



# Coral assemblages of the Serpukhovian–Bashkirian transition from Adarouch (Morocco)

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## Abstract

The Carboniferous outcrops from Adarouch (central Morocco) are composed of siliciclastic and carbonate rocks, and the latter have yielded abundant fossils. The upper part of the marine succession in the Idmarrach Formation and its laterally equivalent Tirhela Formation belong to the Bashkirian. More recent investigations of poorly preserved coral assemblages from the upper part of Idmarrach 2 section and the upper part of the Tirhela Formation are here described. The assemblage from the upper Idmarrach Formation comprises several typical Mississippian taxa, such as *Aulophyllum fungites*, *Dibunophyllum bipartitum*, *Koninckophyllum interruptum*, *Siphonodendron scaleberense* and *Lithostrotion decipiens*, and some highly evolved forms previously undescribed of Mississippian genera such as *Haplolasma* sp., *Arachnolasma* sp., *Siphonodendron* sp., *Diphyphyllum* sp., *Solenodendron* sp., *Clisiophyllum* sp. and a new species *Corwenia tirhelensis* sp. nov. In addition, an undetermined petalaxid has been also recorded. Similarly, the assemblage from near the top of the Tirhela Formation yielded some species regarded usually as Mississippian, such as *Palaeosmilia murchisoni* and *Lithostrotion decipiens*. We also identified the long-ranging tabulate *Syringopora* sp., *Corwenia tirhelensis* sp. nov., and a single species of the fasciculate rugosan, *Siphonodendron tindoufense*, previously described from Bashkirian rocks in the Tindouf Basin (southern Morocco). The presence of the latter taxon in both the Idmarrach and Tirhela sections implies a communication between the Adarouch region and the Saharan basins. The occurrence of *S. tindoufense* at the approximately same stratigraphic level in Tindouf, Taoudenni, Reggan-Ahnet and Adarouch, demonstrates its important regional stratigraphic value in North Africa.

**Keywords** Rugosa · Mississippian · Pennsylvanian · Morocco · Adarouch · Palaeogeography · Biostratigraphy

## Introduction

The Carboniferous stratigraphic successions from Adarouch, in the Moroccan Central Meseta (Fig. 1), are composed both of siliciclastic and carbonate rocks, with the latter rich in diverse fossil groups such as foraminifers, algae, brachiopods, conodonts, bryozoans, crinoids and corals. Termier (1936) first described the stratigraphy of the Palaeozoic

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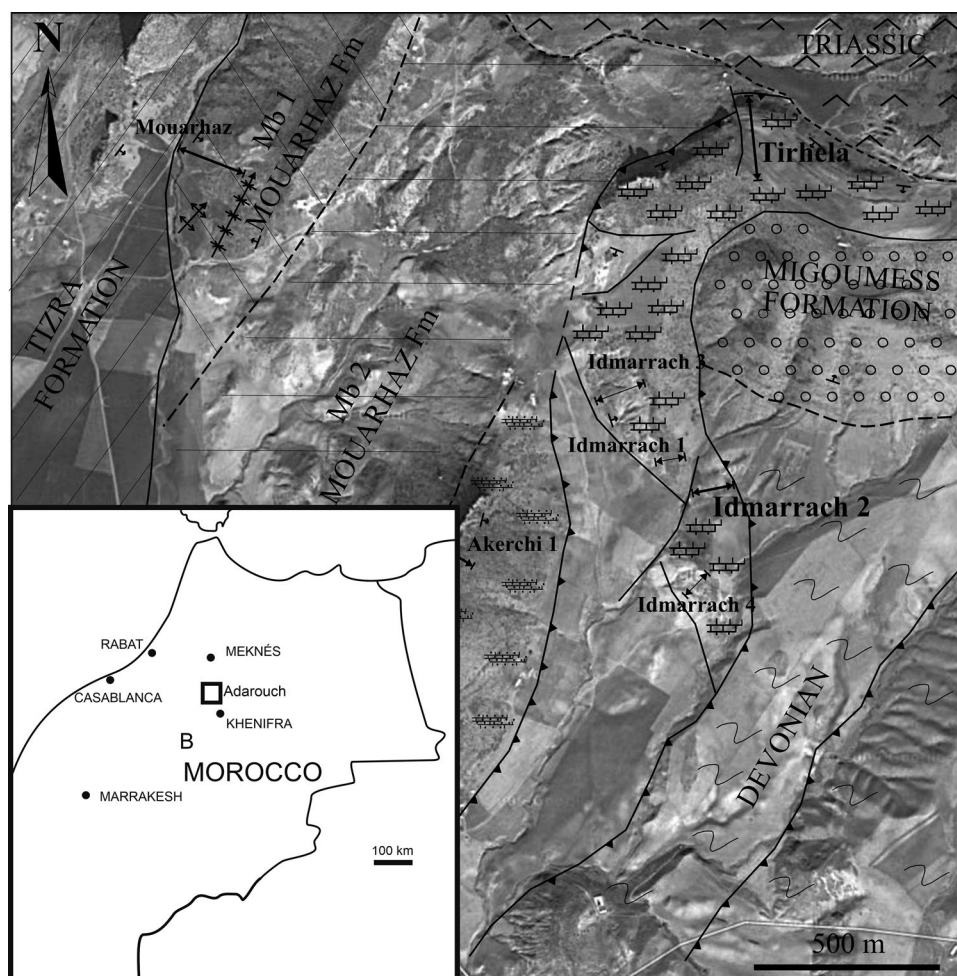
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**Fig. 1** Location of the Adarouch area (encased box) in the Moroccan Meseta. The photo-geological map shows the location of the studied stratigraphic sections. Modified from Cózar et al. (2011)



from the Moroccan Meseta. Termier and Termier (1950) mentioned the Tizra outcrops at Adarouch and described *Dibunophyllum vauhani* from that locality and Dedok and Hollard (1980) identified a probable Westphalian age for the Migoumess Formation, based on the presence of the brachiopod *Brachythyridina strangwaisi*. This dating was confirmed with foraminifers and algae by Berkli and Vachard (2002), who rejected other datings. Termier et al. (1975) regarded the Adarouch outcrops as ranging in age from the Viséan to Serpukhovian. The first detailed stratigraphical and palaeontological studies were undertaken by Berkli (1999), who defined three depositional sequences in the Carboniferous of Adarouch. In that region he defined the Oued Amhares Formation at the base, the Tizra and Mouarhaz formations in the middle and the Akerchi Formation at the top (Fig. 1). In a thrust sheet farther to the east, are the laterally equivalent Idmarrach and Tirhela formations. The continental siliciclastic rocks of the Migoumess Formation crop out further east (Berkli and Vachard 2001, 2002). The coral assemblages from the Tizra, Akerchi and Idmarrach formations were originally described by Said (2005) in an unpublished Ph.D. thesis and later reported by Said et al. (2007). The

aulophyllids from those formations were described by Said et al. (2008). The taphonomical and palaeoecological features of those assemblages and their environmental implications were the aim of two later papers (Said et al. 2010, 2011).

Berkli and Vachard (2001, 2002), based on foraminifers, assigned a Viséan age to the Oued Amhares, Tizra, Mouarhaz, lower Akerchi and Idmarrach formations, and a Serpukhovian age to the upper Akerchi Formation and the top of the Idmarrach Formation. However, Cózar et al. (2008, 2011) subsequently demonstrated that only the base of the Akerchi Formation is uppermost Viséan and that the Idmarrach Formation (and its equivalent, the Tirhela Formation) is almost entirely Serpukhovian, but reaching the Bashkirian in the upper beds. These revised age determinations were based on the analysis of foraminifers and conodonts and implies that the transition from a marine to continental environment in the Adarouch region happened later, in the Bashkirian, and not in the Serpukhovian, as previously inferred. The coral assemblages identified in the lower beds of both the Idmarrach and Tirhela formations comprise typical late Viséan and Serpukhovian species (Said 2005; Said

et al. 2007; Rodríguez et al. 2015, 2016). However, the coral assemblages recorded at the top of the Idmarrach and Tirlhela formations are poorly preserved and were not previously described. They come from a mixed siliciclastic calcareous facies that represents the transition to the Migoumess Formation that is composed of entirely siliciclastic continental rocks.

