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Mississippian coral assemblages from Tabainout mud-mound complex, Khenifra area, Central Morocco

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ABSTRACT. Analysis of Mississippian coral assemblages from the Khenifra region of Central Morocco has demonstrated the presence of a rich and diverse coral fauna. Rugose coral assemblages from the Tabainout mud-mound complex comprise abundant colonial and solitary taxa, particularly in the basal bedded limestones, as well as the upper bedded flank and coquina capping beds. The massive core facies with stromatactoid cavities in contrast has rare solitary corals. The overlying shales, marls and limestone bands which buried the mud-mound are dominated by small non-dissepimented solitary rugosans. The age of the Tabainout mound based on foraminifers is established as upper Viséan (late Asbian-late Brigantian). The coral assemblage strengthens correlations with the Adarouch area in the northern part of the Azrou-Khenifra Basin where similar mud mounds occur. These assemblages also show similarity with coeval coral faunas from the Jerada mud-mounds (buildups) of NE Morocco and together represent part of the same palaeobiogeographic province (Western European Coral Province).

KEYWORDS: Morocco, Azrou-Khenifra Basin, Mississippian, upper Viséan, mud-mounds, rugose coral assemblages, palaeoecology, palaeobiogeography.

1. Introduction

In North Africa, especially Morocco and Algeria, coral-bearing mud-mounds and bioherms are not all that well known from the Carboniferous. The exceptions are the upper Viséan mud-mounds of the Erfoud region, eastern Morocco (Wendt et al., 2001) and bioherms from the Béchar Basin, W. Algeria (Pareyn, 1959, 1961; Semenoff-Tian-Chansky, 1974, 1985; Bourque et al., 1995). Recently, mud-mounds (buildups) containing rugose corals have been described from the Jerada Basin (NE Morocco) (Aretz & Herbig, 2008; Aretz, 2010), as well as corals from mud-mounds and platform limestones in the Adarouch area of north central Morocco in the northern part of the Azrou-Khenifra Basin (Said, 2005; Said & Rodríguez, 2007; Said et al., 2007, 2010, 2011; Cózar et al., 2008) (Fig. 1A). A brief summary of corals recorded from platform limestones and mud-mounds from the Azrou-Khenifra Basin (Central Morocco) have been recently noted (Aretz & Herbig, 2010).

Previous coral collecting from Carboniferous rocks in Morocco has been very limited, with occasional samples collected as part of reconnaissance mapping by the Moroccan Geological Survey (Termier, 1936; Owodenko, 1946; Termier & Termier, 1950). The dating of the Mississippian limestone successions in the Khenifra area of Central Morocco was established subsequently as upper Viséan, based on microfaunal and microfloral studies (Chanton-Güvenç et al., 1971; Chanton-Güvenç & Morin, 1973; Verset, 1988; Huvelin & Mamet, 1997). In 1995, a suite of coral specimens were collected from the Khenifra region (Aretz & Herbig, 2010), but these authors acknowledged that the results of this reconnaissance sampling probably under-represented the coral diversity present in the region.

In this study, we present a detailed description of coral faunas obtained from upper Viséan (Mississippian) limestones in the Khenifra area of central Morocco (Fig. 1B), which lies 70 km SSW of the Adarouch area. The aim of the paper is to document the coral assemblages from the Tabainout mud-mound complex near Khenifra, and compare them to the coral faunas from the Adarouch region and to relate any differences to local changes in facies and palaeoecology. Comparisons will be made also with corals recovered from upper Viséan mud-mounds (buildups) in the Jerada Basin of NE Morocco (Fig. 1A).

2. Geological setting of coral sections at Tabainout

The Palaeozoic Meseta of north central Morocco is divisible into three regions: in the west, near Rabat, the mostly Carboniferous siliciclastic rocks of the Sidi Bettache Basin; a central belt of mainly pre-Carboniferous rocks; and in the east, the Azrou-Khenifra Basin, extending from Azrou in the north to Jebel Hadid in the south (see Aretz & Herbig, 2010, fig. 1). This latter basin comprises Carboniferous siliciclastic and carbonate rocks resting unconformably on, and in thrust contact with, Ordovician and Devonian rocks, all affected by the later Variscan Orogeny (Allary et al., 1976; Hollard, 1978; Piqué, 1983; Hoepffner, 1987; Beauchamp & Izart, 1987; Bouabdelli & Piqué, 1996; Hoepffner et al., 2005).

The Tabainout complex, 20 km west of Khenifra (Figs. 1B-1D), represents an isolated exposure of Mississippian limestones bordered to the west and north by Ordovician siliciclastics and to the south and west by Mississippian shales. The Tournaisian and lower-middle Viséan rocks (where present) are composed mainly of sandstones and conglomerates, with the oldest limestones dated as late Viséan age, associated with a widespread transgression throughout the region (Chanton-Güvenç et al., 1971; Chanton-Güvenç & Morin, 1973; Verset, 1988; Huvelin & Mamet, 1997).

The Khenifra area formed part of a larger basin, the Azrou-Khenifra Basin, which is elongated NE-SW for c. 100 km and is c. 40 km wide (Aretz & Herbig, 2010). This basin has been affected by Variscan tectonics, in particular thrusting, on the eastern side. The Adarouch area lies some 40 km NW of Azrou at the northern end of the basin, where it is surrounded by younger Mesozoic and Cenozoic rocks (Berkhli, 1999; Berkhli & Vachard, 2001, 2002; Berkhli et al., 2001; Cózar et al., 2008).

