International Journal of Earth Sciences (2021) 110:1531–1544
https://doi.org/10.1007/s00531-021-02028-6

ORIGINAL PAPER

Middle and Late Devonian paleogeography of the eastern Anti-Atlas (Morocco)

Jobst Wendt[1]

Received: 22 September 2020 / Accepted: 12 March 2021 / Published online: 17 April 2021

Abstract
The eastern Anti-Atlas of Morocco represents one of the most completely exposed and perfectly documented biostratigraphic records of the entire Devonian worldwide. Paleogeographically it is clearly differentiated into shallow basins, pelagic platforms, and land areas which are newly defined and illustrated, one from the top of the Middle Devonian, the other from the middle Famennian as two of the most characteristic intervals. The dominant paleogeographic feature is the T-shaped Tafilalt Platform which, in spite of common unconformities and hiatuses, provides the best-documented biostratigraphic record through the entire Devonian. The westernmost termination of this platform was emerged during most of the Devonian (and locally even earlier) and became only flooded again by the Tournaisian transgression. In contrast to previous interpretations, this area is considered as autochthonous. In the Mader Basin subsidence was up to one hundred times higher with respect to the adjacent platforms, but water depth during the Middle Devonian to middle Famennian interval generally remained above storm-wave base. Devonian rocks are only patchily and incompletely preserved on the Mader Platform, which can be considered as an intermittently flooded peninsula connected to the Lower Paleozoic farther west. The major paleotectonic element of the entire area is the Great Anti-Atlas Fault, a sinistral strike-slip fault, which sharply confines the above-mentioned realms in the south.

Keywords Devonian · Paleogeography · Anti-Atlas · Morocco · Biostratigraphy

Introduction

The Anti-Atlas is an approximately 800 km long mountain range in southern Morocco which extends from the Algerian/Moroccan border in the east until the Atlantic Ocean in the west. It is situated south of the High Atlas Mountains, which are sharply limited by the South Atlas Fault and passes gradually into the Tindouf Basin in the south (Fig. 1). In the eastern Anti-Atlas, complete sequences from the Upper Precambrian into the Lower Carboniferous are perfectly exposed and, due to relatively weak tectonic shortening, reveal the depositional realms in unique completeness. Due to the absence of vegetation, prominent marker beds can often be followed for tens of kilometers allowing perfect lithostratigraphic correlations and the reconstruction of depositional patterns over large distances. While in the western and central Anti-Atlas Precambrian and Lower Paleozoic rocks prevail, in the eastern part, which covers a surface of about 20,000 km^2, deposits of Devonian age are largely exposed in predominantly E–W trending synclines. They display a wide range of depositional domains comprising pelagic platforms, basins, and land areas including the transitional zones in between. An unusually wealth of index fossils has facilitated the subdivision of the strata with utmost precision making this area a key region for Devonian stratigraphy. For these reasons the eastern Anti-Atlas of Morocco represents one of the paleogeographically most diversified and biostratigraphically best-studied Devonian depositional environments worldwide.

It is the aim of the present study to summarize the results of several decades of personal and foreign studies under the special aspect of the paleogeographic reconstruction of the area during the Middle and Late Devonian. Emphasis is laid on a critical evaluation of all available biostratigraphic and sedimentologic data to obtain the most reliable survey of the driving forces, which have essentially influenced the depositional pattern in the eastern Anti-Atlas.

✉ Jobst Wendt
jobst.wendt@uni-tuebingen.de

1 Fachbereich Geowissenschaften der Universität Tübingen, Tubingen, Germany

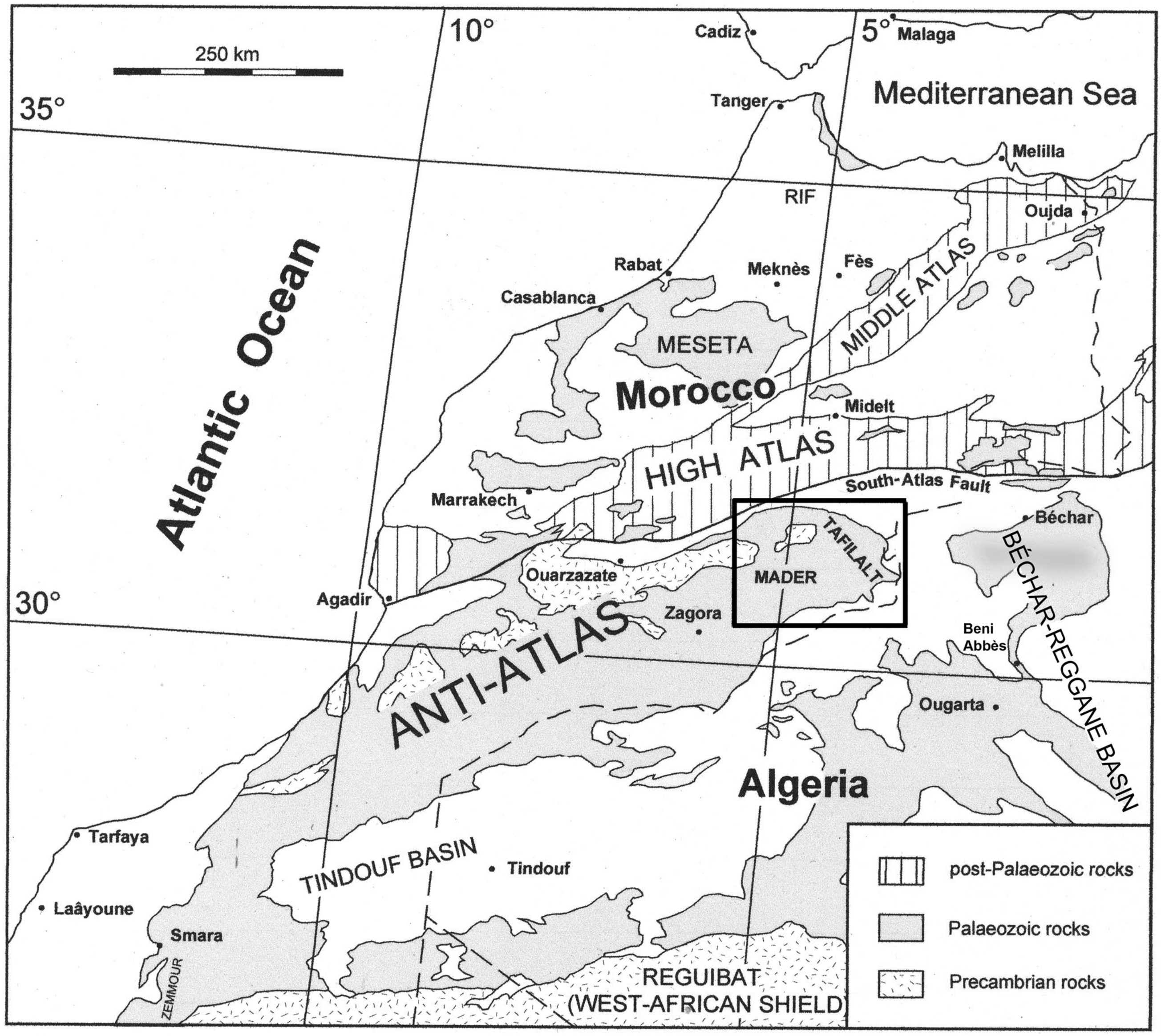

Fig. 1 Major paleogeographic/tectonic units of Morocco and western Algeria. Boxed rectangle marks the location of the study area [Modified from Kaufmann (1998)]

Previous work

Substantial geologic work about the Devonian of the eastern Anti-Atlas started in the first decades of the last century, but these early publications are only of historical interest these days. Suitable summaries of that time were compiled by Choubert et al. (1952) and Hollard (1967). A great step towards a better understanding of the stratigraphic evolution during the Devonian has been the work of Massa et al. (1965) who correlated numerous sections from the Béchar Basin (northwestern Algeria) through the entire Tafilalt and Mader, thus elucidating the significantly diverging thicknesses and lithologies in this area. The most fundamental work on the Devonian, however, was achieved by Henri Hollard (1922–1980) since the late 1950s. Unfortunately, he died too early to summarize the incredible amount of his observations in an overall outline of the Devonian sedimentary realms of which only a posthumous summary was published (Hollard 1981). The first broad survey was presented by Wendt et al. (1984) and Wendt (1988b) with the aim to illustrate the regional depositional patterns and the clearly distinguishable paleogeographic units. Since then an almost unmanageable amount of new biostratigraphic data has been accumulated, of which the reference list represents only an incomplete survey. In this context, the very active working groups of R. T. Becker

(Münster, Germany), the late O. H. Walliser (Göttingen, Germany), D. Korn (Berlin, Germany), C. Klug (Zürich, Switzerland), A. El Hassani (Rabat, Morocco) and several other Moroccan working groups must be particularly distinguished. The enormous and ambitious task of re-mapping the entire eastern Anti-Atlas at the 1:50,000 scale is underway and will certainly provide a solid basis for future stratigraphic and tectonic reconstructions and corrections. For a better understanding of the paleogeographic outlines of the eastern Anti-Atlas during the Devonian, a rigorous consideration of sedimentologic nature is highly desirable for future prospective work in this area.

