The "Avins event": a remarkable worldwide spread of corals at the end of the Tournaisian (Lower Carboniferous)

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Abstract: The "Avins event" is a widespread development of corals at the end of the Tournaisian due to a very high rise of the sea level. On the shallow water shelf of Belgium and northern France, it is marked by the development of oolitic limestones (Avins Member) which correspond to the top of the highstand systems tract of the third-order sequence 4. In Western Europe, it marks a shift between the Tournaisian coral faunas and the Visean faunas, and in the pattern of deposition of the third-order sequences, and is considered as heralding change to a Carboniferous climate with glaciations. The Avins event is characterized by the appearance of the earliest representatives of the genera *Palaeosmilia*, *Merlewoodia*, *Dorlodotia* and *Amygdalophyllum*, which marks the base of the RC4β1 Coral Subzone. It is traced throughout Eurasia and as far as Australia mainly on the basis of its coral association and supported by the foraminifer zonation (assemblage C of the Cf4α1 Subzone). In some areas, the corresponding levels rest directly on an old basement and are the oldest Lower Carboniferous rocks recorded. The Avins event is followed by a strong fall in the sea level during which the common stock of corals gave rise by separate evolutions to endemic Lower Visean coral assemblages, with basins becoming more or less isolated.

Key words: Rugose corals, Tournaisian – Visean boundary, Eurasia, event, eustatics, stratigraphy

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1. INTRODUCTION

In the European Carboniferous, the Upper Tournaisian marine facies are characterized by species belonging to widespread genera such as *Cyathoclisia*, *Uralinia*, *Keyserlingophyllum*, which are guides for the biostratigraphic recognition of this time (Coral Zones RC3 and RC4α of Poty, 1985). These taxa do not reach the top of the Tournaisian and were replaced, a few before the Tournaisian – Visean boundary, by a new assemblage including the first species of *Palaeosmilia*, *Merlewoodia*, *Dorlodotia* and *Amygdalophyllum* (RC4β1 Subzone, this paper; Fig. 1), to whom were added, from the base of the Visean, species of *Clisiophyllum* (a genus not recorded since the Devonian – Carboniferous boundary), *Axophyllum* and *Haplolasma* (RC4β2 Subzone, this paper). Almost all these taxa are common and highly diversified during the Visean.

Corals of the RC4β1 Subzone were widespread throughout Eurasia, allowing good stratigraphic correlations, but not those of the RC4β2 Subzone. The objectives of this paper is to document and to try to explain the wide palaeogeographic distribution of the uppermost Tournaisian corals, and their relations with the endemic lowermost Visean ones.

2. STRATIGRAPHY AND GEOLOGICAL SETTING

2.1. Namur-Dinant Basin of Belgium and northern France

Six tectono-sedimentary areas characterized by different lithostratigraphic settings and evolutions are recognized in the Namur-Dinant Basin (Hance et al., 2001). In three of them, the Namur, Condroz and Southern Avesnois sedimentation areas, shallow-water facies developed usually and contain numerous rugose corals.

The Namur and Condroz areas are situated to the south of the Brabant Massif (emergent during most of the Dinantian). On these, the uppermost Tournaisian corresponds to the Longpré Formation, which includes two members, from base to top: the Flémalle and the Avins Members (Fig. 2). The Flémalle Member is composed of thick-

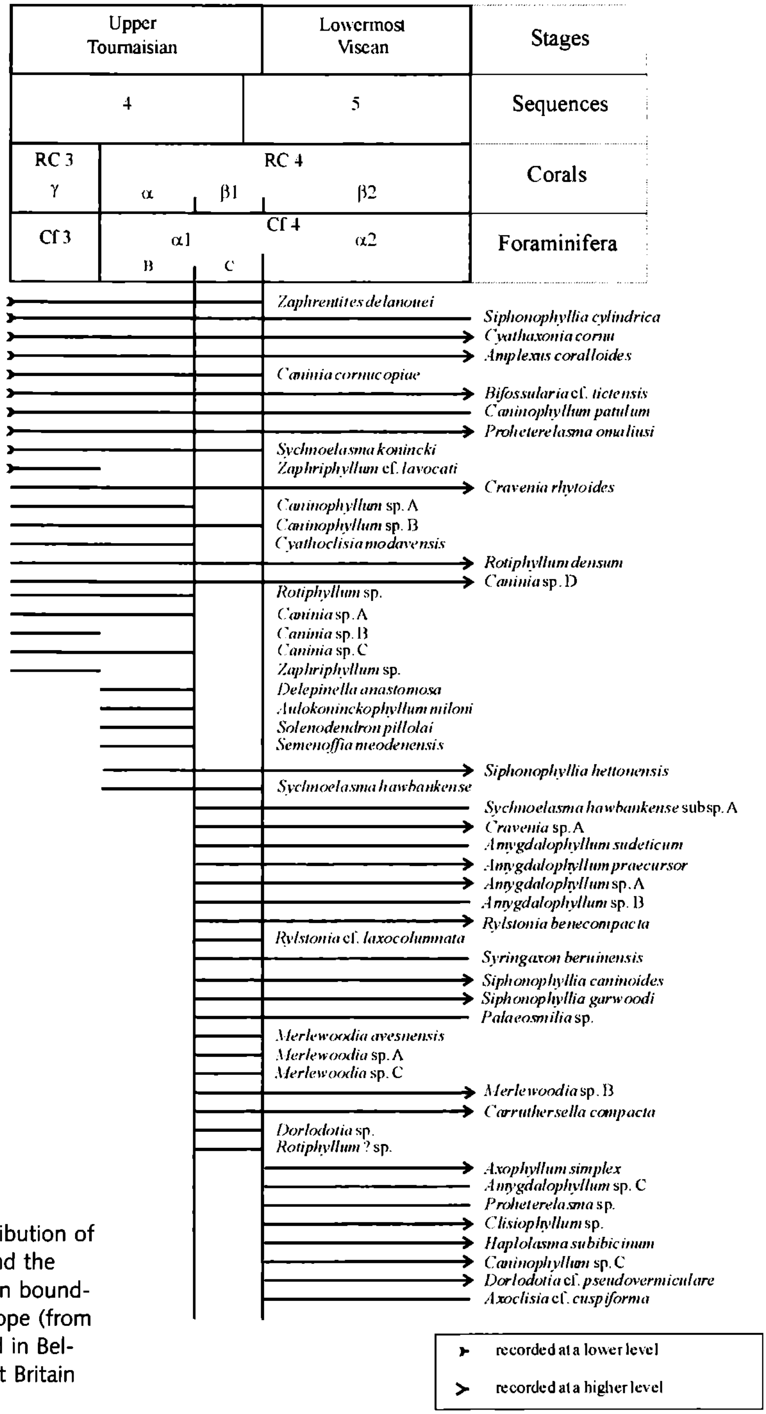

Fig. 1:
Stratigraphical distribution of rugose corals around the Tournaisian – Visean boundary in Western Europe (from specimens collected in Belgium, France, Great Britain and Ireland)