3. Tabainout complex: lithofacies and microfacies

The Tabainout complex (N32°56’59’’-W5°50’35’’) forms a prominent NNE-SSW trending ridge, approximately parallel to the Khenifra - Sidi-Lamine road, composed mainly of massive mud-mound facies (Fig. 1C-1D), and extends c. 5 km to the northeast. The base of the Carboniferous sequence is exposed north of a track cutting E-W through the mud-mound complex, and comprises 2 m of well-bedded, slightly nodular, fine-grained bioclastic wackestone and packstone with thin interbedded shales occurring below the massive mud-mound facies. These beds rest unconformably on Ordovician shales and sandstones (Figs 1D, 2). The bedded limestones are relatively rich in corals, both solitary and colonial. At the SW end of the ridge, below the mound, are massive and brecciated micritic limestones with occasional solitary corals. The base of the succession here comprises 2 m

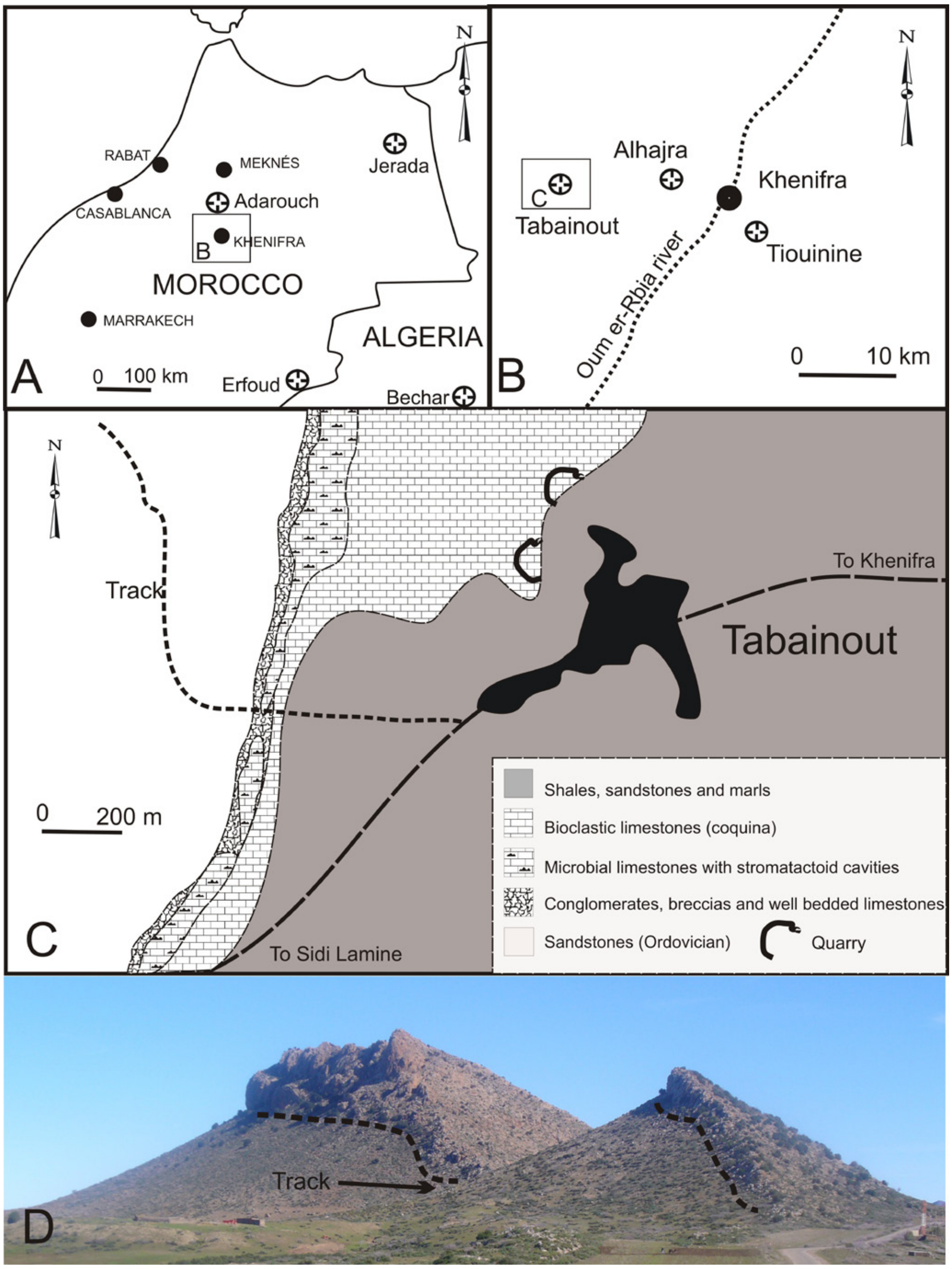

Figure 1. Sketch map with location of coral localities. A: Map of Northern and Central Morocco, with location of Khenifra area and other localities cited in the text. B: Location of Tabainout. C: facies distribution in the Tabainout area. D: General view looking northeast towards the Carboniferous mud-mound complex forming the ridge at Tabainout. The slopes to the west are underlain by Ordovician sandstones and the approximate position of the unconformity is indicated by the dashed black line.

of conglomerate, which thickens to >8 m southwestwards (Figs. 1D, 2), infilling the palaeotopography and is overlain by 1 metre of sandstone. These siliciclastic rocks are not developed below the large mound. The lowest limestone bed here contains angular sandstone clasts. The basal beds of the mud-mound are massive and bioclastic, with micritic facies containing stromatactoid cavities first appearing c. 8 m above the base. The measured thickness of the mound is c. 100 m, however, there are individual smaller mounds separated by thin intervals of bioclastic brecciated micrites and shales with solitary corals (intermound beds) The upper 20-25 m of the mound complex is bedded (cap beds) and locally rich in coquinas (shell bands encrusted with radiaxial fibrous calcite cements) (Fig. 2). These contain rich horizons of brachiopods (including gigantoproductids, and productids), bivalves, goniatites, orthocone nautiloids, crinoids and, locally, concentrations of mostly solitary corals on the flanks north of the track (Figs 1C, 2). These coquinas are interbedded with massive mudstones devoid of fauna and dip 40^0 to SE towards the village of Tabainout, succeeded by supramound shales and marls. Further north of the village the highest beds in the mound have recently been quarried (Fig. 1C). They expose the thick-bedded, shelly coquinas, as well as coarse-grained massive crinoidal grainstones which are laterally equivalent to the coquinas.

