Original article

**The lower-middle Viséan boundary interval in the Palaeotethys: refinements for
the foraminiferal zonal schemes**

running title: New biozones in the early-middle Viséan interval

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Abstract – A new foraminiferal biozone (Cf5 α or MFZ12 α) in between the classical foraminiferal zonal schemes is characterized by the first occurrence of *Archaediscus* at *concavus* stage, primitive species of *Pojarkovella*, as well as the first *Endothyranopsis* s.s.. This interval is widely represented in England, France and Morocco (in the Western Palaeotethys), and it is also recognized in South China, and more widely in Iran (in the Eastern Palaeotethys), where it is partly similar to the MFZ11B subzone defined by previous authors. The position of the biozone within the Livian or Holkerian substages suggests that the new zone has to be considered as part of the mid Viséan and thus, it is proposed here, to abandon this notation as MFZ11B, which includes lower Viséan rocks, and to subdivide the classical MFZ12 and Cf5 zones for the middle Viséan into MFZ12A α or Cf5 α , and MFZ12B β or Cf5 β with the latter containing the classical Livian/Holkerian foraminiferal guides - *Pojarkovella nibelis* and *Koskinotextularia*. Furthermore, the Early Viséan MFZ11 zone can be subdivided in most Palaeotethyan basins into three subzones; a lower MFZ11A α subzone (characterized by the first occurrence of *Uralodiscus rotundus*, as well as most species of *Glomodiscus*), a middle MFZ11B β subzone (characterized by the first occurrence of *Archaediscus* at *involutus* stage and *Conilidiscus*), and an upper MFZ11C γ subzone (characterized by the first occurrence of *Nodosarchaediscus*, *Consobrinellopsis* and *Lituotubella*).

Keywords: biostratigraphy, archaediscids, Livian, Holkerian, stratigraphic gap

1. Introduction

The Viséan stage was defined in the Dinant ~~Syncline~~ **Synclitorium**, close to the ~~city~~ **town** of Visé, following the work of Belgian geologists. The first subdivision of the Viséan into lower, middle and upper parts, with regional names, was also developed in the same area, from the end of the nineteenth century, and refined in the early twentieth century. These subdivisions were associated with the chronozones V1, V2 and V3 (and subdivided into subchronozones), which were initially defined on the basis of macrofossils, such as brachiopods and rugose corals, and later, goniatites were added (see historical revision in Demanet, 1958). It was not until the 1960s when Conil & Lys (1964) and Conil *et al.* (1967) used microfossils (foraminifers, conodonts and rare calcareous algae) to more precisely define each chronozone. Within this zonal scheme, the V1 was equated to the early Viséan, V2 to the middle Viséan and V3 to the late Viséan. Refinements of the zonal schemes, and overall increase in the knowledge of the fauna and lithologies in Belgium and around the World, led to some successive modifications to this zonal scheme. The most important change was introduced by Conil *et al.* (1977), who proposed new names for the substages of the Viséan, namely, Moliniacian, Livian and Warnantian, and their associated new “Cf” foraminiferal zones, replacing the previous names (Assise de Dinant, Assise de Namèche and Assise de Warnant) and previous chronozones and subchronozones (those of the V1a to V3c sup.). This process was not only a simple replacement of names, but also, involved the definition of new stratotypes, and the amended foraminiferal zones compared to worldwide stratigraphical scales. Related to the lower and middle Viséan (Moliniacian and Livian substages), they correlated the base of the Moliniacian with the base of the Chadian in England (base of their Cf4 α = base of the V1a subzone), and thus, considered as the base of the Viséan stage. On the other hand, the base of the Livian

was correlated with the base of the Holkerian in England (base of Cf5 zone = base of V2b subzone), and thus, moving significantly the base of the older middle Viséan (or Assise de Namèche) from the base of the V2a to V2b. Later, Conil *et al.* (1989) proposed that the Tournaisian/Viséan boundary should be situated at the base of the subzone Cf4α2. All these modifications were summarized in the zonal scheme published in Conil *et al.* (1991). A final emendation of the base of the Moliniacian was introduced by Devuyst (in Poty *et al.* 2006) to equate the base of this substage with the base of the Viséan.

More recent studies have recorded ambiguous foraminiferal assemblages around the World that could be assigned to the mid Viséan, as well as to early Viséan, and generally, they were considered as mid Viséan (e.g., Vachard *et al.* 1977; Vieslet, 1983; Vachard & Tahiri, 1991; Fassihi *et al.* 2018). In the past two decades, some authors have proposed the possible existence of an intermediate foraminiferal assemblage in some countries around the World, situated between the early and mid Viséan of the Belgian substages (Izart *et al.* 2001; Devuyst *et al.* 2003; Hance *et al.* 2011; Okuyucu *et al.* 2013; Zandkarimi *et al.* 2016; Fassihi *et al.* 2018), although its occurrence and calibration with the classical outcrops in Western Europe has been never undertaken, and thus, it is not clear if they have to be considered as regional subdivisions or if there is a biozone with worldwide implication.

The aim of this study is to investigate the possible presence (or absence) of a foraminiferal biozone (or subzone) intermediate in position between the formally recognized foraminiferal biozones (Cf4/Cf5 and MFZ11 and MFZ12) in the Western Palaeotethys, and validate its potential synchronous dispersal, by comparison to basins situated in the Eastern Palaeotethys.

2. Lower-middle Viséan boundary interval in Western Palaeotethys

This study is limited to the stratotype for the base of the Livian substage in Belgium, as well as the stratotype for the Holkerian substage in Cumbria (northern England), as well as other sections in the Askrigg Block which include a more continuous succession down to the early Viséan, as well as sections in southern France (Montagne Noire) and the Western Meseta of Morocco. Other basins or countries in the Western Palaeotethys do not contain good transitions between the lower and middle Viséan carbonates, and they are commonly associated with siliciclastics.

2.a. Foraminifers at the base of the Livian in Belgium

The stratotype for the base of the Livian was selected in the transition between the carbonates of the Neffe and Lives formations (Conil *et al.* 1977), although, an argillaceous bentonite of volcanosedimentary origin is located at the boundary, regionally named as the Banc d'Or de Bachant (Fig. 1), and considered as the transition between the Cf4 and Cf5 chronozones. More recent studies (Poty *et al.* 2006, 2014; Hance *et al.* 2006; Poty, 2016) have followed the lithostratigraphical subdivision proposed by Conil *et al.* (1977), and new Mississippian foraminiferal zones were defined (MFZ), justified on the need to standardize more widely distributed foraminiferal guides (Poty *et al.* 2006). For these authors, some of the guide foraminifers defined for the subchronozone in Conil *et al.* (1980, 1991) had too much local character, and could not be identified outside of their influence areas in Belgium.

