atlas, and northern Saghro, Maïder and northern Jbel Ougnate in the eastern Anti-Atlas) to 400 m (Zagora-Foum Zguid depocentre). The base of the formation comprises lag deposits (marking a transgressive surface), rich in ferrigenous breccia, conglomerate and sandstone, broadly up to 1 m thick throughout the Anti-Atlas. In the vicinity of Foum Zguid, this unit can reach 10 m of thickness and has been mapped as an informal lower member (Destombes 1985c; Destombes & Feist 1987) representing the incision of alluvial-to-fluvial sedimentary systems (Álvaro & Vizcaïno 2018).

In the Jbel Ougnate and the Tafilalt district, the Lower Fezouata Formation unconformably overlies the Azlag Formation (Destombes 1960a, b). Its contact is both paraconformable and discordant, the latter representing onlapping geometries of Ordovician shales sealing an inherited palaeorelief topped by Cambrian quartzites (Tazoult n'Ouzina and Jbel Zorg; Álvaro *et al*. 2014c). Throughout the Tafilalt district, two members can be distinguished in the Lower Fezouata Formation, from bottom to top: (i) a set of conglomerates and sandstones, up to 1 m thick in Tazoult n'Ouzina; and (ii) a monotonous shaly succession, up to 400 m thick, locally glauconitic and comprising centimetre-to-decimetre sandstone interbeds.

Upper Fezouata Formation. The formation is subdivided into two members: (i) a cartographically significant greenish package, approximately 20 m thick, composed of glauconitic and ferruginous conglomerates and sandstones rich in glauconitic peloids, iron-rich ooids and hematite cement (Fig. 3A–B), and broadly cropping out in the southern Jbel Saghro, southern Maider and Tafilalt district; and (ii) a package of variegated alternations of shales and sandstones, 300–400 m thick (Destombes *et al*. 1985). The formation either conformably overlies the Lower Fezouata Formation (e.g., in the Tafilalt district) or unconformably overlies the Jbel Afraou and Bailiella formations (e.g., in the northern Jbel Ougnate; Destombes 1962b; Destombes *et al*. 1985; Choukri *et al*. 2004; Choukri & Hamoumi 2005). Both the Lower Fezouata and Upper Fezouata formations are absent in the southwestern area of the Anti-Atlas (Jbels Tachilla and Ouarzemine; Fig. 2), and the latter reaches a thickness maximum (600–700 m) along the Akka-Tata transect.

Tachilla Formation. This unit, up to 1200 m thick in the Jbels Tachilla and Ouarzemine (south of Agadir), is a key cartographic marker throughout the Ordovician of the Anti-Atlas. It consists of ochre-to-blackish, ooidal sandstones rich in iron oxyhydroxides (Fig. 3C–D) with subsidiary green shale interbeds bearing centimetre-thick carbonate nodules. The base of the formation is represented by an erosive paraconformity, whereas its top is conformable. In the Jbels Tachilla and Ouarzemine, the Tachilla Formation is paraconformably overlying the Tabanite Group. In the eastern Anti-Atlas, the formation ranges from 20 m in the northern Tafilalt to 200 m in the southern Maïder district and the Jbel Ougnate.

First Bani Group ('Bani Quartzites' by Choubert & Termier 1947; 'Quartzites of First Bani' by Choubert 1952)

The group forms the most extensive Ordovician sandstone package throughout the Anti-Atlas and accounts for the main relief of the 450 km-long Jbel Bani. It consists of an alternation of variegated sandstones and shales, with common iron ooidal interbeds in its lower part. The Tachilla/First Bani transition is gradual and marked by a progressive enrichment in the sandstone/shale ratio, whereas the top of the group is sharp and marked by the abrupt occurrence of decametre-thick shales. The formation exhibits a gradual increase in thickness from the northern Tafilalt district to the Zagora-Foum Zguid depocentre, ranging from 15 to 700 m (Destombes 1987, 2006a, b). Although this group was originally subdivided in the central

Anti-Atlas into five formations (Destombes *et al*. 1985), its lithostratigraphical subdivision becomes ambiguous northeasternward. Destombes (1985b, 1987, 2006a, b) described it as a single unit in the 1/200,000 Tafilalt-Taouz sheet and the eastern margin of the 1/200,000 Todhra-Ma'der sheet maps. Álvaro *et al*. (2014c) and Benharref *et al*. (2014c) have subdivided the group, in the Tafilalt district, into the Taddrist, Guezzart, Bou-Zeroual, Ouine-Inirne and Izegguirene formations based on the sandstone/shale ratio characterized by the presence/absence of distinct sedimentary structures.

Ktaoua Group (Choubert 1952)

The toponymy originally referred to the shaly plains and jbel flanks cropping out in the surroundings of Tagounite, central Anti-Atlas. It is sandwiched between the weathering-resistant sandstone-quartzite packages of the First and Second Bani groups. After several subdivisions, Destombes (1971) and Destombes *et al*. (1985) finally subdivided the group into three formations highlighting the presence of an intermediate sandstone-dominant package (Upper Tiouririne Formation) separating two shale-dominant units (Lower Ktaoua and Upper Ktaoua formations). Destombes *et al*. (1985) suggested a lateral change of the Upper Tiouririne Formation, to the east of Erfoud, into the 'Khabt-el-Hajar bryozoan limestones', which are distinguished below as a separate formation. The total thickness of the group attains its maximum close to the Ktaoua plain, with about 350 to 400 m.

Lower Ktaoua Formation. This unit is a shale-dominated succession with subsidiary sandstone interbeds and carbonate nodules and concretions parallel to stratification (Fig. 4A). In the Zagora-Foum Zguid depocentre, the base is marked by the occurrence of conglomeratic sandstones rich in ferrugineous ooids. The members distinguished by Destombes *et al*. (1985) in the type area cannot be followed northeasternwards. In the Tafilalt district, Destombes (1987) distinguished three members, in ascending order: (i) the shale-dominated Jbel Bou-Isidane Member, (ii) the shale/sandstone alternations of the Jbel Tiberguent Member (Fig. 4B), and (iii) the heterolithic (sandstone-dominant) Jbel Tafersikt Member. However, the latter was exclusively recognized on jbel summits and, in some cases, will be reported below as the Alnif Member (Upper Formation of the Second Bani Group). A minor sandstone-dominant member, known as the "Middle Tiouririne sandstones" has been used in some maps of the depocentre due to its characteristic fossil content. Only the Jbel Bou-Isidane and Jbel Tiberguent members, reported as (informal) lower and upper subunits were mapped in the 1/50,000 maps of the Tafilalt district (Álvaro *et al.* 2014c, d; Benharref *et al.* 2014a, b, c).

Upper Tiouririne Formation. The presence of significant sandstone-dominated packages marking the middle part of the Ktaoua Group is not clear in the Ktaoua plain and westwards. In contrast, it is distinguishable in the Maider and Tafilalt districts and, to the west of Tagounite, these sandstone packages served to Destombes (1985) to define the Rouïd Aïssa Formation. There, this mappable sedimentary package is represented by a thick succession (150–300 m) of sandstone beds and interbedded shales, calcareous siltites and carbonate nodules parallel to stratification. Due to changes in the sandstone/shale ratio from Zagora to Tafilalt, the base is not clearly distinguished northeasternwards. In the vicinity of Alnif, Álvaro *et al*. (2007b) suggested the presence of a phosphatic limestone infested with the brachiopod *Rafinesquina pomoides* to mark the base of the formation (Fig. 4C). This horizon can be followed in the Tafilalt district, where the formation contains common cobble- to pebble-sized conglomeratic intervals rich in shelly accumulations (Fig. 4D–G); its top is characterized by the presence of sandstone packages with sigmoidal cross-stratified sets, episodically encrusted by ooidal hardgrounds rich in iron oxyhydroxides (e.g., summit of Jbel Adrar; Álvaro *et al*. 2014b; Colmenar & Álvaro 2015: fig. 5a–b).

Upper Ktaoua Formation. This unit is incompletely preserved in the Tafilalt district due to its upper erosive contact with the Second Bani Group. Where present, it can reach up to 80 m of thickness and consists of monotonous shales episodically punctuated by decimetre-thick, orthoceratid-rich calcareous siltstones (Fig. 4H) and sandstones, and scattered centimetre-thick carbonate and phosphatic nodules, parallel to stratification and rich in orthoconic nautiloids. One marker bed is recognizable close to the top of the formation, the so-called “Ouzregui bed”, whose name is derived from the abundance of the trilobite species *Flexicalymene ouzregui*.

Khabt-el-Hajar Formation. To the North-East of Erfoud, some limestone/shale alternations (Fig. 5A), informally named ‘Bryozoan Limestones’ and up to 40 m thick, were reported by Termier & Termier (1950a, b) and Destombes (1962a). They were mapped and formally erected by Destombes *et al*. (1985) as the Khabt-el-Hajar Formation. Several logs were reported by Destombes (2006a) illustrating the presence of some angular discordances and ‘ravinement surfaces’ representing, in fact, erosive surfaces (one of them marking the base of the formation) and onlapping geometries of bryozoan- and echinoderm-rich limestone lenses (Fig. 5B–C). The top of the formation is marked, in its northeasternmost outcrop (Destombes 2006a), by a barren ironstone interval, 3 m thick, which may represent either the Second Bani Group or a Silurian basal lag. Geometrically, the Khabt-el-Hajar Formation unconformably overlies a sandstone package assigned to the Upper Tiouririne Formation by Destombes (2006a), and is unconformably overlain by the above-reported, condensed ironstone level, which is subsequently onlapped by Silurian shales (Destombes 1987, 2006a).

Second Bani Group (‘Sandstones of the Second Bani’ by Choubert & Termier 1947; ‘Sandstones of the Second Bani or Beni Selmane’ by Choubert 1952)

Although originally erected in the vicinity of Zagora, where a Lower Formation was distinguished, the Second Bani Group is only represented in the eastern Anti-Atlas by its upper formation (Destombes *et al*. 1985).

Lower Formation. In the Zagora-Foum Zguid depocentre, the heterolithic Lower Formation, up to 120 m m thick, consists of conglomerates, sandstones and shales commonly separated by scouring surfaces. According to Destombes *et al*. (1985), its base is conformable and located at the occurrence of ooidal limestone nodules and centimetre-thick layers, whereas its top is marked by the glaciogenic unconformity that marks the base of the Upper Formation (Loi *et al*. 2010).

Upper Formation. This formation was formally subdivided close to Alnif by Villas *et al*. (2006) and Álvaro *et al*. (2007b). Its three-fold subdivision (Alnif, Tamekhart and Amouktir members) has been followed in the 1/50,000 geological sheets of the Tafilalt district (Álvaro *et al*. 2014c, d).

Several apparently diachronous unconformities had been traditionally recognized at the top of some jbels of the Ktaoua Group marking the base of variegated conglomerates. According to their scouring position, these conglomerates received different lithostratigraphical names, such as ‘Conglomérat d’Alnif’ or ‘Conglomérat d’Amessoui’ (incising the Lower Ktaoua Formation in the vicinity of the eponymous village and jbel, respectively; Destombes 1985b, c, d, 2006b; Hamoumi 1999; Choukri *et al*. 2004); ‘Conglomérat d’Imzizoui’ (incising the Upper Tiouririne Formation at the homonymous jbel; Destombes 2006a, b; El Maazouz & Hamoumi 2007); some conglomeratic beds forming the top of the Jbel Tafersikt Member (Lower Ktaoua Formation; Destombes 2006a), and the ‘Argiles microconglomératiques’ (Destombes *et al*. 1985) or glaciomarine diamictites (Villas *et al*. 2006). All these apparently diachronous unconformities represent indeed one single glaciogenic erosive unconformity that can be laterally correlated. After mapping in detail this unconformity and its stratigraphical contacts, the overlying Upper Formation (Second Bani Group) is clearly recognizable, on the basis of its deeply erosive lower boundary and the distinct glaciogenic features of its lower part (Álvaro *et al*. 2007b, 2014c, d; Benharref *et al*. 2014a, b, c).

The Alnif Member of the eastern Anti-Atlas represents a discontinuous unit, which comprises the Alnif Conglomerate *sensu* Destombes (1985b), up to 80 m thick, conformably overlain by an upper package of lenticular sandstones, up to 10 m thick (Fig. 5D–G). The Alnif

Member is overlain by a claystone-dominant diamictite, named 'argiles microconglomératiques' by Destombes *et al.* (1985) owing to the presence of scattered quartz granules and pebbles 'floating' in a clayey matrix (Fig. 5H), and Tamekhtart Member by Villas *et al*. (2006); its thickness is highly variable (up to 100 m) and influenced by the bedrock palaeorelief inherited from the aforementioned erosive unconformity. Finally, the uppermost Amouktir Member, 30–60 m thick, is a stratigraphical unit resistant to weathering, composed of sandstone/shale alternations that pass upward into conglomerates (Fig. 5I), and ends at the occurrence of Silurian graptolite-bearing black shales.

Biostratigraphical scale

The global chronostratigraphical subdivisions defined by the *International Subcommission on Ordovician Stratigraphy* (ISOS) are mainly based on the first occurrence datum (FAD) of particular species of graptolites and conodonts. Due to the unsuitable environments for the life and preservation of key graptolites and the scarcity of carbonate interbeds for dissolution to yield conodont elements, leading to rare references of Ordovician conodonts in the Anti-Atlas (El Bourkhissi & Sarmiento 1997; Lehnert *et al*. 2016), the global chronostratigraphy of the Ordovician chart erected by the ISOS is interpolated in the Anti-Atlas on the basis of (i) microphytoplancton (acritarchs and chitinozoans; Elaouad-Debbaj 1984a, b, 1986, 1988a, b; Soufiane & Achab 1993; Paris 1990, 1996, 1999; Paris *et al*. 1995, 1999, 2007; Bourahrouh *et al*. 2004; Nowak *et al*. 2016; Tessitore 2016; Lefebvre *et al*. 2018), graptolites (Gutiérrez-Marco *et al*. 2003, Gutiérrez-Marco & Martin 2016; Lefebvre *et al*. 2018), brachiopods (Havlíček 1970, 1971; Villas *et al*. 2006; Colmenar & Álvaro 2015) and, in its Katian part, by bryozoans (Jiménez-Sánchez *et al*. 2015a, b, 2016). The finest Ordovician zonation of the N African-SW European margin of Gondwana, based on chitinozoans, includes 26 biozones with an average duration close to 2 m.y. per zone. This biozonation can be tentatively correlated to the South Polar regional scale erected for the Ordovician, which includes several stages defined in Bohemia and Iberia (Gutiérrez-Marco *et al.* 2015, 2017b) (Fig. 6).

Tremadocian–Floian

The Lower Fezouata and Upper Fezouata formations are highly fossiliferous and have yielded acritarchs (Deunff 1968a, b), graptolites (Destombes & Willefert 1959), trilobites (Choubert *et al*. 1955; Destombes 1985b, c, d; Destombes *et al.* 1985) and echinoderms (Ubaghs 1963; Lefebvre & Fatka 2003). The scarcity of conodonts precluded any direct correlation with global Tremadocian horizons, but the presence of acritarchs and the graptolite *Rhabdinopora flabelliformis* has traditionally allowed the identification of the Tremadocian in the Anti-Atlas.

Destombes *et al*. (1985) and Destombes (2006a, b) reported an assemblage of graptolites sampled in the Upper Fezouata Formation cropping out in the Jbel Bou Legroun (NW Rissani), Taklimt, Aroudane and Zorg. Subsequently, based on graptolites, Gutiérrez-Marco & Martin (2016) recognized throughout the central and eastern Anti-Atlas the *Anisograptus matanensis–Rhabdinopora flabelliformis anglica*, '*Adelograptus*' *tenellus*, *Aorograptus victoriae*, *Araneograptus murrayi*, *Hunnegraptus copiosus*, ?*Cymatograptus protobalticus*, ?*Baltograptus jacksoni* and *Baltograptus minutus* zones plus the '*Azygograptus interval*', the succession of which represents the Tremadocian (Tr2–Tr3) and Floian (Fl1–Fl3) stage slices of Bergström *et al.* (2009). According to these authors, the base of the Lower Fezouata Formation does not coincide with the base of the Tremadocian, despite earlier studies reporting a Cambrian–Ordovician boundary age (Destombes 1971).

Recently, some strata of the Fezouata Konservat-Lagerstätte in the Tizig Zaouine section (north of Zagora) and the Adrar-Zouggar borehole (about 3 km SW of Zagora) have yielded a Tremadocian (Tr3 stage slice of Bergström *et al*. 2009) age, including the *messaoudensis–trifidum* acritarch assemblage of the upper Tremadocian–lower Floian (Cooper *et al*. 1995; Servais & Molyneux 1997), and the *paschaensis–symmetrica* and *brevis* chitinozoan-based zones (Nowak *et al*. 2015, 2016). Based on conodonts, Lehnert *et al*. (2016) recognized the Tremadocian (Tr3 stage slice) *Paraoistodus proteus* and the Floian (Fl1 slice) *Prioniodus oepiki* zones. A recent biostratigraphical reappraisal for the oldest Fezouata Biota by Lefebvre *et al.* (2018) clearly confirms the late Tremadocian age of the Lagerstätte strata, being mainly correlated with the *Paroistodus proteus* biozone of conodonts, and with the 1–2 sub-assemblage of the *messaoudensis–trifidum* acritarch assemblage.

Darriwilian

Destombes *et al*. (1985) initially proposed four trilobite, two brachiopod and one echinoderm-based zones for the Tachilla Formation and the First Bani Group, which were subsequently assigned to the Fennian (*pars*), Oretanian and Drobotivian stages of the Mediterranean Province by Gutiérrez-Marco *et al*. (2003, 2017b). The regional stages represent the global Darriwilian Stage. These authors tentatively located the Middle–Upper Ordovician boundary below the FAD of the trilobite *Marrolithus* cf. *bureaui* Oehlert, about 20 m above the base of the Izegguirene Formation of the First Bani Group.

The chitinozoan *clavata* (*pars*), *pissotensis* and *ponceti* zones have been recognized in the First Bani Group (Paris 1990), ranging as a whole from the early late Darriwilian to the earliest Sandbian (less than 3 m.y.; Videt *et al*. 2010).

Sandbian–Katian

In the central Anti-Atlas, the *deunffi* and *dalbyensis* chitinozoan zones were reported by Elaouad-Debbaj (1986) in the Assif bou Zeggarh Member of the Lower Ktaoua Formation, whereas, in the Amouguer Member of the same formation, the author recognized the *fistulosa*/*barbata* zones. As a result, the Lower Ktaoua Formation ranges in age from the early Sandbian to the mid Katian. The Upper Tiouririne Formation has yielded chitinozoans (Bourahrouh *et al*. 2004) of the *fistulosa*/*barbata* and *nigerica* (*pars*) zones, pointing to a mid–early late Katian age. The overlying Upper Ktaoua Formation has been assigned, based on chitinozoans, to the *nigerica* (*pars*) Zone (Elaouad-Debbaj 1984a; Destombes *et al*. 1985; Paris 1990; Samuelsson *et al*. 2001; Bourahrouh *et al.* 2004), and correlated with the well J1-81A of NE Lybia (Molyneux & Paris 1985; Paris 1988).

In the vicinity of Alnif and in Tizi-n'Rsas (Al Atrous sheet, Tafilalt district), some calcareous siltstones marking the Lower Ktaoua/Upper Tiouririne transition are rich in brachiopods, which have allowed recognition of the *Tafilaltia destombesi*, *Drabovinella*, *Svobodaina feisti* and *Heterorthis alternata* brachiopod biostratigraphically significant) associations (Villas *et al*. 2006; Álvaro *et al.* 2007b; Colmenar & Álvaro 2015).

Regarding the bryozoan-rich Khabt-el-Hajar Formation, Havlíček (1970, 1971), Termier & Termier (1970), Destombes (1985c, 2006a, b) and Le Menn & Spjeldnaes (1986) reported the presence of endemic trilobites, brachiopods and echinoderms, associated with undetermined conulariids, nautiloids, gastropods and bivalves. The authors claimed that the presence of some Telychian graptolites in marlstone interbeds, reported in older papers, should be ruled out. In addition, the record of the upper Katian brachiopods *Paucicrura catalanica*, *Drabovia* sp. and *Streptis*? sp. (Jiménez-Sánchez *et al*. 2015a; Villas & Colmenar this vol.), as well as of some biostratigraphically significant trilobites (such as *Brongniartella platynota marocana*, *Mucronaspis termieri*) and bryozoan species in the formation, have recently constrained the duration of episodes of carbonate productivity. Fenestrates (e.g., *Enallopora lineata*), cryptostomates (e.g., *Graptodictya meneghinii*, *Ptilodictya exilis*, *Stellatodictya valentinae* and *Ulrichostylus radiatus*) and trepostomates (e.g., *Anaphragma mirabile*, *Cyphotrypa magna*, *Dekayia minima*, *Diplotrypa languedociana*, *Homotrypa miqueli*, *Monotrypa jewensis*, *Prasopora falesi* and *Trematopora sardoa*) of the Khabt-el-Hajar Formation, also occur in the Glauzy and Gabian formations of the Montagne Noire, the Maciurru and Punta S'Argiola Members of the Domusnovas Formation and the units *c* and *e* of Sardinia, the La Peña Member (Cystoid Limestone Formation) of the Iberian Chains, and the Uggwa Formation of the Carnic Alps. Outside the Mediterranean margin, some of these species also occur in the Jövi and Oandu stages ($D_{I\text{-}III}$) and the Kegel Limestone of Estonia, the horizons B_I and B_{II} of the Volkhov and horizons B_I to B_{III} of the Lynna Formation in the Leningrad region (Russia); and in the Richmondian and Mohawkian Series of USA. This biostratigraphic control and that provided by the Kralodvorian brachiopod and trilobite species listed above allowed Havlíček (1970, 1971), Destombes (1985c, 2006a, b), Jiménez-Sánchez *et al*. (2015a, b, 2016) and Villas & Colmenar (this vol.) to date the Khabt-el-Hajar Formation as late Katian.