Although the corals in this present study are quite abundant and diverse, they are commonly dolomitized, silicified and in some cases partly decalcified. The importance of these assemblages is twofold: (1) they represent the last in situ marine fossils present in the Palaeozoic from the Adarouch region, and (2) being recorded in the lowermost Bashkirian, they may represent the transition from Mississippian to Pennsylvanian coral assemblages across the mid-Carboniferous boundary.

## Coral assemblages

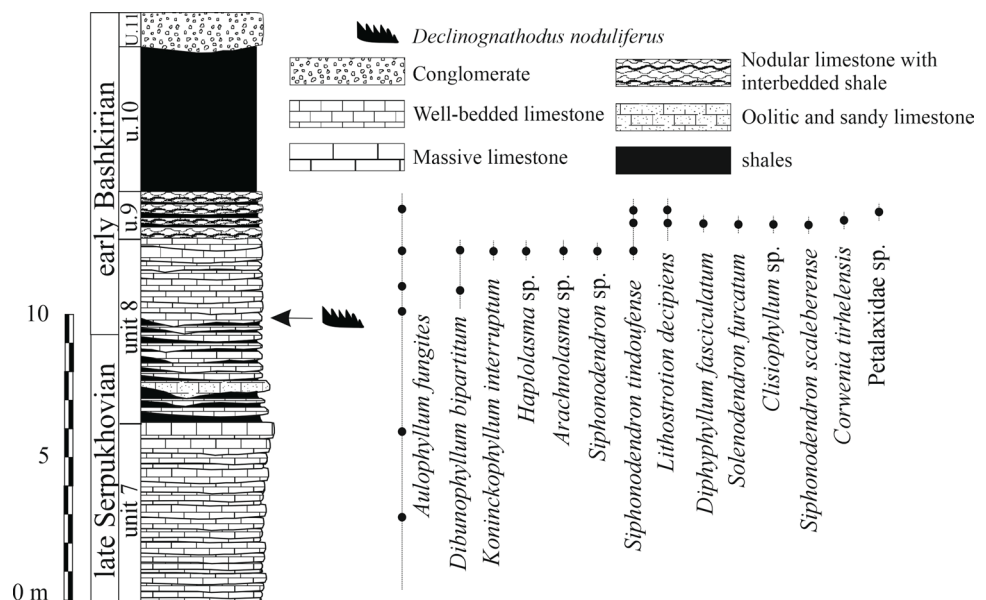
As stated above, the coral assemblages identified from the lower beds of the Idmarrach Formation were listed in Said et al. (2007). New sampling campaigns have been undertaken since then, and the description of corals collected from the Idmarrach and Tirlhela formations was subsequently published (Rodríguez et al. 2015, 2016; Somerville et al. 2016). However, the assemblages recorded in the upper levels of the Idmarrach and Tirlhela formations are very important from a biostratigraphic and palaeogeographic point of view and they are described herein (see Appendix Table 1 and Table 2 for list of specimens and locations). However, for those taxa identified previously from these sections, only brief comments are recorded to highlight diagnostic properties or

unusual features. Comparisons have been made with rugose coral faunas documented from other Serpukhovian and younger locations in Morocco (Rodríguez et al. 2013) and Algeria (Semenoff-Tian-Chansky 1974, 1985; Aretz 2011; Atif et al. 2016).

## Idmarrach formation

Corals are abundant in some levels of the Idmarrach Formation. Three combined logged sections (Idmarrach-1, -2, -3) represent the composite stratigraphy that was previously reported in Cózar et al. (2011). The section Idmarrach-1, and the lower levels of Idmarrach-2 yielded abundant corals that have been described by Said (2005) and listed by Said et al. (2007) and were regarded as Brigantian; the assemblages of section Idmarrach-3, and lower levels of Idmarrach-2 were described in more detail in Rodríguez et al. (2015, 2016), but the upper levels of Idmarrach 2 have been not described yet. The upper levels of Idmarrach-2 section in units 8–9 (Figs. 2, 3:1–2) show a marked and abrupt enrichment in siliciclastics and consequent generally poor preservation of the coral specimens. Nevertheless, the uppermost limestone beds of the formation (IDM2/8, 9; see Fig. 2) are quite rich in corals and yielded a mixed assemblage composed of solitary and colonial rugose corals. Although the diversity is quite high (12 genera), with 6 solitary genera and 6 colonial genera recorded, only a few of the 14 species are abundant (Appendix Table 1). The assemblage is paraautochthonous, because the corals are not in growth position, and many fasciculate colonies are fragmented, but most of the solitary corals show little abrasion (Fig. 3:3). As they have been recorded in a sandy and marly limestone that shows some extraclasts and local erosion surfaces, it is interpreted that

**Fig. 2** Log of the upper part of the Idmarrach-2 Section (units 7–9), showing the coral distribution (adapted from Cózar et al. 2011)







**Fig. 3** Idmarrach-2 section **1.** General view of the section (units 3–8). **2.** Upper part of the Idmarrach-2 section showing the boundary between units 8 and 9. **3.** Detail of a bedding plane in unit 8 showing some solitary corals mainly *Aulophyllum* (black arrows)

the corals were living in the depositional area or nearby, but they were disturbed by periodic siliciclastic inputs. Most corals, mainly in unit, 9 show recrystallization and dolomitisation. The early Bashkirian age of units 8 and 9 is established by the presence of the conodont *Declinognathodus noduliferus* first recorded from the base of unit 8 (Cózar et al. 2011; Fig. 2).

The coral assemblage (Appendix Table 1) is composed of:

*Aulophyllum fungites* (Fleming, 1828) (Fig. 4:1–4)—It is quite common in units 7, 8 and 9, with 17 specimens collected. It

has been also recorded in lower units of the Idmarrach-2 section. The specimens from Idmarrach show quite a high variability in size and thickening of skeletal structures. They show a smaller size than the typical representatives of the species and the dissepimentarium is also narrower. Those differences with older specimens may be explained, either, due to their evolutionary development or perhaps more likely to difficult (stressful) environmental conditions.

*Dibunophyllum bipartitum* (McCoy, 1849) (Fig. 4:5)—Only one fragmentary specimen has been recorded. This species has a long stratigraphic record, being already recorded in the lower Bashkirian from Tindouf Basin (Rodríguez et al. 2013).

*Koninckophyllum interruptum* Thomson and Nicholson, 1876 (Fig. 4:6–7)—Only a single specimen recorded. It shows typical features of the nominal species.