Since the studies of Conil *et al.* (1967, 1977), the guides for the base of the Livian, V2b or Cf5 zone, were considered to be *Pojarkovella nibelis* (Durkina, 1959) and *Koskinotextularia* (the latter, named as *Cribrostomum* in 1967 or cribrate palaeotextulariids in 1977). Later, *Archaediscus* at *concavus* stage was also recognized

as an auxiliary marker (Conil *et al.* 1980, 1991), as well as more questionable or regional taxa such as “primitive *Millerella*”, *Rhodesinella*, *Lituotubella*, *Nodosarchaediscus*, *Omphalotis minima*, *Consobrinellopsis consobrina* (Lipina, 1948) and *Endothyranopsis* (e.g., Conil, 1977; Conil *et al.* 1980, 1991; Poty *et al.* 2006). The evolutionary stage of the *Archaediscus* involving the shape of the sutures between the whorls, *involutus*, *concavus*, *angulatus* and *tenuis*, were early defined by Pirlet & Conil (1974), and later slightly modified by Conil *et al.* (1980) and Vachard (1988a). Certainly, from a taxonomical point of view, they have no value, but their biostratigraphical use have been defended and confirmed by numerous studies in Europe (Conil *et al.* 1977, 1980; Strank, unpub. Ph.D. Univ. Manchester, 1981; Somerville, 2008), as well as in Asia (e.g. Hance *et al.* 2011; Zandkarimi *et al.* 2017, 2018). Another important character within the *Archaediscus* is the progressive reduction of the microgranular layer during its evolution, which led to Brenckle *et al.* (1987) to split the genus into *Paraarchaediscus* (for those forms with well-developed microgranular layer) and *Archaediscus* (those other with reduced microgranular layer). This is a continuum process where the extreme forms are easily distinguished, whereas there are multitude of intermediate forms which is difficult to decide if they belong to one or the other genus due to the ambiguity in the boundary between both genera. Owing to the uncertainty, and thus, questionably taxonomic value, herein is preserved the original definition of *Archaediscus* as the valid genus. The first occurrence of *Pojarkovella nibelis* is some distance above the base of the Lives Formation (at a level 14.3 m above the base, in the 30 m-thick basal Haut-le-Wastia Member in the Livian stratotype section; Fig. 1), and in other regions of Belgium, this species first occurs much higher compared to the base of this substage (Poty & Hance, 2006; Poty *et al.* 2014). *Koskinotextularia* occurs later than *P. nibelis* (Poty *et al.* 2006). These authors

also defined the rugose coral assemblage (RC5 γ), for the Haut-Le-Wastian Member, characterized by the first occurrence of *Siphonodendron irregular* (Phillips, 1936), *Axophyllum vauhani* (Salée, 1913), *Caninophyllum archiaci* (Milne-Edwards & Haime, 1852) and *Clisiophyllum garwoodi* (Salée, 1913) (Fig. 1). Unfortunately, the first occurrence of this assemblage was situated “in the first open-marine bioclastic limestone”, and thus, certainly, not from the base of the unit, which is mostly composed of massive limestones, intraclastic limestones or evaporitic limestones with stromatolites (Hance, 1979).

Some of the previously described auxiliary foraminiferal guides for the Livian are now confidently recognized as first occurring in the early Viséan (Moliniacian), such as *Nodosarchaediscus*, *Omphalotis minima* (Rauzer-Chernousova & Reitlinger in Rauzer-Chernousova *et al.* 1936) and *Consobrinellopsis consobrina*, and in the most recent revision, they are considered as abundant species in the assemblages of the Livian (Poty *et al.* 2006).

The Banc d’Or de Bachant is a volcanosedimentary bentonite with local pedogenic features, and it is recognized as representing a gap in limestone deposition (erosion and/or hiatus), 10 to 30 cm thick (Poty & Hance, 2006). This Banc d’Or de Bachant is recognized in all the regions in Belgium and northern France, and is considered as the base of the sequence 7 (Hance *et al.* 2001). Other authors have correlated this gap of the Banc d’Or de Bachant with similar rocks in Germany and England (A. Huyghe-Buissart, unpub. Ph.D. Univ. Lille, 1993), although the stratigraphic position for this gap in England, at least, does not seem to correspond exactly to the position in Belgium (see below). The presence of this hiatus has been criticized by some authors (e.g., Kalvoda, 2002; Hance *et al.* 2006; Poty, 2016), who have recommended the search for a new stratotype, where there is a record of continuous sedimentation. Taking into

consideration the studies in Britain (Conil *et al.* 1980), the Belgian subdivision can be applied there also, and apparently the hiatus between the Cf4 and Cf5 zones has been traditionally considered as negligible, and consequently, the possible influence/implication of the Banc d'Or de Bachant overlooked. Above the bentonite horizon, the Haut-le-Wastia Member is composed predominantly of lime mudstones, with stromatolites and local breccias due to evaporite dissolution. Therefore, the lower part of the Lives Formation and the Banc d'Or are not exactly the most favourable facies for the recovery of foraminifers (Fig. 1). Thus, there is a 30 m-thick interval where the knowledge of typical early and middle Viséan microfossils is poorly known, and even the positioning of the base of the middle Viséan at the base of the Banc d'Or de Bachant is not supported by any fossil guide.

2.b. The Arundian-Holkerian boundary interval in northern England

The stratotype for the base of the Holkerian is situated at Barker Scar, near Holker Hall in south Cumbria, in northern England. The boundary was located at the contact between the Dalton Beds and the overlying Park Limestone, as originally defined by George *et al.* (1976). The base of the Holkerian was based on macrofossils, such as brachiopods ([*Davidsonina carbonaria* (McCoy, 1852), *Composita ficoidea* (Vaughan, 1903), *Linoprotonia corrugatohemispherica* (Vaughan, 1903)] and rugose corals ([*Axophyllum vaughani* and *Lithostroton minus* (McCoy, 1849)]), as well as microfossils, the foraminifers *Archaeodiscus* at *concavus* stage and double-walled palaeotextulariids. However, in Barker Scar only *Linoprotonia corrugatohemispherica* occurs at the base of the Park Limestone (Rose & Dunham, 1977). These authors also considered *Axophyllum* cf. *vaughani* as typical of the lower beds in the Park Limestone, whereas they considered that *Davidsonina carbonaria*, absent in Barker Scar, occurs at

equivalent levels elsewhere in England. In contrast, *Composita ficoidea* is commonly recorded in the upper part of the Dalton Beds (Fig. 2; beds e and i in Rose & Dunham, 1977). The double-walled palaeotextulariids is readily a misidentification, because they have been never recorded below the late Viséan anywhere within the Palaeotethys, and most probably, they were referring to the single-layered palaeotextulariids.