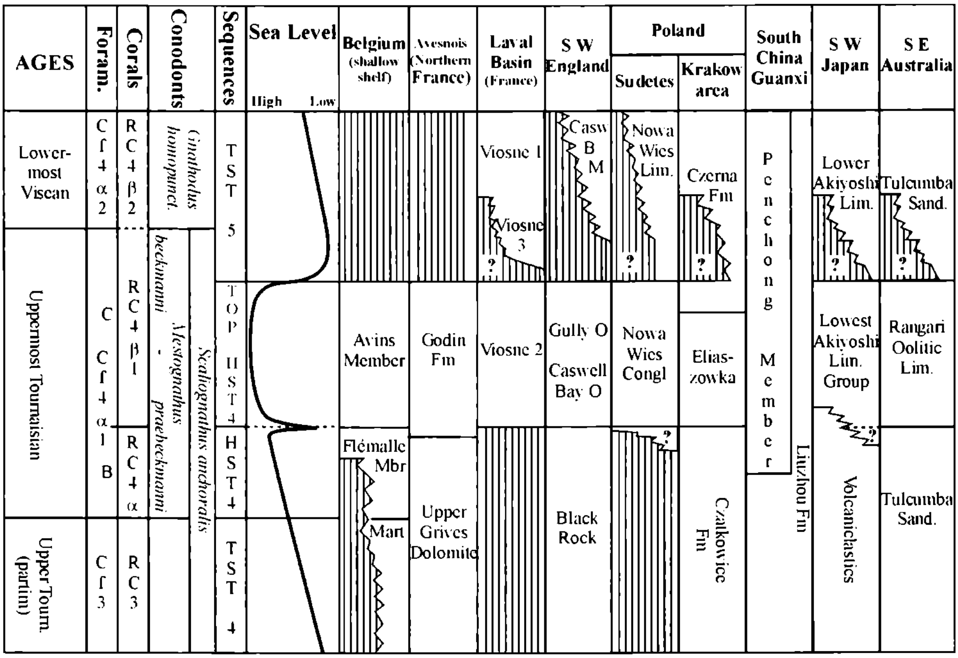

Fig. 2: Stratigraphical correlation of the uppermost Tournaisian throughout Eurasia, Japan and Australia. Vertical lines represent local stratigraphic gaps.
Akiy Lim Group: Akiyoshi Limestone Group; Casw B M: Caswell Bay Mudstone; Congl: Conglomerate; Fm: Formation; HST: high stand system tract; Mart: Martinrive Formation; Mbr: Member; O: Oolite; TST: transgressive system tract.

bedded to massive, pale grey, crinoidal packstones and grainstones, with numerous chonetids, large gastropods and solitary rugose corals. The Avins Member comprises thick-bedded to massive, pale coloured, oolitic grainstones, with the brachiopod *Levitusia humerosa* and some rugose corals. The coral assemblages of the two members were the basis for the definition of two rugose coral subzones (Poty, 1985; Conil et al., 1991; Hance et al., 2001):

- the RC4α Subzone, characterized by *Cyathoclisia modavensis* (Salée, 1913) and *Sychnoelasma hawbankense* Mitchell & Somerville, 1988;
- the RC4β Subzone, whose base is characterized by the first appearance of the genera *Amygdalophyllum* Dun & Benson, 1920, *Merlewoodia* Pickett, 1967, *Palaeosmilia* Milne-Edwards & Haime, 1848, and *Dorlodotia* Salée, 1920.

This latter subzone is here divided into RC4β1 and RC4β2, the base of the second interval corresponding mainly to the appearance of *Haplolasma* Semenoff-Tian-Chansky, 1974, *Axophyllum* Milne-Edwards & Haime, 1850, and to the reappearance of the genus *Clisiophyllum* Dana, 1846, after its absence from above the Devonian – Carboniferous boundary.

The RC4α and the RC4β1 Subzones are correlated respectively with the lower part of the Cf4α1 Foraminifera Subzone of Conil et al. (1989), which is characterized by the foraminifera association B of Hance et al. (2001), and with the upper part of the Cf4α1 characterized by the association C (Fig. 1). The two coral subzones and the Cf4α1 are characteristic of the uppermost Tournaisian (Hance et al., 2001), but were previously considered as lowermost Viséan (Conil et al., 1989, 1991). The base of the RC4β2 Subzone matches approximately the base of the Cfα2 Foraminifera Subzone which coincides with the base of the Viséan.

The Longpré Formation corresponds to the highstand system tract (HST) of the Dinantian third-order sequence 4 of Hance et al. (2001). The boundary between the Flémalle and Avins Members is affected by a slight eustatic fall (resulting in a local paleokarstic surface) immediately followed by a rise, and marks a profound shift in the record pattern of the third-order sequences deposited on the shelf (ibid.). Before it, during the Tournaisian, the transgressive system tracts (TST) of the sequences are mainly characterized by cherty crinoidal limestones and crinoidal limestones interbedded with shales, whereas the HST are usually composed of thick-bedded to massive crinoidal limestones devoid of cherts. In contrast, after this boundary, at the top of the Tournaisian and during the Viséan, the sequences have TST characterized by peritidal limestones to cherty open marine limestones and HST with thick-bedded to massive pale oolitic to bioclastic limestones, both including parasequences. The Flémalle and the Avins Members correspond, respectively, to HST of "Tournaisian type" and of "Visean type".

The sequence 4 was followed by a very strong fall of sea-level which was not completely compensated during the following rise associated with eustatic third-order sequence 5 and which is responsible for the non deposition of this latter sequence on the shallow-water platforms. The sequence 6 (upper part of the Lower Visean) overlying directly disconformably the sequence 4. The Tournaisian-Visean boundary, based on the entry of *Eoparastaffella simplex* (Subzone Cf4α2), is few metres above the base of the sequence 5 in the Dinant area (south of Condroz) where the sequence is well developed because the environment was in a deeper water facies.