Materials and methods

The present work is the result of 19 field seasons performed since 1980, during which every, even the smallest, outcrop of Devonian rocks in the eastern Anti-Atlas has been examined and sampled. The stratigraphic documentation is recorded in about 120 sections through the Middle and Upper Devonian. The intention of this survey has primarily been the dating of significant lithologic boundaries, gaps and depositional turnovers rather than that of high-resolution bed-by-bed biostratigraphy, and has been achieved by the age determination of many hundreds of conodont and ammonoid faunas. Zonal names used in the following paragraphs correspond to the internationally adopted biostratigraphic scheme of Becker et al. (2012). Apart from field observations, sedimentologic interpretations are based on hundreds of thin sections, peels and polished sections. Paleogeographically crucial areas (Amessoui syncline, Jebel Bou Ifarherioun syncline, Jebel Rheris, eastern margin of the Mader Platform, Ziz valley between Taouz and Ouzina, eastern termination of the Tafilalt Platform) were mapped at the 1:10,000 scale by 17 diploma students, whose unpublished works, due to their restricted accessibility, have not been included in the reference list. Larger and regionally important areas have been the subject of five doctoral theses. A significant tool for the recognition of paleogeographic transitional zones is the axis and vergence of slump folds (Woodcock 1979). Though this phenomenon has briefly been mentioned already by Hollard (1974), Kaufmann (1998) and Döring (2002), it has largely been underestimated and was first corroborated by verifiable data by Wendt (1988b, 1993). For the present study, 287 measurements from 37 localities have been compiled which are mostly derived from Middle Devonian strata. Geographical names were adopted from the topographic sheets of the Carte du Maroc 1:100,000. The complete study material is stored in the collections of the Geological Institute and Museum of the University of Tübingen (Germany).

Geological setting

During the Devonian, the eastern Anti-Atlas was a large shelf or ramp as a part of the Northwest African Craton, which in Early Devonian times showed only minor regional differences in sedimentation rates and depositional environments. Due to differential subsidence (and not by synsedimentary faulting, as claimed by Michard et al. 2008), during the Eifelian, the region began to differentiate into platforms and basins which were limited by emerged areas in the northwest and south. From east to west the following paleogeographic realms have been distinguished, whose boundaries are of course transitional: Tafilalt Basin, Tafilalt Platform, Mader Basin, Mader Platform (Wendt et al. 1984; Wendt 1988b). In addition, a remnant of a third basin (Rheris Basin) has been recognized north of the Tafilalt Platform during the Late Devonian (Wendt and Belka 1991) of which the major portion is hidden under the Upper Cretaceous cover farther north. It can be assumed that it continued towards north into the Mesetan Variscides, which in Devonian times were situated close to the Anti-Atlas (Michard et al. 2008). Figures 2, 3 and 4 show the paleogeographic reconstruction of the study area during the Middle Devonian and the middle Famennian (Lower marginifera Zone), two of the most representative intervals illustrating the basin-and-ridge paleotopography. It is commonplace that the basic premise for paleogeographic reconstructions is the assessment and appraisal of as many reliable biostratigraphic data as possible and the interpretation of individual characteristic sedimentological properties. For the Devonian of the eastern Anti-Atlas of Morocco, thousands of such data are available, but many of them are obscured by puzzling local formation or member terms, which partly lack a precise biostratigraphic calibration and therefore are ignored in the following paragraphs.

Paleogeography

Tafilalt Basin

The Tafilalt Basin is the western termination of the Bechar-Reggane Basin of western Algeria, of which the major part is concealed under the Upper Cretaceous/Tertiary deposits of the Hamada du Guir. Middle Devonian deposits consist predominantly of shales with intercalated calcareous mudstones and sandstones. They are exposed only in the area of Hassi Nebech and Oued Kseir (Figs. 2, 3), but most probably continue under the Quaternary cover farther north. Due to several phases of sea-level rise

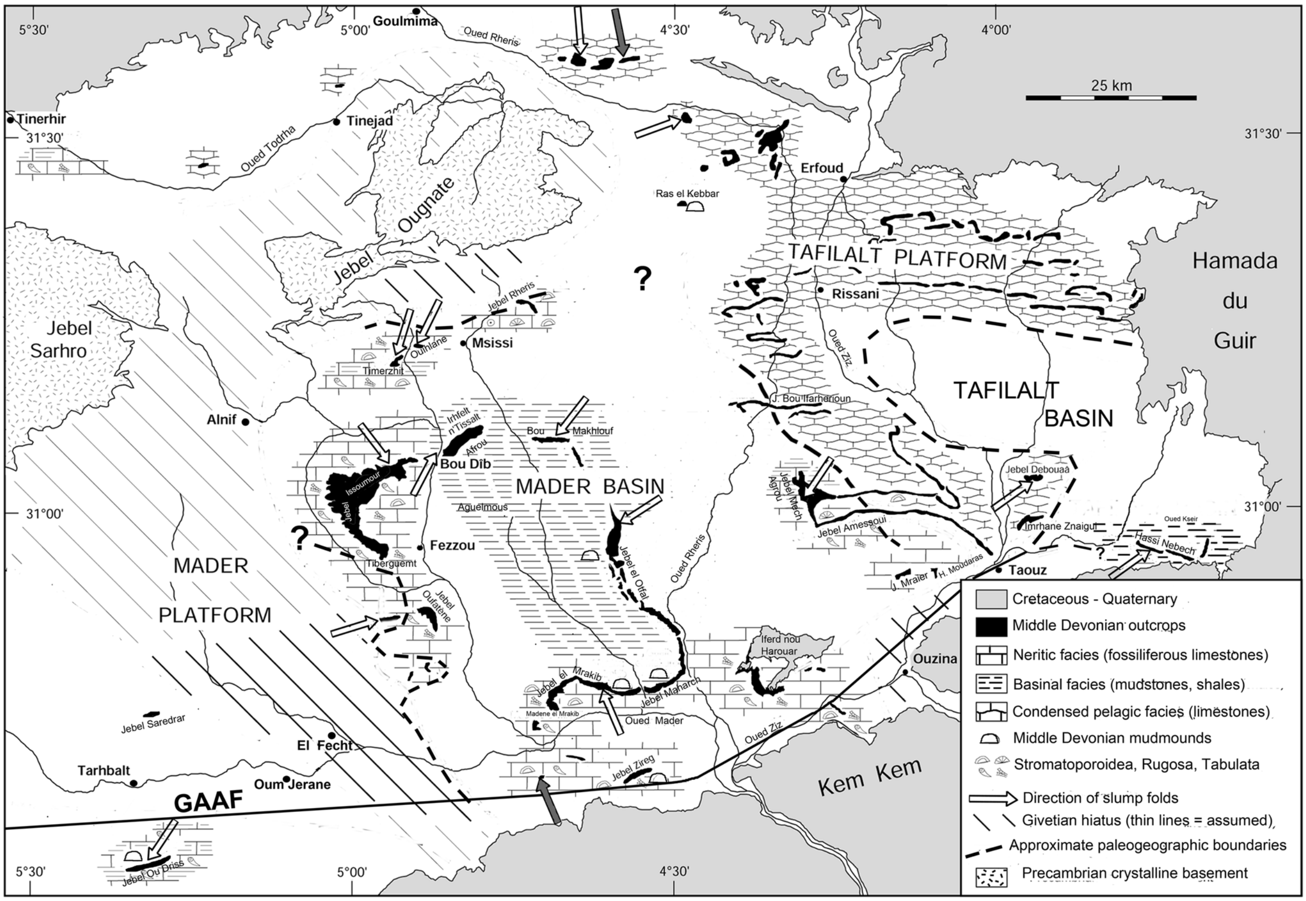

Fig. 2 Middle Devonian paleogeography. The tips of the slumpfold arrows point to the individual localities. Grey arrows indicate lower Frasnian slumpfolds. *GAAF* Great Anti-Atlas Fault [Basemap modified after Kaufmann (1998), paleogeographic boundaries compiled after Wendt et al. (1984), Wendt (1988b), Belka et al. (1997) and later personal data]

during the Late Devonian the basin expanded towards the west including also the areas of Jebel Debouah and Ihmrane Znaigui (Fig. 4). Lower Famennian sandstones of the latter locality display intermittent wave ripples, interference ripple marks and hummocky cross bedding which, near the western margin of the basin, indicate very shallow water depths above wave base. The up to 950 m thick pile of Middle to Upper Devonian deposits (Alvaro et al. 2014) represents an almost continuous sequence, though rare unconformities reveal local gaps (Becker and Abousalam 2015). Occasional slumping phenomena in Middle Devonian rocks (Fig. 2) indicate local slope settings showing that the central part of this basin was located farther east/northeast, hidden under the Upper Cretaceous/Tertiary plateau of the Hamada du Guir.