The bedded limestones at the base of the section are mostly medium-grained wackestone/packstone with extensive micritisation of bioclasts. Calcareous algae and Algospongia are locally very common with kamaenids, *Koninckopora, Borladella*, *Praedonezella cespeformis, Fasciella, Ungdarella uralica, Sparaphralysia tacanica* and *Draffania.* Foraminifers are relatively abundant with *Tetrataxis, Endotaxis, Vissariotaxis, Howchinia* and archaediscids at *angulatus* stage. The heterocoral *Hexaphyllia* is also recorded. The bulk of the Tabainout complex is composed of massive limestones, which in thin section are predominantly lime mudstone and sparse wackestone, with peloidal microbial fabrics and stromatactis cavity networks with geopetal sediment (Fig. 2). Fenestellid bryozoans and encrusting bryozoans can be conspicuous elements, but foraminifers are virtually absent, apart from very rare *Tetrataxis* and endothyrids. The top of the mound is more crinoid-rich with intraclasts, rare algae and foraminifers. The latter include *Neoarchaediscus parvus, N. ovoides, Endostaffella, Archaediscus karreri grandis, A.* at *angulatus* stage with *tenuis* sutures, *Praeplectostaffella, Euxinita efremovi, E. pendleiensis*?, *Pseudocornuspira, Asteroarchaediscus pustulus, Biseriella parva, Endothyranopsis compressa*?/*plana*?, and *Planospirodiscus taimyricus*. Dasyclad algae include *Windsoporella* and *Koninckopora.*

In a stream section south of the main mound yellow and greenish shales, marls and thin interbedded bioclastic limestone

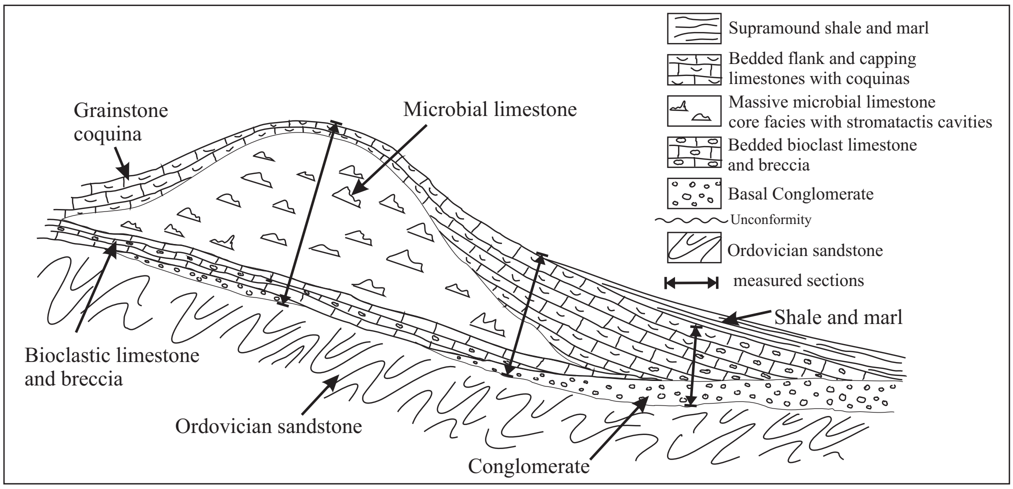

Figure 2. Model of the facies distribution in Tabainout mud-mound (not to scale) with approximate position of measured sections.

bands and nodules contain a rich assemblage of zaphrentid-type solitary corals, together with crinoids and goniatites. This sequence lies stratigraphically above, but also lateral to, the mud-mound, occupying a topographic low position (Figs. 1C, 2).

4. Age of the Tabainout mud-mound complex

Most of the foraminifers and algae at the base of the complex from the bedded limestones below the massive mud-mound facies are typical of late Asbian assemblages, and are comparable with the lower part of the Tizra Formation at Adarouch (Cózar et al., 2008). This is also supported by the presence of the rugose corals *Dibunophyllum bipartitum, Clisiophyllum keyserlingi, Siphonodendron intermedium* and *S. pauciradiale* (See Poty, 1981; Rodríguez & Somerville, 2007). The massive core facies is poor in corals and virtually devoid of foraminifers. The upper part of the mound in the bedded coquina grainstones and flank beds (capping beds), have a locally rich and diagnostic rugose coral assemblage, including *Kizilia* sp*., Diphyphyllum furcatum, D. lateseptatum* and '*Pseudozaphrentoides' juddi*, establishing a Brigantian age (Rodríguez & Somerville, 2007). Moreover, rare samples have a diagnostic foraminiferal assemblage including: *Asteroarchaediscus pustulus, Biseriella parva* and *Planospirodiscus taimyricus* which indicate a late Brigantian age for the uppermost capping beds in the mound. Thus, the age of the limestones in the Tabainout complex ranges from late Asbian to late Brigantian (Cf6γ-Cf6δ, Foraminiferal zones and subzones of Conil et al., 1991). This differs from previous studies, which claimed an entirely Asbian age for the Tabainout mound (Huvelin & Mamet, 1997; Aretz & Herbig, 2010). A similar late Brigantian foraminiferal assemblage has been recorded from the upper part of the Tizra Formation at Adarouch (Cózar et al., 2008, 2011).

Cephalopods collected from coquina float are dominated by *Goniatites crenistria* of latest Asbian-earliest Brigantian age (P1a Zone) (Dieter Korn, pers. com.). Goniatites were also recovered in situ from the marls and limestones in the stream section. They include *Arnsbergites* sp. and *Hibernicoceras hibernicum*? which establish an early-mid Brigantian age (P1b-P1c zones; Riley, 1993) for the lower part of the supramound cover mudstones (Dieter Korn, pers. com.).