In the southern Avesnois sedimentation area (northern France, southwest of the Dinant area), the Flémalle Member corresponds to the uppermost part of the Grives Dolomite Formation and to 2 m of crinoidal limestone at the base of the Godin Formation (Hance et al., 2001; Fig. 2). These yield corals of the RC4α Subzone. The Avins Member corresponds to the oolitic limestone forming most of the Godin Formation. The coral fauna includes *Merlewoodia avesnensis* (Delépine, 1929), *Amygdalophyllum sudeticum* Zolynski, 2000, and *Palaeosmilia* sp.

To the eastern end of the Brabant Massif, the Visé-Maastricht sedimentation area corresponds to a graben that suffered block faulting (Hance et al., 2001). Uppermost Tournaisian deposits are mainly calciturbidites wich yielded a rich coral fauna of the RC4β1 Subzone, including taxa developed in different environments, but transported and brought together by the turbiditic flows.

2.2. England and South Wales

The Gully Oolite of the Bristol area and the Caswell Bay Oolite of South Wales are the equivalents of the Avins Member (Hance et al., 2002). The foraminifers, including primitive *Eoparastaffella* in the Gully Oolite, are of the Cf4α1 Subzone (Fig. 2). They contain a similar but not so diversified coral fauna as the equivalent levels in Belgium and France (RC4β1 Subzone), including *Amygdalophyllum* (*A. praecursor* (Howell, 1938)), *Palaeosmilia* sp. and *Caninophyllum* sp. As in Belgium, the sequence 5 is usually missing and the limestones of the TST of the sequence 6 overlies directly the top of the sequence 4. But in some places, deposits of the sequence 5 can be present and yield the same corals of the RC4β2 Subzone as in Belgium (*Haplolasma*, *Axophyllum*, *Clisiophyllum*).

The RC4β1 and 2 Subzones correspond to the British Visean Coral Zone A of Mitchell (1989).

2.3. Laval Basin (Armorican Massif, France)

The Laval Basin is surrounded to the north, the west and the south by the old cratonic rocks of the Armorican Massif, and to the east disappears under the post-Palaeozoic deposits of the Paris Basin. In the Dinantian Series, the Tournaisian-Viséan boundary is overlapped by the Viosne Limestone (Fig. 2).

The Viosne Limestone comprises three units (Pelhate et al., 1991), from the base to the top :

- the VO2 unit, black bioclastic grainstones with layers of calcareous silty sandstone and small rugose corals;
- the VO3 unit, bioclastic lime mudstones, a few sandy;
- the VO1 unit, bioclastic lime mudstones with *Siphonophyllia*.

The Viosne Limestone rests directly upon Silurian to Lower Devonian deposits and marks here the beginning of the Lower Carboniferous transgression.

The foraminifera of the units were studied by Conil (in Pelhate et al., 1991) who recognized *Condrustella modavensis*, *Lugtonia monilis* (only recorded in the VO2 unit), *Paracaligelloides florennensis*, *Septabrunsiina* (*Spinobrunsiina*) sp., *Paraendothyra* ex. gr. *cummingsi*, uncommon *Tetrataxis* and *Eotextularia diversa*, suggesting to the author that the Viosne Limestone would belong to the base of the Cf4α2 Foraminifera Subzone (lowermost Visean). However, the presence of *Lugtonia monilis*, which is not known above the Subzone Cf4α1 (Hance et al., 2001), and the absence of *Eoparastaffella simplex* indicate that the VO2 unit belongs in fact to the upper part of this subzone, i.e. to the top of the Tournaisian. The age of the overlying units being lowermost Visean. The uppermost Tournaisian age of the VO2 unit is supported by its rugose corals which belong to the RC4β1 Subzone and were described by Vuillemin (in Pelhate et al., 1991). They comprise:

- *Armophyllum vannieri* (Vuillemin, 1990), which is a small coral with a typical amygdalophylloid axial structure, but without dissepiments. It looks like a young stage of the small-sized species of *Amygdalophyllum*, and is either a heterochronic species or an ecotype of a species of the *Amygdalophyllum sudeticum* species group.
- *Nominoephyllum lardeuxi* Vuillemin, 1990, which is a small species of *Merlewoodia* (*Nominoephyllum* Vuillemin is a younger synonym) very close to the species found in the Avins Member in Belgium.

- *Cravenia rhytoides* (Hudson, 1928).
- *Proheterelasma omaliusi* (Milne-Edwards & Haime, 1851).

So, on the basis of foraminifera and corals, the lower unit (VO2) of the Viosne Limestone is well correlated with the Avins Member of Belgium.

2.4. Poland

2.4.1. Bardzkie Mountains (Sudetes)

In the Bardzkie Mountains, the Carboniferous series starts with a gneissic conglomerate (conglomeratic unit of the Nowa Wies Formation) capped by allodapic limestone (limestone unit of the Nowa Wies Formation), which rests on upper Devonian rocks (Fig. 2). The matrix of the conglomerate has yielded rugose corals which were described under the name of *Amygdalophyllum sudeticum* by Zolynski (2000). Being similar to the *Amygdalophyllum* known in the Avins Member of Belgium, this led the author to correlate the gneissic conglomerate with this Member. The allodapic limestones of the top of the Nowa Wies Formation are not well dated but are probably Visean.

2.4.2. Krakow Dinantian carbonate platform (Southern Poland)

On the Krakow Dinantian carbonate platform, the Czatkowice quarry is situated near Krzeszowice, on the eastern flank of the Debnik anticline. It displays a stratigraphic succession, more than 800 m thick, ranging from the uppermost Famennian to the top of the Lower Visean (Paszkowski in Dvoràk et al., 1995; Poty et al., in press). Within that interval, the Ellezowka Formation (Fig. 2) is a unit composed mainly of massive bioclastic packstones that has yielded foraminifera of the Cf4α1 Subzone and specimens of *Dorlodotia* sp. similar to those found in the Avins Member of Belgium (Poty et al., in press). Therefore, it is dated as uppermost Tournaisian (Cf4α1 – RC4β1). The presence of *Dorlodotia* led previously to date the Ellezowka Formation as uppermost lower Visean (Paszkowski in Dvoràk et al., 1995), because *Dorlodotia* was previously considered as characteristic of the RC5 Zone (Poty, 1985). The discovery of some species of the genus at lower horizons does not allow any longer the genus to be used for the definition of the RC5 Zone; only *Dorlodotia briarti briarti* seems to be restricted to the Zone.