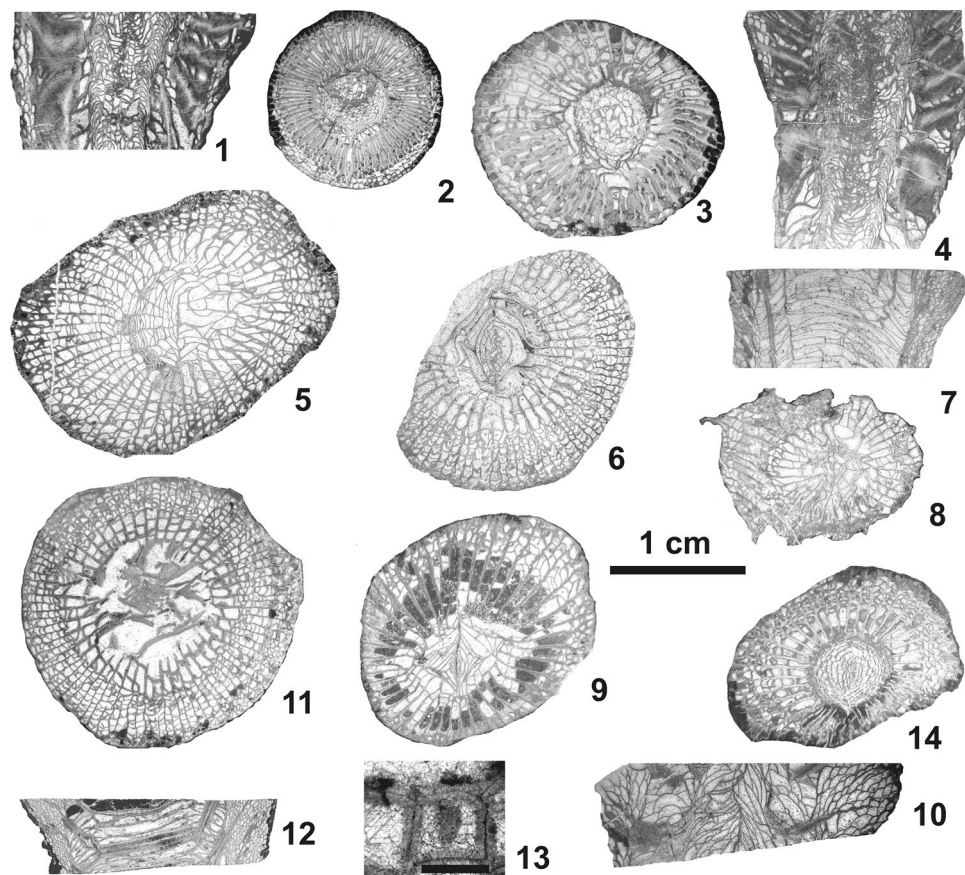
*Arachnolasma* sp. (Fig. 4:8–10)—Five specimens have been recorded and all show a poor preservation that prevents a specific identification, but the generic diagnostic features such as the thick columella and small axial structure without well-defined boundaries are present in all specimens.

*Clisiophyllum* sp. (Fig. 4:13)—One single fragmentary specimen. It shows close similarities to *Clisiophyllum* sp. 1 of Said et al. (2008). It has been recorded at the top of the Tizra Formation (upper Brigantian), in the Akerchi Formation (uppermost Brigantian) and in lower levels of the Idmarrach Formation (Serpukhovian).

*Haplolasma* aff. *parvicarinatum* Semenoff-Tian-Chansky, 1974 (Fig. 4:11–12)—Only a single specimen recorded. Smaller than most species of the genus. Its size is comparable to the Bashkirian species from China *H. lingwueense* (Lee and Chu, 1934), but the Chinese species has a lower number of septa and lacks a cardinal fossula. It shows also clear similarities to the smallest specimens of the Viséan species from the Sahara, *H. parvicarinatum* and *H. lamelliferum* (see Semenoff-Tian-Chansky 1974). The microstructure of the septa is fibrous; consequently, it is closer to *H. parvicarinatum*, despite the fact that it does not show carinae in the dissepimentarium.

*Siphonodendron tindoufense* Rodríguez et al., 2013 (see details in the assemblage from Tirhela at a similar stratigraphical level)—Three specimens show a very poor preservation, but their features and size fit well with the species from the Tindouf Basin (Rodríguez et al. 2013).

*Siphonodendron* sp. (Fig. 5:1–2)—Two recorded specimens show an intermediate size and number of septa between the



**Fig. 4** Solitary rugose corals of the upper beds from Idmarrach-2 Section exposing >35 m of strata. 1–4 *Aulophyllum fungites* (Fleming, 1828). 1–3 specimen IDM2/8-1, 1: longitudinal section, 2: transverse section in juvenile stage, 3: transverse section in mature stage. 4. Specimen IDM2/8-13, longitudinal section 5. *Dibunophyllum bipartitum* McCoy, 1849, specimen IDM2/8-21, transverse section 6–7 *Koninckophyllum interruptum* Thomson and Nicholson, 1876, specimen IDM2/8-23, 6: transverse section, 7: longitudinal

section 8–10 *Arachnolasma* sp. 8, specimen IDM2/8-22, transverse section 9, IDM2/9-14B, transverse section 10, IDM2/9-29, longitudinal section 11–13, *Haplolasma* aff. *parvicarinatum* Semenoff-Tian-Chansky, 1974, specimen IDM8/2-11, 11: transverse section, 12: longitudinal section 13: detail of the fibrous microstructure. 14. *Cliosiphylum* sp., specimen IDM2/9-26, transverse section 1 cm scale bar, same for all pictures, except Fig. 4:13 (1 mm scale bar)

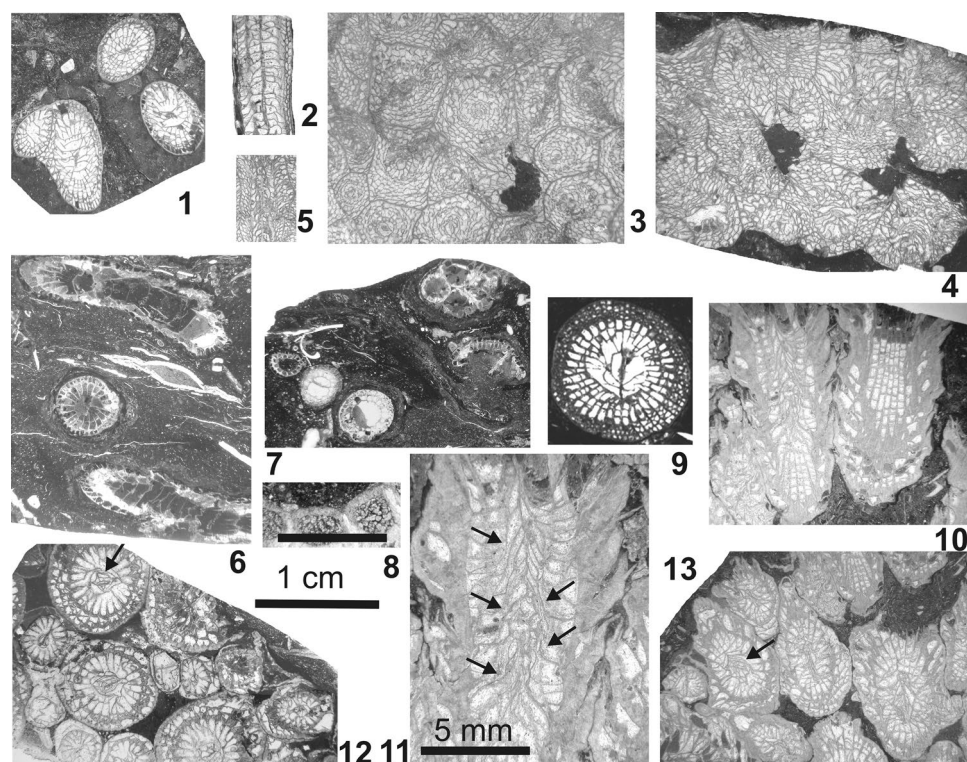
two Bashkirian species (*S. tindoufense* and *S. ouarkizense*), recorded in the Tindouf Basin (Rodríguez et al. 2013) and share with them the main diagnostic features, mostly flat tabulae and discontinuous axial columella.