Tafilalt Platform

The Tafilalt Platform is the dominant Middle/Upper Devonian paleogeographic feature of the eastern Anti-Atlas. Overall it is distinguished by a very low sedimentation rate with many erosional unconformities and hiatuses, which are the result of local omission, submarine erosion and intermittent uplift above sea-level, in particular during the late Frasnian/early Famennian Kellwasser interval (Wendt and Belka 1991). Upper Devonian deposits may be reduced to a few meters in which, understandably, the great majority of time is represented by the hiatuses (Wendt 1988a). In the Famennian the platform displays a roughly T-shaped outline with a W–E branch extending from Tinerhir in the west to the Hamada du Guir in the east and a N–S branch extending from Erfoud in the north to the Great Anti-Atlas Fault (GAAF) in the south (Fig. 4). The latter is a sinistral transform fault which runs along the Ziz valley from Taouz in the east to Oum Jerane (and beyond) in the west. Along this fault, the southern part of the Tafilalt Platform abuts against a depositionally totally different segment farther south. As can be deduced from considerable erosional hiatuses, the latter area was emerged during almost the entire Late Devonian, locally also much earlier, and was flooded again only

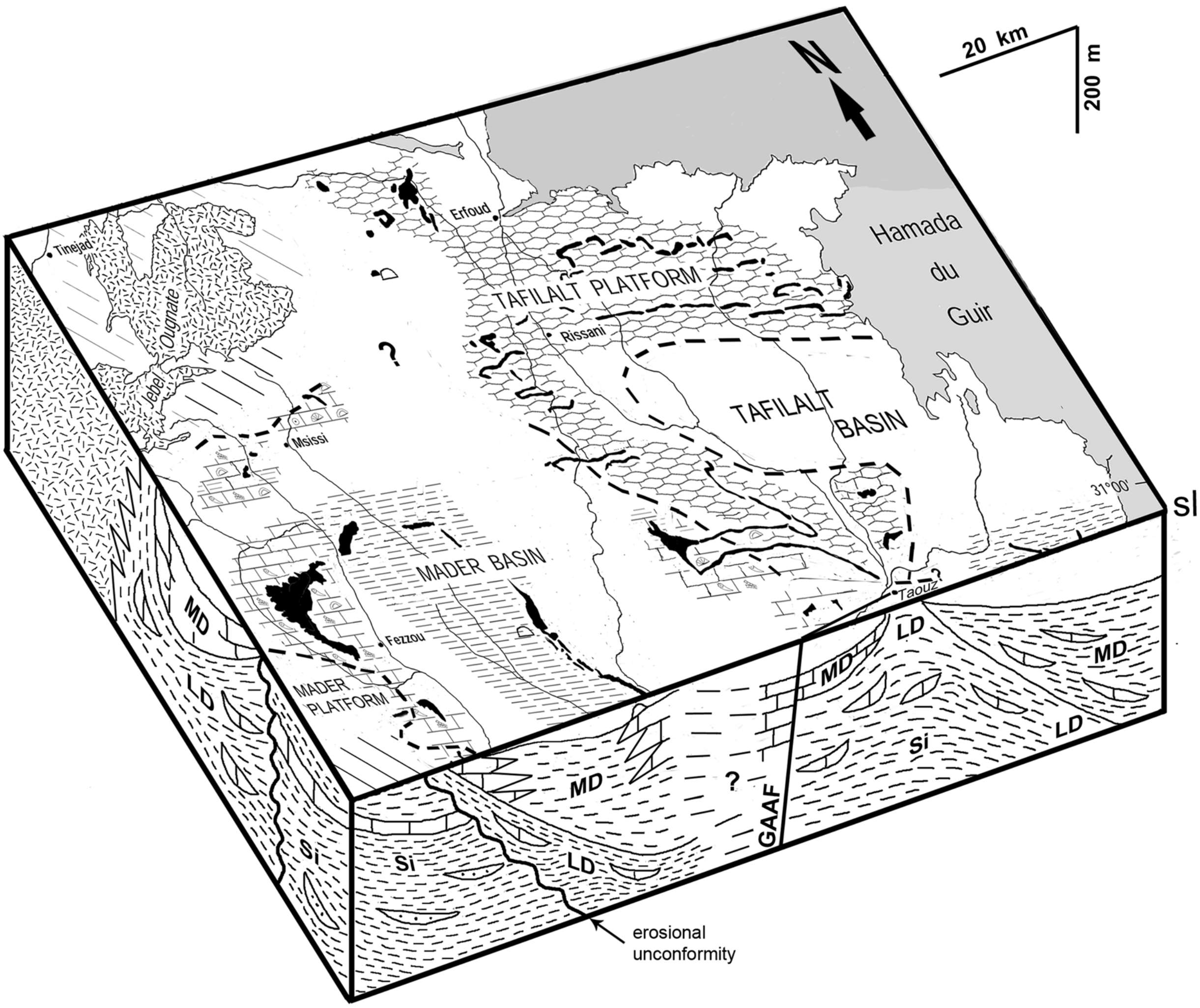

Fig. 3 Block diagram illustrating the Middle Devonian paleogeography and stratigraphy. *GAAF* Great Anti-Atlas Fault, *LD* Lower Devonian, *MD* Middle Devonian, *Si* Silurian, *sl* sea-level (water depth not to scale). Note that the N–S and W–E sections are highly exaggerated. Zigzag line on left face of diagram indicate an uncertain (eroded) boundary

during the late Famennian (Middle expansa Zone). This is a characteristic level with huge *Gonioclymenia*, which transgresses with an angular unconformity of up to 80° over an emerged, deeply eroded, and karstified surface of Ordovician, Silurian or Lower Devonian rocks (Aboussalam et al. 2015; Hartenfels and Becker 2018 and own observations). The eastern prolongation of the GAAF into the Tafilalt Basin remains uncertain because no significant paleogeographic contrasts are observed in this area during the Middle and Late Devonian. It can be suspected that it extends into the unknown southern continuation of the Tafilalt Basin which is concealed by the Cretaceous rocks of the Hamada du Guir. The sinistral displacement of the northern limb of the GAAF implies that the southern one must have been attached to the Mader Platform several tens if not more than a 100 km to the west. The vicinity of the southernmost apron of the Tafilalt Platform to the above-mentioned emerged areas farther south is indicated by strongly reduced and incomplete Middle and Upper Devonian sequences at Hassi Moudaras and Jebel Mraier where pre-Middle expansa Zone caliche crusts document a previous subaerial interval. Other Upper Devonian caliche crusts are preserved in several localities, most of them predating the late Famennian (Middle expansa Zone) transgression. Typical examples were observed along the western side of Jebel Rheris (Fröhlich 2004a) and in several places of the Mader Platform. The most southwestern vestiges of the Tafilalt Platform are exposed south of the Cretaceous "island" of Iferd nou Haouar from where a connection of this platform and the southern Mader Platform during the Late Devonian is probable (Fig. 4).

The great majority of biostratigraphic and paleontologic studies on the Devonian of the eastern Anti-Atlas were devoted to the very fossiliferous deposits of the Tafilalt Platform, and even the Global Boundary Stratotype Section