The lowest part of the overlying Czerna Formation is composed of bedded bioclastic packstones and contains the same uppermost Tournaisian foraminiferal association and the same *Dorlodotia* sp. (and *Corphalia*? sp.) as in the Ellezowka Formation. The rest of the Czerna Formation contains foraminifera of the lowermost Visean Cf4α2 Subzone (including *Eoparastaffella simplex* and *E. rotunda*) and rare *Axophyllum simplex* (Garwood, 1913) indicating the RC4β2 Subzone, followed by Cf4δ foraminifera and RC5 corals (upper part of the Lower Visean).

2.5. South China, Guangxi, Penchong section

The Penchong section, situated 15 km NNE of the town of Liuzhou, in Guangxi, South China, is under discussion to become the new stratotype of the Tournaisian – Visean boundary (Devuyst et al., 2003). In the section, the Penchong Member (Fig. 2) is a unit, about 110 m thick, of dark grey limestones (bioclastic packstones – grainstones with lithoclasts), with layers of dark calcareous shales. The Penchong Member occurs within deep-water siliciclastic "culm" deposits (of the Liuzhou Formation), and corresponds probably to mass-flow deposits (grain flows or high-density turbidites) derived from a shallow-water platform.

Eoparastaffella simplex (the guide foraminifer for the base of the Visean) appears in bed 85 (Cf4α2 Subzone) and *Gnathodus homopunctatus* (a guide conodont for the lowest Visean) in bed 86. An *Amygdalophyllum* sp. of the *A. sudeticum* species group has been found in bed 79, a grainstone with rounded bioclasts and some oolites, situated a few meters below the Tournaisian – Visean boundary and belonging to the Cf4α1 Subzone. The bed consequently can be correlated with the Avins Member of Belgium.

2.6. Australia

2.6.1. New England district of New South Wales (Southeast Australia)

In the Werrie Syncline, in the Tamworth Belt of the New England Orogen, the Rangari Limestone is the oldest Carboniferous limestone unit. The Rangari Limestone is composed of coarse-grained oolitic and oncolitic grainstones and rudstones, including locally small buildups with microbialites and some bryozoans and sponges. It is included in the Tulcumba Sandstone Formation.

From the Rangari Limestone, Pickett (1967) described the oldest Carboniferous rugose and tabulate corals of New South Wales:

- *Naoides rangariensis* Pickett, 1967 (p. 24, Pl. 8, Fig. 11; Pl. 9, Figs. 1–4), ?*Amplexizaphrentis rejuvenescens* Pickett, 1967 (p. 8, Pl. 1, Figs. 4–6, 11), ?*Neozaphrentis australis* Pickett, 1967 (p. 8, Pl. 1, Figs. 7–10; Pl. 19, Figs. 1–3), all species belonging to the genus *Merlewoodia* Pickett, 1967.
- *Amygdalophyllum praecox* Pickett, 1967 (p. 22, Pl. 8, Figs. 4, 5, text-fig. 8), which is closely related to the small-sized *Amygdalophyllum* of the *sudeticum* group species.
- a small aulate coral described as *Permia cylindrica* Pickett, 1967 (p. 7, Pl. 1, Figs. 1–3).
- *Lithostrotion williamsi* Pickett, 1967 (p. 14, Pl. 4, Figs. 4–8), which is possibly an Australian homeomorph of *Siphonodendron* (Webb, 1994).
- *Michelinia porifera* Pickett, 1967 (p. 33, Pl. 15, Figs. 6, 7; Pl. 16, Figs. 1, 2) and *Syringopora septatisiphon* Pickett, 1967 (Pl. 18, Figs. 1–4).

We have also collected *Cyathaxonia* sp. in the microbialite buildups.

The age of the Rangari Limestone is usually considered as uppermost Tournaisian (Fig. 2), which is supported by its coral assemblage and by the well dated uppermost Tournaisian age of a similar coral fauna of the Northeast Australian Gudman Formation (see 2.6.2). We have not found any foraminifera in the Rangari Limestone.

2.6.2. Queensland (Northeast Australia)

A coral fauna similar to the one from the Rangari Limestone was described by Webb (1990) from the Gudman Fm. (Rockhampton Group) of late Tournaisian age (determined from a conodont assemblage). The fauna includes among others small *Amygdalophyllum* (*Amygdalophyllum minimum* WEBB, 1990, and *Amygdalophyllum* sp.) and *Schoenophyllum dalmaensis* WEBB, 1990, a colonial coral considered by the author as closely related to *Siphonodendron williamsi* (PICKETT).

Therefore, apart from the lithostrotionids, the uppermost Tournaisian Australian corals are not as endemic as they are usually considered (FEDOROWSKI, 1981; SANDO, 1991).

The Rangari-Gudman coral association is followed by another association of Visean age including also species of *Amygdalophyllum* and *Merlewoodia*, species of *Symplectophyllum* HILL, 1934, a genus closely related to *Merlewoodia* but having an axial structure, fasciculate and cerioid lithostrotionids showing no affinities with the Visean European ones and considered by WEBB (1994) to result from a parallel evolution, and species of *Aphrophyllum* SMITH, 1920, a cerioid coral belonging to the same family (Aphrophyllidae HILL, 1973) as *Merlewoodia*. This coral fauna is highly endemic by comparison with those known in the Visean everywhere else.

2.7. Southwest Japan, Akiyoshi Limestone Plateau

The Akiyoshi Limestone Group is interpreted to have originated on and around volcanic seamounts on the oceanic floor. Now it is part of an accretionary prism resulting from the subduction of the Pacific plate. The lowest part of the Akiyoshi Limestone Group (Fig. 2) rests upon and interfingers with volcaniclastic deposits. It was dated as upper Tournaisian by conodonts and yields the oldest Carboniferous corals found in the area. These corals were determined and figured by HAIKAWA (1986) and comprises: *Zaphrentites* sp., *Eostrotion* sp., Aphrophyllidae gen. and sp. nov., "*Menophyllum*" sp., *Dagmaraephyllum*? sp., *Rylstonia* sp. A, *Echigophyllum* sp. A, *Echigophyllum* sp. nov., *Akiyoshiphyllum stylophorum* Yabe et Sugiyama, 1942, *Amygdalophyllum* sp. A, *Carcinophyllum* sp. A, *Carcinophyllum* sp. B, *Cyathoclisia*? sp., and *Cyathaxonia* sp.