Hirnantian

The Jbel Bou Ingarf section of east Zagora provides a complete Late Ordovician chitinozoan succession (Elaouad-Debbaj 1987; Paris *et al*. 1995) of the Katian–Hirnantian boundary interval and the Hirnantian. Some taxa, such as *Armoricochitina nigerica*, *Calpichitina lenticularis*, *Jenkinochitina lepta*, *Lagenochitina prussica* and *Ancyrochitina longispira*, occur both in the Upper Ktaoua and the Lower Second Bani formations, whereas other taxa (such as *Ancyrochitina merga*, *Plectochitina sylvanica*, *Spilachitina debbajae*) are restricted to the Upper Ktaoua Formation. The latter assemblage is characteristic of the *merga* Zone (Paris 1990). Based on the presence of an indeterminate species of the brachiopod genus *Hirnantia* in the Lower Formation (Second Bani Group) of the laterally equivalent Aït Issioul section, West of Tagounite, Destombes (1985c, 2006b), Destombes *et al*. (1985), Loi *et al*. (2010) and Videt *et al*. (2010) placed tentatively the Katian–Hirnantian boundary within this formation. However, Colmenar *et al*. (this vol.) has noted the presence of late Katian trilobites in the lower part of this formation at the Aït issoul section, some metres below an undoubtely Hirnantian brachiopod assemblage.

The Tamekhtart and Amouktir members of the Upper Formation have yielded *A. nigerica*, *C. lenticularis*, *Spinachitina* cf. *fragilis* and *Tanuchitina elongata* (Elouad-Debbaj 1984), which Paris *et al*. (1995) referred to the *elongata* Zone. In addition, the *Eostropheodonta jebiletensis* brachiopod association has been reported in the Amouktir Member, which represents the *Aphanomena* (=*Eostropheodonta*)-*Hirnantia* Community (Rong 1986; Wang *et al*. 1987; Colmenar & Álvaro 2005).

Control of sequence framework on the replacement of benthic communities

The Ordovician of the Anti-Atlas comprises the sedimentation of a siliciclastic-dominant platform with subsidiary episodes of reefal-free carbonate productivity. The distal slope-apron and deep basinal deposits of this platform are absent in the Anti-Atlas, and may be placed throughout the northern High Atlas and Coastal meseta outcrops. The Ordovician exhibits the superposition of several orders of sea-level fluctuations. Changes in the rate of subsidence, driven by thermal cooling, global eustatism, sediment loading and/or local tilting were probably responsible for sequence and cyclic sedimentation. Tilting led to the record of low-angle discordances and onlapping features, which change laterally into paraconformities over larger areas. The recorded sequence stratigraphic architecture exerted a primary control on the fossil record, mainly as a result of the onset of sharp environmental changes on flooding surfaces and the erosive role played by scouring surfaces capped by shoaling complexes.

In the Zagora-Foum Zguid depocentre, six Tremadocian–Floian third-order sequences were recognized by Loi *et al*. (2010) and Videt *et al*. (2010) (O1 to O6 in Fig. 7). Although a direct correlation of these six sequences with other Ordovician sequence frameworks is not available (for comparison, see e.g., Ross & Ross 1992, 1995 for Laurentia; Nielsen 2004 for Baltica; Ghienne *et al*. 2007b for the Ougarta Range of Algeria; Videt *et al*. 2010 for the Armorican Massif), some of them can be identified in the Anti-Atlas, such as the *Ceratopyge* Regressive Event of Baltica (*tenellus* graptolite Zone), identified in the Anti-Atlas by the O2 sequence boundary. In the Tafilalt district, the Lower Fezouata/Upper Fezouata contact is well marked by the abundance of glauconitic ironstones, separating two successions of four-order shoaling-upward parasequences (O6 in Fig. 7) in a wave-dominant tide-modulated platform with predominance of offshore clayey substrates (Álvaro *et al*. 2014c, d; Vaucher *et al*. 2017; Saleh *et al*. 2018). About 200 taxa have been reported from these two formations, mainly controlled by the exceptional preservation conditions of the Fezouata Biota (Gaines *et al*. 2012; Lefebvre *et al*. 2016a, b, 2018; see list in Annex 1), the taphonomic conditions of which were virtually controlled by external climatic forcing (Saleh *et al*. 2019). The most representative benthic communities include non-reefal algae, bryozoans, cnidarians, echinoderms (Crinoidea, Diploporita, Edrioasteroidea, Eocrinoidea, Rhombifera, Soluta, Somasteroidea and Stylophora) and sponges, which are associated with brachiopods, molluscs (bivalves, rostroconchs, paragastropods, gastropods and tergomyans), hyoliths, annelids, cycloneuralia, lobopodians, arthropods (agnostoids, radiodonts, trilobites and other euarthropods) and problematica.

The Dapingian gap is marked by the absence of representative fossils in the Anti-Atlas. This paraconformity is sealed by the Darriwilian–Sandbian–Katian First Bani and Ktaoua groups. In some areas of the Anti-Atlas, such as in the Tachilla and Ouarzemine jbels of the western Anti-Atlas, the Darriwilian sedimentation occurs directly sealing an inherited palaeorelief formed by Miaolingian strata; the corresponding Miaolingian–Dapingian gap should be associated with a Dapingian event responsible of uplift, tilting and erosion (Fig. 2). Although no geodynamic explanation has yet been advanced for this gap, a possible distal influence of the Mid–Late Ordovician Sardic Phase may be recorded in this margin of Gondwana. The Sardic Phase has been reported in the eastern branch of the Variscan Ibero-Armorican Arc (Sardinia, Pyrenees, Montagne Noire and Mouthoumet massif of Occitan Domain in South France, and Briançonnais in the Alps), but is virtually absent in the western branch or Iberian Massif (e.g., Stampfli *et al*. 2002; Casas 2010; Oggiano *et al*. 2010; Minzoni 2011; Zubriggen 2015; Álvaro *et al*. 2016b).

The Darriwilian–Katian sedimentary package of the Anti-Atlas comprises the conformable Tachilla Formation and the First Bani and Ktaoua groups, which represent seven (O8 to O15 in Fig. 7) third-order sequences. They consist of interfingering sandstone- and shale-dominant rock packages, subdivisable into four-order parasequences dominated by shallowing-upward trends from deeper water (offshore) sediments shoaling, through aggradation and progradation, to shoreface/foreshore deposits. Some tops show evidence of fluvial point-bar migration and subaerial exposure and widespread precipitation of hematite crusts (Colmenar & Álvaro 2015). Carbonate production was not laterally persistent in the eastern Anti-Atlas (Álvaro *et al*. 2007b; El Maazouz & Hamoumi 2007), except in an area protected from persistent siliciclastic input. To the north of Erfoud, the Khabt-el-Hajar Formation consists of two successive marlstone-limestone units shallowing upward into mixed siliciclastic-limestone packages (Destombes *et al*. 1985).

Most of the sandstone/shale alternations and sandstone packages reported in the Tachilla Formation and the First Bani and Ktaoua groups form coarsening-upwards parasequences indicative of shoaling and/or upwards increase in energy level. They reflect the interplay and feedback between (i) changes in third-order accommodation potential, (ii) episodic progradation of terrigenous wedges, and (iii) distal production of temperate-water (bryonoderm) carbonate shelly factories rich in trepostomate and fenestrate bryozoans. The carbonate production during the HST was less resilient to terrigenous poisoning and was susceptible to localized nucleation of bryozoan–pelmatozoan meadows and thickets. Nearly all the silty and skeletal limestones that occur as decimetre-scale interbeds are inferred to represent stacking of mineralized hardgrounds and increased content of reworked phosphate nodules and crusts, indicating increased sediment starvation.

Darriwilian–Katian benthic communities comprise arthropods (aglaspidid and chelionellid euarthropods, ostracods and trilobites), brachiopods, echinoderms (Asteroidea, Coronata, Crinoidea, Diploporita, Edrioasteroidea, Eocrinoidea, Ophiuroidea, Rhombifera, Soluta and Stylophora), hyoliths, molluscs (bivalves, gastropods, rostroconchs and tergomyans), conulariids, paleoscolecidans, cornulitids, paropsonemid eldonioids, machaeridians and agglutinated problematic tubes (see list in Annex 1). Colmenar & Álvaro (2015) recognized in the Katian of the Tafilalt district, four types of brachiopod-dominant shell accumulations: (i) lag concentrations, interpreted as indicators of erosive surfaces; (ii) event concentrations representing either single or amalgamation of multiple reworking pulses; (iii) hydraulic simple and composite concentrations marking the top of shoal complexes; and (iv) hiatal or condensed concentrations on maximum flooding surfaces.

As stated above, major flooding surfaces reflect the episodic development of echinoderm-bryozoan meadows in outer-platform settings. In the eastern Atlas Basin, some bryozoan thickets flourished locally on Katian silty carbonates of the Ktaoua Group (Álvaro *et* *al*. 2007b, 2014a, b; Benharref *et al*. 2014a, b, c). The onset of echinoderm-bryozoan meadows and mud-mounds had been previously reported in Libya (Buttler & Massa 1996; Buttler *et al*. 2007), the Iberian Peninsula (Vennin *et al*. 1998; Jiménez-Sánchez 2009, 2010; Jiménez-Sánchez & Villas 2010; Jiménez-Sánchez *et al*. 2013) and Sardinia (Conti 1990). The bryozoan assemblages of the upper Katian Khabt-el-Hajar Formation display a diversity close to that documented in the Iberian Chains (Jiménez-Sánchez 2009, 2010; Jiménez-Sánchez & Villas 2010) and Sardinia (Conti 1990), only surpassed in the southwestern Mediterranean region in the southern Montagne Noire (Ernst & Key 2007). Recent taxonomic studies on the bryozoans of the Khabt-el-Hajar Formation (Jiménez-Sánchez *et al*. 2015a, b) have identified 21 species of 12 trepostomate genera and 15 species of 13 cryptostomate, fenestrate and trepostomate genera (Jiménez-Sánchez *et al*. 2016) adapted to offshore-dominated, marly substrates. Many of these species exhibit significantly larger body sizes than congeneric species from lower latitudes. Based on autozooecial sizes, many of them may be examples of subpolar gigantism (Jiménez-Sánchez *et al*. 2016). A complete biogeographical study of mid-high latitude bryozoans from the Mediterranean region (Carnic Alps, Iberian Chains, Libya, Montagne Noire, Morocco and Sardinia) was made by Jiménez-Sánchez & Villas (2010) and Jiménez-Sánchez *et al*. (2016), who concluded that the Moroccan-Libyan transect plot close to the remaining high-latitude Mediterranean assemblages. Bryozoans that invaded the Mediterranean margin of Gondwana, during the late Katian transgression, although preserving Baltic affinities, developed an independent faunal signal, denoting clear environmental differences from those in subtropical palaeocontinents, from which they came.

A distinct Mediterranean biogeographic unit (extending from what is now Syria to NW Argentina; see original definition by Spjeldnaes 1961), postdating the Boda Event and characterized by Avalonian-Baltic affinities with low diversity and marked endemism, emerged at subpolar latitudes. The extinction of several bryozoan genera in tropical seas, simultaneously with their immigration into the Mediterranean cool waters, is consistent with the onset of a late Katian global warming (Boda event) (Taylor & Ernst 2004; Fortey & Cocks 2005; Jiménez-Sánchez & Villas 2010).

The benthic communities that characterize the Katian-Hirnantian transition cannot be studied in the eastern Anti-Atlas due to the absence of the Lower Formation of the Second Bani Group. In the eastern Anti-Atlas, the Upper Ktaoua Formation is unconformably overlain by the Upper Formation of the Second Bani Group, locally forming distinct tunnel channels (Destombes 2006a, b; Álvaro *et al*. 2007b, 2014a, b; Loi *et al*. 2010; Videt *et al*. 2010; Benharref *et al*. 2014a, b, c; Colmenar & Álvaro 2015) (Fig. 2).

Finally, the Hirnantian glaciation has developed two incisions in the Anti-Atlas, (i) the onset of glacial channels from Alnif to the Tafilalt district, subsequently infilled by the alluvial-to-fluvial Alnif Conglomerate and the Tamekhtart glaciomarine diamictites, and (ii) a second erosive (Amouktir Member) capped by marine, fossiliferous strata rich in brachiopods (sequence O16 in Fig. 7). The subsequent palaeorelief was finally sealed by Silurian strata (Álvaro *et al*. 2014c, d; Benharref *et al*. 2014a, b, c).

Concluding Remarks

The Ordovician sediments of the eastern Anti-Atlas are punctuated by three major unconformities: (i) a Furongian break-up unconformity marking the end of the Cambrian Atlas Rift and the development of a passive margin devoid of volcanism; (ii) a Dapingian unconformity that separates a Tremadocian–Floian sedimentary package (Lower and Upper Fezouata formations) from a Darriwilian–Katian sedimentary package (Tachilla Formation and First Bani and Ktaoua groups); and (iii) the Hirnantian incision of tunnel channels and glaciogenic (both continental and glaciomarine) imprint. The final sealing of the Hirnantian palaeorelief was achieved during Silurian times.

Except the Katian Khabt-el-Hajar Formation, erected in the vicinity of Erfoud, the Ordovician lithostratigraphy was originally defined in the Zagora-Foum Zguid depocenter. The Ordovician is dominated by terrigenous deposits sedimented at mid- to high latitudes. Despite the presence of scattered episodes of shelly carbonate production, only a proximal area close to Erfoud has recorded the onset of bryozoan-echinoderm meadows and thickets (Khabt-el-Hajar Formation) that allow identification of the Katian Boda event in this segment of the Gondwanan margin.

Due to the palaeolatitudinal position of the Anti-Atlas Basin during Ordovician times, carbonate production was scattered and mainly associated with the record of shelly pavements. Key conodonts and graptolites have not been recovered to recognize the global chronostratigraphic subdivision erected by the *International Subcommission on Ordovician Stratigraphy*. The thinnest Ordovician zonation of the N African-SW European margin of Gondwana, based on chitinozoans, includes 26 biozones with an average duration close to 2 m.y. per biozone. This chitinozoan scale is the standard in Morocco, to which the stratigraphic ranges of graptolites, trilobites, brachiopods and other taxa are referred. The chronostratigraphical regional South Polar scale, defined in Bohemia and Iberia, is applicable in the Anti-Atlas.

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References

Agard, J., Destombes, J. & Van Leckwijck, W. 1952. Fer. Géologie des gîtes minéraux marocains. *Notes et Mémoires du Service géologique du Maroc*, **87**, 103–112.

Akodad, M., El Hariri, K., Gutierrez-Marco, J. C., Lefebvre, B., Lehnert, O., Martin, E. L. O., Nowak, H. & Servais, T. 2018. The precise age of the Fezouata Lagerstätte, Lower Ordovician, Morocco. *In*: Zhang, Y., Zhan, R., Fan, J. & Muir, L. (eds), *Filling the gap between Cambrian Explosion and the GOBE*. Zhejiang University Press, Zhejiang, 3-7. ISBN 978-7-308-17519-7.

Alessandrello, A. & Bracchi, G. 2003. *Eldonia berbera* n. sp., a new species of the enigmatic genus *Eldonia* Walcott, 1911 from the Rawtheyan (Upper Ordovician) of Anti-Atlas (Erfoud, Tafilalt, Morocco). *Atti della Società italiana di scienze naturali e del Museo civico di storia naturale di Milano*, **144**, 337–358.

Alessandrello, A. & Bracchi, G. 2006. Late Ordovician arachnomorph arthropods from the Anti-Atlas (Morocco). *Atti della Società italiana di scienze naturali e del Museo civico di storia naturale di Milano*, **147**, 305–315.

Allaire, N., Lefebvre, B., Martin, E., Nardin, E. & Vaucher, R. 2015. Taphonomy of new *Rhopalocystis* assemblages in the Lower Ordovician of the Zagora area (central Anti-Atlas, Morocco). *In*: Zamora, S. & Rábano, I. (eds). Progress in Echinoderm Palaeobiology. *Cuadernos del Museo Geominero*, **19**, 21–26.

Allaire, N., Lefebvre, B., Nardin, E., Martin, E. L. O., Vaucher, R. & Escarguel, G. 2017. Morphological disparity and systematic revision of the eocrinoid genus *Rhopalocystis* (Echinodermata, Blastozoa) from the Lower Ordovician of the central Anti- Atlas (Morocco). *Journal of Paleontology*, **91**, 685–714.

Álvaro, J. J. 2013. Late Ediacaran syn-rift/post-rift transition and related fault-driven hydrothermal systems in the Anti-Atlas Mountains, Morocco. *Basin Research*, **25**, 348–360.

Álvaro, J. J. 2014. Rift, pull-apart rift, and continental drift crossword puzzles across the lower–middle Cambrian transition of Iberia and Morocco. *GFF*, **136**, 2–5.

Álvaro, J. J. & Clausen, S. 2007. Botoman (Lower Cambrian) turbid- and clear-water reefs and associated environments from the High Atlas, Morocco. *In*: Álvaro, J. J., Aretz, M., Boulvain, F., Munnecke, A., Vachard, D. & Vennin, E. (eds). Palaeozoic Reefs and Bioaccumulations: Climatic and Evolutionary Controls. *Geological Society, London, Special Publication*, **275**, 51–70.

Álvaro, J. J. & Clausen, S. 2008. Paleoenvironmental significance of Cambrian hiatal shell accumulations in an intra-cratonic aborted rift, Atlas Mountains, Morocco. *In*: Pratt, B. R. & Holmden, C. (eds). Dynamics of Epeiric Seas. *Geological Association of Canada, Special Paper*, **48**, 39–54.

Álvaro, J. J. & Debrenne, F. 2010. The Great Atlasian Reef Complex: an early Cambrian subtropical fringing belt that bordered West Gondwana. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **294**, 120–132.

Álvaro, J. J. & Vizcaïno, D. 2018. The Furongian break-up (rift-drift) transition in the Anti-Atlas, Morocco. *Journal of Iberian Geology*, **44**, 567–587.

Álvaro, J. J., Rouchy, J. M., Bechstädt, T., Boucot, A., Boyer, F., Debrenne, F., Moreno-Eiris, E., Perejón, A. & Vennin, E. 2000. Evaporitic constraints on the southward drifting of the western Gondwana margin during Early Cambrian times. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **160**, 105–122.

Álvaro, J. J., Vennin, E., Villas, E., Destombes, J. & Vizcaïno, D. 2004. Hirnantian valley-glacier sedimentation in the eastern Anti-Atlas, Morocco. *Erlanger Geologische Abhandlungen*, **5**, 18–19.

Álvaro, J. J., Ferretti, F., González-Gómez, C., Serpagli, E., Tortello, M. F., Vecoli, M. & Vizcaïno, D. 2007a. A review of the Late Cambrian (Furongian) palaeogeography in the western Mediterranean region, NW Gondwana. *Earth-Science Reviews*, **85**, 47–81.

Álvaro, J. J., Vennin, E., Villas, E., Destombes, J. & Vizcaïno, D. 2007b. Pre–Hirnantian (latest Ordovician) benthic community assemblages: controls and replacements in a siliciclastic-dominated platform of the eastern Anti-Atlas, Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **245**, 20–36.

Álvaro, J. J., Benziane, F., Thomas, R., Walsh, G. J. & Yazidi, A. 2014a. Neoproterozoic–Cambrian stratigraphic framework of the Anti-Atlas and Ouzellagh promontory (High Atlas), Morocco. *Journal of African Earth Sciences*, **98**, 19–33.

Álvaro, J. J., Bellido, F., Gasquet, D., Pereira, F., Quesada, C. & Sánchez-García, T. 2014b. Diachronism of late Neoproterozoic–Cambrian arc-rift transition of North Gondwana: a comparison of Morocco and the Iberian Ossa-Morena Zone. *Journal of African Earth Sciences*, **98**, 113–132.

Álvaro, J. J., Aretz, M., Benharref, M., Hibti, M., Pouclet, A., El Hadi, H., Koukaya, A., Ettachfini, E. M. & Boudad, L. 2014c. Carte géologique du Maroc au 1/50 000. Feuille Tawz. Mémoire explicatif. *Notes et Mémoires du Service géologique*, **551**bis, 1–127.

Álvaro, J. J., Benharref, M., Hibti, M. & Boudad, L. 2014d. Carte géologique du Maroc au 1/50 000. Feuille Irara. Mémoire explicatif. *Notes et Mémoires du Service géologique du Maroc*, **552**bis, 1–98.