Ramsbottom (1981) considered the same macrofossils as markers for the base of the Holkerian and specified the foraminiferal list of potential markers. He considered the main guides as *Koskinotextularia* and *Pojarkovella nibelis*, but also he mentioned *Archaediscus* at *concavus* stage and transitional forms to the *angulatus* stage, as well as the regional markers *Holkeria* and *Dainella holkeriana* Conil & Longerstaey in Conil *et al.* 1980.

However, the conclusions in A.R.E. Strank, unpub. Ph.D. Univ. Manchester (1981), who also contributed in Ramsbottom (1981), were not exactly the same. She considered that the *Archaediscus* at *concavus* stage are not well developed in England as in other basins, and that these forms appeared inconsistently from the Arundian to the Asbian. In her study, it is possible to find *Omphalotis minima* and *Lituotubella* from the base of the Barker Scar section (> 29 m below the boundary between the Dalton Beds and Park Limestone) and *Archaediscus* at *concavus* stage (*A. varsanofievae* Grozdilova & Lebedeva, 1954 and *A. stilus amplus* Conil & Lys, 1964) nearly from the base of the section (>23 m below the boundary), both from bed a (Fig. 2). On the other hand, she recorded *Consobrinellopsis* (as *Palaeotextularia* sp.) in bed k (2.5 m above the boundary), *Koskinotextularia* and *Pojarkovella nibelis* also in bed k (3.5 m above the boundary; Fig. 2). Thus, it can be concluded, that *Omphalotis minima*, *Lituotubella* and *Archaediscus* at *concavus* stage first occur much earlier than *Koskinotextularia* and *P. nibelis*. Unfortunately, Barker Scar section does not extend down far enough into the

Arundian as to allow more detailed first occurrences of the foraminifers to be recorded during the early Viséan, because the Dalton Beds (Formation) reaches up to 255 m thick, but only the upper *ca.* 30 m is exposed at Barker Scar.

Riley (1993) questioned the validity of the Barker Scar as a stratotype because lateral sections with palaeosols (2 km apart) were correlated with bed i in Barker Scar, where some sandy strata are recorded, and compared to the *Davidsonina carbonaria* beds of Garwood (1913). He assumed a non-sequence zone in the lower part of the succession, also supported by the absence of the transition from fasciculate (*Siphonodendron*) to cerioid (*Lithostrotion*) rugose corals, as recorded in Ireland and Wales.

Johnson *et al.* (2001) revised the stratigraphy in the region and at Plumpton quarries, they described the topmost 1.8 m of the Dalton Formation (lithological units were described for first time as formations in this work) as being composed of compact, pale brown, fine-grained dolomites and sandstones with traces of carbonaceous rootlets, and interpreted as palaeosols. This confirms the non-sequence in the Dalton Formation, but not in the stratotype section at the base of the Park Limestone Formation. In Barker Scar, they considered that beds e to i contained similar sandy and partly dolomitized characteristics of the upper part at Plumpton, including the non-sequence interval (Fig. 2). Furthermore, they described bed j as a grey, dolomitized, bioclastic packstone with quartz grains, and compared it with the Park Limestone Formation, but less darker. They recognized this bed as a mappable horizon, and although no diagnostic fossils were recorded, they considered this bed j as the base for the Park Limestone Formation (Fig. 2).

This lithological change at the base of the Park Limestone Formation was adopted by Waters *et al.* (2011, 2017), although, certainly, the stratigraphic level for the base of

the Holkerian (with diagnostic fossils) was not be modified by Johnson *et al.* (2001) from the original position at the base of bed k.

In the Askrigg Block, the lateral equivalent to the succession in South Cumbria is composed of the Chapel House Limestone and Kilnsey formations (Arthurton *et al.* 1988). The Kilnsey Formation is subdivided into the Scaleber Force Limestone and Scaleber Quarry Limestone members, and the Arundian-Holkerian boundary is supposedly located at the boundary between both members. Foraminifers in the Scaleber Force Limestone Member are typically *Conilidiscus bucculentus* (Conil & Lys, 1964), *C. settlensis* Conil in Conil *et al.* 1980, *Uralodiscus* sp., *Planoarchaediscus* and *Glomodiscus miloni* (Pelhâte, 1967), an assemblage assigned to the Arundian (Strank in Arthurton *et al.* 1988). Important macrofauna in the Scaleber Quarry Limestone Member are *Lithostrotion vorticale* (Parkinson, 1808), *Composita ficoidea*, *Davidsonina carbonaria*, *Linoprotonia corrugatohemispherica* associated with small “*concavus* stage and partial *angulatus* stage *Archaediscus* and *Nodosarchaediscus*”, as well as *Koskinotextularia cribriformis* and *Pojarkovella nibelis* (Arthurton *et al.* 1988). Fossil assemblages can be readily compared with that of the Barker Scar section, as well as some of the macrofauna, and thus, the base of the Scaleber Quarry Limestone Member can be correlated with the base of the Park Limestone Formation.

The occurrence of the non-sequence interval in the upper part of the Chapel House Limestone Formation and *Archaediscus* at *concavus* stage from the base of the Kilnsey Formation led Waters *et al.* (2017) to correlate the base of the latter with the base of the Park Limestone Formation. At the preserved base of the Chapel House Limestone Formation in the Silverdale Borehole (this formation has a maximum thickness of 12 m; Murray, 1983), the assemblage is composed of numerous typical upper Tournaisian and lower Viséan forms *Caligella*, *Dainella*, *Eosinopsis*, *Septabrunsiina*, *Eoparastaffella*,

Septatournayella, *Eblanaia*, *Spinobrunsiina*, *Tournayellina*, *Spinochernella*), as well as *Glomodiscus* sp., *G. miloni*, *Uralodiscus adindanii* (Brenckle & Marchant, 1987), *U. elongatus* (Conil & Lys, 1964), *U. rotundus* (Chernysheva, 1948), *Conilidiscus settlensis*, which in addition to *Latiendothyranopsis menneri solida* (Conil & Lys, 1964), *Nodosarchaediscus*, *Plectogyranopsis moraviae* (Conil & Longerstaey in Conil et al. 1980) and *P. settlensis* (Conil & Longerstaey in Conil et al. 1980)], allow to assign the assemblage to the Cf4δ subzone (Figs. 2-3). The upper part of the formation is dolomitized and does not contain foraminifers, and there is a non-deposition and development of a palaeosol (Fig. 2). At the base of the overlying Kilnsey Formation *Archaediscus* at *concavus* stage, *Omphalotis minima* and *Pojarkovella* sp. were recorded. Seven metres above the base are recorded specimens of *Pojarkovella* sp., *Holkeria?* and *Ninella*, and 2 metres further above, occur typical *Pojarkovella nibelis*, *Koskinotextularia*, *Archaediscus concavus* trans. *angulatus* stage and *Endothyranopsis compressa* (Rauzer-Chernousova & Reitlinger in Rauzer-Chernousova et al. 1936) (Fig. 2). In higher levels of the formation, and occurring in several steps, are *Archaediscus* at *angulatus* stage, *Pseudoendothyra*, and *Endothyranopsis crassa* (Brady, 1876) as well as *Koskinobigenerina*, which suggest a relatively condensed succession from the Arundian to the Early Asbian compared to other regions in northern England, but including all the foraminiferal subzones defined by Conil et al. (1980).