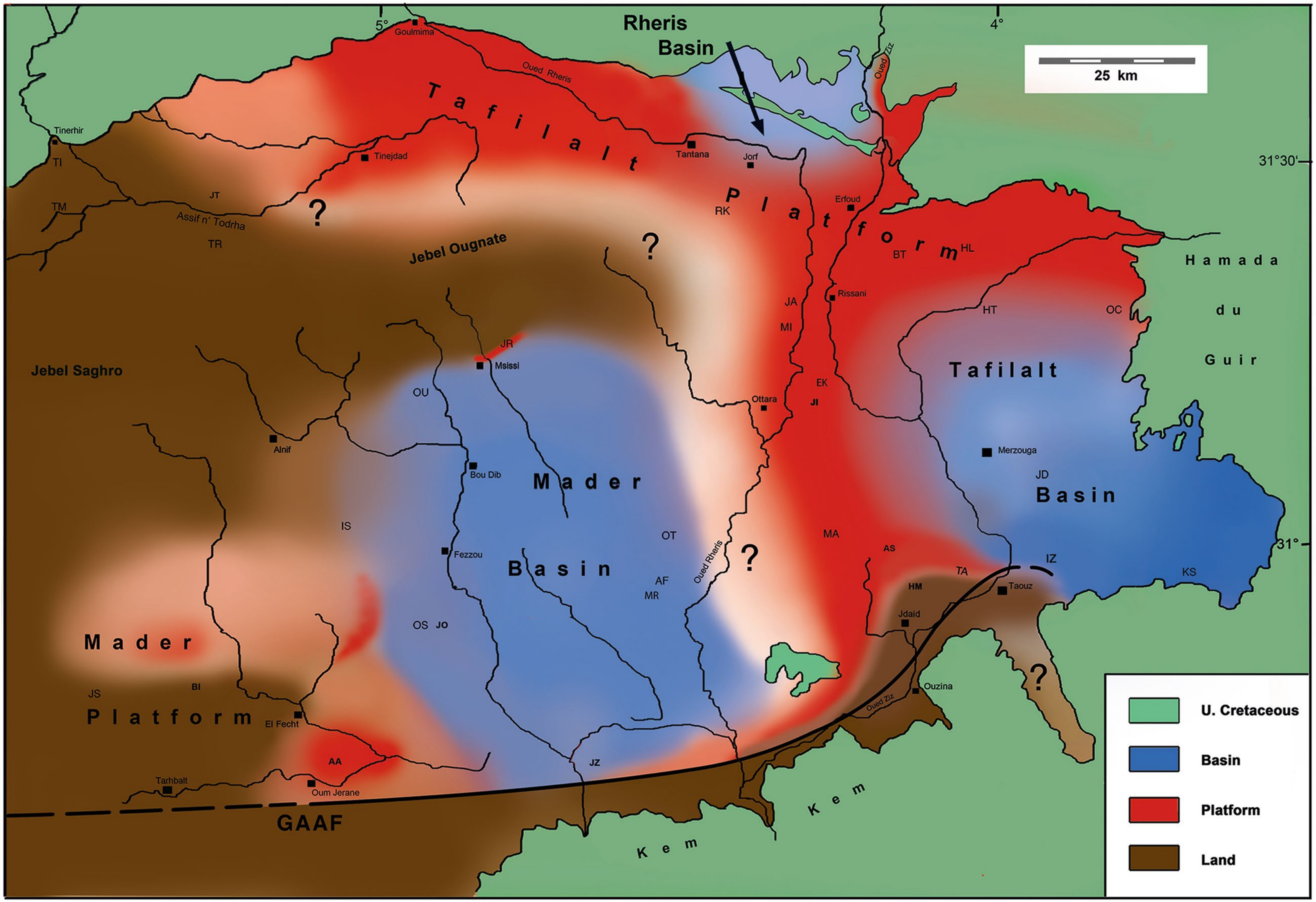

Fig. 4 Paleogeographic map of the eastern Anti-Atlas at the time of the Lower marginifera Zone (base of the middle Famennian). Merging colors mark slope environments or zones of uncertain boundaries due to the total erosion of Devonian rocks. Dark blue colors indicate higher water depths. *GAAF* Great Anti-Atlas Fault, *AA* Afrou n'Akhou, *AF* Aferdou el Mrakib, *AN* Ait ou Nebgui, *AS* Amessoui syncline, *BI* Bou Ibenter, *BK* Bou Kerzia, *BT* Bou Tchrafine, *EK* El Kachla, *HL* Hamar Laghdad, *HM* Hassi Moudaras, *HT* Hassi Tisserdimine, *IR* Jebel Ihrs, *IS* Jebel Issoumour, *IZ* Imrhane Znaigui, *JA* Jebel Amlane, *JB* Jebel Boulchral, *JD* Jebel Debouah, *JI* Jebel Bou Ifarherioun, *JL* Jebel Oufilal, *JM* Jebel Maharch, *JO* Jebel Oufatène, *JR* Jebel Rheris, *JS* Jebel Saredrar, *JT* Jebel Tisdafine, *JZ* Jebel Zireg, *KM* K^{e} Mdouara, *KS* Erg el Kseir, *MA* Jebel Mech Agrou, *MI* Jebel Mech Irdane, *MR* Jebel Mrakib, *OA* Jebel Ouaklim, *OC* Ouidane Chebbi, *OS* Oufatène Srhir, *OT* Jebel Otfal, *OU* Ouihlane, *RK* Ras el Kebbar, *RS* Reg es Sebbah, *TA* Jebel Tadaout, *TI* Tikkedarine, *TK* Tizi Bou Kerzia, *TM* Tizi Tmelallet, *TO* Tizi n'Oufatène, *TR* Taourit n'Rhellil, *TZ* Tizegzaouine

and Point (GSSP) for the Eifelian/Givetian boundary was established on a section of these condensed and often incomplete deposits (Walliser et al. 1996; Becker et al. 2018a). The transition of the Tafilalt Platform into the adjacent basins during the Middle and Late Devonian can be best observed on the eastern and western termination of the Jebel Bou Ifarherioun syncline which extends for about 20 km in an E–W direction, and of the Amessoui syncline farther south (Lubeseder et al. 2010; Becker et al. 2013a; Klug and Pohle 2018). One can virtually walk along both synclines from their eastern slope to the western one, faced with rapid facies changes, gaps, unconformities, and synsedimentary faults (Wendt and Belka 1991). The Amessoui syncline, however, ends abruptly in the west at Jebel Mech Agrou. In this area, Middle Devonian rocks (higher levels are not exposed) show common slumping phenomena, which indicate that it represents the western slope of the Tafilalt Platform (Fig. 2). Small-scale debris flows and slumpings are common also on the central part of the Jebel Bou Ifarherioun syncline, but they have no significance for the larger-scale paleogeographic configuration because they are derived from small local Middle and Upper Devonian horsts.

During the Middle Devonian this segment of the platform developed from a shallow homoclinal ramp into a pelagic ridge with a pronounced submarine topography (Lubeseder et al. 2010), which is caused by the effects of early synsedimentary tectonics. The changing outlines of the platform and basin realms during the late Frasnian/early Famennian Kellwasser interval have been sketched in a series of maps by Belka and Wendt (1992) who have additionally shown that conodonts are much more frequent in the platform than in basin realms. Thicker, more complete and still very fossiliferous sections are exposed in slope environments, in particular along the transition from the eastern Tafilalt Platform into the Tafilalt Basin (Belka et al. 1999). This transitional zone is well exposed from the western margin of the Hamada du Guir in the east to the region SE of Erfoud. Devonian rocks of the western branch of the Tafilalt Platform (i. e. between Tantana and Tinerhir) and the western slope of the southern branch of the platform, which might have shown the transition into the emerged areas farther south (Jebel Ougnate) and the Mader Basin in the west (Figs. 2, 4) are largely eroded and one can only speculate about the approximate boundary between these two realms. But two outcrops of Middle Devonian and lower Frasnian rocks between Erfoud and Goulmima show southward directed slumping phenomena (Fig. 2) indicating a platform slope in this area. Another point, where the possible western boundary of the Tafilalt Platform is exposed, is a remnant of a Middle Devonian Stromatactis mudmound at Ras el Kebbar (Wendt 1993) which is surrounded by debris flows and submarine rockfalls. The clasts and boulders of the latter attain dimensions of several tens of meters and were dated as varcus to falsiovalis Zone suggesting a middle Givetian to early Frasnian age of synsedimentary tectonic movements along this supposed platform/slope transition. In their paleogeographic map of Devonian facies patterns, Baidder et al. (2008) have placed an emerged "Ougnate-Ouzina Ridge" between the Tafilalt Platform and the Mader Basin. Such a high in fact did exist in the southern Ziz valley between Taouz and Ouzina (see above), but farther NNW, that is to say north of Iferd nou Haouar, Devonian rocks are completely eroded, so that the existence of such a ridge during the Devonian is mere speculation. West of the Amessoui syncline and in the eastern portion of the Mader Basin, the vergence of slump folds clearly points to SW (Fig. 2) indicating that the "Ougnate-Ouzina Ridge" in Middle and Late Devonian times was a slope, which was uplifted only much later, that is to say during the Variscan orogeny.

In the westernmost branch of the Tafilalt Platform, i. e. in the area SW and SE of Tinerhir, Devonian and Lower Carboniferous rocks crop out only in a few places. They are faulted and thrusted by the Variscan orogeny and display only fragments of the sequence, among which Emsian, Middle Devonian, Frasnian, upper Famennian, Tournaisian and Visean equivalents have been recognized (Hindermeyer 1954, 1955; Baidder et al. 2007). Published sections from this area are poorly dated and interpreted contradictorily. Michard et al. (1982, 2008) and Feroni et al. (2010) regard the Paleozoic cover of the crystalline basement of the northern Jebel Saghro, exposed at Tizi Tmellalet, as autochthonous while, in contrast, a similar outcrop on the eastern side of Jebel Ouaklim, only 2 km west of Tizi Tmellalet, is said to be allochthonous, same as the farther northeast exposed outcrops of Lower Carboniferous rocks at Jebel Tisdafine,

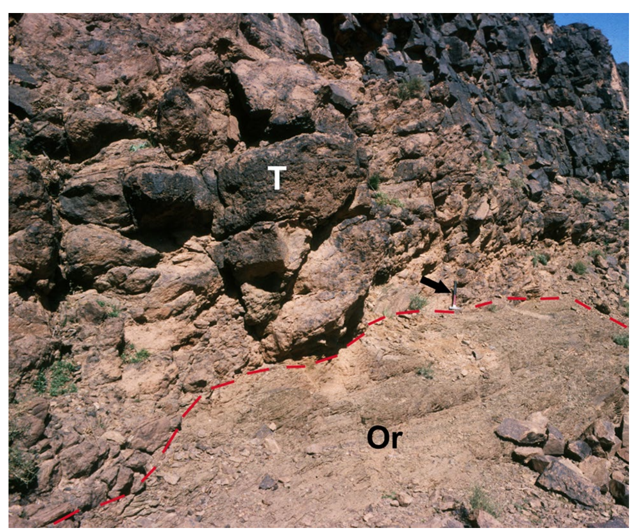

Fig. 5 Tournaisian transgression conglomerate (T) overlying Middle Ordovician sandstones (Or), Tizi Tmellalet. Hammer (arrowed) for scale

Tizegzaouine and Tikkedarine. Their interpretation as an allochthonous complex has been corroborated by Graham and Sevastopulo (2008) and by Rytina et al. (2013). Of particular interest is the upper, transgressive part of the Tizi Tmellalet section, interpreted by Michard et al. (1982) as an Upper Devonian/lower Tournaisian olistostrome at the base of a flysch sequence. It overlies middle Ordovician sandstones with an erosional and angular unconformity (Fig. 5). The alleged olistostrome consists of a several tens of meters thick sequence of coarse conglomerates alternating with cross-bedded sandstones which show current directions towards NW. The conglomerate layers of this up to 70 m thick sequence are composed of well-rounded pebbles of the underlying sandstones and huge (up to several meters across) blocks of shales and limestones. The latter contain little significant organic remains (strophomenids, chaetetids, *Platyceras*) which may indicate a Middle Devonian age.

Rytina et al. (2013) have dated several blocks of a similar sequence at Taourit n'Rhellil south of Jebel Tisdafine with the result that they represent a wide spectrum of ages ranging from the Ordovician into the middle Famennian, exclusive of Frasnian and early Famennian equivalents. A personal finding of *Manticoceras* from this place has proved also the presence of Frasnian rocks. These observations document that the northern slope of Jebel Saghro was covered by Devonian deposits which show a certain similarity to those of the central Tafilalt Platform. The angular to poorly rounded clasts of the conglomerate suggests a nearby provenance; the intercalated cross-bedded sandstones with wave ripples at Tizi Tmellalet indicate a shallow-water environment rather than a flysch-like deposit. Based on these arguments, the statement of Michard et al. (1982), according to which the conglomerate is an olistostrome, derived from the adjacent Jebel Saghro in the south, can no longer be maintained. Moreover, it is difficult to imagine the provenance of an olistostrome from an uplifted crystalline basement. The lithologic diversity of the pebbles and clasts of this conglomerate which range in age from the Middle Ordovician into the middle Famennian cannot be reconciled with the general aspect of an olistostrome.