Álvaro, J. J., Ezzouhairi, H., Clausen, S., Ribeiro, M. L. & Solá, A. R. 2015. Syn-rift unconformities punctuating the lower–middle Cambrian transition of the Atlas Rift, Morocco. *International Journal of Earth Sciences*, **104**, 753–773.

Álvaro, J. J., Shields, G. A., Ahlberg, P., Jensen, S. & Palacios, T. 2016a. Ediacaran–Cambrian phosphorites from the western margins of Gondwana and Baltica. *Sedimentology*, **63**, 350–377.

Álvaro, J.J., Colmenar, J., Monceret, E., Pouclet, A. & Vizcaïno D. 2016b. Late Ordovician (post–Sardic) rifting branches in the North Gondwanan Montagne Noire and Mouthoumet massifs of southern France. *Tectonophysics*, **681**, 111–123.

Azizi, A., Vinn, O., El Hariri, K., Hafid, A. & Kouraiss, K. 2017. First description of *Skolithos* burrows from the Cambrian–Ordovician boundary interval of the Central Anti-Atlas, Morocco. *Estonian Journal of Earth Sciences*, **66**, 174–182.

Babin, C. & Destombes, J. 1990. Les Mollusques Bivalves et Rostroconches ordoviciens de l'Anti-Atlas marocain: Intérêt paléogéographique de leur inventaire. *Géologie Méditerranéenne*, **17**, 243–261.

Beisswenger, M. 1994. A calcichordate interpretation of the new mitrate *Eumitrocystella savilli* from the Ordovician of Morocco. *Paläeontologische Zeitschrift*, **68**, 443–462.

Benharref, M., Álvaro, J. J., Hibti, M., Pouclet, A., El Hadi, H. & Boudad, L. 2014a. Carte géologique du Maroc au 1/50 000. Feuille Marzouga. Mémoire explicatif. *Notes et Mémoires du Service géologique du Maroc*, **553**bis, 1–119.

Benharref, M., Hibti, M., Pouclet, A., El Hadi, H. & Koukaya, A. 2014b. Carte géologique du Maroc au 1/50 000. Feuille MFis. Mémoire explicatif. *Notes et Mémoires du Service géologique du Maroc*, **554**bis, 1–117.

Benharref, M., Álvaro, J. J., Hibti, M., Pouclet, A., El Hadi, H., Koukaya, A. & Ettachfini, E. 2014c. Carte géologique du Maroc au 1/50 000. Feuille Al Atrous. Mémoire explicatif. *Notes et Mémoires du Service géologique du Maroc*, **555**bis, 1–146.

Bergström, S. M., Chen, X., Gutiérrez-Marco, J. C. & Dronov, A. 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to $\delta^{13}C$ chemostratigraphy. *Lethaia*, **42**, 97–107.

Botting, J. P. 2007. "Cambrian" demosponges in the Ordovician of Morocco: insights into the early evolution of sponges. *Geobios*, **40**, 737–748.

Botting, J. P. 2016. Diversity and ecology of sponges in the Early Ordovician Fezouata Biota, Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 75–86.

Botting, J. P. (this vol.). Late Ordovician crinoids from the Anti-Atlas region of Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**, doi: 10.1144/SP485.4

Bourahrouh, A., Paris, F. & Elaouad-Debbaj, Z. 2004. Biostratigraphy, biodiversity and palaeoenvironments of the chitinozoans and associated palynomorphs from the Upper Ordovician of the Central Anti-Atlas, Morocco. *Review of Palaeobotany and Palynology*, **130**, 17–40.

Bruton, D. 2008. A systematic revision of *Selenopeltis* (Trilobita: Odontopleuridae) with description of new material from the Ordovician of the Anti-Atlas region, Morocco. *Paläontologische Zeitschrift*, **82**, 1–16.

Buttler, C. J. & Massa, D. 1996. Late Ordovician bryozoans from carbonate buildups, Tripolitania, Libya. *In*: Gordon, D. P, Smith, A. M. & Grant-Mackie, J. E. (eds) *Bryozoans in Space and Time*. NIWA, Wellington, 63–68.

Buttler, C. J., Cherns, L. & Massa, D. 2007. Bryozoan mud-mounds from the Upper Ordovician Jifarah (Djeffara) formation of Tripolitania, north-west Libya. *Palaeontology*, **50**, 479–494.

Candela, Y. & Harper, D. A. T. 2016. The brachiopod fauna of the Fezouata Shale (Lower Ordovician) of Morocco: preliminary results. *Programme, Abstracts and AGM papers, 60th Annual Meeting of the Palaeontological Association, 14–17 December 2016, Lyon*, 63–64.

Casas, J. M. 2010. Ordovician deformations in the Pyrenees: new insights into the significance of pre-Variscan (“Sardic”) tectonics. Geological Magazine, **147**, 647–689.

Chauvel, J. 1966a. Echinodermes de l’Ordovicien du Maroc. *Cahiers de Paléontologie*, 120 p.

Chauvel, J. 1966b. Présence du genre *Anatifopsis* Barrande (Crustacés) dans l’Ordovicien du Maroc. *Comptes Rendus sommaires de la Société géologique de France*, **8**, 301–302.

Chauvel, J. 1966c. Sur quelques représentants du genre *Plumulites* Barrande (Machairidiés) provenant de l’Ordovicien du Maroc et du Massif armoricain. *Bulletin de la Société géologique et minéralogique de Bretagne* (nouvelle série), **1967**, 73–84.

Chauvel, J. 1969a. Données nouvelles sur le genre *Destombesia* Chauvel (Echinoderme, Cystoïde, Ordovicien de l’Anti-Atlas marocain). *Notes et Mémoires du Service géologique du Maroc*, **129** (213), 25–30.

Chauvel, J. 1969b. Les échinodermes macrocystellidés de l’Anti-Atlas marocain. *Bulletin de la Société géologique et minéralogique de Bretagne* (série C), **1**, 21–32.

Chauvel, J. 1971a. *Rhopalocystis ubaghsi*: un échinoderme du Trémadocien de l’Anti-Atlas marocain. Collection Ordovicien–Silurien, Brest. *Mémoires du BRGM*, **73**, 43–49.

Chauvel, J. 1971b. Les échinodermes carpoïdes du Paléozoïque inférieur marocain. *Notes et Mémoires du Service géologique du Maroc*, **237**, 49–60.

Chauvel, J. 1977. Note complémentaire sur les Cystoïdes Rhombifères (Echinodermes) de l’Ordovicien marocain. *Notes et Mémoires du Service géologique du Maroc*, **268**, 115–139.

Chauvel, J. 1978. Compléments sur les Echinodermes du Paléozoïque marocain (Diploporites, Eocrinoïdes, Edrioastéroïdes). *Notes et Mémoires du Service géologique du Maroc*, **272**, 27–78.

Chauvel, J. & Regnault, S. 1986. Variabilité du genre *Rhopalocystis* Ubaghs, éocrinoïde du Trémadocien de l’Anti-Atlas marocain. *Geobios*, **19**, 863–870.

Choubert, G. 1952. Histoire géologique du domaine de l’Anti-Atlas (Géologie du Maroc, fascicule 1, 2^{e} partie). *Notes et Mémoires du Service géologique du Maroc*, **100**, 75–194.

Choubert, G. & Termier, H. 1947. Sur la stratigraphie de l'Ordovicien marocain. *Comptes Rendus sommaires des Séances de la Société géologique de France*, **1947** (16), 335–337.

Choubert, G., Termier, H. & Termier, G. 1953. Présence du genre *Mimocystites* Barrande dans l'Ordovicien du Maroc. *Notes et Mémoires du Service géologique du Maroc*, **117**, 137–143.

Choubert, G., Hindermeyer, J. & Hupe, P. 1955. Découverte du Trémadoc dans l'Anti-Atlas (Maroc). *Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences de Paris*, **241**, 1592–1594.

Choukri, C. & Hamoumi, N. 2005. L’Arénig–Llanvirn du Haut Atlas occidental et central (Maroc). Environnements sédimentaires, paléogéographie et contrôle de la sédimentation. *Comptes Rendus Géoscience*, **337**, 1026–1034.

Choukri, C., Hamoumi, N. & Attou, A. 2004. Climatic and tectonic control of Ordovician sedimentation in the western and central High Atlas (Morocco). *Journal of African Earth Sciences*, **39**, 329–336.

Clerc, S., Boucristiani, J. F., Guiraud, M., Vennin, E., Desaubliaux, G. & Portier, E. 2013. Subglacial to proglacial depositional environments in an Ordovician glacial tunnel valley, Alnif, Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **370**, 127–144.

Colmenar, J. 2016. Ordovician rafinesquinine brachiopods from peri-Gondwana. *Acta Palaeontologica Polonica*, **61** (2), 293–326.

Colmenar, J. & Álvaro, J. J. 2015. Integrated brachiopod-based bioevents and sequence-stratigraphy framework for a Late Ordovician subpolar platform, eastern Anti-Atlas, Morocco. *Geological Magazine*, **152** (4), 603–620.

Colmenar, J., Pereira, S., Pires, M., Silva, C. M., Sá, A. A. & Young, T. P. 2017. A Kralodvorian (upper Katian, Upper Ordovician) benthic association from the Ferradosa Formation (central Portugal) and its significance for the redefinition and subdivision of the Kralodvorian Stage. *Bulletin of Geosciences*, **92**, 443–464.

Colmenar, J., Villas, E. & Rasmussen, C. M. Ø. (this vol.). A synopsis of Late Ordovician brachiopod diversity in the Anti-Atlas, Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician*

Biodiversification Event: Insights from the Tafilalt Biota, Morocco. Geological Society, London, Special Publication, **485**, doi: 10.1144/SP485.3

CONTI, S. 1990. Upper Ordovician bryozoans from Sardinia. *Palaeontographia Italica*, **77**, 85–165.

COOPER, A. H., RUSHTON, A. W. A., MOLYNEUX, S. G., HUGHES, R. A., MOORE, R. M. & WEBB, B. C. 1995. The stratigraphy, correlation, provenance and palaeogeography of the Skiddaw Group (Ordovician) in the English Lake District. *Geological Magazine*, **132**, 185–211.

CRIPPS, A. P. 1990. A new stem craniate from the Ordovician of Morocco and the search for the sister group of craniate. *Zoological Journal of the Linnean Society*, **100**, 27–71.

DESTOMBES, J. 1954. Sur la présence du Llanvirn à minerai de fer oolithique dans l'anticlinal de Tiflet (Maroc). *Comptes Rendus sommaires de la Société géologique de France*, **13**, 294–296.

DESTOMBES, J. 1958. Les gisements de minerai de fer sédimentaire oolithique de la bordure S de l'Ougnate et du Maïder. *Mines et Géologie, Rabat*, **4**, 32–35.

DESTOMBES, J. 1959. Les minerais de fer oolithiques: idées actuelles sur leur structure et leur genèse. *Mines et Géologie, Rabat*, **6**, 43–52.

DESTOMBES, J. 1960a. Stratigraphie de l'Ordovicien de la partie occidentale du Jbel Bani et du Jbel Zini (Anti-Atlas occidental), Maroc. *Bulletin de la Société géologique de France* (7[e] série), **2**, 747–751.

DESTOMBES, J. 1960b. Sur l'extension du Trémadoc dans le Sud marocain. *Comptes Rendus des Séances mensuelles de la Société des Sciences Naturelles et Physiques du Maroc*, **3**, 45–47

DESTOMBES, J. 1962a. Stratigraphie et paléogéographie de l'Ordovicien de l'Anti-Atlas (Maroc): un essai de synthèse. *Bulletin de la Société géologique de France*, **4**, 453–460.

DESTOMBES, J. 1962b. Sur le caractère transgressif de l'Arénig supérieur dans l'Anti-Atlas nord-occidental (Maroc*). Comptes Rendus sommaires de la Société géologique de France*, **1**, 14–15.

DESTOMBES, J. 1963a. Le Cambrien et la base de l'Ordovicien dans la partie orientale et méridionale du Tafilalt (Maroc). *Bulletin de la Société géologique de France*, **5**, 938–945.

DESTOMBES, J. 1963b. Données stratigraphiques sur l'Ordovicien de l'Anti-Atlas. *Rapport de l'IFP, Paris*, **18**, 1464–1471.

DESTOMBES, J. 1963c. Quelques nouveaux Phacopina (Trilobites) de l'Ordovicien supérieur de l'Anti-Atlas (Maroc). *Notes et Mémoires du Service géologique du Maroc*, **23** (172), 47–65.

DESTOMBES, J. 1966. Quelques *Calymenina* (Trilobita) de l'Ordovicien moyen et supérieur de l'Anti-Atlas (Maroc). *Notes et Mémoires du Service géologique du Maroc*, **26** (188), 33–53.

DESTOMBES, J. 1967a. Distribution et affinités des genres de trilobites de l'Ordovicien de l'Anti-Atlas (Maroc). *Comptes Rendus sommaires de la Société géologique de France*, **4**, 133–134.

DESTOMBES, J. 1967b. Quelques trilobites rares (*Lichas*, *Amphitryon*, *Dionide*) de l'Ashgill (Ordovicien supérieur) de l'Anti-Atlas, Maroc. *Annales de la Société géologique du Nord*, **87**, 123–126.

DESTOMBES, J. 1968a. Sur la présence d'une discordance générale de ravinement d'âge Ashgill supérieur dans l'Ordovicien terminal de l'Anti-Atlas (Maroc). *Comptes Rendus de l'Académie des Sciences, Paris* (série D), **267**, 565–567.

DESTOMBES, J. 1968b. Sur la nature glaciaire des sédiments du groupe du 2^{e} Bani, Ashgill supérieur de l'Anti-Atlas, Maroc. *Comptes Rendus de l'Académie des Sciences, Paris* (série D), **267**, 684–686.

DESTOMBES, J. 1970. Cambrien et Ordovicien. *Notes et Mémoires du Service géologique du Maroc*, **229**, 161–170.

DESTOMBES, J. 1971. L'Ordovicien au Maroc. Essai de synthèse stratigraphique. *Mémoires du BRGM*, **73**, 237–263.

DESTOMBES, J. 1972. Les Trilobites du sous-ordre des Phacopina de l'Ordovicien de l'Anti-Atlas (Maroc). *Notes et Mémoires du Service géologique du Maroc*, **240**, 1–114.

DESTOMBES, J. 1981. Hirnantian (Upper Ordovician) tillites on the north flank of the Tindouf Basin, Anti-Atlas, Morocco. *In*: HAMBREY, M. & HARLAND, W. (eds) Earth's Pre-Pleistocene Glacial Record. Cambridge University Press, Cambridge, 84–88.

DESTOMBES, J. 1985a. Mineralization and non-metallic materials. *In*: HOLLAND, C. H. (ed.) *Lower Palaeozoic Rocks of the World: Lower Palaeozoic Rocks of Northwestern and West-Central Africa*. John Wiley and Sons, Chichester, 321–325.

DESTOMBES, J. 1985b. Notice explicative de la carte géologique du Maroc au 200.000e "Todhra-Maïder" (Anti-Atlas oriental). Cambrien moyen, Ordovicien, base du Silurien. Rapport inédit du Service de la Carte géologique du Maroc (2nd ed. *in* 2003), 80 pp.

DESTOMBES, J. 1985c. Notice explicative de la carte géologique du Maroc au 200.000e "Zagora-Coude du Dra" (Anti-Atlas oriental). Cambrien moyen, Ordovicien, base du Silurien. Rapport inédit du Service de la Carte géologique du Maroc (2nd ed. *in* 2003), 48 pp.

DESTOMBES, J. 1985d. Notice explicative de la carte géologique du Maroc au 200.000e "Saghro-Dadès" (Anti-Atlas oriental). Cambrien moyen, Ordovicien, base du Silurien. Rapport inédit du Service de la Carte géologique du Maroc, 36 pp.

Destombes, J. 1987. Notice explicative de la carte géologique du Maroc au 200.000e “Tafilalt-Taouz” (Anti-Atlas oriental). Cambrien moyen, Ordovicien, base du Silurien. Rapport inédit du Service de la Carte géologique du Maroc, 87 pp.

Destombes, J. 2000. Carte géologique du Maroc au 1/200 000 de l’Anti-Atlas marocain. Ordovicien, base du Silurien de la Feuille Akka-Tafagount-Tata. Mémoire explicatif, Chapitre G. Unpublished Repport of the Service de la Carte géologique du Maroc, Rabat, 40 p.

Destombes, J. 2006a. Carte géologique au 1 : 200 000 de l'Anti- Atlas marocain. Paléozoïque inférieur: Cambrien moyen et supérieur – Ordovicien – base du Silurien. Sommaire général sur les mémoires explicatifs des cartes géologiques au 1/200 000 de l'Anti- Atlas marocain. *Notes et Mémoires du Service Géologique du Maroc*, **515**, 1–150.

Destombes, J. 2006b. Carte géologique au 1/200 000 de l’Anti-Atlas marocain. Paléozoïque inférieur: Cambrien moyen-Ordovicien-base du Silurien. Feuille Goulimine-Dra inférieur au 1/200 000, feuille Fask au 1/100 000 (Anti-Atlas occidental, Maroc). Mémoire explicatif, Chapitre I [written in 2002]. *Notes et Mémoires du Service géologique du Maroc*, **90 bis A**, 34 p.

Destombes, J. 2006c. Carte géologique au 1/200 000 de l’Anti-Atlas marocain. Paléozoïque inférieur : Cambrien moyen-Ordovicien-base du Silurien. Feuille régions de Tan-Tan–Jbel Zini (Province de Tarfaya). Mémoire explicatif, Chapitre J (Anti-Atlas sud-occidental au sud de l’oued Dra) [written in 2003]. *Notes et Mémoires du Service géologique du Maroc*, **90 bis B**, 29 p.

Destombes, J. 2006d. Carte géologique au 1/200 000 de l’Anti-Atlas marocain. Paléozoïque inférieur: Cambrien moyen et supérieur-Ordovicien-base du Silurien. Feuille Telouet Sud, Ouarzazate, Alougoum, Agadir-Tissinnt. Mémoire explicatif, Chapitre F [writtren in 1988]. *Notes et Mémoires du Service géologique du Maroc*, **138 bis**, 43 p.

Destombes, J. 2006e. Carte géologique au 1/200 000 de l’Anti-Atlas marocain. Paléozoïque inférieur (Cambrien moyen et supérieur-Ordovicien-base du Silurien). Feuille Foum el Hassane-Assa. Mémoire explicatif, Chapitre H (Flanc sud de l’Anti-Atlas occidental et des plaines du Dra) [written in 2001]. *Notes et Mémoires du Service géologique du Maroc*, **159 bis**, 35 p.

Destombes, J. 2006f. Carte géologique au 1/200 000 de l’Anti-Atlas marocain. Paléozoïque inférieur. Cambrien moyen et supérieur-Ordovicien-base du Silurien. Feuille Jbel Saghro-Dadès. Mémoire explicatif, Chapitre C [written in 1983]. *Notes et Mémoires du Service géologique du Maroc*, **161 bis**, 41 p.

Destombes, J. 2006g. Carte géologique au 1/200 000 de l’Anti-Atlas marocain. Notice explicative. Paléozoïque inférieur. Cambrien moyen et supérieur-Ordovicien-base du

Silurien. Feuille Todrha- Maïder. Mémoire explicatif, Chapitre D [written in 1985]. *Notes et Mémoires du Service géologique du Maroc*, **243 bis**, 58 p.

Destombes, J. 2006h. Carte géologique au 200 000 de l'Anti-Atlas marocain. Paléozoïque inférieur (Cambrien moyen et supérieur-Ordovicien-base du Silurien). Feuille Tafilalt-Taouz. Mémoire explicatif, Chapitre E (Anti-Atlas oriental) [written in 1987]. *Notes et Mémoires du Service géologique du Maroc*, **244 bis**, 69 p.

Destombes J. 2006i. Carte géologique au 1/200 000 de l'Anti-Atlas marocain. Paléozoïque inférieur. Cambrien moyen et supérieur-Ordovicien-base du Silurien. Feuille Bou Haiara-Zegdou. Mémoire explicatif, Chapitre B [written in 1983]. *Notes et Mémoires du Service géologique du Maroc*, **259 bis**, 30 p.

Destombes, J. 2006j. Carte géologique au 1/200 000 de l'Anti-Atlas marocain. Paléozoïque inférieur. Cambrien moyen et supérieur-Ordovicien-base du Silurien. Feuille Zagora-Coude du Dra. Mémoire explicatif, Chapitre A [written in 1983]. *Notes et Mémoires du Service géologique du Maroc*, **273 bis**, 36 p.

Destombes, J. 2006k. Carte géologique au 200 000 de l'Anti- Atlas marocain. Paléozoïque inférieur: Cambrien moyen et supérieur – Ordovicien – base du Silurien. Feuille Zagora - Coude du Dra. Chapitre A. *Notes et Mémoires du Service Géologique du Maroc*, **273**, 1–54.

Destombes, J. 2006l. Carte géologique au 200 000 de l'Anti-Atlas marocain. Paléozoïque inférieur. Cambrien moyen et supérieur-Ordovicien-base du Silurien. Sommaire général sur les Mémoires explicatifs des cartes géologiques au 1/200 000 de l'Anti-Atlas marocain. *Notes et Mémoires du Service géologique du Maroc*, **515 bis**, 149 p.