*Siphonodendron scaleberense* Nudds and Somerville, 1987 (Fig. 5:8)—Only one branching fragment of a fasciculate colony has been recorded in a debris bed (unit 9). It is smaller in size than the type material (9 mm in tabularium diameter), although the number of major septa (36) is the same. The cardinal fossula is conspicuous which distinguishes it from all other species in the genus. The minor septa do not usually reach the inner dissepimentarium/tabularium border, creating inosculate or herringbone-type inner dissepiments, a feature developed in *S. multiradiale* Nudds and Somerville, 1987, but differs from it in having

less densely packed major septa. The only other comparable species is *S. sociale* (Phillips, 1836), but that species has fewer major septa (29–34) for corallites of the same size (see Nudds 1980; Poty 1981).

*Lithostrotion decipiens* (McCoy, 1849) (Fig. 5:3–5)—It is quite common in the last beds (unit 9) of the Idmarrach Formation. Seven specimens have been collected. They are small cerioid colonies that show some areas changing to phaceloid (subcerioid) surrounded by siliciclastic material mixed with micrite. Five specimens show a tabularium diameter and number of septa that are typical for the species (14–17 major septa and 2–3 mm in tabularium diameter). The other two specimens show slightly larger measurements (19–20 major septa and 3–3.5 mm in tabularium diameter) but are included in the same species.





**Fig. 5** Colonial rugose corals of the upper beds from Idmarrach-2 section 1–2 *Siphonodendron* sp., specimen IDM2/8-25, 1: transverse section, 2: longitudinal section of one single corallite. 3–5 *Lithostrotion decipiens* McCoy, 1849, 3: specimen IDM2/9-32, transverse section 4: specimen IDM2/9-10A, oblique section showing interruptions in the growth. 5: Specimen IDM2/9-30B, longitudinal section of one corallite. 6 *Diphyphyllum fasciculatum*, Fleming, 1828, specimen IDM2/9-16, broken branches showing transverse and longitudinal sections. 7–8. *Solenodendron furcatum* Smith, 1925, specimen IDM2/9-20, 7: broken branches showing transverse section. Note

the parricidal increase (upper right). 8: Detail of the deflected inner border of septa building the aulos. 9. *Siphonodendron scaleberense* Nudds and Somerville, 1987, specimen IDM2/9-11A, broken branch showing transverse section 10–13 Undetermined petalaxid, specimen IDM2/9-12. 10: longitudinal section, 11: detail of the longitudinal section showing periaxial cones (arrows), 12: transverse section; note the presence of lateral lamella (arrow), 13: oblique section; note the presence of lateral lamella (arrow). 1 cm scale bar, same for all pictures, except Fig. 5:10 (5 mm scale bar) and Fig. 5:8, (1 mm scale bar)

*Diphyphyllum fasciculatum* (Fleming, 1828) (Fig. 5:6)—Several branching fragments of fasciculate colonies have been recorded in a debris bed (unit 9). They are broken and compressed. The features of the individual corallites (19–20 major septa, 4.5 mm in diameter, short septa, and absence of axial structure) fit well with those of the type species.

*Solenodendron furcatum* (Smith, 1925) (Fig. 5:7)—It has been recorded only as broken branches, and in the same debris bed as *D. fasciculatum* (unit 9). The individual corallites show 20–21 major septa, 4 mm in diameter, a well-developed aulos and parricidal increase. All these features are identical to the nominal species (see Somerville et al. 2016).

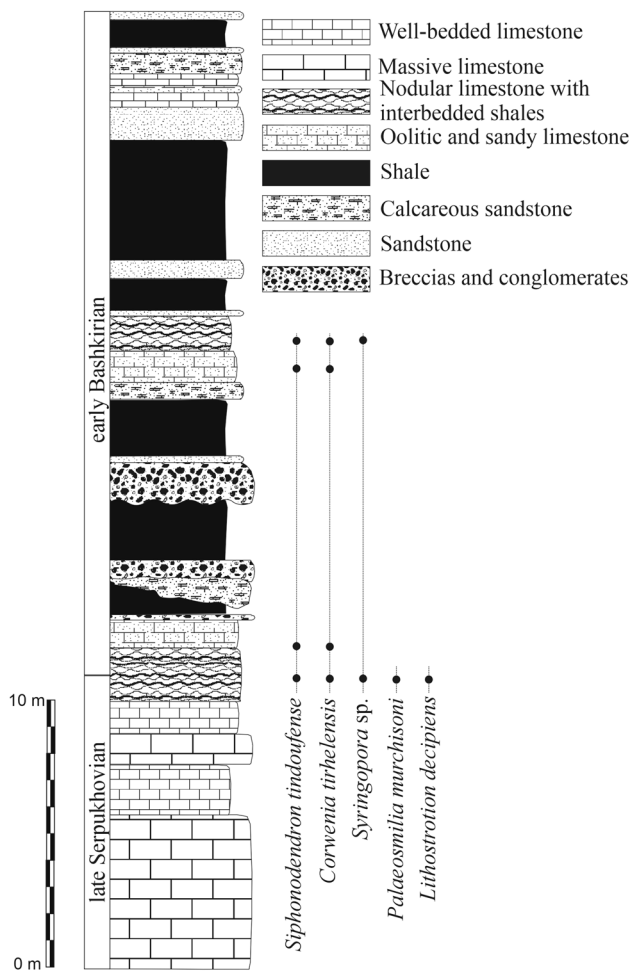
*Corwenia tirhensis* sp. nov. (see details in the systematic section)—Several branches included in coral debris have been identified as belonging to the genus *Corwenia*. Their

features are identical to those of specimens recorded in the Tirhela Formation (see below).

Undetermined petalaxid (Fig. 5:9–12)—One single colonial specimen. This coral has a fasciculate habit, with closely packed corallites. It shows similarities with several genera of the family Petalaxidae and also with corals of the family Lonsdaleiidae, but it does not fit completely with any of them. (See the systematic section).

### Tirhela formation

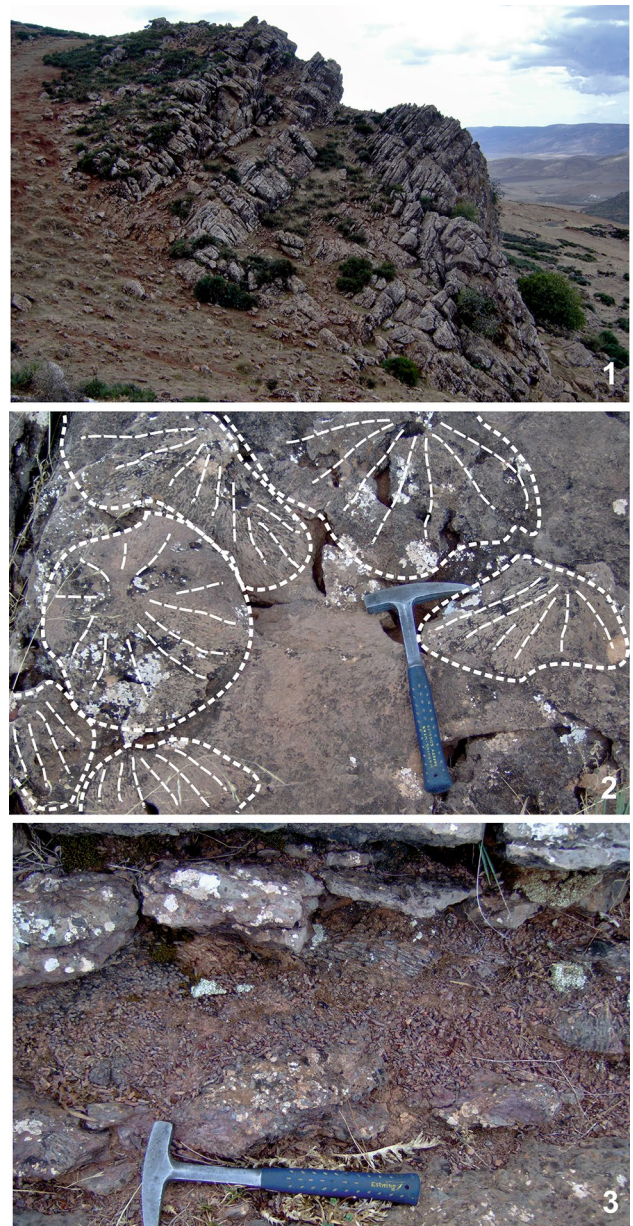
The coral assemblages of the lower beds of the Tirhela Formation have been described in Rodríguez et al. (2015, 2016). Only the coral assemblage recorded in the upper sandy limestone beds (Figs. 6, 7:1) is described here. The upper beds of the Tirhela section (Fig. 1) represent transitional beds to continental siliciclastic beds of the Migoumess Formation, comprising thick red shales, calcareous sandstones and