It is necessary to highlight the interval from the first occurrence of *Archaediscus* at *concavus* stage and *Pojarkovella* sp. up to the first occurrence of *Koskinotextularia* and *P. nibelis*. The latter taxa allow the correlation with bed K of the Park Limestone of the Barker Scar stratotype, and thus, this interval has to be correlated to the upper part of the Dalton Beds, and assigned to the Arundian. The level with *Koskinotextularia*/*P. nibelis* in other outcrops where the Scaleber Force Limestone and Scaleber Quarry

Limestone members are well differentiated, is coincident with the boundary between both members, as well as the above-mentioned macrofauna (Dunham & Wilson, 1985; Arthurton *et al.* 1988). Therefore, the boundary at Scaleber Force Limestone-Scaleber Quarry Limestone members mimics the fossil record to that in the Dalton Formation-Park Limestone Formation boundary.

In the Kilnsey Crag, type locality for the Kilnsey Limestone Formation, the younger member is well exposed and only the top 1-2 m of the Scaleber Force Limestone Member (see Waters *et al.* 2017, fig. 6). There, at the top of the lower member, it recorded the occurrence of *Endothyranopsis compressa*.

2.c. Lower-middle Viséan boundary interval in Southern France

In the Montagne Noire, the transition between the early and middle Viséan is rarely recognized in sections because of the poor exposure and commonly hostile facies for the foraminifers (Cózar *et al.* 2017; Vachard *et al.* 2018). Only at Valuzières section, has *Archaeodiscus* at *concavus* stage been recorded at the same level as *Pojarkovella* sp. and *Endothyranopsis compressa* (Figs. 3-4). However, only 0.8 m above this level *Archaeodiscus* at *concavus* stage transitional to the *angulatus* stage and *Pojarkovella nibelis*, as well as the regional markers such as *Ugurus*, primitive “*Millerella*” and *Cribrospira*, occur (Figs. 3p, 3s). This small difference in the Valuzières section between the first appearances of the taxa does not allow a clear conclusion if this intermediate zone at the top of the early Viséan is present. It could be poorly developed, but additional sections should confirm this short interval. Nevertheless, the succession in shallow water platforms of the Montagne Noire can be also considered as relatively condensed, with a limited thickness. Moreover, below the Valuzières Formation occurs a typical griotte limestone, the Combe Roland Formation, which is rather poor in

foraminifers, but in Tourière (Fig. 43) and in the type sections, it also contains *Archaediscus at concavus* stage, as well as transitional forms to the *angulatus* stage (Cózar *et al.* 2017; Vachard *et al.* 2018). Calciturbidites of the slope does not contain the transition to the early Viséan, however, the lower part of the mid Viséan Colonnes Formation also shows the same first occurrences of the taxa (Fig. 54). The stratigraphic records of the taxa are rather similar to those in northern England.

2.d. Lower-middle Viséan boundary interval in the Western Meseta of Morocco

This study is limited to the Western Meseta because the early and mid Viséan is not documented in the Eastern Meseta (M. Berkhli, unpub. 3^{ème} cycle Thèse, Univ. Lille, 1993). The occurrence of the early Viséan in Morocco has been a much debated point since the early studies in the region, because assemblages older than the V2a are rarely documented (Huvelin & Mamet, 1997). Subsequent to the chronostratigraphical changes introduced by Conil *et al.* (1977), many sections were considered from their bases to be middle Viséan (V2a), and later, a problematic lower Viséan was documented (e.g., Verset, 1983, 1988), although, it is not clear enough if the successions based on those assemblages compared to the V2a were considered as lower or middle Viséan (e.g., Vachard *et al.* 1977). To avoid problems with the comparison with the European zonal scales, these authors proposed a regional zonal scheme for Morocco using foraminifers and calcareous algae (Vachard, 1988b; Vachard & Tahiri, 1991), which has been updated (in stratigraphic ranges and guides) in subsequent studies (Vachard & Berkhli, 1992; Berkhli *et al.* 2000; Izart *et al.* 2001, 2017).

The basal zone, Cfm1, is characterized by the primitive forms of *Uralodiscus* and *Glomodiscus*, and with *U. rotundus* as a marker and *Archaediscus convexus* Grozdilova & Lebedeva in Dain & Grozdilova, 1953 in its upper part. This zone is typically

represented in the Sidi Sebaa Formation (Fig. 65), and was correlated with the upper part of the Moliniacian and lower part of the Livian, and also upper Arundian and lower Holkerian, upper MFZ11 and lower MFZ12, upper V2a and lower V2b, upper Cf4δ and lower Cf5 (Izart *et al.* 2017). The base of the succession in the Western Meseta seems to be only present at the Sidi Sebaa section, where in lithological unit E2 (Fig. 56), occur *Uralodiscus rotundus*, *Glomodiscus oblongus*, *Lapparentidiscus nanus* (Reitlinger, 1969) and *Archaediscus* at *involutus* stage (Vachard & Fadli, 1991). This assemblage can be compared with the Cf4γ-Cf4δ of Conil *et al.* (1980, 1991), most of the MFZ11 of Poty *et al.* (2006), as well as the upper Moliniacian (Devuyst *et al.* 2006). Above this level, the first change in the assemblages is characterized by the appearance of *Archaediscus* at *concavus* stage, which in addition to Sidi Sebaa, it is also recognized at north Oulmès (Vachard & Tahiri, 1991; Izart *et al.* 2001), Agouraï (M. Ben Abbou, unpub. 3^{ème} cycle Thèse, Univ. Sidi Mohamed ben Abdellah, Fès, 1990) and it is also present at Skoura boutonnière (Izart *et al.* 1989; and unpublished data). In this interval, *Endothyranopsis compressa* has been documented, although generally as ex group species or in open nomenclature (*E.* cf. *compressa* and *E.* aff. *compressa*) (Vachard & Tahiri, 1991; Izart *et al.* 2001).

In an early attempt, Izart *et al.* (2001), subdivided the Cfm1 zone into the Cfm1a subzone characterized by *Uralodiscus rotundus*, and a younger Cfm1b subzone characterized by *Archaediscus convexus* (Fig. 67), although these subzones have been never been used in later studies.