Aphrophyllidae gen. and sp. nov., "*Menophyllum*" sp., and *Dagmaraephyllum*? sp. (see Pl. 2, Fig. 1) belong in fact to the genus *Merlewoodia*; *Carcinophyllum* sp. A and *Carcinophyllum* sp. B are *Merlewoodia* with irregular axial septal lobes; *Rylstonia* sp. A, *Echigophyllum* sp. A, *Echigophyllum* sp. nov. (see Pl. 1, Fig. 1), *Akiyoshiphyllum stylophorum*, and *Amygdalophyllum* sp. A all belong to the genus *Amygdalophyllum*. Therefore, considering its Upper Tournaisian age based on conodonts, and the occurrence of species of *Merlewoodia* and *Amygdalophyllum*, the lowest part of the Akiyoshi Limestone Group can be correlated with the Avins Member of Belgium.

The corals succeeding that association (see HAIKAWA & OTA, 1983; HAIKAWA, 1986) comprise endemic taxa such as *Nagatophyllum satoi* OZAWA, 1925, a genus characterized by its naotic dissepimentarium probably arising from *Amygdalophyllum*, and *Lonsdaleia enormis* OZAWA, 1925, a solitary coral with an axial structure closely related to *Merlewoodia* (and belonging not to *Carcinophyllum* as considered by HAIKAWA & OTA, 1983).

3. REVISED DIAGNOSES AND DISCUSSION OF THE GENERA *MERLEWOODIA*, *AMYGDALOPHYLLUM* AND *DORLODOTIA*

3.1. *Merlewoodia* Pickett, 1967

Family Aphrophyllidae Hill, 1973
Genus *Merlewoodia* Pickett, 1967

1967 – *Merlewoodia* Pickett, p. 24
1967 – *Naoides* Pickett, p. 24
1981 – *Merlewoodia* Pickett; Hill, F376
1990 – *Merlewoodia* Pickett; Webb, p. 70

Type species: *Merlewoodia bensoni* Pickett, 1967, Swain's Gully Limestone Member, Namoi Formation, Lower Visean.

Diagnosis: Solitary, medium to large, cylindrical corals. Septa numerous and usually thickened, may be coalescent in the tabularium; major septa reaching or not the axis and sometimes forming axial irregular lobes. They can be sinuous and/or irregularly pinnate, but not confluent. Cardinal septum short and counter long. Cardinal and alar fossula usually well marked but often fully filled up with thickenings. Minor septa short to long. Dissepiments simple in the inner part of the dissepimentarium, packed and lonsdaleoid to naotic in the outer part, often thickened. Tabulae complete to more or less divided, slightly domed to depressed axially and laterally declined towards the dissepimentarium.

Discussion: For its author, *Naoides* Pickett, 1967, differs mainly from *Merlewoodia* by its long major septa, more thickened and coalescent in the dissepimentarium. Because this character is variable in *Naoides* and occurs also in *Merlewoodia*, *Naoides* is here considered as a synonym of the latter. *Symplectophyllum* Hill, 1934, is close to *Merlewoodia* but develops an axial structure. Note that *Merlewoodia* can show septal axial lobes (see Pl. 2, Fig. 1). Species of *Merlewoodia* may be small to large (up to 6 cm in diameter and more than 20 cm long for *Merlewoodia avesnensis*).

Stratigraphic range: *Merlewoodia* is known from the uppermost Tournaisian up to the upper Visean (at Visé in Belgium), but is uncommon except at the base of its biozone.

3.2. *Amygdalophyllum* Dun & Benson, 1920

Family Aulophyllidae Dybowski, 1873
Subfamily Amygdalophyllinae Grabau, 1935
Genus *Amygdalophyllum* Dun & Benson, 1920

1920 – *Amygdalophyllum* DUN & BENSON, p. 339
1934 – *Amygdalophyllum* DUN & BENSON; HILL, p. 66
1967 – *Amygdalophyllum* DUN & BENSON; PICKETT, p. 21
1974 – *Amygdalophyllum* DUN & BENSON; SEMENOFF-TIAN-CHANSKY, p. 148
1981 – *Amygdalophyllum* DUN & BENSON; HILL, p. F355

Type species: *Amygdalophyllum etheridgei* DUN & BENSON, 1920, Burindi Series, Visean, Babbinboon, New South Wales.

Diagnosis: Small to large solitary coral with a more or less dense axial structure. Axial structure composed of a thick median plate and more or less contiguous thickened septal lamellae and axial tabellae. Axial structure may be cuspidate towards the cardinal septum and sometimes towards the counter. Cardinal fossula more or less conspicuous. Septa numerous, carinate or not, more or less thickened along the whole length or only in the tabularium. Major septa extending to axial structure or a few withdrawn. Minor septa usually long and thinner than the majors, sometimes contraclined or contratingent. Dissepimentarium wide, with small concentric dissepiments and with or not peripheral lonsdaleoid dissepiments. Inner margin may be thickened. Tabulae incomplete conical and commonly thickened to the axis, moderately to strongly declined abaxially, sometimes forming a peripheral gutter. Increase occurs sometimes.

Discussion: What is an *Amygdalophyllum*? Authors have usually considered as belonging to the genus *Amygdalophyllum* only corals having a strong compact axial structure (see for example HILL, 1981). But the study of topotypes of the type species *Amygdalophyllum etheridgei* DUN & BENSON, 1920, has shown that in the same specimen, the axial structure could be more or less dense. Moreover, the axial structure either can be poorly developed, as in *Koninckophyllum*, or to have a clisiophyllid-like pattern. In the same way, the presence of lonsdaleoid dissepiments does not allow to reject amygdalophylloid species from the genus. That explains why only a few species were assigned to the genus *Amygdalophyllum* outside Australia, being assigned to other genera, for example *Koninckophyllum* in Great Britain (such as *K. praecursor* HOWELL, 1938), or *Rylstonia* (*R.* sp. A HAIKAWA, 1986), and *Echigophyllum* (*E.* sp. nov. HAIKAWA, 1986) in Japan. The sizes of the species are also variable, ranging at mature stage from diameters less than 10 mm (as in *A. minimum* WEBB, 1990) up to 60 mm (as in the type species). Size of species recorded in the RC4β1 Subzone range usually from less than 10 mm up to 30 mm.