**Fig. 6** Log of the upper levels of the Tirlhela section, showing the distribution of corals (adapted from Cózar et al. 2011)

breccias (Fig. 6). Corals in the upper beds of the Tirlhela Formation are abundant and can form biostromes (Fig. 7:2–3). However, the diversity is quite low (5 genera), with only four colonial genera and one solitary genus, and five species recorded (Appendix Table 2). In spite of the short distance (about one kilometre) between the Tirlhela and Idmarrach sections (Fig. 1), and similar transitional marine to non-marine facies, the Tirlhela and Idmarrach assemblages only have three rugose species in common, and the abundance of each species is different in both sections. The dominant species in Tirlhela are *Siphonodendron tindoufense* and *Corwenia tirhelensis* sp. nov., that are very scarce in Idmarrach, and the most common species from the latter section (*Aulophylum fungites*) is absent in the former (Appendix Table 2).

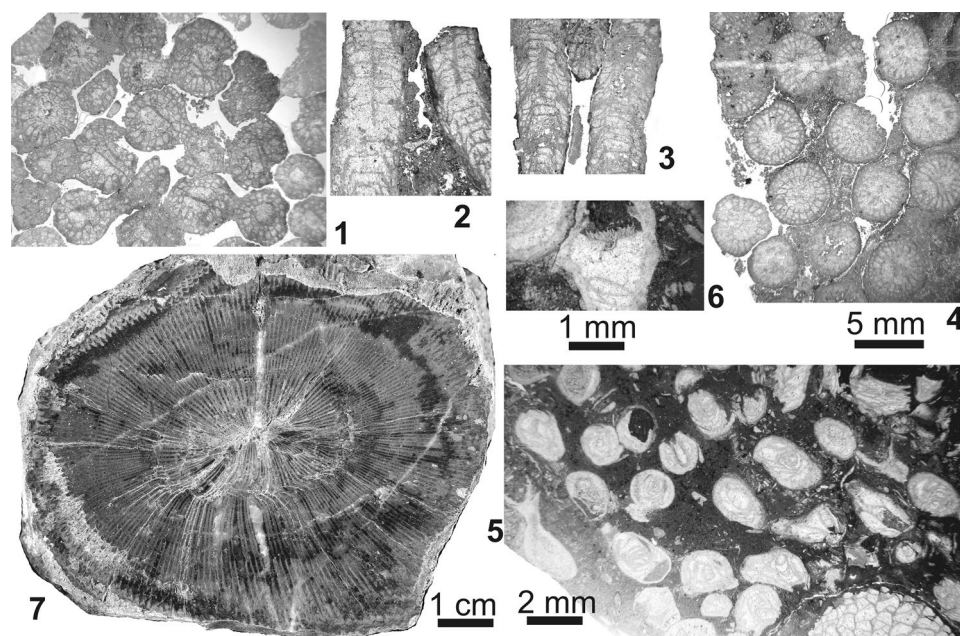
The coral assemblage (Appendix Table 2) is composed of:



**Fig. 7** The Tirlhela section 1. General view of Tirlhela 2 section with steeply dipping beds to the south, showing massive and well-bedded limestones passing up to nodular bedded limestones and shales and sandy limestones (> 20 m thick). 2. Detail of one bed showing abundant fasciculate coral colonies. 3. Biostromal bed composed mainly of broken branches of *Siphonodendron tindoufense* Rodríguez et al., 2013

*Siphonodendron tindoufense* Rodríguez et al., 2013 (Fig. 8:1–4)—It is particularly abundant, being the dominant species in some beds (Fig. 7:3). Most specimens are in growth position or almost. Eleven specimens have been collected. All of them show corallites with a discontinuous columella, horizontal to slightly conical tabulae, 3.5–4.5 mm in diameter and 18–22 major septa, which are identical features





**Fig. 8** Corals from the upper carbonate beds at the Tirthela section 1–4 *Siphonodendron tindoufense* Rodríguez et al., 2013 1–2, specimen TIR2/2-1, 1: transverse section, 2: longitudinal section 3–4, specimen TIR2/2-7, 3: longitudinal section, 4: transverse section 5–6 *Syringopora* sp. 5: specimen TIR2/2-27, transverse section of a part of the colony. 6: specimen TIR2/2-23B, detail of the calyx of a cor-

allite showing the presence of sclerites similar to those of *Termieralcyon* (see Fernández-Martínez et al., 2018). 7 *Palaeosmilia murchisoni* Milne-Edwards and Haime, 1848, specimen TIR2/2-28, transverse polished section 5 mm scale bar for Fig. 8:1–4, scale bar 2 mm for Fig. 8:5, scale bar 1 mm for Fig. 8:6 and scale bar 1 cm for Fig. 8:7

to the specimens from the Tindouf Basin (Rodríguez et al. 2013).

*Corwenia tirhelensis* sp. nov. (Fig. 9:1–8)—Also very abundant and being dominant in some beds. Twenty-four specimens have been collected. Some colonies are entire and in growth position, but some others are broken fragments showing only a few branches. (See the systematic section).

*Lithostrotion decipiens* (McCoy, 1849) (see details in Idmarrach assemblage)—One single colony has been recorded in Tirthela showing a mean corallite diameter of 3 mm and 19–20 major septa.

*Syringopora* sp. (Fig. 8:5–6)—Two specimens that grew together with specimens of *Corwenia* sp. have been recorded. They have corallites 2 mm in diameter, show infundibuliform tabulae and common septal spines and show symbiosis with the alcyonarian *Termieralcyon* (Fernández-Martínez et al., 2018).

*Palaeosmilia murchisoni* Milne-Edwards and Haime, 1848 (Fig. 8:7)—Two very large specimens have been collected (more specimens have been identified in the field). The coralla are 70 and 85 mm in diameter and have 103 and 106

septa, respectively. Both specimens show a naotic peripheral dissepimentarium. They are the only solitary corals recorded in the upper beds of the Tirthela Formation.