The implication is therefore, that continued upward growth of the mound complex was maintained during the Brigantian, when relief of tens of metres was developed. This led to shallower-water carbonates forming on the crest and upper flanks of the mound, whereas on the lower flanks and adjacent to the mound only marls accumulated in deeper water.

5. Description of the coral faunas

A total of c. 270 coral specimens was collected from the Tabainout complex and all of the material is reposited in the Departamento de Paleontología, Facultad de Ciencias Geológicas, Universidad Compultense de Madrid (Spain).

Corals are recorded at several distinct stratigraphic levels within the Tabainout complex. Below the massive mounds in thickly-bedded bioclastic limestones (Table 1, col. 1) was recorded a relatively rich assemblage of solitary and colonial rugose corals: *Amplexizaphrentis* sp., '*Amplexocarinia'* sp., *Arachnolasma cylindricum* Yu, 1934 (Fig. 3E), *Clisiophyllum keyserlingi* M'Coy, 1849, *Dibunophyllum bipartitum* (M'Coy,

	Genus & species	Tabainout complex 1	2	3	4	5	Adarouch	Jerada
Rugosa	*Amplexus* sp.	X	X		X	X		
	Kizilia sp.			X		X		
	'Amplexocarinia' sp.	X		X		X		
	Cyathaxonia cornu				X	X		
	Amplexizaphrentis sp.	X				X	X	
	Claviphyllum sp.				X	X		
	Rotiphyllum sp.	X		X	X	X	X	
	Bradyphyllum sp.				X	X		
	Ufimia sp.						X	
	'Pseudozaphrentoides' juddi	sp.		X		X		
	Siphonophyllia samsonensis	X				X	X	X
	Siphonophyllia siblyi						X	
	Clisiophyllum keyserlingi	X				X		
	Clisiophyllum garwoodi						X	
	Clisiophyllum sp.						X	
	?Axoclisia sp.						X	X
	Dibunophyllum bipartitum	X				X	X	X
	Corwenia spp.						X	
	Arachnolasma cylindricum	X		X		X	sp.	
	Haplolasma densum						X	
	Haplolasma sp.			X		X	X	
	Koninckophyllum sp.						X	
	*Palaeosmilia murchisoni**	X		X		X	X	X
	Palastraea regia						X	
	Lithostrotion araneum	X		X		X	X	
	Lithostrotion maccoyanum							X
	*Lithostrotion vorticale**	X		X		X	X	X
	Siphonodendron intermedium	X				X	X	
	Siphonodendron irregulare	X		X		X	X	X
	Siphonodendron junceum							X
	Siphonodendron martini	X		X		X	X	X
	Siphonodendron pauciradiale	X		X		X		X
	Siphonodendron sociale	X		X		X		
	Diphyphyllum furcatum			X		X	X	
	Diphyphyllum lateseptatum			X		X	X	
	Tizraia berkhlii						X	X
	Tizraia sp.						X	
	Aulokoninckophyllum carinatum						X	
	Axophyllum densum						X	
	Axophyllum aff. *pseudokirsopianum**	sp.	X	X		X	X	X
	Pareynia splendens							X
	Total number of rugose species	18	2	16	5	26	28	13
	Total number of rugose genera	13	2	11	5	19	19	9
Tabulata	*Michelinia* spp.	X	X	X	X	X	X	
	Syringopora sp.			X	X	X	X	
Hetero corals	*Hexaphyllia* sp.*	X				X		

*Taxa illustrated in Aretz & Herbig (2010)

Table 1. Comparison of coral taxa recorded from the Tabainout complex (columns 1-5) with Adarouch in the northern part of the Azrou-Khenifra Basin and Jerada (NE Morocco). The coral data from Adarouch is from the Tizra Fm (Said et al., 2007; Said & Rodríguez, 2007; Cózar et al., 2008). The coral data from Jerada is from the youngest Viséan Koudiat Es-Senn Fm containing mud-mounds (Aretz, 2010). The corals recorded from the Tabainout complex are: col. 1 = lowest bedded limestones and strata below the massive core facies, col. 2 = massive core facies, col. 3 = upper strata in the mounds (bedded coquina horizons and flanking beds), col. 4 = supramound shales, col. 5= combined data for columns 1-4. N.B.: The listing of genera follows the order in Hill (1981).