Distribution: *Amygdalophyllum* is known through Eurasia and Australia, from the uppermost Tournaisian up to the upper Visean. Records in the Serpukhovian and in the Upper Carboniferous have to be checked.

3.3. *Dorlodotia* Salée, 1920

? Family Lonsdaleidae Chapman, 1893
Genus *Dorlodotia* Salée, 1920

1920 – *Dorlodotia* Salée, p. 145
1929 – *Syringophyllum* Grabau & Yoh, in Yoh, p. 2
1931 – *Kwangsiphyllum* Grabau & Yoh, in Yoh, p. 79
1934 – *Thysanophyllum* Nicholson & Thomson; Yü, p. 41
1955 – *Pseudodorlodotia* Minato, p. 91
1981 – *Dorlodotia* Salée; Hill, p. 391
1981 – *Dorlodotia* Salée; Poty, p. 67
1983 – *Thysanophylloides* Yü et al., p. 151

Type species: *Dorlodotia briarti* Salée, 1920, Neffe Formation, Cf4δ Foraminifera Subzone and RC5 Coral Zone, uppermost lower Visean, Landelies, river Sambre valley, Belgium.

Diagnosis: Corallum fasciculate. Major septa usually withdrawn from the axis. Minor septa short or not developed. Columella present or not, composed of a single axial plate, more or less thickened. Dissepimentarium more or less developed, typically composed of large lonsdaleoid dissepiments, and some simple dissepiments. The latter usually dominant in small-sized corallites. Inner ring often thickened and forming an inner wall. Tabulae complete, conical when a columella exists, horizontal to slightly domed when there is no columella. Outer wall thick and festooned. Increase lateral.

Discussion: The revision of *Dorlodotia briarti* Salée (Poty, 1975, 1981) has shown that the variability of the species was very high: in the corallites of a single colony, the columella could be present or not, the lonsdaleoid dissepiments well developed or not and sometimes replaced by simple dissepiments, minor septa short to not developed, and the skeleton more or less thickened. The consequence of that variability is that some genera were defined to include species showing characters supposed to be different from those considered as typical for *Dorlodotia*. Thus, *Thysanophylloides* was created by Yü et al. (1983) to include fasciculate species considered by the authors as having a columella not so stable as in *Dorlodotia*, and previously assigned to *Thysanophyllum* Nicholson & Thomson, this genus being reserved only for cerioid corals (and indeed is close to *Koninckophyllum* and attributed to the family Aulophyllidae, subfamily Dibunophyllinae by Poty & Hecker, 2003). Species such as *Dorlodotia longiseptatum* (Yabe & Hayasaka, 1915) and *D. kakimii* (Minato, 1955), where the columella is poorly developed and not everywhere present, have been included by Minato (1955) in his genus *Pseudodorlodotia*. And others such as *D. permicum* (Grabau & Yoh, 1929) where there is no columella at all and also no dissepiments, led Grabau & Yoh (in Yoh, 1929) to create the genus *Syringophyllum* (= *Kwangsiphyllum* Grabau & Yoh in Yoh,

1931) for them. We consider here that these genera are all junior synonyms of *Dorlodotia*.

Distribution: *Dorlodotia* is largely present in Eurasia, but has usually been misidentified (see above). It is known from the uppermost Tournaisian of Belgium and Poland (and China ?) and extends up to the top of the Lower Visean. Records in younger levels have to be checked.

3.4. Origin of taxa

Amygdalophyllum is very close to *"Lophophyllum"* sp. of Poty (1989), from the upper Hastarian (Lower Tournaisian) of the Namur-Dinant basin in Belgium, and also to *Cyathoclisia*, from the Ivorian (Upper Tournaisian) of Eurasia. These corals have similar axial structures showing typically a columella which can be thickened and cuspidate towards the cardinal and conical axial tabellae (see for example in Poty, 1989), and in some species septal lamellae. It could quite arise from a representative of these taxa before its spread at the end of the Tournaisian. The origins and the phyletic relationships of *Merlewoodia* and *Dorlodotia* are doubtful. No coral similar to the first has been recorded before its appearance at the top of the Tournaisian, and the second show caninioid characters, i.e. relatively simple, which suggest possible relations with a so-called Tournaisian *"Caninia"*.

Concerning *Palaeosmilia* (not discussed above), the oldest species, i.e. *Palaeosmilia* sp. found in the Avins Member in Belgium and in its stratigraphical equivalents in England and Southern Avesnois, has usually carinate septa and depressed axial tabellae which tend sometimes to form an aulos as in *Aulokoninckophyllum* Sando, 1976. This latter genus is known in the Upper Tournaisian (for example in Belgium and Armorica) and could have given rise to the former.

4. CONCLUSIONS

At the top of the Tournaisian, the Belgian Avins Member and its Western European lateral equivalents contain a relatively rich rugose coral fauna among which are the oldest known species of *Amygdalophyllum*, *Merlewoodia*, *Dorlodotia* and *Palaeosmilia*. These "Visean-type" corals replaced "Upper Tournaisian-type" ones, such as *Cyathoclisia*, and are the basis for the definition of the rugose coral Subzone RC4β1. Everywhere, this new wave of rugose corals is linked to development of shallow-water oolitic and crinoidal grainstones (as recorded in the Dublin Basin by Somerville, 1994). These taxa are joined, from the base of the Visean, by others including species of *Clisiophyllum*, *Axophyllum* and *Haplolasma*, allowing to define a RC4β2 Subzone. The corals of the RC4β1 Subzone have allowed to correlate this interval outside Western Europe, with Poland, China, Japan and Australia. These correlations were also based or supported, when present, by foraminifera (association C of Hance et al., 2001, in the upper part of the Cf4α1 Foraminifera Subzone), but usually not by conodonts, because most of the correlated lithostratigraphic units being composed of grainstones, often oolitic, commonly with crinoids and lithoclasts, are typically devoid of them. Everywhere, the top of the Tournaisian is characterized by the first appearances of the genera *Amygdalophyllum* and *Merlewoodia*, and secondarily by *Dorlodotia* and *Palaeosmilia*, indicating easy connections between these areas at the end of the Tournaisian. Note that most authors, who described the uppermost Tournaisian corals under discussion here, concluded that they were highly endemic. It is, however, the exact opposite!