The outcrops of coeval sequences farther north and east of those mentioned above, are regarded by Michard et al. (1982) as allochthonous flysch. Soualhine et al. (2003), however, regard Jebel Tisdafine as an autochthonous pull-apart basin established on an older carbonate platform, which I consider as the western prolongation of the Tafilalt Platform. During Tournaisian to Namurian times, it was filled with a thick sequence of shallow-water sandstones, shales, and calcareous mudstones. This opinion can be confirmed by personal studies at Jebel Tisdafine which have shown that Tournaisian sandstones transgress with a basal conglomerate and an angular unconformity over lower Emsian (former dehiscens Zone) styliolinid mudstones. Baidder et al. (2007) report also remnants of Givetian and Famennian limestones from the southeastern part of Jebel Tisdafine showing that the Lower Carboniferous (pre-Visean and post-Upper Devonian) transgression had cut down to various levels of the underlying Ordovician to Devonian basement. These authors favor again the interpretation as a flysch basin not excluding, however, a deltaic environment. The conception of a flysch basin at Jebel Tisdafine is also accepted by the collaborators of the geological 1:50,000 map of this area (Djerrari et al. 2007). In this context, it should be borne in mind that a flysch sequence as a typical deep-water deposit on a continental slope can never be transgressive. Later, Graham and Sevastopulo (2008) have resuscitated the flysch interpretation of the Jebel Tisdafine basin without discussing, however, the previous one of Soualhine et al. (2003). They calculated the total thickness of the sandstone/limestone pile as at least 1500 m and assigned it, based on shallow-water foraminifera, calcareous algae and rare conodonts, a late Visean age. Unfortunately, these datings conceal from which levels they are derived. The occurrence of these shallow-water fossils and the transgressive base of the sequence leave some doubts about the deep-water environment of the so-called Tisdafine basin. I have only examined its basal layers and consider the up to 20 m thick basal conglomerate as the Tournaisian transgression over deeply eroded Devonian platform deposits, a conclusion which had already been expressed by Hindermeyer (1954). In addition, the occurrence of Kinneya ripples in the basal part of the overlying sandstones clearly indicates deposition in very shallow water (Fig. 6g). The above-mentioned conglomerates have never been dated so far, but the fact that they obviously contain no components younger than middle Famennian (Rytina et al. 2013) points to an early to early late Tournaisian age.

It can be concluded that the region southwest to the east of Tinerhir, exposed in the above-mentioned localities, can be considered as the western termination of the Tafilalt Platform of which, apart from some remnants of Emsian to middle Famenian rocks, only the Tournasian equivalents are largely exposed in several localities. Their paleogeographic position and their sedimentological characters strongly suggest that this area is autochthonous and that the existence of an allochthonous Hercynian basin in this area should be abandoned.

Mader Basin

The Mader Basin is a roughly circular pull-apart basin which developed north of the Great Anti-Atlas Fault. It displays a N–S extension of about 75 km and a W–E extension of about 60–70 km and is characterized by strong subsidence and high sedimentation rates during the Middle and Late Devonian. Due to the complete erosion of Devonian rocks,

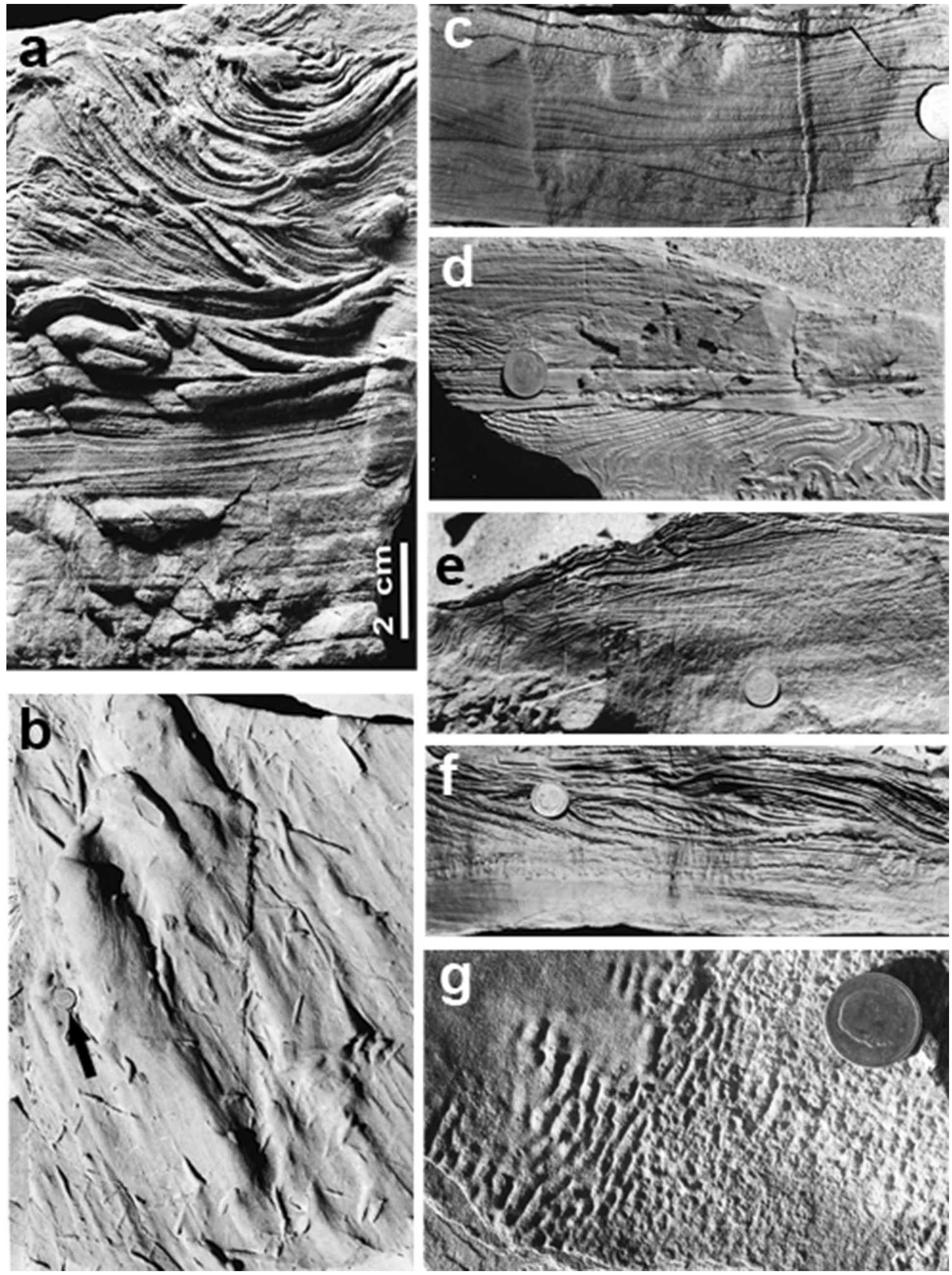

Fig. 6 Sedimentary structures in sandstones of the central Mader Basin (transect Irhfelt n'Tissalt to Aguelmous) and on the western Tafilalt Platform indicating very shallow water depths. **a** Tempestite showing hummocky cross bedding (below) passing into dewatering structures (above), Givetian, Irhfelt n'Tissalt. **b** Multidirectional current marks, Givetian, Irhfelt n'Tissalt. **c** Hummocky cross bedding, Frasnian, Afrou. **d** Dewatering structures within hummocky cross bedding, lower Famennian, Afrou. **e** Hummocky cross bedding (below) passing into wave ripples (above), upper Famennian (Lower expansa Zone), E of Aguelmous. **f** Hummocky cross bedding, upper Famennian, same locality as e. **g** Kinneya ripples in Tournaisian sandstones, SW of Jebel Tisdafine

the northwestern and eastern boundaries of the basin remain uncertain. The basin developed from a late Emsian to early Givetian carbonate ramp, which was gently inclined towards NNE with a gradient of 1° and an opposite slightly steeper one (1°–2°) towards SSW (Döring 2002). It appears as a wide, open syncline which geographically is confined by the arcuate Lower/Middle Devonian fringe of Jebel Issoumour in the west and the coeval mountain arc of Jebel Mrakib, Jebel Maharch and Jebel el Otfal in the southeast and east (Fig. 2). Subsidence was strongest during the Middle and early Late Devonian, whose predominantly argillaceous and arenaceous sediments, due to the scarcity of index fossils, are poorly dated. The sandstones show typical shallow-water features such as bidirectional current marks, hummocky cross-bedding, wave and current ripples indicating deposition above wave base (Fig. 6a–d). Rare intercalated turbiditic sequences with incomplete Bouma cycles, flute and load casts and dewatering structures indicate very high sedimentation rates but not necessarily deeper water environments.