## Systematic palaeontology

Phylum **Coelenterata** Frey and Leuckart, 1847

Subphylum **Cnidaria** Hatschek, 1888

Class **Anthozoa** Ehrenberg, 1834

Subclass **Rugosa** Milne-Edwards and Haime, 1850

Family **Aulophyllidae** Dybowski, 1873

Genus ***Corwenia*** Smith and Ryder, 1926

***Corwenia tirhelensis*** sp. nov.

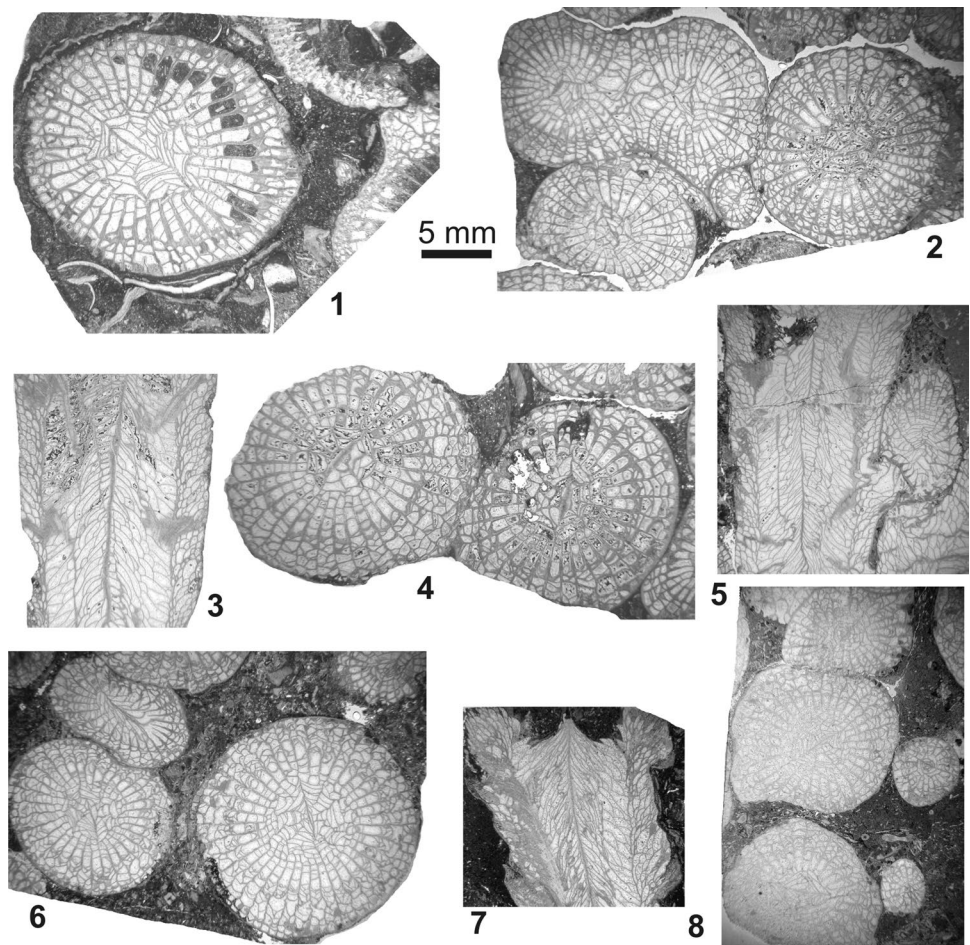
Figure 9:1–8

**Holotype.** Specimen TIR2/2-21. Upper beds of the Tirthela Formation. All other specimens of the collection are regarded as paratypes.

**Material.** 27 specimens have been collected; 24 from Tirthela, 3 from Idmarrach (Appendix Table 2).



**Fig. 9** *Corwenia tirhensis* sp. nov. 1: specimen IDM2/9-14A (paratype), transverse section 2: specimen TIR2/2-12 (paratype), transverse section 3–4, specimen TIR2/2-13, 3: longitudinal section, 4: transverse section 5–6: specimen TIR2/2-21 (holotype), 5: longitudinal section showing an offset, 6: transverse section 7–8, specimen TIR2/2-24 (paratype), 7: longitudinal section, 8: transverse section 5 mm scale bar for all pictures



*Location, horizon and age.* Upper beds from the Tirhela and Idmarrach formations, Adarouch region, Moroccan Meseta. Lower Bashkirian.

*Diagnosis.* Fasciculate coral. The corallites have typically 34–37 major septa and 13.5–17 mm in diameter. The corallites show a large dibunophylloid axial structure, long septa that reach the axial structure, slightly or not thickened in the tabularium. Minor septa irregular or absent, substituted by angulate to inosculate dissepiments.

*Description.* Fasciculate coral showing densely packed corallites. The alar diameter of colonies varies between 13.5 and 17 mm, the maximum being 20 mm; the tabularium diameter of colonies typically varies between 9 and 12 mm, the maximum being 15 mm; the axial structure diameter of colonies varies between 3 and 5 mm, the maximum being 6 mm. The number of major septa varies between 34 and 37, the maximum being 39.

The wall is thin and smooth, but it may show slight local thickenings. Where corallites are in contact, the two walls are distinctly separated (Fig. 9:2, 6). The septa are long; most of them reach the axial structure and some of them

are in continuity with radial lamellae. They are thin and irregular in the dissepimentarium, very slightly thickened in the outer tabularium and straight, slightly tapering axially (Fig. 9:2, 4, 6). The cardinal and the counter septa are not different from other septa. Both are joined to the median lamella (Fig. 9:1, 4, 6). The cardinal fossula is absent. The minor septa are short and irregular or absent (Fig. 9:4), only in the specimens from Idmarrach are there some short minor septa that reach the dissepimentarium/tabularium boundary (Fig. 9:1). In juvenile stages the septa are somewhat shorter and only the cardinal and the counter septa are joined to a simple median lamella (Fig. 9:2, 8). The axial structure is typically dibunophylloid, composed of a somewhat thickened median lamella, 6–10 thin and irregular radial lamellae, and abundant, densely packed conical tabellae. It occupies about 1/3–1/4 of the diameter (Fig. 9:1, 2, 4, 6). The dissepimentarium occupies 1/3–1/4 of the radius. In mature stages, it is composed of 3–7 rows of angulate to inosculate, less commonly regular dissepiments (Fig. 9:2, 6). The inner row may be slightly thickened (Fig. 9:1, 4). In longitudinal section, they are globose to slightly elongated and very steeply declined (60–90°, Fig. 9:3, 5, 7). The tabulae are thin, incomplete and divided in two series of tabellae. The

axial tabellae are conical, convex and declined 30°–60° to the periphery; 5–8 of them are intersected in transverse section. The periaxial tabellae are also convex, but less densely packed than the axial tabellae, and slightly less steeply declined to the periphery (Fig. 9:3, 7). The microstructure of the wall is microlamellar. The tabulae and dissepiments are microgranular with fibrous thickenings. The septa show mesoplasm with fibers organized in fascicles and fibronormal stereoplasm.

**Remarks.** The specimens from Idmarrach show slight differences with those from Tihela: they are slightly larger, the minor septa are better developed and the dissepimentarium is somewhat narrower. But all other features are identical and those differences are considered as local variations and adaptations.

The features of this species do not fit with any previously described species of the genus. It is similar to the type species *Corwenia rugosa* (McCoy, 1849) in the dibunophylloid axial structure, in the length and thickness of septa and in the structure of the tabularium, but it is larger, possesses more septa and lacks a conspicuous cardinal fossula. Other species are even smaller, including those recorded in the Bashkirian (*Corwenia longiseptata* Fomichev, 1953, *Corwenia cantabrica* De Groot, 1963). Only the Serpukhovian species *C. densicolumellata* Bykova, 1966 shows a similar size (even larger) and number of septa, but it differs clearly in having a smaller axial structure and thicker median plate. The Brigantian unnamed species (*Corwenia* sp.) described by Said et al. (2008) from the Tizra Formation shows also a similar size, but the number of septa is lower, the axial structure is also smaller and more irregular and the juvenile stages lack an axial structure.