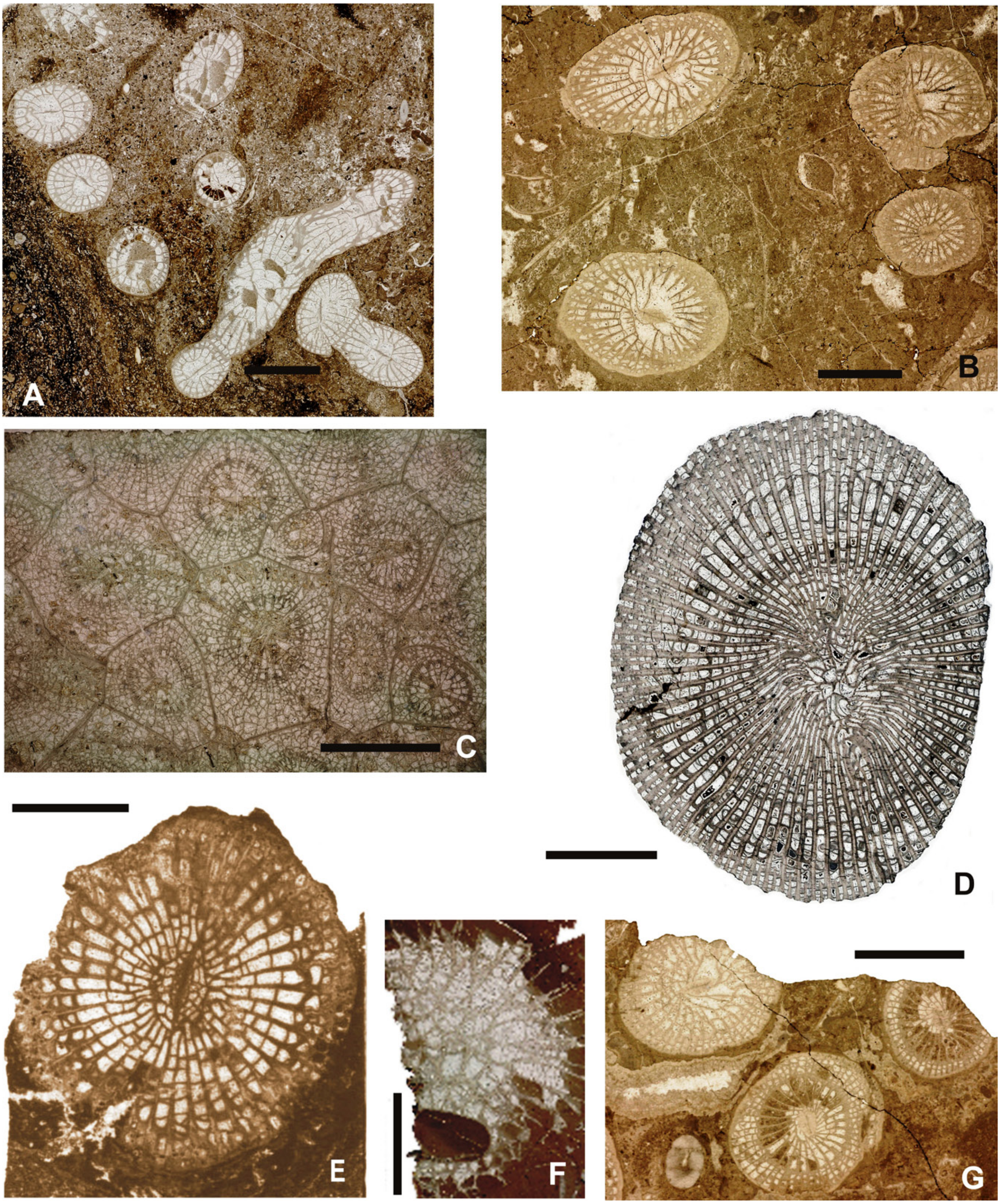

Figure 3. Corals from basal beds at Tabainout. A: *Siphonodendron pauciradiale* TAB/1-35. B: *Siphonodendron martini* TAB/2-5. C: *Lithostrotion vorticale* TAB/1-42a. D: *Palaeosmilia murchisoni* TAB/1-14. E: *Arachnolasma cylindrica* TAB/1-32. F: *Michelinia* sp. TAB/1-109a. G: *Siphonodendron sociale* TAB/1-2. Scale bars equal 5 mm.

1849), *Lithostrotion vorticale* (Parkinson, 1808) (Fig. 3C), *Palaeosmilia murchisoni* Milne-Edwards & Haime, 1851(Fig. 3D), *'Pseudozaphrentoides'* sp., *Rotiphyllum* sp., *Siphonodendron irregulare* (Phillips, 1836), *S. martini* (Milne-Edwards & Haime, 1848) (Fig. 3B), *S. intermedium* Poty, 1981, *S. pauciradiale* (M'Coy, 1844) (Fig. 3A), *S. sociale* (Phillips, 1836) (Fig. 3G), and *Siphonophyllia samsonensis* (Salée, 1913).

In the lower part of the massive limestones, particularly in the brecciated micritic facies that is interbedded with thickly-bedded bioclastic limestones, occur solitary corals, notably *Amplexus* sp., *Axophyllum* sp., *Rotiphyllum* and *Palaeosmilia*, with the tabulate *Michelinia* (Fig. 3F), and rare fragments of colonies of *Lithostrotion araneum* (M'Coy, 1844), *L. vorticale, Siphonodendron martini* and *S. sociale*. In addition, was recovered the heterocoral (*Hexaphyllia* sp.) (Table 1, col. 1).

In the main massive mud-mound facies characterised by the presence of stromatactid cavities were recorded rare *Amplexus* sp. (Fig. 4F), *Axophyllum* aff. *pseudokirsopianum* Semenoff-Tian-Chansky, 1974 and *Michelinia* (Table 1, col. 2).

In the upper part of the mud-mound which shows layers of bivalve/brachiopod and goniatite-rich coquinas interbedded with microbial limestones with stromatactoid cavities, are locally, rich pockets of rugose corals including *Diphyphyllum furcatum* (Hill, 1940) (Fig. 4B), *Lithostrotion araneum, Palaeosmilia* *murchisoni*, *Siphonodendron irregulare*, *S. martini*, *S. pauciradiale*, *S. sociale,* and a rare gregarious form of *Axophyllum* with budding (Fig. 4A). In the mound flank on the northern side close to the E-W track, similar capping bed facies are locally rich in large solitary corals, especially '*Pseudozaphrentoides' juddi* (Thomson, 1893) (Fig. 4J) and *Palaeosmilia murchisoni*. In addition, were recorded '*Amplexocarinia'* sp. (a gregarious form showing microbialite encrustation) (Fig. 4G)*, Arachnolasma cylindricum*, *Diphyphyllum lateseptatum* (M'Coy, 1849) (Fig. 4C), *Kizilia* sp. (Fig. 4D), *Lithostrotion verticale*, *Haplolasma* sp.*, Rotiphyllum* sp., *Siphonodendron martini, S. pauciradiale,* as well as the tabulates *Michelinia* spp. (two species; one with a large diameter corallite and the other with a smaller diameter corallite) and *Syringopora* sp. (Table 1, col. 3).

In the stream section above the mud-mound within the shales, marls and interbedded limestone bands were recorded mostly non-dissepimented solitary rugose corals including '*Amplexus', Bradyphyllum* (Fig. 4H), *Claviphyllum*? sp. (Fig. 4I), *Cyathaxonia cornu* Michelin, 1846 and *Rotiphyllum* sp. (Fig. 4E). Occasional tabulate corals recorded include *Michelinia* sp.*,* and *Syringopora* sp. (Table 1, Col. 4).