The only rather well-exposed transect through the central part of the basin can be traced from Irhfelt n'Tissalt in the north, across Afrou to Aguelmous in the south, of which the about 500 m thick Givetian portion was examined and dated by Hollard (1974). In a posthumous publication of

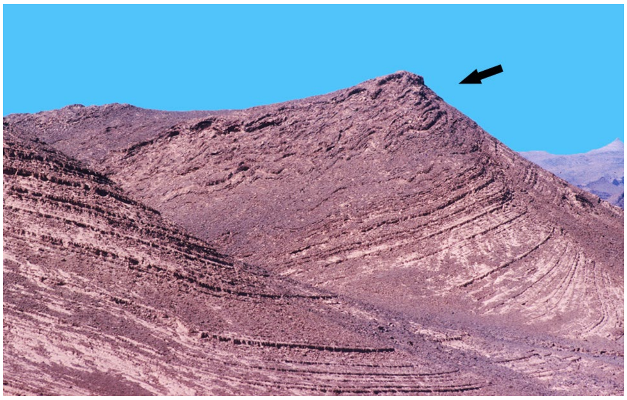

Fig. 7 Givetian slump folds (arrowed) near the northern margin of the Mader Basin SW of Timerzit

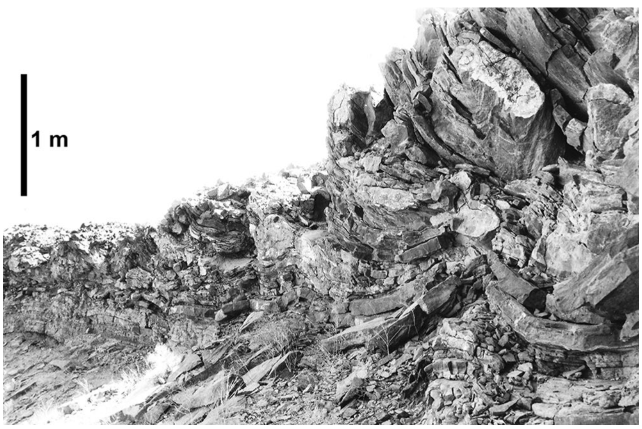

Fig. 8 Slumping in Givetian (Middle varcus Zone = ansatus Zone) mudstones. Western termination of Irhfelt n'Tissalt, central Mader Basin. Scale bar refers to right side of photograph

Fig. 9 Breccia (channel-fill) of crystalline rocks (asterisks) and quartzites at Bou Makhlouf (central part of the Mader Basin)

Hollard (1981) also the upper Devonian part of the sequence was provided with some conodont data. Due to the low dip of the strata (5°–10°) and a consequently expanded outcrop of about 10 km, a calculation of its thickness can be only approximate. Personal measurements accounted for a total thickness of about 1600 m for the Givetian to topmost Famennian sequence, while Döring (2002) presumed a thickness of 1400 m for the Middle Devonian to Frasnian portion only. Up to 25 m thick very obvious slump levels of Givetian age, underlying small patch reefs at Ouihlane, i. e. near the northern margin of the basin, but curiously not mentioned by Massa et al. (1965), Schröder and Kazmierczak (1999) and Döring (2002), show a clear vergence towards SSW (average of 200°). The same phenomenon and vergence can be observed in the syncline of Timerzit (Figs. 2, 7), 5 km WSW of Ouihlane, which exposes a coeval sequence, terminating with lower Givetian floatstones (Döring and Kazmierczak 2001; Döring 2002). Farther basinward, at the northeastern termination of Jebel Issoumour, again a southeastern vergence of Middle Devonian slump folds can be recognized. However, an opposite (NE) direction of gravitational sliding in Givetian (Middle varcus Zone = ansatus Zone) rocks is observed near the western termination of Irhfelt n'Tissalt about 3 km NNE of Bou Dib (Figs. 2, 8). Spectacular coeval slump levels, again with a SE vergence, cannot be overlooked in the central part of Irhfelt n'Tissalt and in the younger ridges farther south, some of which attain 100 m of thickness. Another locality with impressive slump levels, which show the same SE direction, is at Bou Makhlouf, 13 km ESE of Irhfelt n'Tissalt (Fig. 2). These diverging directions of slumping phenomena show that the center of the basin was situated in the plain east and south of Bou Dib. Just in this area a unique, up to one meter thick, level of crystalline (granite, diorite, monzonite) and Lower Paleozoic sedimentary clasts (cherts, dolomites, Fig. 9) has been discovered at the base of the "calcaire bleu marine" (Hollard 1974), a distinctive marker bed of early/middle Givetian age. It is apparently a channel-fill derived from the Jebel Ougnate north of the Mader Basin, which at this time was already denuded from most of its Paleozoic cover. It is surprising that this only awesome witness of an emerged area farther north, has been found just in the central parts of the Mader Basin but not near the coast.

The about 220 m thick Frasnian part of the section is exposed in several prominent ridges at Afrou and farther southeast, but it is only insufficiently dated by a few goniatites and conodonts indicating an early Frasnian age. Hummocky cross-bedding in sandstone intercalations indicate very shallow water depth (Fig. 6c). The lower Famennian portion of the section is mostly covered by sand and gravel and was designated by Hollard (1967) as "Flysch de Bou Dib". His assumed thickness of 1300 m was later corrected as about 600 m (Wendt 1988b), but moreover, Hollard's interpretation of a flysch sequence can no longer be maintained. The prevailing marls and clays contain some up to 10 m thick sandstone intercalations with hummocky cross-bedding (Fig. 6d), indicating persisting shallow water depth, which higher up in the section, however, pass into deeper water deposits. In other places of the central Mader Basin equivalents of the lower Famennian consist of barren or poorly fossiliferous thin-bedded platy limestones and marls which have been dated only in one locality (Bou Terga, 10 km SW of Bou Dib) as Middle triangularis to Lower crepida Zone (= delicatula platys to crepida Zone). It can be concluded that in spite of the high subsidence during the Middle and Late Devonian, the basin mostly remained rather shallow, often above storm wave base. Upper Famennian black shales are well exposed along the margins of the flat dipping syncline of Aguelmous and have yielded extremely rich ammonoid faunas (Becker et al. 2018b). They indicate quiet water conditions and thus the deepest parts of the Mader Basin. But intercalated sandstone levels in the uppermost Famennian portion with hummocky cross bedding and wave ripples (Fig. 6e, f) document intermittent shallowing-up cycles as precursor phases of the subsequent regressive deltaic interval near the Famennian/Tournaisian boundary.

On the eastern homoclinal ramp of the basin, several small upper Eifelian (kockelianus Zone) to middle Givetian (Lower varcus Zone) mud mounds and a giant lower/middle Givetian (hemiansatus to Lower varcus Zone) reef mound (Aferdou el Mrakib) developed (Wendt 1993; Kaufmann 1998; Jakubowicz et al. 2019). The southern margin of the Mader Basin is represented by the W–E striking Great Anti-Atlas Fault, which can be approximately located near the occurrence of three, small lower Givetian (Lower varcus Zone) crinoid mud mounds south of Jebel Zireg (Kaufmann 1998). Their paleogeographic position is inferred, because this kind of Middle Devonian carbonate buildups in the eastern Anti-Atlas and in southern Algeria (Wendt et al. 2006) always occurs in slope environments. Wood remains suggesting the presence of not very remote land areas are common in all basin and platform environments. Predominantly they occur in various levels of the Kellwasser lithology, which ranges in age from the late Frasnian into the early Famennian (Upper rhenana–Upper crepida Zone = MN Zone 11 to glabra pectinata Zone). They are never so frequent as at Madene el Mrakib near the southeastern margin of the Mader Basin (Meyer-Berthaud et al. 1997) that we called it the "petrified forest". Average orientation of the up to 5 m long logs and roots is about 100°, suggesting that they were possibly derived from emerged areas of the Mader Platform farther west.

The northern boundary of the Mader Basin is only visible along the northern and western edge of Jebel Rheris where marginal basin deposits abut against an emerged area farther north close to the southern margin of Jebel Ougnate. Between both areas a small band is exposed (exaggerated in Fig. 4) along which strongly reduced upper Famennian platform deposits transgress over Middle Devonian or older (Ordovician to Lower Devonian rocks (Fröhlich 2004a; Korn et al. 2004; Becker et al. 2013b and own observations). On the basis of the rapidly increasing thicknesses of Upper Devonian rocks from a few meters in the north and west to about 300 m in the east of Jebel Rheris, a general slope angle of 1°–2° can be calculated, which may have been increased by (not yet detected) stepwise synsedimentary normal faults. Surprisingly slumping phenomena have not been discovered at Jebel Rheris. Mapping of this area and its surroundings at the 1:10,000 scale has revealed an only negligible clastic influx from the emerged Jebel Ougnate, such as quartz grains and Ordovician pebbles in Upper Devonian deposits (Fröhlich 2004b).

Mader Platform

The Mader Platform constitutes the southwestern boundary of the Mader Basin, but its existence is proved only by a few

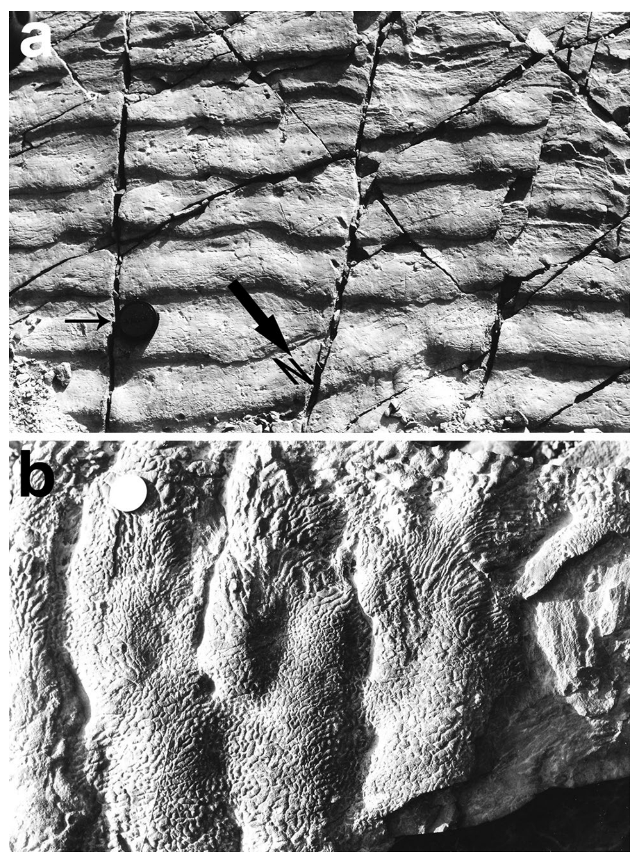

Fig. 10 Sedimentary structures in "Strunian" sandstones of Jebel Oufilal (north of Taouz). **a** Current ripples. Note current direction towards NE. Lens cap (arrowed) for scale. **b** Kinneya ripples (coin for scale)