Family **Petalaxidae** Fomichev, 1953

**Gen. et sp. unknown**

Figure 5:9–12

**Material.** A single specimen from Idmarrach IDM2/9-12 (Appendix Table 1).

**Description.** Phaceloid colony. Corallites closely spaced and irregularly distributed; wall generally thin, sinuous in longitudinal section, somewhat thickened by septal bases, septal furrows well marked. In mature stage (Fig. 5:11, 12) number of septa normally 22–23, at corallite diameter 4.5–5.0 mm; major septa long, reaching or almost the axial structure, slightly thickened near the wall and in the outer part of the tabularium, radial, commonly interrupted by lonsdaleoid dissepiments; cardinal septum straight, slightly thickened, connected to median lamella of axial structure, but locally detached from it; minor septa developed only in adult stages,

short, thickened at wall, adaxially tapered, forming ridges on wall in early adult stages, becoming slightly longer in maturity and just penetrating the outermost tabularium, discontinuous in dissepimentarium. Axial structure well developed, with variably thickened median lamella, bearing few short septal lamellae and axial tabellae. Dissepiments lonsdaleoid forming almost complete rings in some corallites (Fig. 5:11, 12). In longitudinal section, large dissepiments, moderately convex, steeply inclined in one or more rarely two rows. Thick deposit on their inner border. Tabulae moderately spaced (8–10 in 1 cm corallite length), thin, complete, concave or planar, moderately elevated adaxially, more strongly elevated at median lamella, which is irregular and sinuous. Periaxial cones well developed (Fig. 5:10).

**Remarks.** It is a phaceloid coral that shows many typical features of the family Petalaxidae. However, the only fasciculate genera included in that family (Hill 1981; Bamber et al. 2017) are *Lytvophyllum*, and *Schoenophyllum*.

*Lytvophyllum* is known from the early Bashkirian in Donets and Novaya Zemlya (Kossovaya 1996), but a recent paper by Fedorowski (2021) stated that the Ukrainian specimens and probably also those from Novaya Zemlya are solitary or protocolonial and included them in his new family Krinkaphyllidae. It lacks the slightly complex axial structure, the lateral lamellae and the periaxial cones that are present in the specimen from Idmarrach. Some species of the genus *Schoenophyllum* show similar development of the lonsdaleoid dissepimentarium and densely packed corallites, but they have a more simple axial structure and a very peculiar lateral increase that distinguish that genus from our specimen. A close genus is *Cystolonsdaleia*, to which this specimen was previously tentatively assigned (Rodríguez et al. 2016) which shows also all those features, but it is cerioid. The specimen from Idmarrach has very densely packed corallites and in part of the colony some of them share walls showing a subcerioid habit, but it is clearly fasciculate, not massive. It could be regarded as a derivation of *Cystolonsdaleia* that developed a fasciculate habit. Alternatively, it could be considered as a possible ancestor of cerioid *Cystolonsdaleia*. It could be also related to the family Lonsdaleiidae, because most of the features present in the specimen from Idmarrach are shared with *Lonsdaleia* and its subgenus *Serraphyllum*, which shows intermediate features between fasciculate and cerioid habitus. Hecker (2012) demonstrated the presence of periaxial cones and a biform tabularium in these genera. However, the axial structure of *Lonsdaleia* is more complex and it does not possess lateral lamellae, which is a typical feature of the Petalaxidae. If the specimen from Idmarrach belongs to the Petalaxidae, it would represent the first record of that family in North Africa, and could imply certain biogeographical relationships with the eastern European Basins (Donets, Moscow,



Ural Mountains), as well as the Cantabrian Mountains (N. Spain), where representatives of this family are common in the Bashkirian (De Groot 1963; Rodríguez 1984). Some Petalaxidae have been also described from the Mississippian and Pennsylvanian from North America (Bamber and Fedorowski 1998; Bamber et al. 2017; Sando 1983).

## Discussion

The coral assemblages recorded in the uppermost rocks of the Tirlhela and Idmarrach formations are composed mainly of rugose species, usually regarded as Mississippian. However, as the Bashkirian age of those rocks is well established using foraminifers and conodonts (see Cózar et al. 2011), it implies that some of the species are being recorded for the first time in the Bashkirian: *Lithostrotion decipiens*, *Aulophyllum fungites*, *Koninckophyllum interruptum*, *Diphyphyllum fasciculatum*, *Siphonodendron scaleberense*, *Solenodendron furcatum* and the genus *Clisiophyllum* extending their stratigraphical distribution to the lower Bashkirian. In addition, some other species and genera typically recorded in the Mississippian (*Palaeosmilia murchisoni*, *Dibunophyllum bipartitum*, *Arachnolasma* sp.) were previously recorded in the lower Bashkirian from the Tindouf Basin (Rodríguez et al. 2013; Cózar et al. 2014b) and hence their Bashkirian distribution is confirmed here. The rugose genera *Corwenia* and *Haplolasma* and the tabulate *Syringopora* have long stratigraphical ranges and are common in Bashkirian rocks (Lee and Chu 1934; Gorsky 1951; De Groot 1963; Rodríguez 1984; Fedorowski 2004, etc.).

The presence of many Mississippian-type corals in the Bashkirian rocks from Adarouch confirm the presence of a refuge for corals in North Africa (Cózar et al. 2014a) and indicates that it was not restricted to the Saharan basins, but also expanded to northern North African basins (Adarouch area of central Morocco Meseta). There were also other similar refuges where Mississippian corals reached the Bashkirian: *Palaeosmilia* and *Diphyphyllum* in Novaya Zemlya (Kossovaya 1996), *Dibunophyllum*, *Palaeosmilia*, *Lonsdaleia* and *Tizraia* in Ellesmere Island (Fedorowski et al. 2012) and *Dibunophyllum*, *Caninostrotion*, *Nemistium* and *Kizilia* in the Cantabrian Mountains (Rodríguez 1984).

The species *Siphonodendron tindoufense* was found in a similar stratigraphical level at the top of the marine carbonate succession in several Saharan basins: Reggan-Ahnet, Taoudenni (Semenoff-Tian-Chansky 1985), Tindouf (Fabre 1955; Rodríguez et al. 2013). Semenoff-Tian-Chansky (1985) proposed an identical stratigraphical position for the *Siphonodendron tindoufense* beds in all those basins, as uppermost Serpukhovian. As it was demonstrated that in Tindouf it is lower Bashkirian, the age in Reggan-Ahnet and Taoudenni must be checked; but in those basins, as in

Tindouf, the cited species is related to the brachiopod-rich *Titanaria* beds and a similar if not identical stratigraphic position could be assumed. Consequently, it could be considered as an index fossil for the lower Bashkirian in North Africa. The presence of that species indicates also a communication between the Sahara and the Moroccan Meseta up to and including the Bashkirian, in spite of the rising of the Atlas Mountains, Reguibat Shield and Ougarta High (Cózar et al. 2014c). Some other species are also recorded in both the Tindouf Basin and Adarouch: *Dibunophyllum bipartitum* and *Palaeosmilia murchisoni*, but it is not significant, since both species are cosmopolitan. On the other hand, some of the most common species in the Bashkirian from the Tindouf Basin, such as *Axophyllum moroccoense* and *Actinocyathus sarytschevae* are not present in Adarouch and *Corwenia* and *Syringopora* that are common in Adarouch have not been recorded in the Bashkirian from the Tindouf Basin.

## Conclusions

The coral assemblages from the upper part of the Idmarrach and Tirlhela formations, which have been identified as lower Bashkirian age based on foraminifers and conodonts, comprise some typical Mississippian species, such as *Aulophyllum fungites*, *Dibunophyllum bipartitum*, *Koninckophyllum interruptum*, *Lithostrotion decipiens*, *Siphonodendron scaleberense*, *Solenodendron furcatum*, *Diphyphyllum fasciculatum* and *Palaeosmilia murchisoni*. In addition, some unidentified species of typical Mississippian genera have been also recorded (*Arachnolasma* sp., *Clisiophyllum* sp.). It implies the extension of the stratigraphical ranges of those genera and species. The long-ranging genera *Syringopora*, *Corwenia* and *Haplolasma* are also recorded, as well as a new species of *Corwenia*, *C. tirlhelenese* sp. nov.