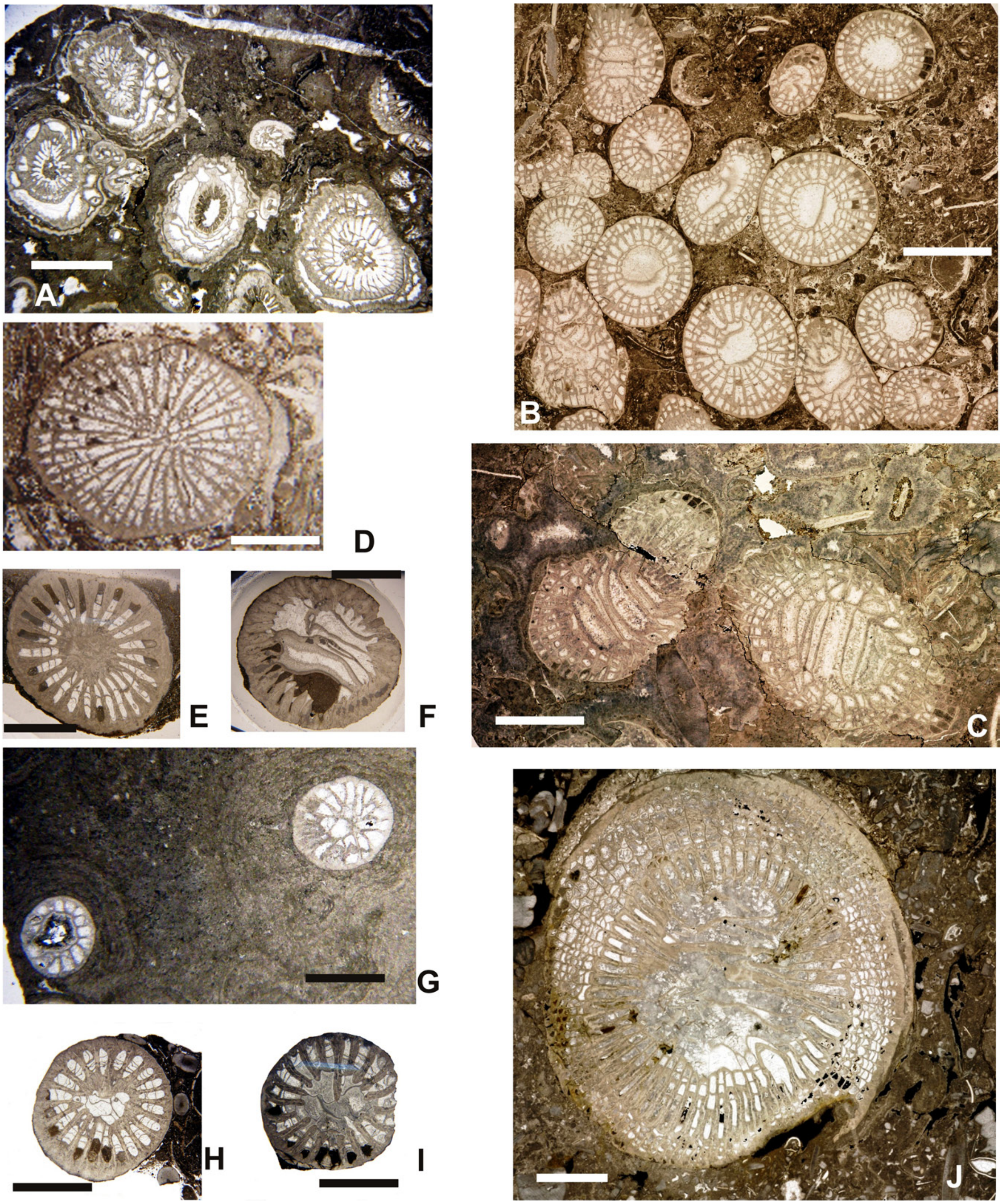

Figure 4. Corals from the mound and the surrounding shales. A: gregarious *Axophyllum* with budding exhibited in far left specimen TAB/1-27. B: *Diphyphyllum furcatum* TAB/1-3. C: *Diphyphyllum lateseptatum* TAB/1-25. D: *Kizilia* sp. TAB/1-81. E: *Rotiphyllum* sp. TAB/2-73, F: *Amplexus coralloides* TAB/2-31. G: *'Amplexocarinia'* sp. with microbialite encrustation TAB/1-42b, H: *Bradyphyllum* sp. TAB/2-6. I: *Claviphyllum*? sp. TAB/22-28. J: '*Pseudozaphrentoides' juddi* TAB/1-68. Scale bars equal 5 mm.

6. Analysis of Tabainout coral faunas

6.1. Comparison with previous coral studies in the region

In Tabainout there is a marked difference in the coral records presented here and in Aretz & Herbig (2010). The latter authors did not record any rugose corals from the massive mound core ('reefal limestone') and only three taxa below the 'reef' (*Lithostrotion vorticale*, *Siphonodendron irregulare* and *Palaeosmilia murchisoni*) in their 'bedded lower limestone'. They also recorded *Siphonodendron martini, S. pauciradiale, Axophyllum* sp. and *Amygdalophyllum* sp. in the 'bedded upper limestones'. Our recent sampling of the mud-mound complex has recorded 13 genera and 18 species of rugose corals from beds below the massive core facies of the mound, 2 rugosan genera and species from the massive core facies, and 11 genera and 16 species of rugosans from the flank beds and coquinas (capping beds) in the upper part of the mud-mound complex (Table 1). In addition, the shales, marls and limestones above the mound have yielded 5 genera and 5 species of solitary rugosans, and 2 genera and species of tabulate corals. Thus in total, 19 rugose genera and 26 species have been collected from the Tabainout complex, as well as 2 tabulate genera and 3 species (Table 1, col.5).