Assemblages composed of *Uralodiscus*/*Glomodiscus*/*Archaediscus* at *involutus* stage are predominant in this interval, which can be correlated to the unnamed zone recorded in England at the top of the Arundian.

The Cfm2 zone is currently characterized by *Uralodiscus* and *Conilidiscus* as markers (e.g., Berkhli *et al.* 2000), but also by *Endothyranopsis compressa* and *Forschia parvula* (Rauzer-Chernousova, 1948b) in older works (Vachard, 1988b). The zone was correlated with parts of the Cf5, MFZ12, Livian, Holkerian and upper part of the V2b (Izart *et al.* 2017). Its type locality is Tizi Ezzouit. In this case, the foraminiferal stratigraphic record in different sections is not as consistent as for the previous stratigraphic records. In the Mdakra Massif and El Hamman Ridge, *Conilidiscus* appears much earlier than *Endothyranopsis compressa* (Vachard & Fadli, 1991; Izart *et al.* 2001), whereas in Oulmès, *E. compressa* occurs much earlier (Vachard & Tahiri, 1991). In Agouraï, both taxa occur from the base of the succession, with *E. compressa* in the basal conglomeratic/sandy unit (Berkhli *et al.* 2000). In Skoura, only *Conilidiscus* occurs (Izart *et al.* 1989, as *Tubispirodiscus*). Therefore, the subdivision of the Cfm1b and Cfm2 does not seem useful, because the late occurrence of *Conilidiscus* compared to taxa such as *A. at concavus* stage and *E. compressa* is not clear enough, and the succession is in need of revision. The suite of foraminifers recorded in this interval might be also compared to those of the unnamed interval at the top of the Arundian.

The Cfm3 zone is characterized by *Koskinotextularia bradyi* (Möller, 1879) as guide. It is correlated with the upper part of the Cf5, Holkerian, Livian, MFZ12 and with the V3a. The second marker, *Pojarkovella nibelis*, is only known in one section, close to Tiflet town (Vieslet, 1983), whereas the taxon is mostly recorded in the upper Viséan limestones of Morocco (Vachard & Tahiri, 1991). The type locality of this zone is at Irhzer Aoujgal. Unquestionable middle Viséan markers are only recognized from this Cfm3 zone. The virtual lack of *Pojarkovella nibelis* is a handicap for comparison to Europe, because *Koskinotextularia* is comparatively a rare taxon, whereas *P. nibelis*

from its basal range is rather commonly recorded, and thus, more useful for the recognition of middle Viséan carbonates.

These chronozones are temporally slightly out of phase compared to European zones, and some of the European markers arrived later to the Meseta (Vachard & Tahiri, 1991). The occurrences of typical taxa of the Cfm1 and Cfm2 in sections assigned to the Cfm3 zone (e.g., Vieslet, 1983) complicate significantly the recognition of the early and middle Viséan in Morocco.

3. Lower-middle Viséan boundary interval in Eastern Palaeotethys

Unusual foraminiferal assemblages have been described from China, Iran and Turkey, whereas they are unknown from other countries in this region, such as Australia.

3.a. Lower-middle Viséan boundary interval in China

Devuyst *et al.* (2003) and Devuyst (2006) suggested the presence of an interval zone at the top of the Pengchong section (Tournaisian-Viséan boundary GSSP) unrecognized in Belgium. This interval zone was based on the presence of primitive archaedisks (*Uralodiscus*, *Glomodiscus* and *Conilidiscus*) after the first occurrence of *Pojarkovella nibelis*. This zone was named as zone G in Devuyst *et al.* (2004) following the zones defined previously in the section by Hance *et al.* (1997). However, the Pengchong section is characterized, overall, by poor archaedisks assemblages, attributed by the authors to a lack of deep-water foraminifers in turbidites, due to little down-slope mixing of the fauna (Devuyst *et al.* 2004). The occurrence of primitive assemblages of archaedisks at the base of inferred middle Viséan rocks is not sufficient to justify the occurrence of this new zone, because this fact is also recognized in Morocco, Moravia, Russia and Kazakhstan (e.g., Reitlinger *et al.* 1996; Kalvoda, 2002; Brenckle &

Milkina, 2003; Kulagina *et al.* 2003), and this can be only a matter of longer persistence of the taxa for regional ecological factors.

Hance *et al.* (2011) subdivided the MFZ11 – *Uralodiscus rotundus* Zone into a lower subzone (MFZ11A), containing mostly the classical markers defined in Poty *et al.* (2006), and an upper subzone (MFZ11B), characterized by the first occurrence of *Pojarkovella* (Fig. 67), with more primitive species than *P. nibelis*, a marker for the MFZ12 Zone. This MFZ11B subzone was only recognized in two sections, Mopanshan and Jiushi, but none of them contains the transition into the MFZ12, and thus, the transition into the mid Viséan cannot be studied in detail. Other sections in the region contain poorer assemblages in the upper part of the lower Viséan, and the MFZ11B subzone could not be distinguished, and contrary to the previously studied Pengchong and Yajiao sections by Devuyst *et al.* (2003, 2004–2006) and Devuyst (2006), they only recognized the MFZ11 and MFZ12 zones. It has to be highlighted that Hance *et al.* (2011) considered *Endothyranopsis ex gr. compressa* as typical of the early Viséan MFZ11 zone, but was only illustrated from the MFZ11B subzone. It must be also noted that the first occurrence of *Conilidiscus* is located by those authors in the MFZ11A subzone.

The unusual record of the primitive archaedisks in China represents a significant complication when trying to calibrate the first occurrences of other taxa, as well as establish a precise definition of the foraminiferal zones. But it has to be also added that the first occurrence of *Archaediscus* at *concavus* stage and the transitional forms to the *angulatus* stage are both recorded from the MFZ12 zone (e.g. Hance *et al.* 2011, pl. 51, fig. 14) and only *Pojarkovella* first occurs below this substage.

3.b. Lower-middle Viséan boundary interval in Turkey

Okuyucu *et al.* (2013) studied material assigned to the MFZ11B subzone in the Istanbul terrane. These authors considered characteristic of the MFZ11 zone: the first appearances of *Uralodiscus rotundus* (and other species of the genus), *Paraarchaediscus*, *Cribranopsis*, *Conilidiscus* and the disappearance of *Eoendothyranopsis*, *Eoparastaffella*, *Pseudolituotubella*, *Condrustella* and *Eotextularia*. They interpreted that *Paraarchaediscus* and *Conilidiscus* might be guides for the MFZ11B subzone. However, these taxa are recorded from near the base of the MFZ11 zone in Belgium (Poty *et al.* 2006), as well as from the MFZ11A subzone in China (Hance *et al.* 2011). Thus, they might be only used as regional markers, but have difficulty being used to characterize a global MFZ11B subzone.