Destombes, J. & Feist, R. 1987. Découverte du Cambrien supérieur en Afrique (Anti-Atlas central, Maroc). *Comptes Rendus de l'Académie des Sciences, Paris*, **304**, 719–724.

Destombes, J. & Henry, J. L. 1987. Trilobites Calmoniidae de l'Ordovicien supérieur du Maroc et les origines de la Province Malvino-Cafre. *Lethaia*, **20**, 129–139.

Destombes, J. & Jeanette, A. 1962. Carte métallogénique du Maroc. Carte des gîtes sédimentaires au 1/2.000.000. *Notes et Mémoires du Service géologique du Maroc*, **169**.

Destombes, J. & Willefert, S. 1959. Sur la présence de *Dictyonema* dans le Trémadoc de l'Anti-Atlas (Maroc). *Comptes Rendus de l'Académie des Sciences, Paris*, **249**, 1246–1247.

Destombes, J. & Willefert, S. 1988. The Ordovician–Silurian boundary in Morocco. *Bulletin of the British Museum of Natural History (Geological Series)*, **43**, 165–170.

Destombes, J., Termier, H. & Termier, G. 1971. Sur quelques bryozoaires ectoproctes de l'Ordovicien supérieur du Sud marocain. *Notes et Mémoires du Service géologique du Maroc*, **237**, 61–64.

Destombes, J., Hollard, H. & Willefert, S. 1985. Lower Palaeozoic rocks of Morocco. *In*: Holland, C. H. (ed.) *Lower Palaeozoic Rocks of the World: Lower Palaeozoic Rocks of Northwestern and West-Central Africa*. John Wiley & Sons, Chichester, **4**, 91–136.

Deunff, J. 1968a. *Arbusculidium*, genre nouveau d'Acritarche du Trémadoc marocain. *Comptes Rendus sommaires de la Société géologique de France*, **3**, 101–102.

Deunff, J. 1968b. Sur une forme nouvelle d'acritarche possédant une ouverture polaire (*Veryhachium miloni* n. sp.) et sur la présence d'une colonie de *Veryhachium* dans le Trémadocien marocain. *Comptes Rendus de l'Académie des Sciences, Paris*, **267**, 46–49.

Deunff, J. 1977. Un microplancton à Acritarches dans les schistes llanvirniens de l'Anti-Atlas (Zagora, Maroc). *Notes et Mémoires du Service géologique du Maroc*, **268**, 141–151.

Donovan, S. K. & Savill, J. J. 1988. *Ramseyocrinus* (Crinoidea) from the Arenig of Morocco. *Journal of Paleontology*, **62**, 283–285.

Drage, H. B., Vandenbroucke, T. R. A., Van Roy, P. & Daley, A. C. 2019. Sequence of post-moult exoskeleton hardening preserved in a trilobite mass moult assemblage from the Lower Ordovician Fezouata Konservat-Lagerstätte, Morocco. *Acta Palaeontologica Polonica*, **64**, 261–273.

Ebbestad, J. O. R. 2016. Gastropoda, Tergomya and Paragastropoda (Mollusca) from the Lower Ordovician Fezouata Formation, Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 87–96.

Ebbestad, J. O. R. & Lefebvre, B. 2015. An unusual onychochilid mollusc from the Ordovician (Tremadocian) Fezouata Formation, Morocco. *Geobios*, **48**, 427–438.

Ebbestad, J. O. R., Polechová, M., Kröger, B. & Gutiérrez-Marco, J. C. (this vol.). Late Ordovician molluscs of eastern Anti-Atlas, Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publications, **485,** doi: 10.1144/SP485.9.

El Bourkhissi, M. & Sarmiento, G. N. 1997. Primeros conodontos ordovícicos del Anti-Atlas (Marruecos). *In*: Grandal d'Anglade, A., Gutiérrez-Marco, J. C. & Santos Fidalgo, L. (eds). *Comunicaciones de las XIII Jornadas de Paleontología. V Reunión Internacional PIGC 351*, 56–59.

El Maazouz, B. & Hamoumi, N. 2007. Différentiation paléogéographique à l'Ordovicien supérieur dans le Tafilalt (Anti-Atlas oriental, Maroc) sous l'interaction de la glaciation et de la tectonique. *Comptes Rendus Geoscience*, **339**, 562–571.

Elaouad-Debbaj, Z. 1984a. Acritarches et Chitinozoaires de l'Arenig-Llanvirn de l'Anti-Atlas (Maroc). *Review of Palaeobotany and Palynology*, **43**, 67–88.

Elaouad-Debbaj, Z. 1984b. Chitinozoaires ashgilliens de l'Anti-Atlas (Maroc). *Geobios*, **17**, 45–68.

Elaouad-Debbaj, Z. 1986. Chitinozoaires de la Formation du Ktaoua Inférieur, Ordovicien Supérieur de l'Anti-Atlas (Maroc). *Hercynica* (série 2), **1**, 35–55.

Elaouad-Debbaj, Z. 1988a. Acritarches et Chitinozoaires du Trémadoc de l'Anti-Atlas central (Maroc). *Revue de Micropaléontologie*, **31**, 85–128.

Elaouad-Debbaj, Z. 1988b. Acritarches de l'Ordovicien supérieur (Caradoc, Ashgill) de l'Anti-Atlas, Maroc. *Revue de Micropaleontologie*, **30**, 232–248.

Ennih, N. & Liégeois, J. P. 2008. The boundaries of the West African craton, with special reference to the basement of the Moroccan metacratonic Anti-Atlas belt. In: Ennih, N. & Liégeois, J. P. (eds) The Boundaries of the West African Craton. *Geological Society, London, Special Volume*, **297**, 1–17.

Ernst, A. & Key, M. 2007. Upper Ordovician bryozoans from the Montagne Noire, Southern France. *Journal of Systematic Palaeontology*, **5**, 359–428.

Ernst, A., Jimenez-Sanchez, A. & Baidder, L. 2015. Bryozoan fauna of the Upper Ordovician (Katian) of Alnif, Morocco. *Palaeobiodiversity and Palaeoenvironments*, **95**, 537–553.

Evans, D. A. D. 2003. True polar wander and supercontinents. *Tectonophysics*, **362**, 303–320.

Fortey, R. A. 2009. A new giant asaphid trilobite from the Lower Ordovician of Morocco. *Memoirs of the Association of Australasian Palaeontologists*, **37**, 9–16.

Fortey, R. A. 2011a. Trilobites of the genus *Dikelokephalina* from Ordovician Gondwana and Avalonia. *Geological Journal*, **46**, 405–415.

Fortey, R. A. 2011b. The first known complete lichakephalid trilobite. *Memoirs of the Association of Australasian Palaeontologists*, **42**, 1–7.

Fortey, R. & Cocks, L. R. M. 2005. Late Ordovician global warming **-** the Boda event. *Geology*, **35**, 405–408.

Fortey, R. A. & Edgecombe, G. D. 2017. An Upper Ordovician (Katian) trilobite fauna from the Lower Ktaoua Formation, Morocco. *Bulletin of Geosciences*, **92**, 311–322.

Gaines, R. R., Briggs, D. E. G., Orr, P. J. & Van Roy, P. 2012. Preservation of giant anomalocaridids in silica- chlorite concretions from the Early Ordovician of Morocco. *Palaios*, **27**, 317–325.

Ghienne, J. F., Le Heron, D., Moreau, J., Denis, M. & Deynoux, M. 2007a. The Late Ordovician glacial sedimentary system of the North Gondwana platform. *In*: Hambrey, M., Christoffersen, P., Glasser, N., Janssen, P., Hubbard, B. & Siegert, M. (eds) Glacial Sedimentary Processes and Products. *International Association of Sedimentologists, Special Publication*, **39**, 295–319.

Ghienne, J. F., Boumendjel, K., Paris, F., Videt, B., Racheboeuf, P. & Aït Salem, H. 2007b. The Cambrian–Ordovician succession in the Ougarta Range (Algeria, North Africa) and interference of the Late Ordovician glaciation on the development of the

Lower Palaeozoic transgression on northern Gondwana. *Bulletin of Geosciences*, **82**, 183–214.

Gibb, S., Chatterton, B. D. E. & Gingras, M. K. 2010. *Rusophycus carleyi* (James, 1885), trace fossils from the Lower Ordovician of Southern Morocco, and the trilobites that made them. *Ichnos*, **17**, 271–283.

Gutiérrez-Marco, J. C. & García-Bellido, D. C. 2015. Micrometric detail in palaeoscolecid worms from Late Ordovician sandstones of the Tafilalt Konservat-Lagerstätte, Morocco. *Gondwana Research*, **28**, 875–881.

Gutiérrez-Marco, J. C. & Martin, E. L. O. 2016. Biostratigraphy and palaeoecology of Lower Ordovician graptolites from the Fezouata Shale (Moroccan Anti-Atlas). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 35–49.

Gutiérrez-Marco, J. C. & Vinn, O. 2018. Cornulitids (tubeworms) from the Late Ordovician *Hirnantia* fauna of Morocco. *Journal of African Earth Sciences*, **137**, 61–68.

Gutiérrez-Marco, J. C., Destombes, J., Rábano, I., Aceñolaza, G. F., Sarmiento, G. N. & San José, M. A. 2003. El Ordovícico Medio del Anti-Atlas marroquí: paleodiversidad, actualización bioestratigráfica y correlación. *Geobios*, **36**, 151–177.

Gutiérrez-Marco, J.C., Sá, A.A., Rábano, I., Sarmiento, G.N., García-Bellido, D.C., Bernárdez, E., Lorenzo, S., Villas, E., Jiménez-Sánchez, A., Colmenar, J. & Zamora, S. 2015. Iberian Ordovician and its international correlation. *Stratigraphy*, **12** (3-4), 257–263.

Gutiérrez-Marco, J. C., García-Bellido, D. C., Rábano, I. & Sá, A. A. 2017a. Digestive and appendicular soft-parts, with behavioural implications, in a large Ordovician trilobite from the Fezouata Lagerstätte, Morocco. *Scientific Reports*, **7**: 39728, 7 p.

Gutiérrez-Marco, J. C., Sá, A. A., García-Bellido, D. C. & Rábano, I. 2017b. The Bohemo-Iberian regional chronostratigraphic scale for the Ordovician System and palaeontological correlations within South Gondwana. *Lethaia*, **50** (2), 258–295.

Gutiérrez-Marco, J. C., Pereira, S., García-Bellido, D. C. & Rábano, I. (this vol. a). Ordovician trilobites from the Tafilalt Lagerstätte: new data and reappraisal of the Bou Nemrou assemblage. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**.

Gutiérrez-Marco, J. C., Muir, L. A. & Mitchell, C. E. (this vol. b). Upper Ordovician graptolites and other benthic colonial organisms from the Tafilalt Biota, southeastern Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**.

Gutiérrez-Marco, J. C., Rábano, I. & García-Bellido, D. C. . 2019. The nileid trilobite *Symphysurus* from upper Tremadocian strata of the Moroccan Anti-Atlas: taxonomic reappraisal and palaeoenvironmental implications. *Fossils & Strata*, **64**, 155–171.

Hamoumi, N. 1999. Upper Ordovician glaciation spreading and its sedimentary record in Moroccan north Gondwanan margin. *Acta Universitatis Carolinae, Geologica*, **43**, 111–114.

Havlíček, V. 1970. Heterorthidae (Brachiopoda) in the Mediterranean Province. *Sborník Geologických Věd, Paleontologie*, **12**, 7–39.

Havlíček, V. 1971. Brachiopodes de l'Ordovicien du Maroc. *Notes et Mémoires du Service géologique du Maroc*, **230**, 1–135.

Henry, J. L. 1991. Clasification de quelques Calymenina (Trilobita) ordoviciens: Calymenidae ou Homalonotidae? *Geobios*, **29**, 331–340.

Henry, J. L. & Destombes, J. 1991. Un biofaciès à Trilobites Homalonotidae dans l'Ordovicien de la marge nord-gondwanienne: implications paléobiologiques et paléogéographiques. *Lethaia*, **24**, 249–253.

Henry, J. L., Vizcaïno, D. & Destombes, J. 1992. Evolution de l'œil et hétérochronie chez les Trilobites ordoviciens *Ormathops* Delo 1935 et *Toletanaspis* Rábano 1989 (Dalmanitidae, Zeliszkellinae). *Paläontologische Zeitschrift*, **66**, 277–290.

Horný, R. D. 1997a. Ordovician Tergomya and Gastropoda (Mollusca) of the Anti-Atlas (Morocco). *Acta Musei Nationalis Pragae, Series B - Historia Naturalis*, **53** (3–4), 37–78.

Horný, R. D. 1997b. *Quasisinuites rapax* gen. et sp. n., a new sinuate cyrtonellid mollusc (Class Tergomya) with involute shell from the Ordovician of Morocco. *Věstnik Ceského geologickňeho ústavu*, **72**, 345–350.

Horný, R. D. 1997c. Circumbilical retractor muscle attachment area in the Ordovician trilobed bellerophontoidean gastropod *Tritonophon peeli* (Mollusca). *Věstnik Ceského geologického ústavu*, **72**, 333–338.

Hunter, A. W. & Ortega-Hernández, J. 2017. A primitive starfish ancestor from the Early Ordovician of Morocco reveals the origin of crown group Echinodermata. *bioRxiv*. Publisher's Version, doi: 10.1101/216101.

Jiménez-Sánchez, A. 2009. The upper Katian (Ordovician) bryozoans from the Eastern Iberian Chains (NE Spain). *Bulletin of Geosciences*, **84**, 687–738.

Jiménez-Sánchez, A. 2010. New monticuliporidae (Trepostomata) from the Cystoid Limestone Formation (Upper Ordovician) of the Iberian Chains (NE Spain). *Geodiversitas*, **32**,177–199.

Jiménez-Sánchez, A. & Villas, E. 2010. The bryozoan dispersion into the Mediterranean margin of Gondwana during the pre-glacial Late Ordovician. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **294**, 220–231.

Jiménez-Sánchez, A., Taylor, P. D. & Gómez, J. B. 2013. Palaeogeographical patterns in Late Ordovician bryozoan morphology as proxies for temperature. *Bulletin of Geosciences*, **88**, 417–426.

Jiménez-Sánchez, A., Vennin, E. & Villas, E. 2015a. Trepostomate bryozoans from the upper Katian (Upper Ordovician) of Morocco: gigantism in the high latitude Gondwana platforms. *Journal of Paleontology*, **89** (2), 195–221.

Jiménez-Sánchez, A., Villas, E. & Vennin, E. 2015b. New trepostomate bryozoans from the Upper Ordovician of Morocco and the temperature influence on zooid size. *Journal of Paleontology*, **89** (3), 385–404.

Jimenez-Sanchez, A., Ernst, A.,Vennin, E. & Villas, E. 2016. New bryozoans from the Upper Ordovician of Morocco and their place in the temperate-to-cool water Mediterranean Province. *Bulletin of Geosciences*, **91**, 23–50.

Kouraiss, K., El Hariri, K., El Albani, A., Azizi, A., Mazurier, A. & Vannier, J. 2018. X-ray microtomography applied to fossils preserved in compression: palaeoscolecid worms from the Lower Ordovician Fezouata Shale. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **508**, 48–58.

Kröger, B. & Lefebvre, B. 2012. Palaeogeography and palaeoecology of early Floian (Early Ordovician) cephalopods from the Upper Fezouata Formation, Anti-Atlas, Morocco. *Fossil Record*, **15**, 61–75.

Le Heron, D. P. 2007. Late Ordovician glacial record of the Anti-Atlas, Morocco. *Sedimentary Geology*, **201**, 93–110.

Le Heron, D. P. & Craig, K. 2008. First-order reconstructions of a Late Ordovician Saharan ice sheet. *Journal of the Geological Society*, **165**, 19–29.

Le Heron, D. P., Ghienne, J. F., El Houicha, M., Khoukhi, Y. & Rubino, J. L. 2007. Maximum extent of ice sheets in Morocco during the Late Ordovician glaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **245**, 200–226.

Le Heron, D. P., Khoukhi, Y., Paris, F., Ghienne, J. F. & Le Herisse, A. 2008. Black shale, grey shale, fossils and glaciers: Anatomy of the Upper Ordovician–Silurian succession in the Tazzeka Massif of eastern Morocco. *Gondwana Research*, **14**, 483–496.

Le Menn, J. & Spjeldnaes, N. 1996. Un nouveau crinoïde Dimerocrinitidae (Camerata, Diplobathrida) de l'Ordovicien supérieur du Maroc: *Rosfacrinus robustus* nov. gen., nov. sp. *Geobios*, **29**, 341–351.

Lefebvre, B. 2007. Early Palaeozoic palaeobiogeography and palaeoecology of stylophoran echinoderms. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **245**, 156–199.

Lefebvre, B. & Botting, J. P. 2007. First report of the mitrate *Peltocystis cornuta* Thoral (Echinodermata, Stylophora) in the Lower Ordovician of central Anti- Atlas (Morocco). *Annales de Paléontologie*, **93**, 183–198.

Lefebvre, B. & Fatka, O. 2003. Palaeogeographical and palaeoecological aspects of the Cambrian–Ordovician radiation of echinoderms in Gondwanan Africa and peri-Gondwanan Europe. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **195**, 73–97.

Lefebvre, B. & Roch, R. 2009. A la poursuite d'une chimère: reconstitution de la morphologie de *Plasiacystis mobilis*, un solute (Echinodermata, Blastozoa) atypique de l'Ordovicien péri-gondwanien. *Journal de l'Association Paléontologique Française*, **56**, 44–45.

Lefebvre, B., Nardin, E., Hunter, A. W. & Regnault, S. 2007. Les échinodermes de l'Ordovicien supérieur de l'Anti-Atlas (Maroc): biostratigraphie et paléobiodiversité. *Africa Geoscience Review*, **14**, 123–148.

Lefebvre, B., Noailles, F., Hunter, A.W., Nardin, E., Regnault, S., Franzin, B., Van Roy P. & El Hariri, K. 2008. Les niveaux à échinodermes de Bou Nemrou, un gisement à préservation exceptionnelle de l'Ordovicien supérieur du Tafilalt occidental (Maroc). *Mésogée*, **64**, 7–25.

Lefebvre, B., Nouailles, F., Franzin, B., Regnault, S., Nardin, E., Hunter, A. W., Zamora, S., Van Roy, P., El Hariri, K. & Lazreq, N. 2010. Les gisements à échinodermes de l'Ordovicien supérieur de l'Anti-Atlas oriental (Maroc): un patrimoine scientifique exceptionnel à préserver. *Bulletin de l'Institut Scientifique, Rabat*, 1–17.

Lefebvre, B., Lerosey- Aubril, R., Servais, T. & Van Roy, P. 2016a. The Fezouata Biota: an exceptional window on the Cambro–Ordovician faunal transition. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 1–6.

Lefebvre, B., El Hariri, K., Lerosey- Aubril, R., Servais, T. & Van Roy, P. 2016b. The Fezouata Shale (Lower Ordovician, Anti- Atlas, Morocco): a historical review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 7–23

Lefebvre, B., Allaire, N., Guensburg, T. E., Hunter, A. W., Kouraïss, K., Martin, E. L. O., Nardin, E., Noailles, F., Pittet, B., Sumrall, C. D. & Zamora, S. 2016c. Palaeoecological aspects of the diversification of echinoderms in the Lower Ordovician of central Anti- Atlas, Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 97–121

Lefebvre, B., Gutiérrez-Marco, J. C., Lehnert, O., Martin, E. L. O., Nowak, H., Akodad, M., El Hariri, K. & Servais, T. 2018. Age calibration of the Lower Ordovician Fezouata Lagerstätte, Morocco. *Lethaia*, **51** (2), 296–311.

Lefebvre, B., Guensburg, T. E., Martin, E. L. O., Mooi, R., Nardin, E., Nohejlová, M., Saleh, F., Kouraïss, K., El Hariri, K. & David, B. 2019. Exceptionally preserved soft parts in fossils from the Lower Ordovician of Morocco clarify stylophoran affinities within basal deuterostomes. *Geobios*, **52**, 27–36.

Lefebvre, B., Nohejlova, M., Kasicka, L. & Zicha, O. (this vol. a). New Peri-Gondwanan occurrences of the Ordovician genus *Diamphidiocystis* (Echinodermata, Stylophora) - Implications for mitrocystitid palaeobiogeography and diversity. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**.

Lefebvre, B., Nohejlova, M., Martin, E. L. O., Kasicka, L. & Zicha, O. & Gutiérrez-Marco, J. C. (this vol. b). New Middle and Late Ordovician cornute stylophorans (Echinodermata) from Morocco and other peri-Gondwanan areas. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**.

Lehnert, H., Nowak, H., Sarmiento, G. N., Gutiérrez-Marco, J. C., Akodad, M. & Servais, T. 2016. Conodonts from the Lower Ordovician of Morocco -contributions to age and faunal diversity of the Fezouata Lagerstätte and peri-Gondwana biogeography. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 50–61.