6.2. Variations in coral diversity in the Tabainout complex and palaeoecological interpretations

The studied outcrops in the Tabainout complex show a high variation in coral diversity, as each section shows different palaeoecological settings and environmental conditions (water depth, substrate, turbidity, turbulence and light levels), providing different possibilities for adaptation and settling of colonial and solitary corals. The Tabainout complex exhibits large mud-mounds with clear differentiation of basal bedded limestones, massive microbial mound core facies, bedded coquina grainstones and flank beds in the upper part of the mound (capping beds) and supramound shaly facies (Fig. 2). The bedded limestones below the massive part of the mound contain a rich and diverse assemblage of both solitary and colonial rugosans. In particular, *Siphonodendron* and *Lithostrotion* colonies are abundant, as well as large dissepimented solitary taxa (*Dibunophyllum, 'Pseudozaphrentoides'*, *Siphonophyllia*, *Clisiophyllum* and *Palaeosmilia*). These bedded limestones which are dominated by solitary rugosans are typical of Rugose Coral Association (RCA) 5 of Somerville & Rodríguez (2007). These packstones are also characterised by the presence of abundant dasycladacean algae, foraminifers, heterocorals and micritised grains, indicative of shallow water, moderately turbulent, euphotic conditions.

In contrast, the massive core facies has very rare corals, comprising small axophyllids and *Amplexus*. The absence of calcareous algae and foraminifers in the fine microbial lime mud sediment and the lack of allochems obviously inhibited coral attachment, and only specialist corals could adapt to the presumed deeper and quieter water conditions associated with the transgression.

The upper part of the mud-mound shows a significant increase in coral diversity, and locally, corals are very abundant in the coquina horizons, along with productid brachiopods, bivalves and goniatites. Large solitary corals can be locally conspicuous in these beds (*Palaeosmilia, 'Pseudozaphrentoides'*). In the flank beds colonial corals are present (*Diphyphyllum, Lithostrotion* and *Siphonodendron*). Interestingly, a gregarious form of *Axophyllum* with buddings is recorded from the upper part of the mound, which is distinguished from *Lonsdaleia* by its simpler axophyllid axial structure and dissepimentarium, and from *Howthia* by its larger size, more prominent axial structure and wider lonsdaleoid dissepimentarium. This taxon, together with gregarious '*Amplexocarinia'*, suggests that potential evolutionary opportunities were present in a shallower-water phase of later mound growth (cf. Rodríguez & Somerville, 2010; Somerville & Rodríguez, 2010). Interestingly, Mundy (1994) recorded abundant *Amplexocarinia* and *Cyathaxonia* in the upper part of the late Viséan Stebden Hill buildup in N. England. These solitary rugosans, that were encrusted in microbialite, were interpreted as forming a framework in a shallow-water niche.

The upper part of the mud-mound facies with its high diversity and abundance of rugose corals (11 genera and 16 species) is typical of RCA6. (Somerville & Rodríguez, 2007), and is characteristic of large upper Viséan (late Asbian-Brigantian) mud-mounds (c. 100 m thick) which grew up into shallower water, where colonial corals in particular could flourish (see Somerville et al., 1996; Somerville, 1997; Rodríguez & Somerville, 2007; Denayer and Aretz, 2011). A shallower-water setting for the upper part of the mound is also suggested by the presence of dasycladacean green algae.

The solitary corals of the supramound shales are typical of the RCA8 of Somerville & Rodríguez (2007), and characterised by small, undissepimented taxa (the *Cyathaxonia* fauna). They are representative of the basinal or flysch-type sediments that buried the mounds, particularly on their lower flanks and introduced much deeper water conditions into the Tabainout area, where colonial corals, apart from tabulates, are absent, and goniatites and crinoids are the only other distinctive faunal elements. A similar assemblage dominated by solitary corals was identified by Sando (1980) as having a very low indication of a shallow-water habitat.

7. Comparison with other Moroccan areas

7.1. Adarouch

Carboniferous rugose corals have been previously studied in detail in the Adarouch region (northern Azrou-Khenifra Basin), in particular, in the age-equivalent (late Asbian-Brigantian) Tizra Formation (Said, 2005; Said et al., 2007; Cózar et al. 2008; Said et al., 2011), which contains a development of large mud-mounds, similar to those at Tabainout. The basal bedded limestone facies of the mounds and mound core facies show similar features in both localities and, consequently, the coral assemblages have many taxa in common, notably large solitary cyathopsids, aulophyllids, colonial lithostrotionids, and axophyllids in the mound core facies (11 species, Table 1). Also, the flank beds in both regions can be locally dominated by small solitary corals and *Michelinia*. The main differences are related with the facies developed in the upper part of the mounds and above them. Spectacular coquinas containing large solitary and some colonial corals are developed as flank beds in Tabainout. On the other hand, biostromal beds dominated by fasciculate corals (e.g. *Siphonodendron*, *Diphyphyllum* and *Tizraia*) occur some metres above the mounds in Tizra (Said et al., 2011). Two of these genera are known from Tabainout, but *Tizraia*, an endemic genus to Morocco (Said & Rodríguez, 2007; Aretz, 2010), is absent. However, it is recorded at Tiouinine, southeast of Khenifra (Fig. 1B, Said et al., in press). Thus, in general, there are many close similarities of the rugose coral assemblages between Adarouch and Tabainout, not only at species level, but also in the distribution of corals within and adjacent to the mud-mound complexes (Table 1).