The uppermost Tournaisian corresponds to the HST of the third-order sequence 4 defined in Western Europe (HANCE et al., 2001) and, because in some areas (Laval Basin, Bardzkie Mountains in Sudetes, Akiyoshi Limestone Plateau) the units correlated with the Avins Member rest on an old basement, it is deduced that these units were deposited during a very high sea level corresponding to the acme of the highstand. This very high sea level should be responsible for the good connections between marine basins and the widespread nature of the corals. During the fall in sea level which followed this highstand and which persisted during the sequence 5 (the sequence 5 never reached the shallow-water marine platforms as highlighted by HANCE et al., 2001), areas previously well connected became more or less isolated. Because of this isolation, the common stock of corals gave rise, by separate evolutions, to the lowermost Visean coral assemblages, which usually are endemic and difficult to correlate.

Note that in most areas, the levels recording the event are usually thin (usually less than 10 m in Belgium) and sometimes dolomitized (because they were exposed during the lowest Visean), so, that the event may remain unnoticed. Until now, it is not yet recognized in North America. This will form a future topic for study.

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Plate 1

Fig. 1: *Amygdalophyllum* sp. (*"Echigophyllum"* sp. nov. HAIKAWA, 1986, or *Amygdalophyllum* sp. A HAIKAWA, 1986); x 5. Specimen Jap 1999–3/5–1/4, Lowest part of the Akiyoshi Limestone Group, Ohkubo, Yamaguchi Prefecture, Southwest Japan.

Fig. 2: *Amygdalophyllum* sp.; x 5. Specimen Pen 2001–79/1, Uppermost Tournaisian, Penchong Member, Liuzhou Formation, Penchong, Guangxi, China.

Fig. 3: *Amygdalophyllum* sp.; x 5. Specimen NSW 1988–7/26, Rangari Limestone, Parish Rangari (locality 202 of PICKETT, 1967), County Nandewar.

Figs. 4–6: *Amygdalophyllum* cf. *sudeticum* ZOLYNSKI, 2000.

Fig. 4: Specimen Eng-45; transverse section in a specimen showing an elongated axial structure; x 5. It is very close to the Australian *Amygdalophyllum* sp. of Fig. 3.

Fig. 5: Specimen Eng-54; transverse section; x 5

Fig. 6: Specimen Eng 2001/62-I; transverse section in a wide thickened amygdalophylloid axial structure; x 10. It is similar to the axial structure of the Japanese *Amygdalophyllum* of Fig. 7. Specimens 4–6 are from the Avins Member, Engihoul quarry, Namur area, Belgium.

Fig. 7: *Amygdalophyllum* sp. (*Rylstonia* sp. A HAIKAWA, 1986); x 10. Specimen Jap 1999–3/5–1/3, Lowest part of the Akiyoshi Limestone Group, Ohkubo, Yamaguchi Prefecture, Southwest Japan.

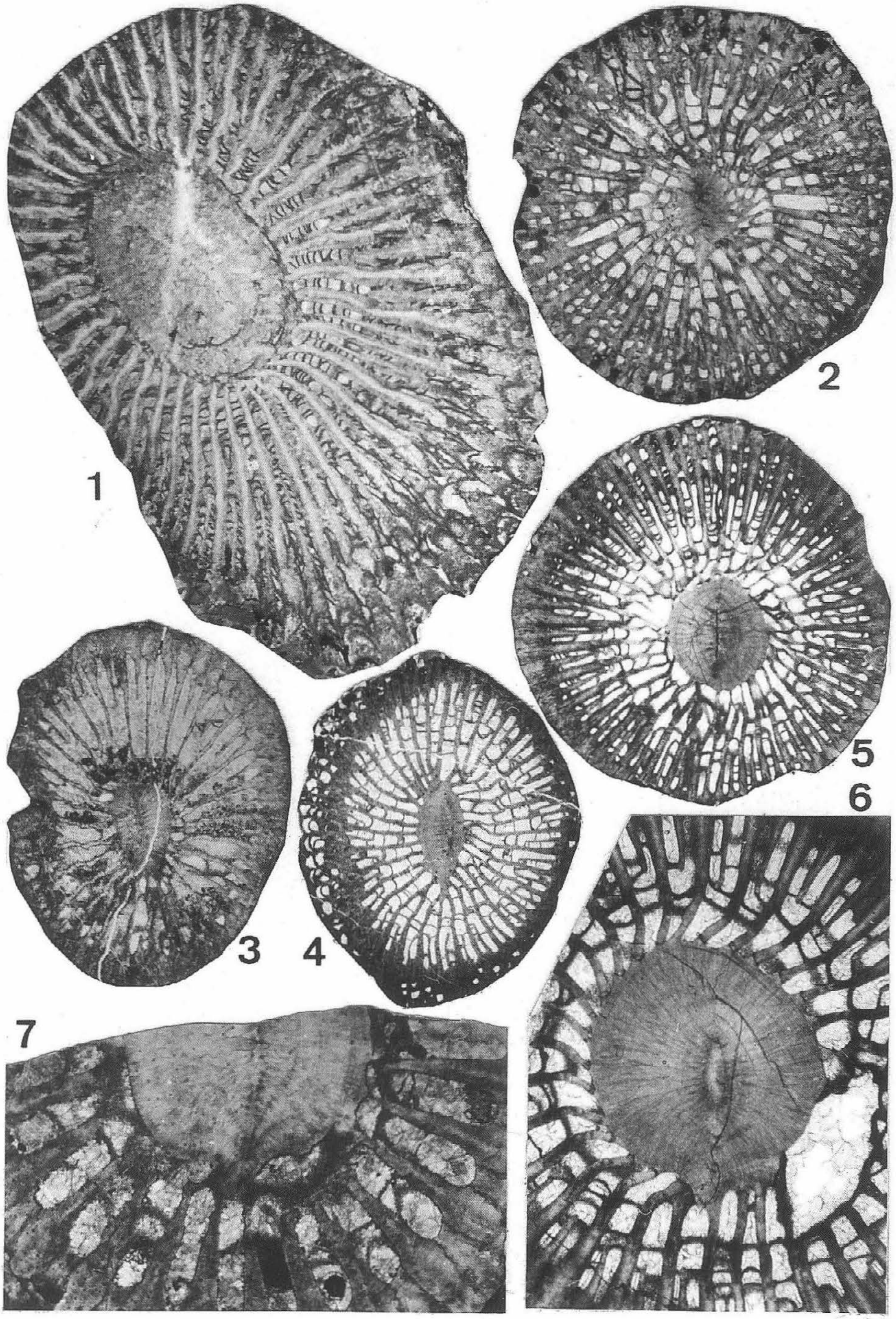
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Plate 2