occurrences of Middle and Upper Devonian rocks. These incomplete and strongly condensed series crop out along a small band from Tiberguemt in the north to east of Bou Kerzia in the south (Figs. 2, 4). Isolated patches of more strongly reduced Upper Devonian deposits are exposed south of Oued King and at Afrou n'Akhou, where upper Famennian *Gonioclymenia* limestones transgress over Middle Devonian or Silurian rocks (Hollard 1974, 1981 and own observations). Between the two latter areas an emerged zone existed during the Late Devonian which extends from west of El Fecht to Jebel Saredrar northwest of Tarhbalt (Fig. 4). The southernmost outcrop of Devonian rocks in the Mader region is Jebel Ou Driss in the Zagora graben, but it exposes only Emsian to lower Givetian rocks (Hollard 1974, 1981) and thus does not yield any information about the Late Devonian paleogeography. The axis of Eifelian slump folds in this syncline are oriented NW–SE and show a vergence towards SW (Fig. 2). In addition, the occurrence of a small Eifelian mud-mound in this syncline (Kaufmann 1998) indicates a slope environment, so that this area is probably located on the southern slope of the Mader Platform or the northern margin of the Tindouf Basin. The most northeastern Upper Devonian outcrop of the Tindouf Basin at Hassi Mellah (about 90 km SSE of Zagora) shows already a typical basin facies. From these scarce informations it can be assumed that the Mader Platform formed a peninsula attached to the uplifted lower Paleozoic area north of Zagora between the Mader Basin in the northeast and the Tindouf Basin in the south.

The platform and basin configuration outlined in the preceding paragraphs is completely buried by up to 300 m thick "Strunian" (uppermost Famennian/lowermost Tournaisian) deltaic sandstones, which represent an important regression and level the pre-existing paleotopography (Hollard 1971; Wendt et al. 1984)). Different kinds of ripple marks (current, oscillation and Kinneya ripples; Fig. 10a, b) clearly indicate deposition in very shallow water. Current directions show provenance of the sandstone bodies from SE and SW (Kaiser et al. 2011 and own observations). This regression is often marked by a basal conglomerate, locally with huge (up to several meters across) boulders of reworked older rocks. It is widespread over almost the entire Tafilalt Platform and flooded again large parts of the central Mader Platform. The "Strunian" regression is also well expressed in the Rheris Basin where topmost Famennian/lowermost Tournaisian sandstones cap uppermost Famennian (praesulcata Zone) shales with a basal conglomerate composed of the underlying Famennian crinoid limestones and older rocks, locally even of Kellwasser limestone.

In this uniform deltaic sea, only some islands emerged during the early Tournaisian, such as at Jebel Erfoud, where upper Tournaisian sandstones and sideritic shales conformably overlie uppermost Famennian limestones, and probably also farther south at Bou Tchrafine, Jebel Ihrs, Hamar Laghdad and parts of Jebel Mraier (pers. communication by R. T. Becker, Münster, Germany). About 15 km WSW of Taouz lower Visean shales (texanus Zone, not Famennian, as erroneously pretended by Baidder et al. 2008), overly Caradocian sandstones with a transgression conglomerate of meter-sized boulders at the base (Wendt 1991). Likewise, south and east of Tinerhir the transgression over deeply eroded Ordovician to Famennian strata probably occurred only in the middle Tournaisian or early Visean.

Conclusions

In the eastern Anti-Atlas of Morocco, a unique ancient underwater and continental scenery of Middle and Upper Devonian rocks is perfectly exposed over an area of about 20,000 km^2. Due to the virtual absence of vegetation, weak Variscan folding and faulting, and an extraordinary wealth of fossil remains, the individual large-scale paleogeographic realms of basins, pelagic platforms, and land areas and their biostratigraphic evolution can be reconstructed more precisely than before. These are (from E to W): Tafilalt Basin, Tafilalt Platform, Mader Basin and Mader Platform. In addition, a remnant of a third basin (Rheris Basin) north of the Tafilalt Platform has been identified. The Tafilalt Basin is the western termination of the Bechar-Reggane Basin in western Algeria, of which the major part is hidden under the Upper Cretaceous/Tertiary deposits of the Hamada du Guir. Slumping structures reveal that the center of this basin was situated farther east. In the south, these depositional realms are sharply cut by the transform Great Anti-Altas Fault.

The T-shaped Tafilalt Platform is the dominant paleogeographic element, which in the east passes into the Tafilalt Basin. Transitional zones into the Mader Basin along the western margin of the Tafilalt Platform are largely eroded and can be well recognized only on the western extremities of two major synclines. This platform is characterized by very low subsidence, frequent gaps, caused by omissions, synsedimentary faults and reworking, erosional unconformities and occasional temporary uplifts above sea-level. Long-lasting continental intervals are particularly evident on the westernmost branch of the platform, where Tournaisian conglomerates, sandstones, and shales transgress over deeply eroded older (Ordovician to Upper Devonian) rocks. The duration of these continental intervals can only be vaguely estimated, but they are probably in the order of up to tens of million years. In contrast to previous tectonic reconstructions, the Devonian/Tournaisian deposits in this area are considered as autochthonous and of shallow-water origin.

The Mader Basin is an almost circular basin which is distinguished by increased subsidence rates which are up to a hundred times higher than those of the adjacent platforms.

During the Middle and early Late Devonian, the deposits of this depocenter are predominantly of shallow-water origin and were deposited on an inclined carbonate ramp. The boundaries of this basin can be precisely distinguished only in a few areas in the north (Jebel Rheris), southwest (Mader Platform) and south (Great Anti-Atlas fault). Devonian deposits on the Mader Platform are only patchily preserved and display large gaps, erosional unconformities and intermittent uplifts above sea-level. These few areas document that, apart from its eastern margin, large parts of this platform were emerged during most of the Devonian. These continental areas continue into the Paleozoic massifs farther west, in which Devonian deposits have been totally eroded. Therefore, the Mader Platform can be considered as a partly emerged peninsula which sloped gently into the Tindouf Basin in the south. Over tens of kilometers the transitional zone between these two realms is deeply eroded and therefore does not allow any speculations about their paleogeography at Devonian times.

Acknowledgements First of all, I want to express my gratitude to Z. Belka (Poznan, Poland), who for many years accompanied me into the field, contributed many ideas and moreover determined all our conodont samples. Without his assistance the present work would have been impossible. For several years B. Kaufmann (Bremen, Germany) was a permanent colleague in the field and is also accounted for many ideas. T. Aigner (Tübingen, Germany) interpreted the depositional structures in sandstones. G. Jantschke (Berlin, Germany) performed the map of Fig. 4. I am also very grateful to my diploma and doctoral students for their arduous mapping of crucial zones in the field and their analysis of particular aspects and problems of the regional geology. I am indebted to the two reviewers R. T. Becker (Münster, Germany) and A. El Hassani (Rabat, Morocco) who read the manuscript with great accuracy, thus making important corrections and improvements.

Funding Open Access funding enabled and organized by Projekt DEAL.

References

Aboussalem ZS, Becker RT, Bultynck P (2015) Emsian (lower Devonian) conodont stratigraphy and correlation of the Anti-Atlas (Southern Morocco). Bull Geosci 90:893–980

Alvaro JJ, Aretz M, Benharref M, Hibti M, Pouclet A, El Hadi H, Koukaya A, Ettachfini EM, Boudad L (2014) Carte géologique du Maroc au 1/50000 feuille Tawz - Mémoire explicative. Notes Mém Serv Géol Maroc 551bis:1–127

Baidder L, Cerrina Feroni A, Ellero A, Giselli F, Malusà M, Mazzarini F, Musumeci G, Ottria G, Ouanaimi H, Pertusati PC, Polino R (2007) Carte géologique du Maroc au 1/50 000 feuille Taroucht. Note explicative. Couvertures paléozoïques. Notes Mém Géol Serv Géol Maroc 520bis:47–58

Baidder L, Raddi Y, Tahiri M, Michard A (2008) Devonian extension of the Pan-African crust north of the West African craton, and its bearing on the Variscan foreland deformation: evidence from the eastern Anti-Atlas (Morocco). Geol Soc Lond Spec Publ 297:453–465

Becker RT, Aboussalam ZS (2015) Annexe II Coupe du secteur de Hassi Nebech. In: Alvaro JJ, Aretz M, Benharref M, Hibti M, Pouclet A, El Hadi H, Koukaya A, Ettachfini EM, Boudad L (eds) Carte géologique du Maroc au 1/50 000, feuille Tawz, Mémoire explicative. Notes Mém Serv Géol Maroc, vol 551bis, pp 109–119

Becker RT, Gradstein FM, Hammer O (2012) The Devonian period. In: Gradstein FM, Ogg JG, Schmitz MD, Ogg GM (eds) A geological time scale 2012, vol 2, pp 559–602

Becker RT, Aboussalam ZS, Hartenfels S, El Hassani A, Fischer T (2013a) The Givetian – Famennian at Oum el Jerane (Amessoui Syncline, southern Tafilalt. In: Becker RT, El Hassani A, Tahiri A (eds) International field symposium "The Devonian and Lower Carboniferous of northern Gondwana" field guidebook, Doc Inst Scient Rabat, vol 27, pp 41–50

Becker RT, Hartenfels S, Aboussalam ZS, Tragelehn H, Brice D, El Hassani A (2013b) The Devonian - Carboniferous boundary at Lalla Mimouna (northern Maider) – progress report. In: Becker RT, El Hassani A, Tahiri A (eds) International field symposium "The Devonian and Lower Carboniferous of northern Gondwana", Field Guidebook, Docum Inst Scient Rabat, vol 27, pp 109–120