Loi, A., Ghienne, J. F., Dabard, M. P., Paris, F., Botquelen, A., Christ, N., Elaouad-Debbaj, Z., Gorini, A., Vidal, M., Videt, B. & Destombes, J. 2010. The Late Ordovician glacio-eustatic record from a high-latitude storm-dominated shelf succession: the Bou Ingarf section (Anti-Atlas, Southern Morocco). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 332–358.

MacGabhann, B.A. 2012. *A solution to Darwin's dilemma: Differential taphonomy of Palaeozoic and Ediacaran non-mineralised discoidal fossils*. Earth and Ocean Sciences, National University of Ireland, Galway, Ireland, 657 pp.

MacGabhann, B.A., Schiffbauer, J.D., Hagadorn, J.W., Van Roy, P., Lynch, E.P., Morrison, L. & Murray, J. 2019. Resolution of the earliest metazoan record: Differential taphonomy of Ediacaran and Paleozoic fossils molds and casts. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **513**, 146–165.

Marek, L. 1983. The Ordovician hyoliths of Anti-Atlas (Morocco). *Sborník Národního Muzea v Praze [B]*, **39**, 1–36.

Martí Mus, M. 2016. A hyolithid with preserved soft parts from the Ordovician Fezouata Konservat-Lagerstätte of Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 122–129

Martin, E., Lefebvre, B. & Vaucher, R. 2015. Taphonomy of a stylophoran- dominated assemblage in the Lower Ordovician of Zagora area (central Anti- Atlas, Morocco). *In*:

ZAMORA, S. & RÁBANO, I. (eds). Progress in Echinoderm Palaeobiology. *Cuadernos del Museo Geominero*, **19**, 95–100.

MARTIN, E. L. O., PITTET, B., GUTIÉRREZ- MARCO, J. C., VANNIER, J., EL HARIRI, K., LEROSEY- AUBRIL, R., MASROUR, M., NOWAK, H., SERVAIS, T., VANDENBROUCKE, T. R. A., VAN ROY, P., VAUCHER, R. & LEFEBVRE, B. 2016a. The Lower Ordovician Fezouata Konservat- Lagerstätte: age, environment and evolutionary perspectives. *Gondwana Research*, **34**, 274–283.

MARTIN, E. L. O., VIDAL, M., VIZCAÏNO, D., VAUCHER, R., SANJOFRE, P., LEFEBVRE, B. & DESTOMBES, J. 2016b. Biostratigraphic and palaeoenvironmental controls on the trilobite associations from the Lower Ordovician Fezouata Shale of the central Anti- Atlas, Morocco. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 142–154.

MARTIN, E. L. O., LEROSEY-AUBRIL, R. & VANNIER, J. 2016c. Palaeoscolecid worms from the Lower Ordovician Fezouata Lagerstätte, Morocco: Palaeoecological and palaeogeographical implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 130–141.

MERGL, M. 1981. The genus *Orbithele* (Brachiopoda, Inarticulata) from the Lower Ordovician of Bohemia and Morocco. *Věstnik Ustředniho ústavu geologickeho*, **56**, 287–292.

MERGL, M. 1983. New brachiopods (Cambrian–Ordovician) from Algeria and Morocco (Mediterranean Province). *Casopis pro Mineralogii a Geologii*, **28** (4), 337–348.

MICHARD, A., HOEPFFNER, C., SOULAIMANI, A. & BAIDDER, L. 2008. The Variscan belt. *In*: MICHARD, A., SADDIQI, O., CHALOUAN, A. & FRIZON DE LAMOTTE, D. (eds) *Continental Evolution: The Geology of Morocco*. Springer, Berlin, 65–131.

MINZONI, N. 2011. Transtensional tectonics played a key role during the Variscan cycle in the Sardinia-Corsica massif. *In*: SCHATTNER, U. (ed.) New Frontiers in Tectonic Research- At the Midst of Plate Convergence. In Tech, Rijeka, Croatia.

MOLYNEUX, S. M. & PARIS, F. 1985. Late Ordovician Palynomorphs. *Journal of Micropalaeontology*, **4**, 11–26.

MUIR, L. A., BOTTING, J. P., WALKER, S. N. A., SCHIFFBAUER, J. D. & MACGABHANN, B. A. (this vol.). *Onuphionella corusca* sp. nov.: and early Cambrian-type agglutinated tube from Upper Ordovician strata of Morocco. *In*: HUNTER, A. W., ÁLVARO, J. J., LEFEBVRE, B., VAN ROY, P. & ZAMORA, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**, doi: 10.1144/SP485.7

NARDIN, E. 2007. New occurrence of the Ordovician eocrinoid *Cardiocystites*: Palaeogeographical and palaeoecological implications. *Acta Palaeontologica Polonica*, **52**, 17–26.

Nardin, E. & Régnault, S. 2015. Palaeoecology of *Ascocystites*-dominated assemblages (Echinoderata, Blastozoa, Eocrinoidea) from the Moroccan Anti-Atlas. *In*: Zamora, S. & Rábano, I. (eds). Progress in Echinoderm Palaeobiology. *Cuadernos del Museo Geominero*, **19**, 109–114.

Nielsen, A. T. 2004. Ordovician sea level changes: a Baltoscandian perspective. *In*: Webby, B. D., Paris, F., Droser, M. L. & Percival, I. G. (eds) *The Great Ordovician Biodiversification Event*. Columbia University Press, New York, 84–93.

Noailles, F., Lefebvre, B., Guensburg, T. E., Hunter, A. W., Nardin, E., Sumrall, C. D. & Zamora, S. 2010. New echinoderm- Lagerstätten from the Lower Ordovician of central Anti- Atlas (Zagora area, Morocco): a Gondwanan perspective of the Great Ordovician Biodiversification Event. *In*: Reich, M., Reitner, J., Roden, V. & Thuy, B. (eds). *Echinoderm Research* (Universitätsverlag Göttingen, Göttingen), **2010**, 77–78.

Nowak, H., Akodak, M., Lefebvre, B. & Servais, T. 2015. Discovery of the *messaoudensis–trifidum* acritarch assemblage (upper Tremadocian–lower Floian, Lower Ordovician) in the subsurface of Morocco. *Estonian Journal of Earth Sciences*, **64**, 80–83.

Nowak, H., Servais, T., Pittet, B., Vaucher, R., Akodad, M., Gaines, R. R. & Vandenbroucke, T. R. A. 2016. Palynomorphs of the Fezouata Shale (Lower Ordovician, Morocco): Age and environmental constraints of the Fezouata Biota. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 62–74.

Oggiano, C., Gaggero, I., Funneda, A., Buzzi, L. & Tiepolo, M. 2010. Multiple early Paleozoic volcanic events at the northern Gondwana margin: U–Pb age evidence from the Southern Variscan branch (Sardinia, Italy). *Gondwana Research*, **17**, 44–58.

Ortega- Hernández, J., Van Roy, P. & Lerosey- Aubril, R. 2016. A new aglaspidid euarthropod with a six- segmented trunk from the Lower Ordovician Fezouata Konservat- Lagerstätte, Morocco. *Geological Magazine*, **153**, 524–536.

Ouanaimi, H. 1998. Le passage Ordovicien–Silurien à Tizi n'Tichka (Haut Atlas, Maroc): variations du niveau marin. *Comptes Rendus de l'Académie des Sciences, Paris*, **326**, 65–70.

Ouanaimi, H., Soulaimani, A., Hoepffner, C. & Michard, A. 2006. The Atlas-Meseta Red Beds basin (Morocco) and the Lower Ordovician rifting of NW-Gondwana. *Bulletin de la Société géologique de France*, **187**, 155–168.

Paris, F. 1988. Late Ordovician and Early Silurian chitinozoans from central and southern Cyrenaica. *In*: El-Arnauti, A., Owens, B. & Thusu, B. (eds) Subsurface Palynostratigraphy of Northeast Libya. Garyounis University Publications, Benghazi, Libya, 77–87.

Paris, F. 1990. The Ordovician chitinozoan biozones of the Northern Gondwana Domain. *Review of Palaeobotany and Palynology*, **66**, 181–209.

Paris, F. 1996. Chitinozoan biostratigraphy and palaeogeography. In: Jansonius, J. & McGregor, D. C. (eds) *Palynology: Principles and Applications*. American Association of Stratigraphic Palinologist Fondation, Volume 2, Chapter 17, 531–532.

Paris, F. 1999. Palaeobiodiversification of Ordovician chitinozoans from northern Gondwana. *Acta Universitatis Carolinae, Geologica*, **43**, 283–286.

Paris, F., Elaouad-Debbaj, Z., Jaglin, J. C., Massa, D. & Oulebsir, L. 1995. Chitinozoans and Late Ordovician glacial events on Gondwana. *In*: Cooper, J. D., Droser, M. L. & Finney, S. C. (eds) *Ordovician Odyssey: Short Papers for the 7th International Symposium on the Ordovician System, Las Vegas Nevada*. Fullerton, California: Pacific Section Society for Sedimentary Geology (SEPM), 171–176.

Paris, F., Verniers, J., Achab, A., Albani, R., Ancilletta, A., Asselin, E., Chen, X. H., Fatka, O., Grahn, Y., Molyneux, S., Nolvak, J., Samuelsson, J., Sennikov , N. V., Soufiane, A., Wang, X. F. & Winchester Seeto, T. 1999. Correlation of Ordovician regional chitinozoan biozonations. *Acta Universitatis Carolinae, Geologica*, **43**, 291–294.

Paris, F., Boumendjel, K., Dabard, M. P., Ghienne, J. F., Loi, A., Tang, P., Videt, B. & Achab, A. 2007. Chitinozoan-based calibration of Early–Mid Ordovician transgression events on northern Gondwana. *Acta Paleontologica Sinica*, **46**, 370–375.

Parsley R. L. & Gutiérrez-Marco J. C. 2005. Stylophorans in middle Arenig shallow water siliciclastics: *Vizcainocarpus* from the Imfout Syncline in Morocco’s western Meseta. *Bulletin of Geosciences*, **80**, 185–192.

Paul, C. R. C. 1968. *Macrocystella* Callaway, the earliest glyptocystitid cystoid. *Palaeontology*, **11**, 580–600

Pereira, S., Silva, C. M., Sa, A. A., Pires, M., Marques Guedes, A., Budil, P., Laibl, L. & Rábano, I. 2017. The illaenid trilobites *Vysocania* (Vanek & Vokác, 1997) and *Octillaenus* (Barrande, 1846) from the Upper Ordovician of the Czech Republic, Portugal, Spain and Morocco. *Bulletin of Geosciences*, **92** (4), 465–490.

Polechová, M. 2016. The bivalve fauna from the Fezouata Formation (Lower Ordovician) of Morocco and its significance for palaeobiogeography, palaeoecology and early diversification of bivalves. *Palaeogeography, Palaeoecology, Palaeoclimatology*, **460**, 155–169.

Pouclet, A., Aarab, A., Fekkak, A. & Benharref, M. 2007. Geodynamic evolution of the northwestern Paleo-Gondwanan margin in the Moroccan Atlas at the Precambrian–Cambrian boundary. *In*: Linnemann, U., Nance, R. D., Kraft, P. & Zulauf, G. (eds) The Evolution of the Rheic Ocean: From Avalonian–Cadomian Active Margin to

Alleghenian–Variscan Collision. *Geological Society of America, Special Paper*, **423**, 27–60.

POUCLET, A., EL HADI, H., ÁLVARO, J. J., BARDINTZEFF, J. M., BENHARREF, M. & FEKKAK, A. 2018. Review of the Cambrian volcanic activity in Morocco: geochemical fingerprints and geotectonic implications for the rifting of West Gondwana. *International Journal of Earth Sciences*, **107**, 2101–2123.

RÁBANO, I. 1990. Trilobites del Museo GeoMinero. I. *Platypeltoides magrebiensis* n. sp. (Asaphina, Nileidae), del Ordovícico inferior del Anti- Atlas central (Marruecos). *Boletín Geológico y Minero*, **101**, 21–27.

RÁBANO, I., SÁ, A. A., GUTIÉRREZ-MARCO, J. C. & GARCÍA BELLIDO, D. 2010. Two more Bohemian trilobites from the Ordovician of Portugal and Morocco. *Bulletin of Geosciences*, **85**, 415–424.

RÁBANO, I., GUTIÉRREZ-MARCO, J. C. & GARCÍA-BELLIDO, D. C. 2014. A remarkable illaenid trilobite from the Middle Ordovician of Morocco. *Bulletin of Geosciences*, **89**, 365–374.

RADDI, Y., BAIDDER, L., RJIMATI, E. C. & AIT BRAHIM, L. 2011. Le fer oolithique d'Imi n'Tourza au sud du J. Saghro. *In*: MICHARD, A., SADDIQI, O., CHALOUAN, A., RJIMATI, E. C. & MOUTTAQI, A. (eds) Nouveaux guides géologiques et miniers du Maroc. *Notes et Mémoires du Service géologique du Maroc*, **564**, 41–44.

RADDI, Y., TAHIRI, M., DERRE, C., LECOLLE, M., BAIDDER, L. 2006. Carte géologique du Maroc au 1/50 000. Feuille Oukhit. *Notes et Mémoires du Service géologique du Maroc*, **475**. Notice explicative 475 bis.

RADDI, Y., DERRE, C., LECOLLE, M., MICHARD, A., BAIDDER, L., TAHIRI, M. 2012. Carte géologique du Maroc au 1/50 000. Feuille Bou Adil. *Notes et Mémoires du Service géologique du Maroc*, **477**. Notice explicative 477 bis

RAVIER, E., BOUNCRISTIANI, J. F., GUIRAUD, M., MENZIES, J., CLERC, S., GOUPY, B., & PORTIER, E. 2014. Porewater pressure control on subglacial soft sediment remobilization and tunnel valley formation: a case study from the Alnif tunnel valley (Morocco). *Sedimentary Geology*, **304**, 71–95.

REGNAULT, S. 2007. Présence de l'éocrinoïde *Ascocystites* Barrande (Echinodermata, Blastozoa) dans l'Ordovicien supérieur (Caradoc) de l'Anti-Atlas (Maroc): premières données. *Annales de Paléontologie*, **93**, 215–227.

REICH, M., SPRINKLE, J., LEFEBVRE, B., RÖSSNER, G.E. & ZAMORA, S. 2017. The first Ordovician cyclocystoid (Echinodermata) from Gondwana and its morphology, paleoecology, taphonomy, and paleogeography. *Journal of Paleontology*, **91**, 735–754.

RONG, J. Y. 1984. Distribution of the Hirnantia fauna and its meaning. *In*: BRUTON, D. L. (ed.) Aspects of the Ordovician System. *Paleontological Contributions from the University of Oslo*, **295**, 101–112.

Rong, J. Y. 1986. Ecostratigraphy and community analysis of Late Ordovician and Silurian in southern China. *In*: Palaeontological Society of China (ed.) *Selected Papers of the 13th and 14th Annual Convention of the Palaeontological Society of China*. Anhui Science and Technology Publishing House, Hefei, 1–24 [in Chinese with English summary].

Ross, J. R. P. & Ross, C. A. 1992. Ordovician sea-level fluctuations. *In*: Webby, B. D. & Laurie, J. R. (eds) *Global Perspectives on Ordovician Geology*. Proceedings of the 6th International Symposium on the Ordovician System. Balkema, Rotterdam, 327–335.

Ross, C. A. & Ross, J. R. P. 1995. North American Ordovician depositional sequences and correlations. *In*: Cooper, J., Droser, M. L. & Finney, S. (eds) *Ordovician Odyssey*. 7th International Symposium of the Ordovician System. Las Vegas, The Pacific Section Society of Sedimentary Geology (SEPM), Fullerton, 309–313.

Ruta, M. 1999. A new stylophoran echinoderm, *Juliaecarpus milnerorum*, from the late Ordovician Upper Ktaoua Formation of Morocco. *Bulletin of Natural History Museum of London (Geology)*, **55**, 47–79.

Saleh, F., Candela, Y., Harper, D. A. T., Polechová, M., Lefebvre, B. & Pittet, B. 2018. Storm-induced community dynamics in the Fezouata Biota (Lower Ordovician, Morocco). *Palaios*, **33**, 1–7.

Saleh, F., Pittet, B., Perrillat, J. P. & Lefebvre, B. 2019. Orbital control on exceptional fossil preservation. *Geology*, 47, 103–106.

Samuelsson, J., Van Roy, P. & Vecoli, M. 2001. Micropalaeontology of a Moroccan Ordovician deposit yielding soft-bodied organisms showing Ediacara-like preservation. *Geobios*, **34**, 365–373.

Sánchez-García, T., Chichorro, M., Solá, R., Álvaro, J. J., Díez, A., Bellido, F., Ribeiro, M. L., Quesada, C. & Carrilho Lopes, J. 2019. Rifting Stage. *In*: Quesada, C. & Oliveira, J. T. (eds) The Geology of Iberia: A Geodynamic Approach. Regional Geology Reviews Series, Springer, Heidelberg.

Servais, T. & Molyneux, S. G. 1997. The messaoudensis-trifidum acritarch assemblage (Ordovician: late Tremadoc-early Arenig) from the subsurface of Rügen (Baltic Sea, NE Germany). *Palaeontographia Italiana*, **84**, 113–161.

Smith, A. G. 1997. Estimates of the Earth’s spin (geographic) axis relative to Gondwana from glacial sediments and palaeomagnetism. *Earth-Science Reviews*, **42**, 161–169.

Soufiane, A. & Achab, A. 1993. Quelques assemblages de Chitinozoaires de l’Ordovicien du Maroc, Bassin de Tadla. *Geobios*, **26**, 535–553.

Soulaimani, A., Bouabdelli, M. & Pique, A. L. 2003. L'extension continentale au Néoprotérozoïque supérieur–Cambrien inférieur dans l'Anti-Atlas (Maroc). *Bulletin de la Société géologique de France*, **174**, 83–92.

Stampfli, G. M., von Raumer, J. F. & Borel, G. D. 2002. Paleozoic evolution of pre-Variscan terranes: from Gondwana to the Variscan collision. *In*: Martínez Catalán, J. R., Hatcher, R. D., Arenas, R. & Díaz García, F. (eds) Variscan-Appalachian dynamics: the Building of the Late Paleozoic Basement. *Geological Society of America, Special Paper*, **364**, 263–280.

Sumrall, C. D. & Zamora, S. 2011. Ordovician edrioasteroids from Morocco: faunal exchanges across the Rheic Ocean. *Journal of Systematic Palaeontology*, **9**, 425–454.

Sumrall, C. D. & Zamora, S. (this vol.). New Upper Ordovician edrioasteroids from Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**, doi: 10.1144/SP485.6

Sutcliffe, O. E., Harper, D. A. T., Aït Salem, A., Whittington, R. J. & Craig, J. 2001. The development of an atypical *Hirnantia*-brachiopod Fauna and the onset of the glaciation in the Late Ordovician of Gondwana. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **92**, 1–14.

Taylor, P. D. & Ernst, A. 2004. Bryozoan diversification during the Ordovician. *In*: Webby, B. D., Droser, M. L. & Paris, F. (eds) *The Great Ordovician Biodiversification Event*. Columbia University Press, New York, 147–156.

Termier, G. & Termier, H. 1950a. *Paléontologie marocaine*. II: Invertébrés de l’Ère Primaire, fascicule 2. Bryozoaires et brachiopodes, 1–20. Hermann & Cie, Paris.

Termier, G. & Termier, H. 1950b. *Paléontologie marocaine*. II. Invertébrés de l’Ere Primaire, fascicule 4. Annélides, arthropodes, échinodermes, conularides et graptolithes. *Notes et Mémoires du Service géologique du Maroc*, **79**, 1–281.

Termier, H. & Termier, G. 1970. Un échinoderme encroûtant de l'Ashgill (Ordovicien supérieur) du Tafilalt (Sud marocain): *Herpetocystis destombesi* nov. gen. nov. sp. *Comptes Rendus de l’Académie des Sciences, Paris*, **271**, 1260–1263.

Tessitore, L. 2016. La biostratigraphie des chitinozoaires dans le décryptage de la glaciation fini-ordovicienne sur les marges gondwaniennes. Ph.D., Université de Lille 1, 192 pp.

Ubaghs, G. 1963. *Rhopalocystis destombesi* n.g., n.sp. Eocrinoïde de l’Ordovicien inférieur (Trémadocien supérieur) du Sud marocain. *Notes et Mémoires du Service géologique du Maroc*, **23** (172), 25–39.

Ubaghs, G. 1968. Eocrinoids. *In*: Moore, R.C. (ed.) Treatise on Invertebrate Paleontology Pt. S, Echinodermata, 1 (2), S455–S495.

Ubaghs, G. 1969. *Aethocrinus moorei* Ubaghs, nov. gen., nov. sp., le plus ancien crinoïde dicyclique connu. *University of Kansas Paleontological Contributions*, **38**, 1–25.

Valent, M. & Corbacho, J. 2015. *Pauxillites thaddei* a new Lower Ordovician hyolith from Morocco. *Sborník Národního Muzea v Praze [B]*, **71**, 51–54.

Van Iten, H., Muir, L., Simões, M. G., Marques, A. C. & Yoder, N. 2016. Palaeobiogeography, palaeoecology and evolution of Lower Ordovician conulariids and *Sphenothallus* (Medusozoa, Cnidaria), with emphasis on the Fezouata Shale of southeastern Morocco. *Palaeogeography, Palaeoecology, Palaeoclimatology*, **460**, 170–178.