7.2. Jerada Basin

The Jerada Basin is located in northeastern Morocco, 375 km NE of Khenifra (Fig. 1A), and shows similar lithological features to the Tabainout complex, particularly in the development of large mounds in the youngest upper Viséan rocks (Koudiat Es-Senn Fm), of probable late Asbian-Brigantian age (Vachard & Berkhli, 2002; Aretz, 2010). Consequently, the coral assemblages are comparable in general, but show some differences in detail (Table 1). Fasciculate corals are dominant in Jerada, and the same genera present in Tabainout are recorded (except *Tizraia*). However, *Siphonodendron junceum* is present in Jerada but absent in Tabainout. On the other hand, larger species such as *S. sociale* are absent in Jerada. Aulophyllidae, Cyathopsidae and Axophyllidae are the most common solitary corals in Jerada (as well as in Tabainout), with at least 4 species in common (*Dibunophyllum bipartitum, Palaeosmilia murchisoni, Siphonophyllia samsonensis* and *Axophyllum* aff. *pseudokirsopianum*) (Table 1). In total, 8 rugose coral genera and species (>60% of the taxa) are common to Jerada and Tabainout, demonstrating that both areas belong to the same palaeobiogeographical province (see below). However, the presence of *Pareynia splendens* Semenoff-Tian-Chansky, 1974 in Jerada, which is absent in Tabainout, demonstrates some affinity with the fauna of the central Saharan basins to the south in Algeria e.g., Béchar Basin (Fig. 1A; Semenoff-Tian-Chansky, 1974; Aretz, 2010, 2011a).

7.3. Tafilalt Basin

In the eastern Anti-Atlas Mountains Wendt et al. (2001) described Viséan mud-mounds from the Zrigat Formation in the southeastern part of the Tafilalt Basin near Erfoud, eastern Morocco, 350 km SE of Khenifra (Fig. 1A). In the upper part of the formation the mounds are of late Viséan age (late Asbian to Brigantian) based on limited conodont and goniatite data. A sparse coral fauna was recorded from the mound and intermound facies with rare *Lithostrotion* (= *Siphonodendron*) colonies present in the massive core facies and in the intermound facies, as well as isolated specimens of undetermined solitary rugosans. The tabulate coral *Michelinia* was recorded in the intermound facies. Interestingly, below the mounds in the shaly facies, Wendt et al. (2001) recorded *Cyathaxonia*, lophophyllids, caniniids, hapsiphyllids, as well as *Dibunophyllum*. Unfortunately, because of the limited identification of coral taxa from these mounds, it is not easy to make a direct comparison with the coral fauna from the Tabainout complex. However, it would appear that although some taxa are present in both areas, the overall diversity and abundance is much lower in the Tafilalt area.

7.4. Discussion

The Tabainout mud-mound complex, as a whole, shows a much higher coral diversity compared to most other examples in Morocco (and Europe). However, the mound core facies ("microbial mound" facies) is particularly poor in corals, with only the occasional amplexid or axophyllid solitary rugosan, except where there are thin developments of intermound crinoidal limestone and shale. The remarkable features of this mud-mound that are not present in other mud-mounds (e.g.,Tizra, Jerada in Morocco and in Sierra Morena, SW Spain, see Cózar et al., 2003; Rodríguez-Martínez et al., 2003) are bedded flank facies and coquinas that contain a rich rugose coral assemblage. It is not comparable to the biostromes at the top of the Tizra mounds, because they lie above the mound, whereas in Tabainout, the corals occur interbedded with horizons showing stromatactid cavities and thus can be regarded as part of the mud-mound complex. At Tizra the mud-mounds are surrounded by marly limestones containing solitary corals and tabulates, but do not have the cemented coquinas alternating with beds having microbial textures. The total coral assemblage from the Tabainout mud-mound complex comprises 21 genera and 28 species. It represents an unusually high diversity for a mound, resulting from the presence of a diverse suite of environments of variable water depths hosting the rugose and tabulate corals.

8. Palaeobiogeography

The upper Viséan Tabainout assemblages contain many rugose genera and species that are also relatively common throughout Western Europe (SW Spain, Belgium, France, British Isles), e.g., *Siphonodendron pauciradiale, S. martini, S. sociale, Lithostrotion vorticale, L. decipiens, Diphyphyllum furcatum, D. lateseptatum, Siphonophyllia samsonensis*, and *Dibunophyllum bipartitum,* as well as rare taxa including *Kizilia* sp.. Moreover, assemblages corresponding to similar environments in Europe are dominated by the same species (cf. the standard upper Viséan assemblages of Somerville & Rodríguez, 2007). Consequently, the Tabainout upper Viséan coral assemblages indicate that the Azrou-Khenifra Basin should be considered as part of the Western European Coral Province (Fedorowski, 1981, fig. 2; Hill, 1981; Sando, 1990; Aretz & Herbig, 2010) and Western Palaeotethyan fauna (Hill, 1981). Thus, much of North Africa, north of the Atlas Transform Fault, including Tabainout, Adarouch and Jerada, can be included in this same palaeobiogeographic realm. Aretz (2011b) has recently grouped together these Moroccan basins, based on a statistical study of the rugose coral faunas , and referred to them as the 'Moroccan Meseta Province'.

9. Conclusions

Carboniferous (Mississippian) rocks from Tabainout in the southern part of the Azrou-Khenifra Basin contain rich coral assemblages. Detailed analysis of the coral faunas from the mud-mound complex has established that they are richer and more diverse than those recorded in previous studies, especially in the bedded limestones at the base and in the upper flank beds and coquinas (cap beds).

Comparison of the upper Viséan (late Asbian-Brigantian) coral assemblages at Tabainout with those previously recorded at Adarouch, in the northern part of the Azrou-Khenifra Basin, has recognised many similarities in the composition of the rugose taxa between both areas. Moreover, similar association are recorded from different facies in the mud-mounds from Tabainout and Tizra.

Further comparison of the Azrou-Khenifra Basin assemblages with coral assemblages in other parts of the Western Palaeotethys shows recognition of close similarities with assemblages from the Jerada Basin (NE Morocco), and south-western Spain (Sierra-Morena), where mud-mounds are recorded, establishing the location of all these areas within the same palaeobiogeographic province (Western European Coral Province).

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