Compared to the European zones, this modification into the MFZ11B should be correlated with the Cf4 γ - δ , and clearly, it cannot be compared to the MFZ11B in China (Fig. 76). There is no mention of other important taxa in Turkey, such as primitive *Pojarkovella*, the first *Endothyranopsis*, and thus, there is no evidence of any unusual foraminiferal assemblage below the typical middle Viséan.

3.c. Lower-middle Viséan boundary interval in Iran

Zandkarimi *et al.* (2016) identified the MFZ11B subzone on the basis of advanced *Glomodiscus* and *Archaediscus* in northwest Alborz. This definition is rather similar to that in Turkey (Fig. 76). The rest of the assemblage contains *Archaediscus/Paraarchaediscus* at *involutus* stage, *Ammarchaediscus*, *Planoarchaediscus*, *Eotextularia*, etc.; therefore, the assemblage should be also correlated to the Cf4 γ - δ subzones of Conil *et al.* (1980, 1991), and with a classical concept of the MFZ11 in Poty *et al.* (2006). The first occurrence of primitive *Pojarkovella* is at the same horizon as *P. nibelis*, and no difference exists.

Zandkarimi et al (2017, 2018) only recognized the MFZ11 and MFZ12 zones in northern Alborz, and they did not subdivide the former zone. There, in the main stratigraphic sections at Naserabad and Dozdehban, the occurrence of *Pojarkovella* spp. is synchronous, and also coincident with the first appearance of *Koskinotextularia*. Zandkarimi *et al.* (2018) described the occurrence of *Endothyranopsis compressa* from the MFZ11 zone, although this species (in general, very rare in the region) was used for the recognition of the base of the middle Viséan at the Naserabad section (at sample Ns102), whereas *P. nibelis* occurs 1 m above (at Ns103). Other specimens recorded in older rocks are identified with a question mark, and thus, its presence in the early Viséan of Iran is questioned.

However, although not acknowledged by the authors, *Archaediscus at concavus* stage are recorded from the early Viséan (Zandkarimi *et al.* 2016, figs. 7.35, 7.38; Zandkarimi *et al.* 2017, figs. 7.29-7.30). Furthermore, although Zandkarimi *et al.* (2017) recognized the occurrence of *Archaediscus at concavus* transitional to the *angulatus* stage from the middle part of the mid Viséan, specimens are recorded from closer positions to the base of the mid Viséan (Zandkarimi *et al.* 2016, fig. 9.12; Zandkarimi *et al.* 2017, figs. 7.37, 7.38, 7.40).

Fassihi *et al.* (2018) subdivided the succession at the Sanandaj-Sirjan region in Central Iran into two local zones. The older zone was correlated with the MFZ11B subzone due to the occurrence of *Glomodiscus*, *Uralodiscus* and *Paraarchaediscus* and assigned to the latest early Viséan (Fig. 76). The youngest local zone was characterized by the appearance of *Lapparentidiscus bokanensis* Vachard, 1980 and the disappearance of dainellids. These authors correlated this zone with the earliest “late” Viséan or MFZ12 of Belgium [It must be noted that in the Russian scale, the Viséan is only divided into lower and upper, and the Tulian substage, more or less equivalent to the

mid Viséan in Western Europe is the lower part of the upper Viséan]. However, there is no any foraminifer which suggests a mid Viséan age within this assemblage, and the entire succession should be assigned to the Cf4 γ - δ subzones in the early Viséan.

4. Proposal of the biozone and correlation

The biostratigraphic records of the analyzed basins/sections confirm the existence of an intermediate interval (biozone), between the classical well-known chronozones (V2a and V2b) defined in Western Europe (Fig. 78). Some authors interpreted it as an interval zone (Devuyst *et al.* 2003) and that it should be characterized by the coexistence of typical early and mid Viséan fauna. However, this suggestion is rather problematical, because it is difficult to establish precisely the last occurrence (disappearance) of the key taxa, as well as ecological factors which allowed the longer survival of fauna which is not acknowledged. These problems can be exemplified with the succession in the Western Meseta of Morocco, where some taxa arrived later to the region, and others survived longer (i.e. had extended stratigraphic ranges) than in the neighbouring European basins (Vieslet, 1983; Vachard & Tahiri, 1991).

Herein, it is considered more appropriate to establish precisely the first occurrences of taxa to characterize this biozone rather than the last occurrences. The main guides for the zone are considered to be the first occurrence of *Archaediscus* at *concavus* stage and primitive *Pojarkovella* (Fig. 3a-3b, 3h-3j). Furthermore, *Endothyranopsis compressa* first occurs slightly higher in the zone (Fig. 3q), whereas the first *Endothyranopsis* s.s. (named in the literature as *E. ex gr. compressa* or aff. *compressa* or cf. *compressa*) might first occur from the base of the zone (Fig. 3l). Indirectly, this zone usually contains a mixture of preserved early Viséan genera (*Uralodiscus*, *Glomodiscus*, *Conilidiscus*), although this fact cannot be considered as a definitive feature.

It must be highlighted that in the younger zone (Cf5, MFZ12, V2b), with the same main guides as classically known, *Pojarkovella nibelis* and *Koskinotextularia*, the *Archaediscus at concavus* transitional forms to the *angulatus* stage are recorded (Figs. 3c, 3g, 3k, 3t) nearly from the base (Fig. 78).

In terms of nomenclature, this new zone is a problem. It corresponds to the MFZ11B subzone defined in China by Hance *et al.* (2011), as well as the MFZ11B subzone in Iran (*sensu* Zandkarimi *et al.* 2016), but differs from the MFZ11B subzone in Turkey (*sensu* Okuyucu *et al.* 2013). Furthermore, this notation, MFZ11B, suggests intuitively that it is part of the early Viséan, whereas compared with the stratotype of the Livian in Belgium, considered as the base of the mid Viséan and where the MFZ zones were defined, the zone is herein considered as part of the mid Viséan. Therefore, a subdivision into a MFZ12A α (with the newly proposed guides) and a MFZ12B β (with the classical taxa described by Poty *et al.* 2006) would be more appropriate (Figs. 78-9). Compared to the classical chronozones, the Cf5 zone was defined on the basis of *Koskinotextularia*, *Pojarkovella nibelis* and *Archaediscus at concavus* stage (Conil *et al.* 1980, 1991), and thus, a subdivision into a Cf5 α (this new one) and Cf5 β (typical Cf5) should be the most logical subdivision, because it is correlated to the non-sequence interval in the Lives section of Belgium, and considered as mid Viséan (Fig. 78).