Van Iten, H., Gutiérrez-Marco, J. C., Muir, L. A., Simoes, M. G. & Leme, J. M. (this vol.). Ordovician conulariids from the Upper Tiouririne Formation (Katian), Eastern Anti-Atlas mountains, southern Morocco. *In*: Hunter, A.W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publications, **485**, doi: 10.1144/SP485.5.

Van Roy, P. 2006a. Non-trilobite arthropods from the Ordovician of Morocco. Universiteit Gent, unpublished Ph.D dissertation.

Van Roy, P. 2006b. An aglaspidid arthropod from the Late Ordovician of Morocco with remarks on the affinities and limitations of Aglaspidida. *Transactions of the Royal Society of Edinburgh, Earth Sciences*, **96**, 327–350.

Van Roy, P. & Briggs, D. E. G. 2011. A giant Ordovician anomalocaridid. *Nature*, **473**, 510–513.

Van Roy, P. & Tetlie, O. E. 2006. A spinose appendage of a problematic arthropod from the Early Ordovician of Morocco. *Acta Palaeontologica Polonica*, **51**, 239–246.

Van Roy, P., Orr, P. J., Botting, J. P., Muir, L. A., Vinther, J., Lefebvre, B., El Hariri, K. & Briggs, D. E. G. 2010. Ordovician faunas of Burgess Shale type. *Nature*, **465**, 215–218.

Van Roy, P., Daley, A. C. & Briggs, D. E. G. 2015a. Anomalocaridid trunk limb homology revealed by a giant filter- feeder with paired flaps. *Nature*, **522**, 77–80.

Van Roy, P., Briggs, D. E. G. & Gaines, R. R. 2015b. The Fezouata fossils of Morocco; an extraordinary record of marine life in the Early Ordovician. *Journal of the Geological Society*, **172**, 541–549.

Vaucher, R., Martin, E. L. O., Hormière, H. & Pittet, B. 2016. A genetic link between *Konzentrat-* and *Konservat- Lagerstätten* in the Fezouata Shale (Lower Ordovician, Morocco). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **460**, 24–34.

Vaucher, R., Pittet, B., Hormière, H., Martin, E. L. O. & Lefebvre, B. 2017. A wave-dominated, tide- modulated model for the Lower Ordovician of the Anti- Atlas, Morocco. *Sedimentology*, **64**, 777–807.

Vennin, E., Álvaro, J. J. & Villas, E. 1998. High-latitude pelmatozoan-bryozoan mud-mounds from the Late Ordovician northern Gondwana platform. *Geological Journal*, **3**, 121–140.

Vidal, M. 1998a. Le modèle des biofaciès à trilobites: un test dans l'Ordovicien inférieur de l'Anti-Atlas, Maroc. *Comptes Rendus de l'Académie des Sciences, Paris*, **327**, 327–333.

Vidal, M. 1998b. Trilobites (Asaphidae et Raphiophoridae) de l'Ordovicien inférieur de l'Anti-Atlas, Maroc. *Palaeontographica Abteilung A*, **251**, 39–77.

Videt, B., Paris, F., Rubino, J. L., Boumendjel, K., Dabard, M. P., Loi, A., Ghienne, J. F., Marante, A. & Gorino, A. 2010. Biostratigraphical calibration of third order Ordovician sequences on the northern Gondwana platform. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 359–375.

Villas, E. & Colmenar, J. (this vol.). Brachiopods from the Upper Ordovician of Erfoud (eastern Anti-Atlas, Morocco) and the stratigraphic correlation of the bryozoan-rich Khabt-el Hajar Formation. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485,** doi 10.1144/SP485.2

Villas, E., Vizcaïno, D., Álvaro, J. J., Destombes, J. & Vennin, E. 2006. Biostratigraphic control based on brachiopods of the latest Ordovician glaciogenic unconformity in Alnif, eastern Anti-Atlas, Morocco. *Geobios*, **39** (5), 727–737.

Vinther, J., van Roy, P. & Briggs, D. E. G. 2007. Machaeridians are Palaeozoic armoured annelids. *Nature*, **451**, 185–188.

Vinther, J., Parry, L., Briggs, D. E. G. & Van Roy, P. 2017. Ancestral morphology of crown- group molluscs revealed by a new Ordovician stem aculiferan. *Nature*, **542**, 471–474.

Wang, Y., Boucot, A. J., Rong, J. Y. & Yang, X. C. 1987. Community paleoecology as a geologic tool: the Chinese Ashgillian–Eifelian (latest Ordovician through Devonian) as an example. *Geological Society of America, Special Papers*, **211**, 1–100.

Ware, D. & Lefebvre, B. 2007. Abnormalities in the Lower Ordovician cornute *Phyllocystis* Thoral (Echinodermata: Stylophora) of Montagne Noire (southern France): implications for plate homology and phylogeny. *Journal of Paleontology*, **81**, 779–787.

Zalasiewicz, J., Taylor, L. S., Rushton, A. W. A., Loydell, D. K., Rickards, R. B. & Williams, M. 2009. Graptolites in British stratigraphy. *Geological Magazine*, **146** (6), 785–850.

Zamora, S. & Sumrall, C. D. (this vol. a). *Hexedriocystis*, an aberrant eocrinoid convergent with edrioasteroids from the Upper Ordovician of Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**, doi: 10.1144/SP485.

Zamora, S. & Sumrall, C. D. (this vol. b). The first report of coronates (Echinodermata) from Africa. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485**.

Zamora, S., Rahman, I. A. & Ausich, W. I. 2015. Palaeogeographic implications of a new iocrinid (Disparida) from the Ordovician (Darriwilian) of Morocco. *Peer Journal*, **3**, e1540, doi: 10.7717/peerj.1450.

Zamora, S., Nardin, E., Esteve, J. & Gutiérrez-Marco, J. C. (this vol.). New rhombiferan blastozoans (Echinodermata) from the Late Ordovician of Morocco. *In*: Hunter, A. W., Álvaro, J. J., Lefebvre, B., van Roy, P. & Zamora, S. (eds), *The Great Ordovician Biodiversification Event: Insights from the Tafilalt Biota, Morocco*. Geological Society, London, Special Publication, **485,** doi: 10.1144/SP485.10.

Zurbriggen, R. 2015. Ordovician orogeny in the Alps: a reappraisal. *International Journal of Earth Sciences*, **104**, 335–350.

FIGURE CAPTIONS

Figure 1. A. Sketch of main geographical units in NW Africa. B. Geological sketch showing the geographical distribution of Ordovician exposures throughout the Anti-Atlas, High Atlas and Ouagarta massif; modified from Destombes *et al*. (1985); abbreviations: Ar- Aroudane jbel, BI- Bou Ingarf jbel, BK- Bou el-Khoualb, BR- Bou Rdim, OU- Ouzina jbel, Ti- Timzizouit jbel and TR- Tizi n'Rsas.

Figure 2. Stratigraphical chart of the Miaolingian-Hirnantian in the Anti-Atlas with setting of main gaps; abbreviations of Hirnantian glacial tunnels: Ad- Adrar (Merzouga sheet), Am- Amessoui, Ar- Aroudane, Im-Ti- Imzizoui-Timzizouit, Ti- Taouirt n'Irjdelen, TR: Tizi n'Rsas; modified from Álvaro *et al*. (2014c, d), Benharref *et al*. (2014a, b, c) and Álvaro & Vizcaïno (2018).

Figure 3. Field aspect of the Feijas Externes Group in the Tafilalt district. A. Centimetre-scale glauconitic sandstone/siltstone alternations rich in hematite cement, forming the basal part of the Upper Fezouata Formation, South of Jbel Ouzina. B. Thin-section photomicrograph (parallel light) of clast-supported glauconitic-quartz sandstone cemented with hematite; detail of previous picture; scale = 1 mm. C. Three shallowing-upward cycles (tops arrowed) forming the Tachilla Formation, North of Jbel Ouzina. D. Thin-section photomicrogrpah of a clast- to cement-supported ironstone with scattered ooids from the Tachilla Formation; detail of previous image; scale = 1 mm.

Figure 4. Field aspect of the Ktaoua Group in the Maider-Tafilalt district. A. Claystone-dominated succession with scattered metre-scale carbonate concretions of the Lower Ktaoua Formation, close to Alnif; scale = 1 m. B. Channels interbedded in the shales of the Lower Ktaoua Formation showing angular cobble clasts embedded in a brachiopod shell matrix, reflecting high-energy episodes, close to Alnif. C. Phosphatic layer marking the Lower Ktaoua/Upper Tiouririne contact at Alnif. D. Coquina on a silty carbonate surface with branching bryozoans (b), orthoceratids (o), tentaculitids (te) and trilobites (tr), from the Upper Tiouririne Formation at Jbel Aroudane; scale = 4 cm. E. Channel interbeds of the Upper Tiouririne Formation with superposed scouring surfaces and granule-to-boulder clasts, close to Alnif. F. Thin-section photomicrograph (parallel light) of a bryozoan floatstone with disarticulated echinodermossicles and brachiopods, embedded in a silty carbonate matrix; Upper Tirouririne Formation at Jbel Aroudane; scale = 1 mm.G. Coquina of disarticulated echinoderm plates from the top of the Upper Tiouririne Formation at Tizi n'Rsas. H. Thin-section photomicrograph (parallel light) illustrating the traditional orthoceratid-rich carbonate siltstone

that punctuate the monotonous shales of the Upper Ktaoua Formation, Jbel Aroudane; scale = 1 mm.

Figure 5. Field aspect of the Khabt-el-Hajar Formation and the Upper Formation of the Second Bani Group in the Maider-Tafilalt district. A. Second shallowing-upward trend of marlstone-to-limestone rich in echinoderm-bryozoan debris from the northwestern edge exposure of the formation, north of Erfoud. B. Destombes' (1987) "ravinement surface" (arrowed) separating two packages of echinoderm-bryozoan limestones, reinterpreted as an onlapping geometry of a palaeorelief formed by skeletal shoals, north of Erfoud. C. Aspect of bryozoan meadows from the upper part of the Khabt-el-Hajar Formation exhibiting parautochthonous robust and fragile branching and dendroid bryozoans, north of Erfoud. D. Alluvial channel (scouring base arrowed) infilled with clast-supported conglomerates of the Alnif Member, subsequently capped by fluvial sandstone bars at the base of Jbel Boulakoualeb. E. Western contact (arrowed) of the Hirnantian Alnif tunnel channel, incised in the Upper Tiouririne Formation (subhorizontal beds on the left). F. Alternating conglomerate and sandstone beds with subparallel and low-angle laminae reflecting pulsations in the infill of the Hirnantian Alnif tunnel channel. G. Clast-supported conglomerate highlighted by the orange colour of the silty carbonate clasts eroded from the Lower Ktaoua and Upper Tiouririne formations; Alnif Member at Tizi n'Rsas tunnel channel. H. Outsized sandstone clasts embedded in a homogeneous claystone of the Tamekhart Member; glaciogenic diamictite at Jbel Imzizoui. I. Overlying cross-stratified sandstones of the Amouktir Member at Jbel Imzizoui.

Figure 6. Updated litho-and chronostratigraphical charts of the Ordovician in the Anti-Atlas, Morocco. Global chronostratigraphic scale subdivisions according to Bergström *et al.* (2009); regional scale updated by Gutiérrez-Marco *et al.* (2017) and Colmenar *et al.* (2017). Lithostratigraphy after Destombes (in Destombes *et al*.1985). Chitinozoan zonation updated from Paris *et al*. (1990, 1999) in Gutiérrez-Marco *et al.* (2015, 2017b). Graptolite zones after Gutiérrez-Marco & Martin (2016) and Gutiérrez Marco *et al*. (2017b).

Figure 7. Chronostratigraphical distribution of third-order sequences described in the Zagora-Foum Zguid depocentre and the Maider-Tafilalt districts, central and eastern Anti-Atlas; based on Destombes *et al*. (1985), Álvaro *et al*. (2007b, 2014c, d), Ghienne *et al*. (2007a), Loi *et al*. (2010), Benharref *et al*. (2014a, b, c), Colmenar & Álvaro (2015), and Álvaro & Vizcaïno (2018).

ANNEX 1. Updated Ordovician fossil record

In the Anti-Atlas, taxonomic works have been focusing on trilobites (Choubert et al. 1955; Destombes 1963c, 1966, 1967a, b, 1972, 1985a, b, c, d, 1987, 2000, 2006a-j; Destombes & Henry 1987; Rábano 1990; Henry 1991; Henry & Destombes 1991; Henry *et al*. 1992; Vidal 1998a, b; Bruton 2008; Fortey 2009, 2011a, b; Rábano *et al*. 2010, 2014; Martin *et al*. 2016b; Fortey & Edgecombe 2017; Pereira *et al*. 2017; Gutiérrez-Marco *et al*. 2017, 2019; Drage *et al.* 2019), radiodonts (Van Roy & Tetlie 2006; Van Roy & Briggs 2011; Van Roy *et al.* 2015a), aglaspidids (Van Roy 2006a, b; Ortega-Hernández *et al.* 2016), cheloniellid arthropods (Alessandrello & Bracchi 2006, Van Roy 2006a), echinoderms (Termier & Termier 1950a, b, 1970; Ubaghs 1963, 1968, 1969; Choubert *et al*. 1953; Chauvel 1966a, b, 1969a, b, 1971a, b, 1977, 1978; Paul 1968; Chauvel & Régnault 1986; Donovan & Savill 1988; Cripps 1990; Beisswenger 1994; Le Menn & Spjeldnaes 1996; Ruta 1999; Lefebvre & Fatka 2003; Parsley & Gutiérrez Marco 2005; Lefebvre 2007; Lefebvre & Botting 2007; Lefebvre *et al*. 2007, 2008, 2010, 2016c, 2019; Nardin 2007; Régnault 2007; Ware & Lefebvre 2007; Lefebvre & Roch 2009; Noailles *et al*. 2010; Sumrall & Zamora 2011; Allaire *et al*. 2015, 2017; Martin *et al.* 2015; Nardin & Régnault 2015; Zamora *et al.* 2015; Reich *et al.* 2017; Hunter & Ortega-Hernández 2017), brachiopods (Havlíček 1970, 1971; Mergl 1981, 1983; Villas *et al*. 2006; Colmenar & Álvaro 2015; Candela & Harper 2016; Colmenar 2016), hyoliths (Marek 1983; Valent & Corbacho 2015; Martí Mus 2016), sachitids (Vinther *et al.* 2017), bivalves and rostroconchs (Termier & Termier 1950b; Babin & Destombes 1990; Polechová 2016), gastropods, paragastropods and tergomiids (Horný 1997a, b, c; Ebbestad & Lefebvre 2015; Ebbestad 2016), graptolites (Destombes & Willefert 1959; Martin *et al.* 2016a; Gutiérrez-Marco & Martin 2016), conodonts (El Bourkhissi & Sarmiento 1997; Lehnert *et al*. 2016), ostracods (Gutiérrez-Marco *et al*. 1997), sponges (Botting 2007, 2016), conulariids (Van Iten *et al.* 2016), cephalopods (Kröger & Lefebvre 2012), machaeridians (Chauvel 1966c; Vinther *et al.* 2007), palaeoscolecids and soft-bodied metazoans (Samuelsson *et al*. 2001; Alessandrello & Bracchi 2003; Van Roy 2006a; Gaines *et al*. 2012; McGabhan 2012; Gutiérrez-Marco & García-Bellido 2015; Martin *et al.* 2016c; Gutiérrez Marco *et al*. 2017a; Kouraiss *et al*. 2018; McGabhan *et al*. 2019), cornulitids (Gutiérrez-Marco & Vinn 2018), bryozoans (Destombes *et al*. 1971; Ernst *et al*. 2015; Jiménez-Sánchez *et al*. 2015a, b, 2016), organic-walled microfossils (Deunff 1968a, b, 1977; Elaouad-Debbaj, 1984a, b, 1986, 1988a, b; Paris 1990; Nowak *et al*. 2015, 2016) and some ichnofossils (Gibb *et al.* 2010; Azizi *et al.* 2017). To these fossil associations are added the palaeontological contributions reported in this special volume, which include conulariids (Van Iten *et al.*), brachiopods (Colmenar *et al.*; Villas & Colmenar), echinoderms (crinoids by Botting this vol.; stylophorans by Lefebvre *et al*.; edrioasteroids by Sumrall & Zamora; coronates and *Hexedriocystis* by Zamora & Sumrall; and rhombiferans by Zamora *et al*.), graptolites (Gutiérrez-Marco *et al*.), molluscs (Ebbestad *et al*.), trilobites (Gutiérrez-Marco *et al*. this vol.), and problematica (agglutinated tubes by Muir *et al*.).

The Lower Fezouata and Upper Fezouata formations contain about 200 taxa that have been reported in the so-called Fezouata Biota (Van Roy *et al.* 2010, 2015b; Lefebvre *et al*. 2016b, c; Vaucher *et al*. 2016, 2017; Saleh *et al.* 2018, 2019), many of which still remain undescribed. The biota includes algae (such as chaetocladids); sponges (*Choia*, *Choiaella*, *Hamptonia*, *Pirania*, *Valospongia* and other demosponges, hexactinellids, leptomitids and wapkiids); cnidarians (*Archaeoconularia*, *Eoconularia* and *Sphenothallus*); brachiopods (*Angusticardinia*, *Celdobolus*, *Elliptoglossa*, *Monobolina*, *Orbithele*, *Paurorhis*, *Plectorthis*, *Ranorthis*, *Tarfaya* and *Wosekella*); undeterminated bryozoans; molluscs such as bivalves (*Alococoncha*?, *Babinka*, *Cardiolaria*?, *Cienagomya*?, *Coxiconchia*, *Ekaterodonta*, *Glyptarca*, *Praenucula*? and *Redonia*), rostroconchs (*Ribeiria*, *Tolmachovia*?), paragastropods (*Pelecyogyra*), gastropods (*Lesueurilla* and *Sinuites*), tergomyans (*Carcassonnella* and *Thoralispira*), cephalopods (a.o. *Bactroceras*, *Bathmoceras*, *Destombesiceras*, *Polymeres*, *Protocyptendoceras* and *Rioceras*) and other stem mollusc groups (sachitids such as *Calvapilosa*, halkieriids, helcionellids and wiwaxiids); hyoliths (*Cavernolites*, *Gompholites*, *Elegantilites*, *Gamalites*?, *Nephrotheca*? *and Pauxilites*); annelids (*Plumulites*, different polychaetes and isolated scolecodonts), cycloneuralia (*Palaeoscolex*? and priapulids), lobopodians, radiodonts (*Aegirocassis* and other hurdiids, and amplectobeluids), euarthropods (*Brachyaglaspis*, *Mollisonia*, *Pseudoangustidontus*, *Thelxiope*, *Tremaglaspis*, canadaspidids, leanchoiliids, aglaspidids, cheloniellids, basal chelicerates, xiphosurids, chasmataspidids, eurypterids, liwiids, naraoiids, marrellid and acercostracan marrellomorphs, and possible helmetiids, pycnogonids and retifaciids); trilobites (*Agerina*, *Ampyx*, *Anacheirurus*, *Apatokephalus*, *Asaphellus*, *Asaphopsis*, *Basilicus*, *Bathycheilus*, *Bavarilla*, *Cnemidopyge*, *Colpocoryphe*, *Dikelokephalina*, *Eoharpes*, *Euloma*, *Harpides*, *Foulonia*, *Kierarges*, *Lichakephalus*, *Megistaspis*, *Neseuretus*, *Nileus*, *Orometopus*, *Ogyginus*, *Parabathycheilus*, *Platycoryphe*, *Platypeltoides*, *Pharostomina*, *Pradoella*, *Prionocheilus*, *Selenopeltis*, *Symphysurus*, *Toletanaspis and Uralichas*) and agnostoids (*Geragnostus*), phyllocarids, ostracods, angustidontids and lepadomorph barnacles; echinoderms such as Crinoidea (*Iocrinus and Ramseyocrinus*), Diploporita (*Aristocystites* and *Palaeosphaeronites*), Edrioasteroidea (*Anedriophus*, *Argodiscus* and Rhenopyrgidae), Eocrinoidea (*Balantiocystis*, *Lingulocystis*, *Pareocrinus*? and *Rhopalocystis*), Rhombifera (*Macrocystella*), Soluta (*Plasiacystis*), Somasteroidea (*Cantabrigiaster*, a.o.), Stylophora (*Ampelocarpus*, *Amygdalotheca*, *Anatifopsis*, *Aspidocarpus*, *Balanocystites*, *Bohemiaecystis*, *Chauvelicystis*, *Chinianocarpos*, *Flabellicarpus*, *Galliaecystis*, *Hanusia*, *Lagynocystis*, *Nanocarpus*, *Peltocystis*, *Phyllocystis*, *Procothurnocystis*, *Prokopicystis and Vizcainocarpus*); graptolites (‘*Adelograptus*’, *Ancoragraptus*, *Araneograptus*, *Azygograptus*, *Baltograptus*, *Choristograptus*, *Clonograptus*, *Cymatograptus*?, *Dictyonema*, ‘*Didymograptus’*, *Hunnegraptus*, ‘*Kiaerograptus*’, *Koremagraptus*, *Paradelograptus*, *Paratemnograptus*, *Rhabdinopora*, *Schizograptus*?, ‘*Tetragraptus*’ and ?tuboids); conodonts (*Acodus, Cornuodus, Drepanodus, Drepanoistodus, Paltodus, Parapaltodus, Paroistodus, Periodon, Prioniodus, Scalpellodus, Scolopodus, Semiacontiodus, Stolodus, Tripodus* and *Tropodus*); chordates (dermal plates) and problematica (e.g., Van Roy *et al*. 2010, 2015b; Martin *et al*. 2016a, b).