In addition, a single colonial specimen identified as belonging to the family Petalaxidae has been recorded in the Idmarrach Formation. It could represent an undescribed genus; the family Petalaxidae, is common in the Bashkirian from the Western Palaeotethys (Eastern European basins and Cantabrian Mountains), indicating a possible connection with those basins.

The abundance of the species *Siphonodendron tindoufense* that has been previously described from Bashkirian rocks in the Saharan Tindouf Basin, has a twofold importance: (1) This species may be regarded as an index fossil for the lower Bashkirian in North Africa (to be confirmed in the Reggan-Ahnet and Taoudenni basins), (2) it proves a communication between the Saharan Basins and the Moroccan Meseta during the Bashkirian.

## Appendix

See Tables 1, 2.

**Table 1** List of coral species recorded from Idmarrach, with figure numbers of illustrated specimens

Species	Number	Illustration
<i>Aulophyllum fungites</i>	IDM2/7-1	Figure 4:1–3
<i>Aulophyllum fungites</i>	IDM2/8-1	
<i>Aulophyllum fungites</i>	IDM2/8-2	
<i>Aulophyllum fungites</i>	IDM2/8-3	
<i>Aulophyllum fungites</i>	IDM2/8-7	
<i>Aulophyllum fungites</i>	IDM2/8-8	
<i>Aulophyllum fungites</i>	IDM2/8-9	
<i>Aulophyllum fungites</i>	IDM2/8-10	
<i>Aulophyllum fungites</i>	IDM2/8-12	
<i>Aulophyllum fungites</i>	IDM2/8-13	
<i>Aulophyllum fungites</i>	IDM2/9-19A	
<i>Aulophyllum fungites</i>	IDM2/9-25	
<i>Aulophyllum fungites</i>	IDM2/9-28	
<i>Aulophyllum fungites</i>	IDM2/9-6	Figure 4:4
<i>Aulophyllum fungites</i>	IDM2/9-8	
<i>Aulophyllum fungites</i>	IDM2/9-9	
<i>Dibunophyllum bipartitum</i>	IDM2/8-21	
<i>Koninckophyllum interruptum</i>	IDM2/8-23	
<i>Arachnolasma</i> sp.	IDM2/8-4	
<i>Arachnolasma</i> sp.	IDM2/8-15	
<i>Arachnolasma</i> sp.	IDM2/8-22	
<i>Arachnolasma</i> sp.	IDM2/9-14B	
<i>Arachnolasma</i> sp.	IDM2/9-29	
<i>Clisiophyllum</i> sp.	IDM2/9-26	
<i>Haploasma</i> aff. <i>parvicarinatum</i>	IDM2/8-11	
<i>Siphonodendron tindoufense</i>	IDM2/9-1	Figure 4:5
<i>Siphonodendron tindoufense</i>	IDM2/9-2	
<i>Siphonodendron tindoufense</i>	IDM2/9-3	
<i>Siphonodendron</i> sp.	IDM2/8-24	
<i>Siphonodendron</i> sp.	IDM2/8-25	
<i>Siphonodendron scaleberense</i>	IDM2/9-11A	
<i>Lithostrotion decipiens</i>	IDM2/9-10A	
<i>Lithostrotion decipiens</i>	IDM2/9-11B	
<i>Lithostrotion decipiens</i>	IDM2/9-27	
<i>Lithostrotion decipiens</i>	IDM2/9-30	
<i>Lithostrotion decipiens</i>	IDM2/9-31	
<i>Lithostrotion decipiens</i>	IDM2/9-32	
<i>Lithostrotion decipiens</i>	IDM2/9-33	Figure 5:1–2
<i>Diphyphyllum fasciculatum</i>	IDM2/9-4	
<i>Diphyphyllum fasciculatum</i>	IDM2/9-5	
<i>Diphyphyllum fasciculatum</i>	IDM2/9-7	
<i>Diphyphyllum fasciculatum</i>	IDM2/9-15A	
<i>Diphyphyllum fasciculatum</i>	IDM2/9-16	

**Table 1** (continued)

Species	Number	Illustration
<i>Solenodendron furcatum</i>	IDM2/9-19B	Figure 5:7
<i>Solenodendron furcatum</i>	IDM2/9-20	
<i>Solenodendron furcatum</i>	IDM2/9-21	
<i>Solenodendron furcatum</i>	IDM2/9-22	Figure 9:1 (Paratype)
<i>Corwenia tirhelensis</i>	IDM2/9-14A	
<i>Corwenia tirhelensis</i>	IDM2/9-15B	
<i>Corwenia tirhelensis</i>	IDM2/9-17	Figure 5:9–12
Undetermined petalaxid	IDM2/9-12	

**Table 2** List of coral species recorded from Tirhela, with figure numbers of illustrated specimens

Species	Number	Illustration
<i>Siphonodendron tindoufense</i>	TIR2/2-1	Figure 8:1–2
<i>Siphonodendron tindoufense</i>	TIR2/2-2	
<i>Siphonodendron tindoufense</i>	TIR2/2-3	
<i>Siphonodendron tindoufense</i>	TIR2/2-4	Figure 8:3–4
<i>Siphonodendron tindoufense</i>	TIR2/2-5	
<i>Siphonodendron tindoufense</i>	TIR2/2-6	
<i>Siphonodendron tindoufense</i>	TIR2/2-7	
<i>Siphonodendron tindoufense</i>	TIR2/2-8	
<i>Siphonodendron tindoufense</i>	TIR2/2-18	
<i>Siphonodendron tindoufense</i>	TIR2/2-19	
<i>Siphonodendron tindoufense</i>	TIR2/2-20	
<i>Corwenia tirhelensis</i>	TIR2/2-9	
<i>Corwenia tirhelensis</i>	TIR2/2-11	
<i>Corwenia tirhelensis</i>	TIR2/2-12	
<i>Corwenia tirhelensis</i>	TIR2/2-13	
<i>Corwenia tirhelensis</i>	TIR2/2-14	Figure 9:2 (Paratype)
<i>Corwenia tirhelensis</i>	TIR2/2-15	
<i>Corwenia tirhelensis</i>	TIR2/2-16	
<i>Corwenia tirhelensis</i>	TIR2/2-17	
<i>Corwenia tirhelensis</i>	TIR2/2-21	
<i>Corwenia tirhelensis</i>	TIR2/2-23A	
<i>Corwenia tirhelensis</i>	TIR2/2-24	
<i>Corwenia tirhelensis</i>	TIR2/2-25A	
<i>Corwenia tirhelensis</i>	TIR2/2-26	
<i>Corwenia tirhelensis</i>	TIR2/2-27A	
<i>Corwenia tirhelensis</i>	TIR2/2-30	



**Table 2** (continued)

Species	Number	Illustration
<i>Corwenia tirhelensis</i>	TIR2/2-31	
<i>Corwenia tirhelensis</i>	TIR2/2-32	
<i>Corwenia tirhelensis</i>	TIR2/2-33	
<i>Corwenia tirhelensis</i>	TIR2/2-34	
<i>Corwenia tirhelensis</i>	TIR2/2-35	
<i>Corwenia tirhelensis</i>	TIR2/2-36	
<i>Corwenia tirhelensis</i>	TIR2/2-37	
<i>Corwenia tirhelensis</i>	TIR2/2-38	
<i>Corwenia tirhelensis</i>	TIR2/2-39	
<i>Corwenia tirhelensis</i>	TIR2/2-40	
<i>Lithostrotion decipiens</i>	TIR2/2-10	
<i>Syringopora</i> sp.	TIR2/2-23B	Figure 8:6
<i>Syringopora</i> sp.	TIR2/2-25B	
<i>Syringopora</i> sp.	TIR2/2-27B	Figure 8:5
<i>Palaeosmilium murchisoni</i>	TIR2/2-28	Figure 8:8
<i>Palaeosmilium murchisoni</i>	TIR2/2-29	

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