5. Discussion

The occurrence of this MFZ12A α or Cf5 α subzone from the western extreme of the Palaeotethys across to the eastern basins of this ocean confirms the validity of this subzone, and that it should be considered as a potential global event, and certainly useful for foraminiferal correlations throughout Palaeotethys. However, its occurrence has not been demonstrated in geographically intermediate positions regions of the

Palaeotethys, such as Russia. It is difficult to validate the stratigraphic record of the involved species in this region because the Tulian substage or its lateral equivalents are commonly of little thickness. Usually, biozones described there, list numerous foraminiferal guides to characterize this substage. However, they do not record the first occurrence of individual taxa, nor the presence of any type of successive steps in assemblages. Within this list of markers, can be mentioned *Endothyranopsis* s.s., *Globoendothyra* s.s., *Lituotubella*, *Mstinia* (as *Haplophragmella*), *Urbanella miranda* (Rauzer-Chernousova, 1948a), *Eostaffella*, *Pseudoendothyra* (as *Parastaffella*), *Vissariotaxis exilis* (Vissarionova, 1948), *Criboospira*, *Omphalotis omphalota* (Rauzer-Chernousova & Reitlinger in Rauzer-Chernousova *et al.* 1936), *O. minima*, *Archaediscus krestovnikovi* (Rauzer-Chernousova, 1948d), *A. moelleri* (Rauzer-Chernousova, 1948a) (Lipina & Reitlinger, 1970), and also *Koskinotextularia* (Rauzer-Chernousova, 1948), *Pojarkovella nibelis* (Gibshman, 1997), *Consobrinella oposis*, *Cribrostomum*, *Palaeotextularia* (e.g., Rauzer-Chernousova, 1948c; Lipina & Reitlinger 1970; Gibshman, 1997; Kulagina *et al.* 2003). In most zonal schemes, the main guides of the Tulian are restricted to *Endothyranopsis compressa* and *Archaediscus krestovnikovi*.

This foraminiferal list suggests that the Tulian (and equivalents) contains amalgamated foraminiferal markers for the middle Viséan and lower part of the upper Viséan in Western Europe (surely induced by the poor carbonate precipitation in this Russian stage), from the Cf5 to the Cf6 β zones and subzones of Conil *et al.* (1991). However, in general, the main guides are similar to those of the Cf5 α and MFZ12A α , and that they first occur together at the base of this substage in some published sections (Rauzer-Chernousova, 1948c; Postoyalko, 1975; Kulagina *et al.* 2003; Kulagina, 2011), whereas *Pojarkovella nibelis* first appears in younger beds, as well as some of the

above-listed Tulian markers (Kulagina & Klimenko, 2014; Klimenko *et al.* 2018). It must be noted that under the name of *Archaediscus krestovnikovi*, both *concavus* and *angulatus* stages are indistinctly identified, but those specimens illustrated from the base of the substage seem to correspond to the *concavus* stage. Additionally, the co-occurrence of the primitive archaediscids at the base of the Tulian is a common feature (Reitlinger *et al.* 1996; Bensch *et al.* 1996; Brenckle & Milkina, 2003; Kulagina *et al.* 2003).

Thus, it can be interpreted that this Cf5 α or MFZ12A α subzone also occurs in these intermediate (central) positions of the Palaeotethys, but that more detailed biostratigraphic ranges of the foraminifers during the Tulian (Fig. 7) are necessary to clarify if there, the markers are exactly the same, or if they present some particularities.

On the other hand, the validity of the MFZ11B subzone cannot be retained as because although it marks the first occurrence of the *Archaediscus/Paraarchaediscus* at *involutus* stage as well as *Conilidiscus*, although removing from previous but original definitions in China also includes the first occurrence of the primitive *Pojarkovella*, which is situated during the middle Viséan (Fig. 8). However, the occurrence of *Archaediscus* and *Conilidiscus* This MFZ11B subzone would correspond to the Cf4 γ - δ subzones of Conil *et al.* (1991), although certainly, due to the poverty in archaediscids in China (Devuyst *et al.* 2003; Hance *et al.* 2011) it is not always possible to be recognized in some sections. The guides for the recognition of the Cf4 δ subzone of Conil *et al.* (1980), were relatively limited, which makes its recognition in other basins more difficult (as early criticized by Poty *et al.* 2006). However, in this interval is recognized the first occurrence of *Latiendothyranopsis menneri solida* (Fig. 3m) and *Cribranopsis*, but also, the first *Nodosarchaediscus* (Figs. 3d-3f), *Consobrinellopsis*, *Lituotubella*, *Plectogyranopsis settlensis* (Fig. 3o), *Plectogyranopsis moraviae* (Fig. 3n),

some of them, of a wider or even worldwide distribution, and thus, more useful taxa than the original guides. This suite of foraminifers would allow the subdivision of the MFZ11 into three subzones; MFZ11 α , MFZ11 β and MFZ11 γ (Fig. 89):

- The MFZ11 α subzone is characterized by the first occurrence of *Uralodiscus rotundus*, as well as common species of the *Glomodiscus* (e.g., *G. miloni*) and *Uralodiscus* (*U. elongatus*).

- The MFZ11 β subzone is characterized by the first occurrence of primitive *Archaeodiscus* at *involutus* stage with well-developed microgranular layer (*Paraarchaeodiscus* autc.; *Propermodiscus* autc.), and *Conilidiscus*.

- The MFZ11 γ is characterized by the first occurrence of *Latiendothyranopsis menneri solida*, *Cribranopsis*, *Nodosarchaeodiscus*, *Consobrinellopsis*, *Lituotubella*, the first *Endothyranopsis* s.s. and large species of *Plectogyranopsis* (*Plectogyranopsis settlensis* and *P. moraviae*). The first occurrences of these species seems to have small differences in Belgium and northern France (e.g., Conil *et al.* 1980, 1991; Poty *et al.* 2006), although the species described have a limited geographic dispersion, whereas in other close regions (southern northern France and England), they seem to occur more or less synchronously. Nevertheless, the establishment of precise first occurrence of each individual taxon needs further investigation.

6. Conclusions

Revision of selected sections spanning the lower-middle Viséan boundary interval in the Western and Eastern Palaeotethys basins, including also the stratotypes of the Livian in Belgium and Holkerian in England suggests the occurrence of a new foraminiferal zone in between the classical chronozones defined in those countries. This new zone (Cf5 α or MFZ12 α) is characterized by the first occurrences of *Archaeodiscus* at *concavus* stage,

primitive species of *Pojarkovella* and the first representatives of the genus *Endothyranopsis*, including the first occurrence of *Endothyranopsis compressa*, at least from the middle part of this zone. The zone is intercalated within the classical V2a and V2b, Cf4δ and Cf5 and the MFZ11 and MFZ12 zones. In part, it is similar to the MFZ11B zone proposed in China by previous authors, although, due to its position compared to the stratotype section for the early-mid Viséan boundary interval in Belgium, the zone is assigned to the mid Viséan, and a new nomenclature is proposed to avoid the ambiguity of using the existing MFZ11B zone, that was originally assigned to the early Viséan.