The Tachilla Formation has yielded trilobites (*Bathycheilus*, *Colpocoryphe*, *Dionide*, *Ectillaenus*, *Eohomalonotus*, *Morgatia*, *Neseuretus*, *Ormathops*, *Placoparia*, *Plaesiacomia*, *Selenopeltis* and ‘*Zeliszkella’*), brachiopods (*Euorthisina* and ‘*Orthambonites*’), ostracods (*Brephocharieis*), echinoderms [Diploporita (*Calix*), Stylophora (*Bohemiaecystis*)], hyoliths (*Elegantilites*, *Gompholites* and *Pauxillites*), bivalves (*Praenucula* and *Redonia*), tergomyans (*Cyrtodiscus, Tachillanella* and *Thoralispira*?), gastropods (*Lesueurilla*, *Ptychonema*, *Sinuites*, *Selesinuites* and *Tropidodiscus*), graptolites (*Aulograptus*?, *Corymbograptus*, *Didymograptus*, *Hustedograptus*?, *Jenkinsograptus* and *Xiphograptus*?) and undetermined lingulaceans, orthoconic nautiloids and conulariids.

The First Bani Group contains trilobites (such as *Basilicus*, *Bathycheilus*, *Caudillaenus*, *Cekovia*, *Colpocoryphe*, *Crozonaspis*, *Degamella*, *Eccoptochile*, *Ectillaenus*, *Eoharpes*, *Eohomalonotus*, *Iberocoryphe*, *Isabelinia*, *Kerfornella*, *Marrolithus*, *Morgatia*, *Mytocephala*, *Neseuretus*, *Nobiliasaphus*, *Parabarrandia*, *Phacopidina*, *Placoparia*, *Plaesiacomia*, *Selenopeltis and Uralichas*), cheloniellid euarthropods (*Duslia* and possibly *Triopus*), brachiopods (*Atlantida*, *Euorthisina*, *Mimella*, ‘*Orthambonites’*, *Paterorthis*, *Tafilaltia* and *Tissintia*); echinoderms including Crinoidea (*Iocrinus* and *Trichinocrinus*?), Diploporita (*Aristocystites, Calix, Oretanocalix*, *Isidalocystis*, *Phlyctocystis* and *Sphaeronites*?), Edrioasteroidea (*Belochthus*?, *Isorophus* and *Moroccodiscus*), Eocrinoidea (*Ascocystites*), Ophiuroidea, Stylophora (*Anatifopsis, Aspidocarpus, Bohemiaecystis, Destombesicarpus, Diamphidiocystis, Eumitrocystella, Milonicystis, Nanocarpus, Procothurnocystis* and *Scotiaecystis*) and incertae sedis (*Hexedriocystis*); molluscs such as tergomyans (*Quasisinuites*), bivalves (*Cardiolaria*, *Coxiconchia, Cyrtodontula*?, *Hemiprionodonta* and *Redonia*) and rostroconchs (*Ribeiria*); hyoliths (*Elegantilites* and *Gompholites*), graptolites (*Didymograptus, Dendrograptus* and *Ptilograptus*), conulariids (*Archaeoconularia*), paleoscolecidans (*Gamascolex*), conodonts (*Coleocerodontus*?, *Distomodus*?, *Drepanoistodus*?, *Paraprioniodus*?, *Phragmodus*?, *Plectodina* and ‘*Scandodus’*), ostracods (‘*Dilobella*’, ‘*Piretopsis’*, *Quadrijugator*?*, Reuentalina* and *Sigmoopsis*?), paropsonemid eldonioids (*Discophyllum*), agglutinated problematic tubes (*Onuphionella*) and undetermined lingulaceans, asterozoans, nautiloids, and bryozoans.

The Lower Ktaoua Formation has yielded trilobites (*Actinopeltis, Calymenella, Colpocoryphe, Crozonaspis*, *Dalmanitina, Deanaspis*, *Eccoptochile*, *Eohomalonotus*, *Eudolatites*, *Flexicalymene*, *Kloucekia*, *Mucronaspis*, '*Ogmasaphus'*, *Onnia*, *Ormathops*, *Placoparia*, *Plaesiacomia*, *Primaspis*, *Prionocheilus*, '*Scotiella*', *Selenopeltis*, *Sokhretia* and *Stenopareia*), brachiopods (*Aegiromena*, *Bicuspina*, *Dalmanella*, *Drabovia*, *Drabovinella*, *Eostropheodonta*, *Gelidorthis*, *Heterorthis*, *Howellites*, *Irhirea*, *Mimella*, *Onniella*, *Protomendacella*, *Rafinesquina*, *Rostricellula*, *Schizocrania*, *Svobodaina*, *Tafilaltia*, *Tazzarinia Triplesia*), echinoderms such as Diploporita (*Calix*, *Codiacystis*, *Destombesia*, *Maghrebocystis* and *Phlyctocystis*), Edrioasteroidea (*Isorophusella*, *Spinadiscus* and *Streptaster*), Eocrinoidea (*Cardiocystites*), Ophiuroidea, Rhombifera (*Arachnocystites*, *Deutocystites*, *Echinosphaerites*, *Heliocrinites* and *Homocystites*), Soluta (*Dendrocystites*) and Stylophora (*Anatifopsis*, *Aspidocarpus*, *Barrandeocarpus* and *Eumitrocystella*?); molluscs such as tergomyans (*Sinuitopsis*), gastropods (*Atlantophon*, *Bucanopsina*, *Deaechospira*, *Nonorios*, *Radvanospira* and *Tritonophon*) and bivalves (*Myoplusia*, *Phestia*?, *Pseudarca*? and *Praenucula*); hyoliths (*Elegantilites*, *Joachimilites*?, *Leolites*, *Nephroteca*, *Panitheca* and *Sololites*?), machaeridians (*Plumulites*), graptolites (*Climacograptus*, *Dictyonema* and *Ptilograptus*), paropsonemid eldonioids (*Discophyllum* and *Praeclarus*), agglutinated problematic tubes (*Onuphionella*) and undetermined conulariids, bivalves, ostracods, asterozoans, and bryozoans.

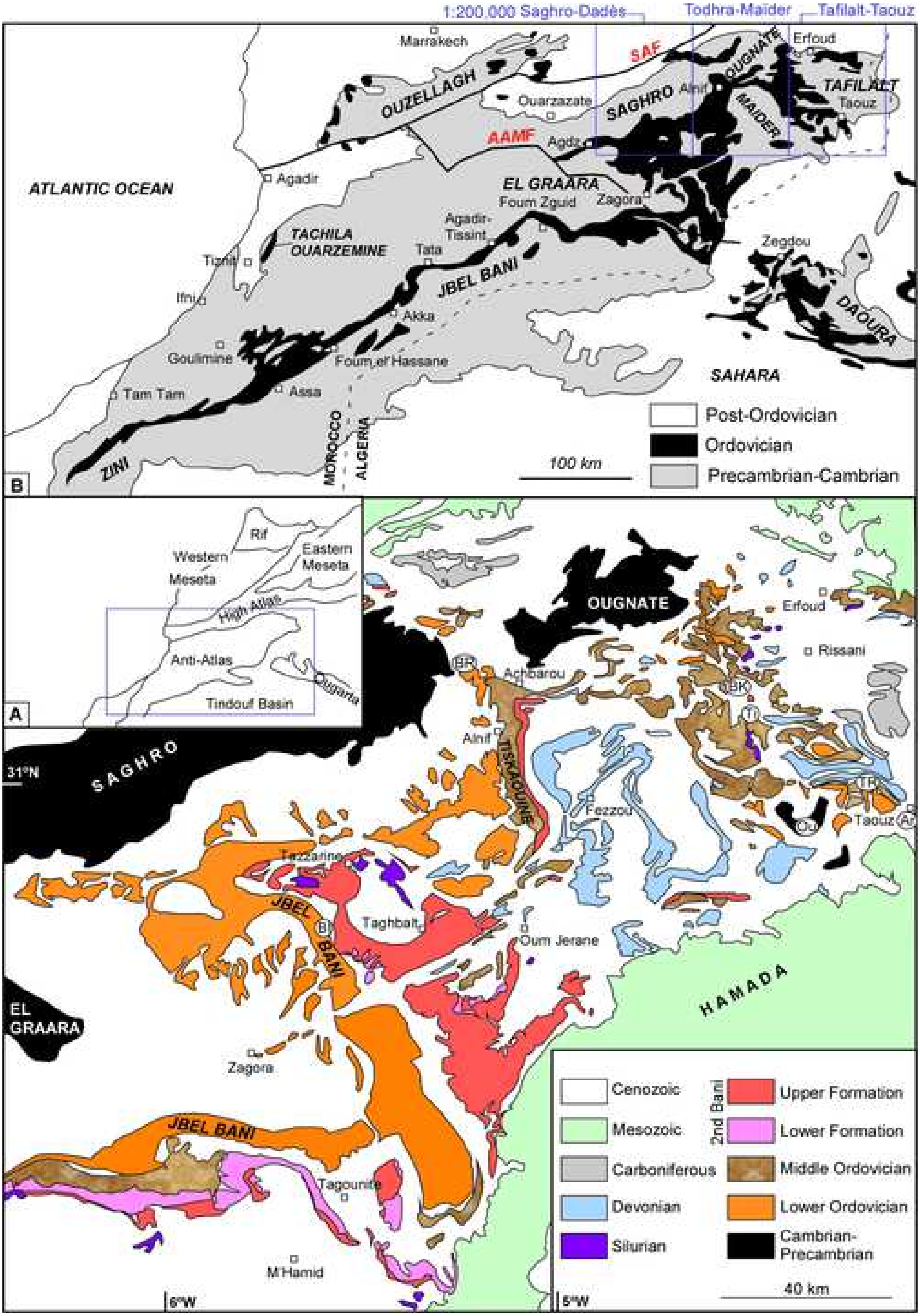
The Upper Tiouririne Formation contains trilobites (*Actinopeltis*, *Baniaspis*, *Calymenella*, *Cyclopyge*, *Declivolithus*, *Delgadoa*, *Eudolatites*, *Flexicalymene*, *Heterocyclopyge*, *Kloucekia*, *Mucronaspis*, *Nobiliasaphus*, *Onnia*, *Pricyclopyge*, *Prionocheilus*, *Selenopeltis* and *Sokhretia*), agnostoids (*Corrugatagnostus*), aglaspidid and chelionellid arthropods (*Chlupacaris* and *Triopus*), brachiopods (*Aegiromena*, *Cliftonia*, *Destombesium*, *Drabovia*, *Drabovinella*, *Eostropheodonta*, *Hirnantia*, *Heterorthis*, *Eostropheodonta*, *Heterorthis*, *Kiaeromena*?, *Orbiculoidea*, *Rafinesquina*, *Rostricellula*, *Sbovodaina*, *Schizocrania* and *Tafilaltia*), echinoderms such as Asteroidea, Coronata (*Mespilocystites*), Crinoidea (*Euptychocrinus*?, *Isthloucrinus* and *Rosfacrinus*), Diploporita (*Codiacystis*, *Destombesia* and *Maghrebocystis*), Edrioasteroidea (*Euryeschatia*, *Hemicystites*, *Moroccopyrgus*, *Panidiscus* and *Streptaster*), Ophiuroidea, Rhombifera (*Echinosphaerites*), Stylophora (*Aspidocarpus*, *Barrandeocarpus*? and *Eumitrocystella*?), and incertae sedis (*Hexedriocystis*); molluscs such as tergomyans (*Sinuitopsis*), gastropods (*Sinuites*, *Deaechospira* and *Radvanospira*), bivalves (*Praenucula*) and cephalopods (*Tafadnatoceras*), conulariids (*Archaeoconularia* and *Pseudoconularia*), cornulitids, paropsonemid eldonioids (*Discophyllum*), biserial graptolites (*Neodiplograptus*? and *Normalograptus*?) and agglutinated problematic tubes (*Onuphionella*).

The Upper Ktaoua Formation has yielded trilobites (*Actinopeltis*, *Amphitryon*, *Baniaspis*, *Brogniartella*, *Calymenella*, *Chlustinia*, *Dionide*, *Dreyfussina*, *Eccoptochile*, *Eudolatites*, *Flexicalymene*, *Kloucekia*, *Lichas*, *Mucronaspis*, *Octillaenus*, *Onnia* and *Selenopeltis*), brachiopods (*Chonetoidea*, *Comatopoma*, *Eochonetes* and *Eostropheodonta*), echinoderms such as Diploporita (*Destombesia* and *Maghrebocystis*), Rhombifera (*Arachnocystites*, *Echinosphaerites* and *Heliocrinites*) and Stylophora (*Barrandeocarpus*?); molluscs, including cephalopods (*Armenoceras, Wadema* and ormoceratids), gastropods (*Allossospira*, *Lophospira* and *Sinuites*) and bivalves (*Sluha*, *Cleionychia* and *Praenucula*); hyoliths (*Elegantilites*), conularids (*Archaeoconularia, Pseudoconularia*), machaeridians (*Plumulites*) and undetermined ostracods, rostroconch molluscs, and biserial graptolites (*Normalograptus*?).

In the Khabt-el-Hajar Formation, a complete assemblage of bryozoans has been described by Jiménez-Sánchez *et al.* (2015a, b, 2016), including cryptostomates (*Graptodictya*, *Ptilodictya*, *Stallodictya* and *Ulrichostylus*), fenestrates (*Enallopora*) and trepostomates (*Anaphragma, Aostipora*, *Atactoporella*, *Calloporella*, *Cyphotrypa*, *Decayia*, *Diplotrypa*, *Eridotrypa*, *Heterotrypa*, *Homotrypa, Monotrypa*, *Monticulipora*, *Parvohallopora*, *Prasopora*, *Radiotrypa* and *Trematopora*); associated with trilobites (*Brogniartella* and *Mucronaspis*; Destombes 1985c, 2006a, b; Le Menn & Spjeldnaes 1986) and brachiopods (*Drabovia* and *Paucicrura*; Havlíček 1970,1971; Villas & Colmenar this vol.)

The Katian-Hirnantian boundary lies within the Lower Formation of the Second Bani Formation. Its latest Katian part has yielded brachiopods (*Dalejina*, *Destombesium, Eostropheodonta* and *Hirnantia*), trilobites (*Actinopeltis*, *Cekovia*, *Dreyfussina*, *Mucronaspis* and *Onnia*) and diploporite echinoderms (*Herpetocystis* and *Magrebocystis*). In contrast, the Hirnantian part contains a diversified Hirnantia fauna including brachiopods (*Arenorthis, Clarkeia*, *Dalejina*, *Destombesium, Eostropheodonta, Fehamya, Hirnantia, Horderleyella, Kinnella, Plectothyrella* and '*Resserella*'), trilobites (*Calymenella* and *Mucronaspis*), gastropods (*Tritonophon, Radvanospira* and *Sinuites*), bivalves (*Ambonychia, Cleionychia, Cyrtodonta, Dzeruska, Modiolopsis* and *Nuculites*); echinoderms including Diploporita (*Magrebocystis*), Stylophora (*Anatifopsis*, *Barrandeocarpus*?, *Enoploura*? and *Nanocarpus*) and undetermined asterozoans and crinoids; cornulitids (*Cornulites*) and some bryozoans (Destombes 2006a, b; Álvaro *et al*. 2014a, b; Colmenar & Álvaro 2015; Gutiérrez-Marco & Vinn 2018; Ebbestad *et al.* this vol.; Colmenar *et al.* this vol.).

Boulders included in the glaciogenic sediments of the Alnif Member have yielded a redeposited fauna from the underlying Ktaoua Group, including allochthonous esthonioporine, trepostome and rhabdosemine bryozoans (Ernst *et al.* 2015), brachiopods (e.g., *Destombesium akkaensis* and *Eostropheodonta*? *tafilaltensis*; Colmenar & Álvaro 2015), bivalves, gastropods, echinoderms, cornulitids and orthoconic nautiloids mainly sourced from the Upper Tiouririne Formation. Finally, the Tamekhtart Member of the Upper Second Bani Formation has yielded brachiopods (*Arenorthis*, *Destombesium* and *Eostropheodonta*) and undetermined bryozoans, bivalves and trilobites. Sandstone interbeds of the Amouktir Member are locally rich in the brachiopods *Eostropheodonta*, *Hirnantia*, *Kinnella* and *Plectothyrella*; the latter represents the so-called *E. jebiletensis* association (Colmenar & Álvaro 2015), typical of the *Aphanomena* (=*Eostropheodonta*)-*Hirnantia* Community (Rong 1984, 1986; Wang *et al*. 1987).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Todhra-Maïder
Tafilalt-Taouz
Marrakech
Erfoud
SAF
OUZELLAGH
OUGNATE
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Taouz
Ouarzazate
SAGHRO
MAIDER
AAMF
Agdz
Agadir
ATLANTIC OCEAN
EL GRAARA
Foum Zguid
Zagora
Agadir-Tissint
TACHILA OUARZEMINE
Tata
Tiznit
Zegdou
JBEL BANI
Ifni
Akka
DAOURA
Goulimine
Foum el Hassane
SAHARA
Tam Tam
Assa
MOROCCO
ALGERIA
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Ordovician
Precambrian-Cambrian
B
Rif
Western Meseta
Eastern Meseta
High Atlas
Anti-Atlas
Ougarta
Tindouf Basin
A
OUGNATE
Erfoud
Rissani
BR
Achbarou
BK
T
Alnif
TISKAOUINE
31°N
SAGHRO
Fezzou
TR
Taouz
Ar
Ou
Tazzarine
JBEL BANI
BI
Taghbalt
Oum Jerane
HAMADA
EL GRAARA
Zagora
JBEL BANI
Tagounite
M'Hamid
6°W
5°W
Cenozoic
Mesozoic
Carboniferous
Devonian
Silurian
2nd Bani
Upper Formation
Lower Formation
Middle Ordovician
Lower Ordovician
Cambrian-Precambrian
40 km

figure 2

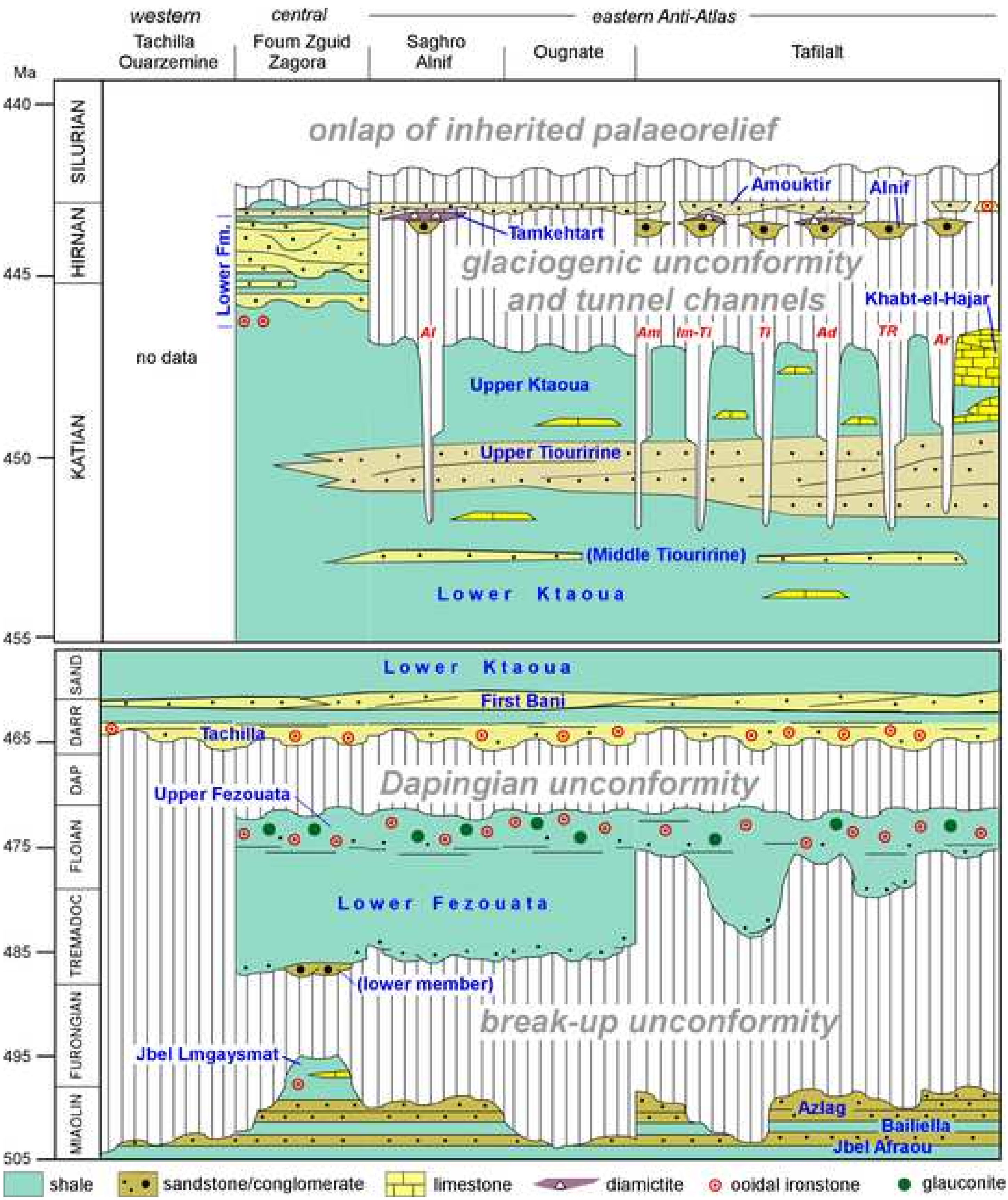

western
central
eastern Anti-Atlas
Tachilla Ouarzemine
Foum Zguid Zagora
Saghro Alnif
Ougnate
Tafilalt
Ma
440
445
450
455
465
475
485
495
505
SILURIAN
HIRNAN
KATIAN
SAND
DARR
DAP
FLOIAN
TREMADOC
FURONGIAN
MIAOLIN
onlap of inherited palaeorelief
Amouktir
Alnif
Tamkehtart
Lower Fm.
glaciogenic unconformity
and tunnel channels
Khabt-el-Hajar
Al
Am
Im-Ti
Ti
Ad
TR
Ar
no data
Upper Ktaoua
Upper Tiouririne
(Middle Tiouririne)
Lower Ktaoua
Lower Ktaoua
First Bani
Tachilla
Dapingian unconformity
Upper Fezouata
Lower Fezouata
(lower member)
break-up unconformity
Jbel Lmgaysmat
Azlag
Bailiella
Jbel Afraou
shale
sandstone/conglomerate
limestone
diamictite
ooidal ironstone
glauconite