Fig. 1: *Merlewoodia* sp. (*Dagmaraephyllum*? sp. HAIKAWA, 1986), transverse section; x 5. Specimen Jap 1999–3/5–1/6, Lowest part of the Akiyoshi Limestone Group, Ohkubo, Yamaguchi Prefecture, Southwest Japan.

Fig. 2: *Merlewoodia* sp. transverse section; x 5. Specimen Eng 37, Avins Member, Engihoul quarry, Namur area, Belgium.

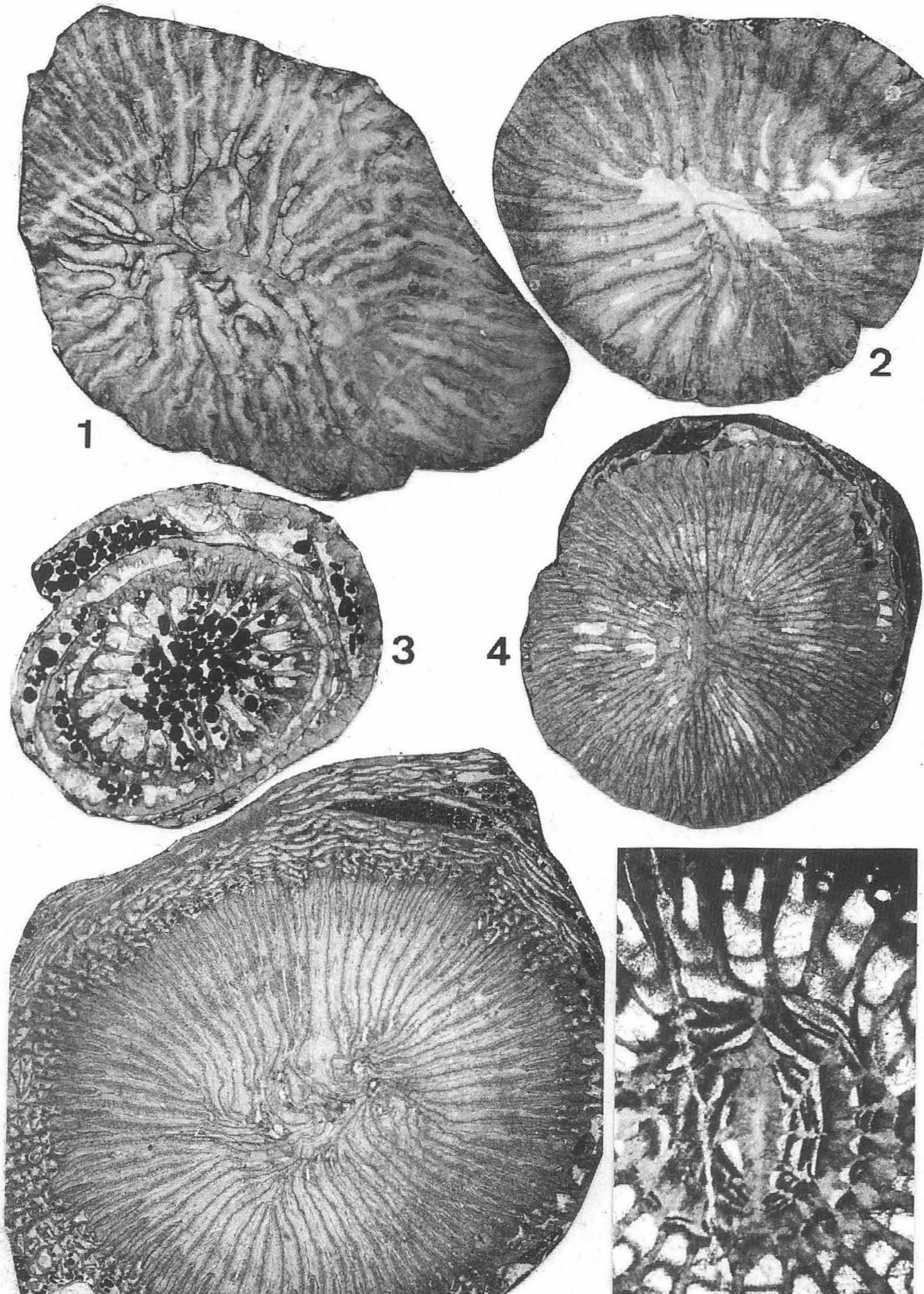
Figs. 3, 5: *Merlewoodia avesnensis* (DELÉPINE, 1929)

Fig. 3: Specimen God 98, transverse section in a young stage; x 5. This section is very close to the section of *Merlewoodia australis* figured by PICKETT (1967, Pl. 1, Fig. 7), from the Rangari Limestone.

Fig. 5: Specimen God 83, transverse section in a mature stage; x 3. Godin Formation, Bocahut quarry, Godin, Avesne, Southern Avesnois area, France.

Fig. 4: *Merlewoodia rangariensis* (PICKETT, 1967); transverse section in a topotype of *Naoides rangariensis* PICKETT, 1967; x 3. Specimen NSW 1999–9/6, Rangari Limestone, Keepit – Oxley highway (loc. 213 of PICKETT, 1967), New South Wales.

Fig. 6: *Amygdalophyllum praecursor* (HOWELL, 1938); transverse section in an axial structure composed of thickened but not contiguous median plate, concentric axial tabulae and septal lamellae. Both this type of axial structure and the compact, more typical one, are common in the species of *Amygdalophyllum* and are present in the type species (*Amygdalophyllum etheridgei* DUN & BENSON, 1920). Specimen CB 1982–47, Caswell Bay Oolite, Caswell Bay, Gower, South Wales.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