Becker RT, Aboussalam ZS, El Hassani A (2018a) Jebel Mech Irdane – the Eifelian/Givetian boundary GSSP and an important cephalopod locality. Münst Forsch Geol Paläont 110:214–228

Becker RT, Hartenfels S, Klug C, Aboussalam ZS, Afhüppe L (2018b) The cephalopod-rich Famennian and Tournaisian of the Aguelmous Syncline (southern Maïder). Münst Forsch Geol Paläont 110:273–306

Belka Z, Wendt J (1992) Conodont biofacies patterns in the Kellwasser facies (upper Frasnian/lower Famennian) of the eastern Anti-Atlas, Morocco. Palaeogeogr Palaeoclimatol Palaeoecol 91:143–173

Belka Z, Kaufmann B, Bultynck P (1997) Conodont-based quantitative biostratigraphy for the Eifelian of the eastern Anti-Atlas, Morocco. Geol Soc Am Bull 109:643–651

Belka Z, Klug C, Kaufmann B, Korn D, Döring S, Feist R, Wendt J (1999) Devonian conodont and ammonoid succession of the eastern Tafilalt (Ouidane Chebbi section), Anti-Atlas, Morocco. Acta Geol Pol 49:1–23

Choubert G, Clariond L, Hindermeyer J (1952) Livret-guide de l'excursion C 36. Anti-Atlas central et oriental. In: Congr Géol Intern, Session XIX Alger Sér. Maroc, vol 11, pp 1–8

Djerrari A, Ouanaimi H, Taj Eddine K, Witam O (2007) Carte Géologique du Maroc au 1/50000 feuille Imtir. Notes Mém Serv Geol Maroc 518:45–60

Döring S (2002) Sedimentological evolution of the late Emsian to early Givetian carbonate ramp in the Mader (eastern Anti-Atlas, SE-Morocco). Dissertation, University of Tübingen, pp 1–80

Döring S, Kazmierczak M (2001) Stratigraphy, geometry, and facies of a Middle Devonian ramp-to-basin transect (eastern Anti-Atlas, SE Morocco). Facies 44:137–150

Feroni AC, Ellero A, Malusà MG, Musumecci G, Ottria G, Polino R, Leoni L (2010) Transpressional tectonics and nappe stacking along the Southern Front of Morocco. Geol Rdsch 99:1111–1122

Fröhlich S (2004a) Evolution of a Devonian carbonate shelf at the northern margin of Gondwana (Jebel Rheris, eastern Anti-Atlas, Morocco). Dissertation, University of Tübingen, pp 1–71

Fröhlich S (2004b) Phosphatic black pebbles and nodules on a Devonian carbonate shelf (Anti-Atlas, Morocco). J Afr Earth Sci 38:243–254

Graham JR, Sevastopulo GD (2008) Mississippian platform and basin successions from the Todrha valley (northeastern Anti-Atlas), southern Morocco. Geol J 43:361–382. https://doi.org/10.1002/gj.1095

Hartenfels S, Becker RT (2018) Age and correlation of the transgressive *Gonioclymenia* Limestone (Famennian, Tafilalt, eastern Anti-Atlas, Morocco). Geol Mag 155:586–629

Hindermeyer J (1954) Découverte de Tournaisian prémonitoire hercynienne dans la region de Tinerhir (flanc Nord du Sarho-Ougnat). C R Acad Sci Paris 239:1824–1826

Hindermeyer J (1955) Sur le Dévonien et l'existence de mouvements calédoniens dans la region de Tinerhir. C R Acad Sci Paris 240:2547–2549

Hollard H (1967) Le Dévonien du Maroc et du Sahara nord-occidental. In: Oswald DH (ed) International symposium on the Devonian system. Alberta Soc Petrol Geol Calgary, vol 1, pp 203–244

Hollard H (1971) Sur la transgression dinantienne au Maroc présaharien. In: CR 6me Congr Intern Stratigr Géol Carbonifère Sheffield 1967, vol III, pp 923–936

Hollard H (1974) Recherches sur la stratigraphie des formations du Dévonien moyen, de l'Emsien supérieur au Frasnien, dans le Sud du Tafilalt et dans le Ma'der (Anti-Atlas oriental). Notes Mém Serv Géol Maroc 264:7–68

Hollard H (1981) Tableaux de corrélations du Silurien et du Dévonien de l'Anti-Atlas. Notes Mém Serv Géol Maroc 42:15–21

Jakubowicz M, Król J, Zapalski MK, Wrzolek T, Wolniewicz P (2019) At the southern limits of the Devonian reef zone: Palaeoecology of the Aferdou el Mrakib reef (Givetian, eastern Anti-Atlas, Morocco). Geol Journ 54:10–38

Kaiser SI, Becker RT, Steuber T, Aboussalam SZ (2011) Climate-controlled mass extinctions, facies, and sea-level changes around the Devonian-Carboniferous boundary in the eastern Anti-Atlas (SE Morocco). Palaeogeogr Palaeoclimatol Palaeoecol 310:340–364

Kaufmann B (1998) Facies, stratigraphy and diagenesis of Middle Devonian reef- and mud-mounds in the Mader (eastern Anti-Atlas, Morocco). Acta Geol Pol 48:43–106

Klug C, Pohle A (2018) The eastern Amessoui syncline – a hotspot for Silurian to Carboniferous cephalopod research. Münst Forsch Geol Paläont 110:244–260

Korn D, Belka Z, Fröhlich S, Rücklin M, Wendt J (2004) The youngest African clymeniids (Ammonoidea, Late Devonian) – failed survivors of the Hangenberg event. Lethaia 37:307–315

Lubeseder S, Rath J, Rücklin M, Messbacher R (2010) Controls on Devonian hemi-pelagic limestone deposition analyzed on cephalopod ridge to slope sections, Eastern Anti-Atlas, Morocco. Facies 56:295–315

Massa D, Combaz A, Manderscheid G (1965) Observations sur les séries siluro-dévoniennes des confins algéro-marocains du sud (1954–1955). Notes Mém Comp Franç Petrol 8:1–187

Meyer-Berthaud B, Wendt J, Galtier J (1997) First record of a large *Callixylon* trunk from the late Devonian of Gondwana. Geol Mag 134:847–853

Michard A, Yazidi A, Benziane F, Hollard H, Willefert S (1982) Foreland thrusts and olistromes [*sic*!] on the pre-Sahara margin of the Variscan orogen, Morocco. Geology 10:253–256

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. Lect Notes Earth Sci, pp 65–132

Rytina MK, Becker RT, Aboussalam ZS, Hartenfels S, Helling,S, Stichling S, Ward D (2013) The allochthonous Silurian-Devonian in olistostomes at "the southern Variscan front" (Tinerhir region, SE Morocco) – preliminary data. In: Becker RT, El Hassani A, Tahiri, A (eds) International field symposium "The Devonian and Lower Carboniferous of northern Gondwana", field guidebook, Docum Inst Sci Rabat, vol 27, pp 11–21

Schröder S, Kazmierczak M (1999) The Middle Devonian „coral reef" of Ouihlane (Morocco) – new data on the geology and rugose coral fauna. Geol Palaeontol 33:93–115

Soualhine S, Tejera de Leon J, Hoepffner C (2003) Les faciès sédimentaires carbonifères de Tisdafine (Anti-Atlas oriental): remplissage deltaïque d'un bassin en "pull-apart" sur la bordure méridionale de l'accident sud-atlasique. Bull Inst Sci Rabat 25:31–41

Walliser OH, Bultynck P, Weddige K, Becker RT, House MR (1996) Definition of the Eifelian-Givetian stage boundary. Episodes 18:107–115

Wendt J (1988a) Condensed carbonate sedimentation in the late Devonian of the eastern Anti-Atlas (Morocco). Ecl geol Helv 81:155–173

Wendt J (1988b) Facies pattern and paleogeography of the Middle and Late Devonian in the eastern Anti-Atlas (Morocco). In: McMillan NJ, Embry AF, Glass DJ (eds) Devonian of the world. Proc 2nd intern symp Devonian system, Alberta, Canad Soc Petrol Geol Mem, vol 14, issue 1, pp 467–480

Wendt J (1991) Depositional and structural evolution of the Middle and Late Devonian on the northwestern margin of the Sahara Craton (Morocco, Algeria, Libya). In: Salem MJ, Sbeta AM, Bakbak MR (eds) The geology of Libya 6. Elsevier, New York, pp 2195–2210

Wendt J (1993) Steep-sided carbonate mud mounds in the Middle Devonian of the eastern Anti-Atlas, Morocco. Geol Mag 130:69–83

Wendt J, Aigner T, Neugebauer J (1984) Cephalopod limestone deposition on a shallow pelagic ridge: the Tafilalt Platform (upper Devonian, eastern Anti-Atlas, Morocco). Sedimentology 31:601–625

Wendt J, Belka Z (1991) Age and depositional environment of upper Devonian (early Frasnian to early Famennian) black shales and limestones (Kellwasser facies) in the eastern Anti-Atlas, Morocco. Facies 25:51–90

Wendt J, Kaufmann B, Belka Z, Klug C, Lubeseder S (2006) Sedimentary evolution of a Palaeozoic basin and ridge system: the Middle and Upper Devonian of the Ahnet and Mouydir (Algerian Sahara). Geol Mag 143:269–299. https://doi.org/10.1017/S0016756806001737

Woodcock NH (1979) The use of slump structures as palaeoslope orientation estimators. Sedimentology 26:83–99