figure 3

Click here to access/download;figure;figu3.jpg

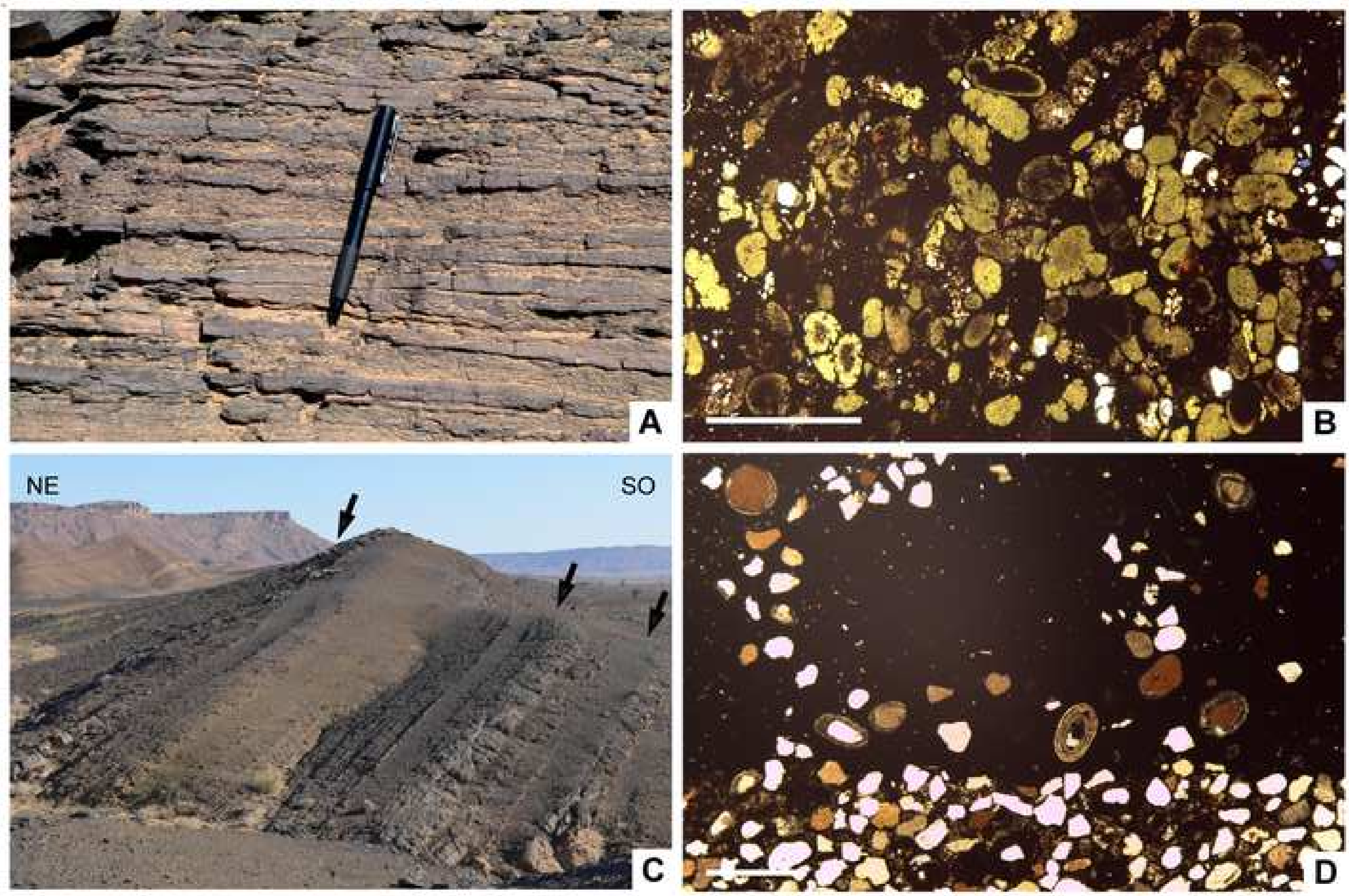


figure 4

Click here to access/download;figure;figu4.jpg

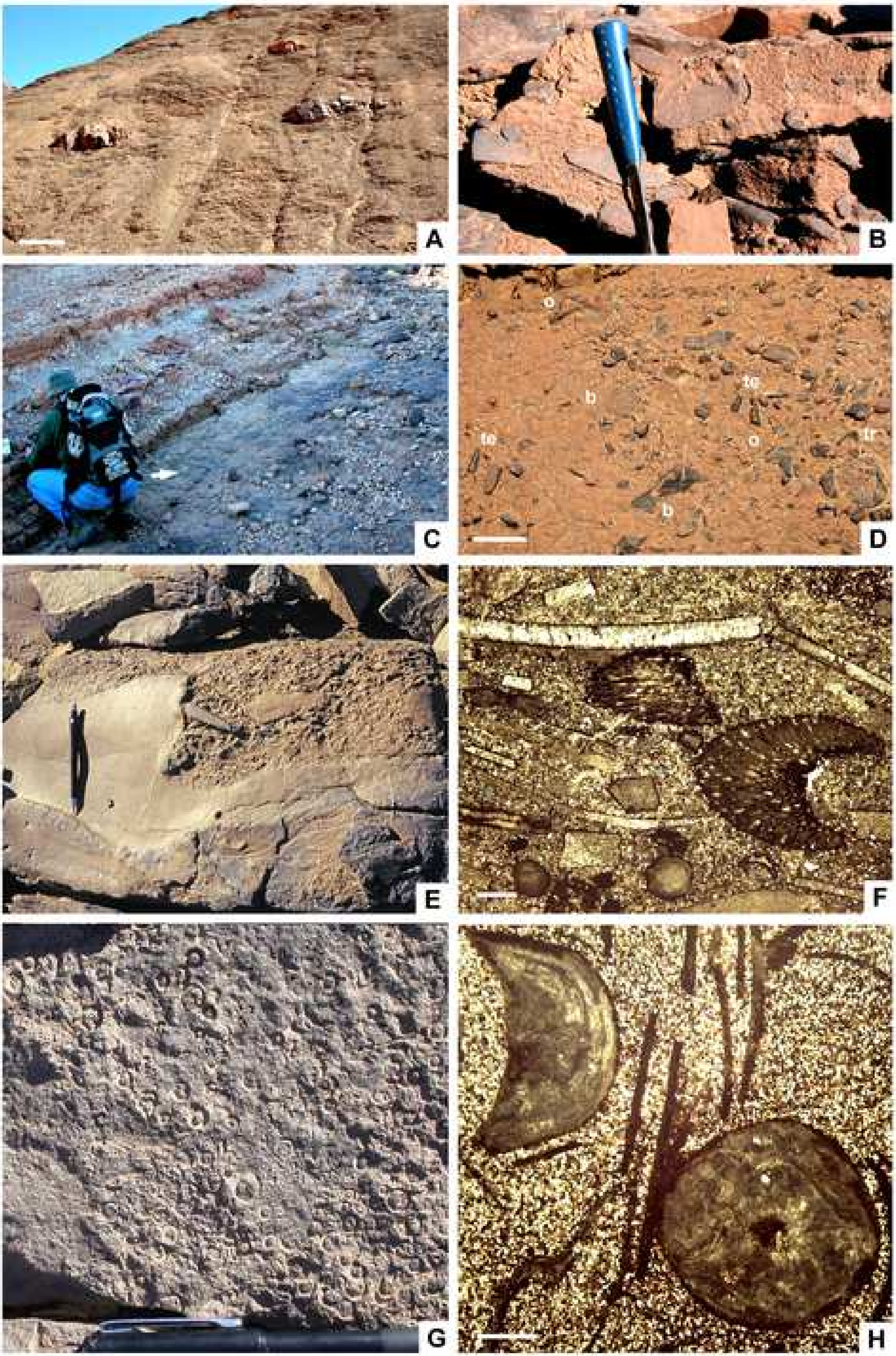


figure 5

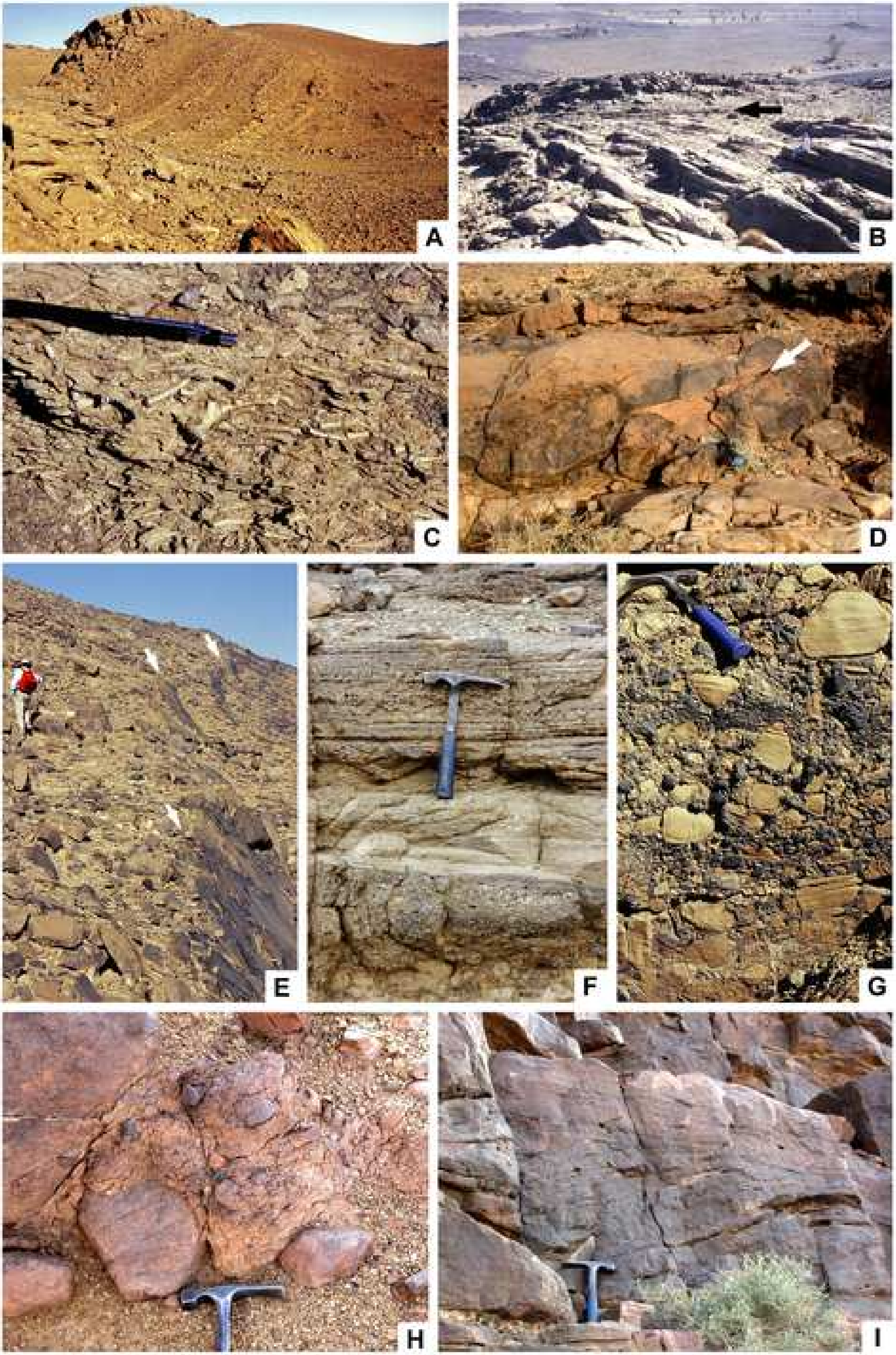


figure 6

Click here to access/download;figure;figu6.jpg

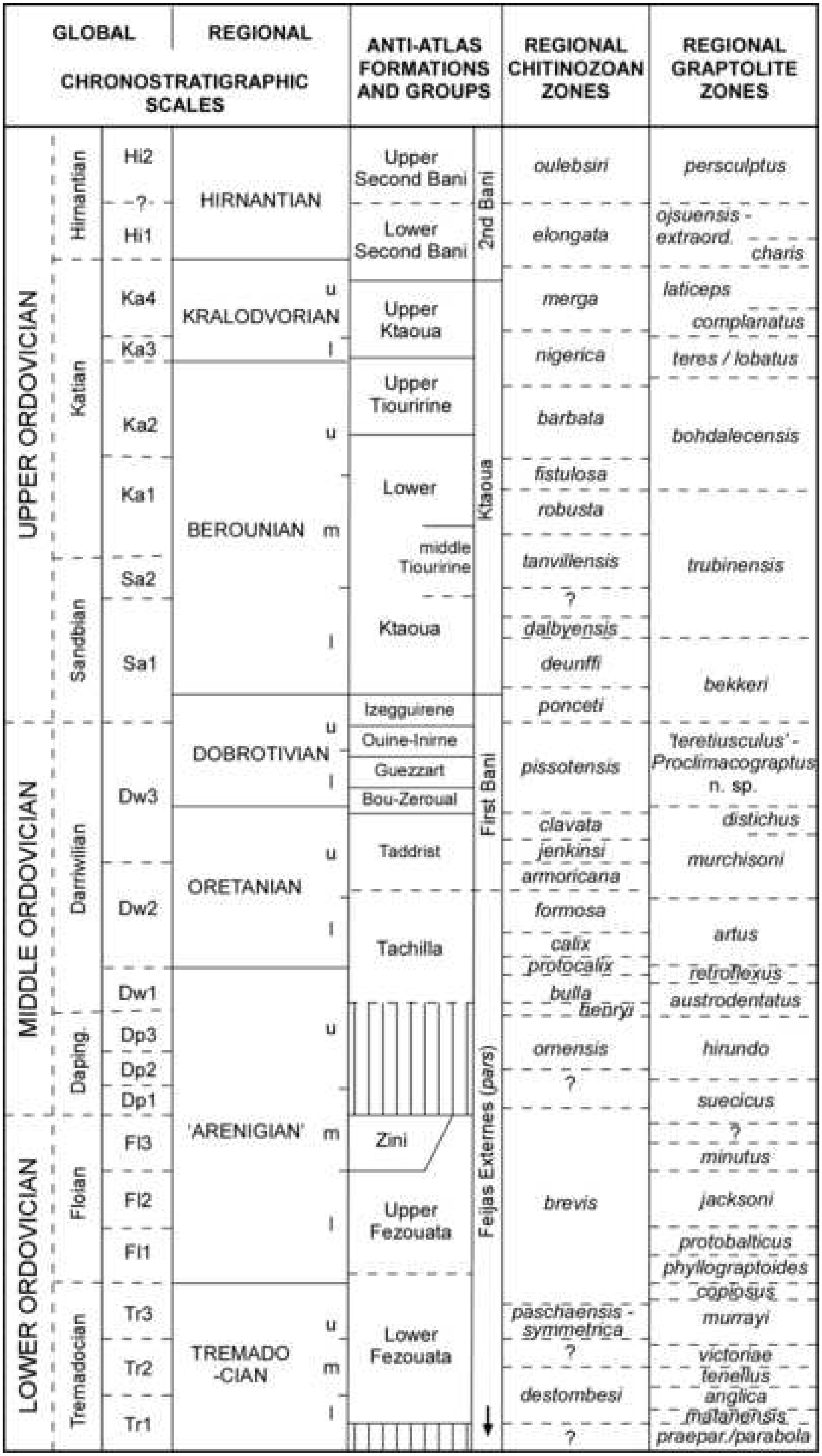
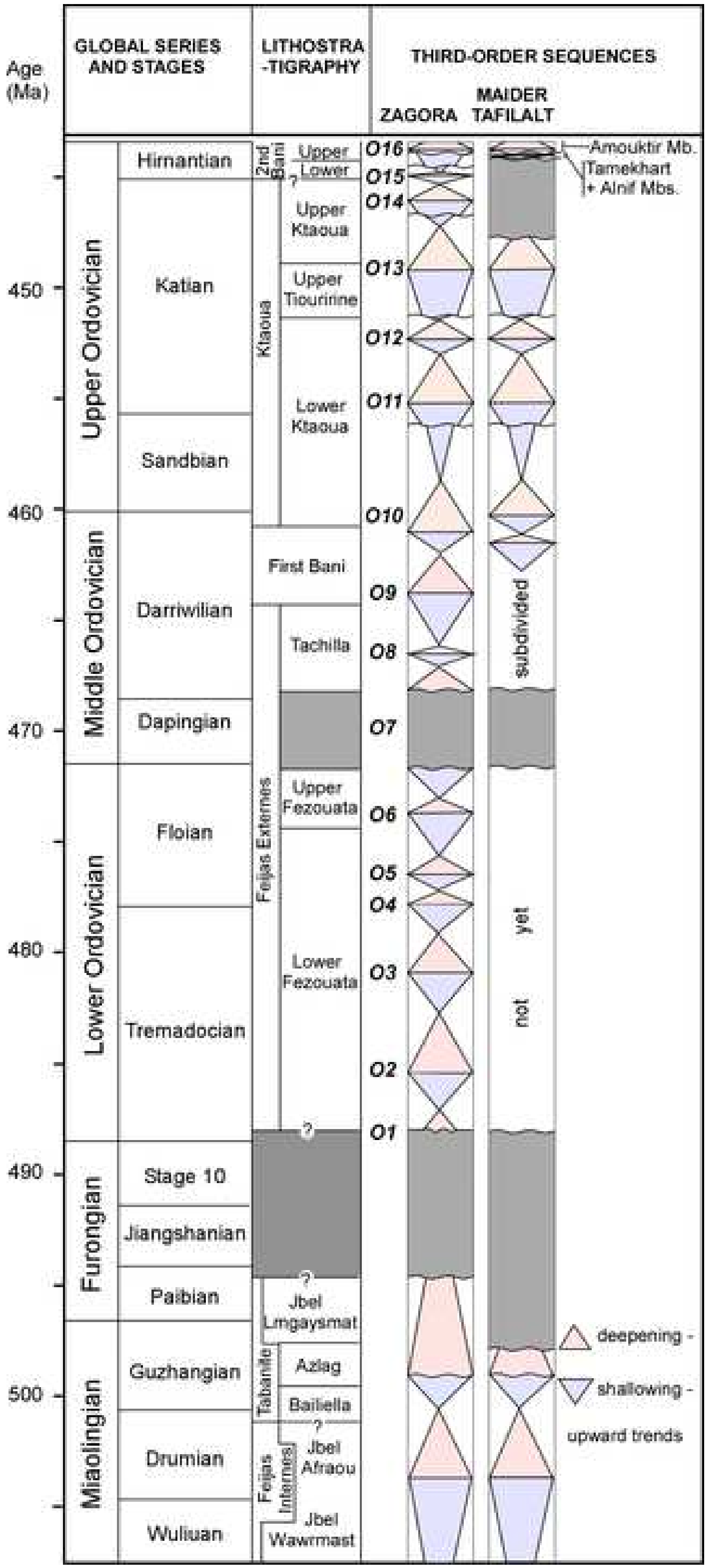


figure 7 Click here to access/download;figure;figu7.jpg



Apendix

Click here to access/download
supplementary material (not datasets)
APPENDIX.docx