The zone allows a precise correlation between the middle Viséan rocks or regional stages between the base of the Livian in Belgium with the upper part of the Arundian in England, as well as to define clearly which limestones from the Western Meseta of Morocco should be considered as early or mid Viséan (a matter of discussion for a long time), as well as those equivalents in the Eastern Palaeotethys (China and Iran). The succession in more central positions of the Palaeotethys (such as Russia) seems to have this biozone present, although further analyses are necessary, there, to subdivide with precision the Tullan substage.

It is proposed to subdivide the classical Cf5 zone in a lower Cf5α subzone (for this new zone) and an upper Cf5β subzone, characterized by the classical guides *Pojarkovella nibelis* and *Koskinotextularia*, or, in the zonal scheme of Poty *et al.* (2006), to a MFZ12Aα and MFZ12Bβ subzones respectively. Revision of the markers for the “MFZ11” also suggest that the MFZ11 zone, as defined by Poty *et al.* (2006), can be subdivided in most basins into 3 subzones; a lower MFZ11Aα subzone (characterized by the first occurrence of *Uralodiscus rotundus*, as well as most species of *Glomodiscus*), a middle MFZ11Bβ subzone (characterized by the first occurrence of

Archaediscus at *involutus* stage and *Conilidiscus*), and an upper MFZ11 *Cy* subzone (characterized by the first occurrence of *Nodosarchaediscus*, *Consobrinellopsis*, and *Lituotubella* and some species of *Latiendothyranopsis*, *Endothyranopsis* and *Plectogyranopsis*).

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Figure captions

Figure 1. Biostratigraphic sketch of the Moliniacian-Livian boundary interval stratotype at Lives section in Belgium. Source of the data in the text. Diagonal striped lines have no foraminifer record because of unfavourable facies or a gap.

Figure 2. Biostratigraphical sketch of the Arundian-Holkerian boundary interval stratotype at Barker Scar (Cumbria) and lower part of the Silverdale Borehole (Askrigg). Bed thickness of the Barker Scar according to Rose & Dunham (1977) and Silverdale Borehole sensu Murray (1983) Waters *et al.* (2017). Base of the Park Formation according to Johnson *et al.* (2001). Diagonal striped lines have no foraminifers because of gaps.

Figure 3. Selected foraminiferal key species from the Askrig Block in northern England and in Montagne Noire in southern France. Scale bar is 200 microns for a to g, and 400 microns for h to t. (a) *Archaediscus at concavus* stage, level Pc5339, Valuzière section. (b) *Archaediscus at concavus* stage, level EWJ1565, Silverdale Borehole. (c) *Archaediscus at concavus* stage transitional to the *angulatus* stage, level EWJ1565, Silverdale Borehole. (d) *Nodosarchaediscus cornua* (Conil & Lys, 1964), level Pc5339, Valuzière section. (e) *Nodosarchaediscus cf. saleei* (Conil & Lys, 1964), level Pc4660, Puech de la Suque section. (f) *Nodosarchaediscus* sp., level Pc5148, Puech de la Suque Hill 248 section. (g) *Archaediscus at concavus* stage transitional to the *angulatus* stage, level Pc5337, Valuzière section. (h) *Pojarkovella* sp., level EWJ1563, Silverdale Borehole. (i) *Pojarkovella* sp., level EWJ1566, Silverdale Borehole. (j) *Pojarkovella*

sp., level EWJ1562, Silverdale Borehole. (k) *Pojarkovella nibelis*, level EWJ1561, Silverdale Borehole. (l) *Endothyranopsis* aff. *compressa*, level EWJ1573, Silverdale Borehole. (m) *Latiendothyranopsis menneri solida*, level EWJ1573, Silverdale Borehole. (n) *Plectogyranopsis moraviae*, level EWJ1573, Silverdale Borehole. (o) *Plectogyranopsis settlensis*, level Pc4900, Pic de Vissou section. (p) *Ugurus intermedius* Vachard *et al.* 2018, level Pc5537, Valuzière section. (q) *Endothyranopsis compressa*, level EWJ1562, Silverdale Borehole. (r) *Omphalotis minima*, level Pc4983, Puech de la Suque section. (s) “*Millerella*” aff. *infulaeformis* Ganelina, 1951, level Pc4896, Pic de Vissou section. (t) *Koskinotextularia* sp., level Pc4660, Puech de la Suque section.

Figure 43. (colour online) Biostratigraphic sketch of the Valuzières and Tourière sections. Abbreviations: CB, Combe Rolland Formation; Tou, Tourière Formation.

Figure 54. (colour online) Biostratigraphic sketch of the Puech de la Suque-Hill 248 and Pic de Vissou sections.

Figure 65. (colour online) Biostratigraphic sketch of the Sidi Sebaa section. Bed thickness based on D. Fadli, unpub. Ph. D., Univ. Rabat, 1990.

Figure 76. Correlation of the different proposals for the MFZ11B subzone in Eastern Palaeotethys basins and the Cfm1b subzone from Morocco according to their authors.

Figure 87. Stratigraphic range of the main foraminiferal markers.

Figure 98. Proposal of this study of the new biostratigraphic zone and correlation of previous biozones. Boxes with diagonal lines mean hiatus or absence of recognized faunas.

lower Viséan	middle Viséan
Moliniacian (p.p.)	Livian (p.p.)
Neffe Formation	<div> <div> <div>30 m</div> <div>20 m</div> <div>10 m</div> </div> <div> <div> <div>Haut-Le-Wastia Member</div> <div>(Lives Formation)</div> </div> <div> <div> <div>RC5γ</div> <div> <i>Clisophyllum garwoodi</i> <i>Caninophyllum archiaci</i> <i>Siphonodendron irregulare</i> <i>Axophyllum vaughani</i> </div> <div> <div>Pojarkovella nibelis</div> <div> </div> </div> </div> <div> <div>Banc d'Or de Bachant</div> </div> </div> </div></div>
	Sequence 7
	V2b (=Cf5) MFZ12
Sequence 6	<div> <div>RC5β</div> <div><i>Corphalia mosae</i></div> </div>
	V2a (Cf4 γ -Cf4 δ) MFZ11

Valuzières Section

Tourière Section

Puech de la Suque-Hill 248 Section

Pic de Vissou Section

Morocco				Turkey	Iran	China
middle Viséan	Cf5	V3a	Cfm3 <i>Koskinotextularia</i>	MFZ12 <i>Pojarkovella nibelis</i> - <i>Koskinotextularia</i>		
		V2b	Cfm2 <i>Conilidiscus</i> <i>Endothyranopsis compressa</i>			
lower Viséan	Cf4 δ	V2a	Cfm1b <i>Archaediscus convexus</i>	MFZ11B <i>Conilidiscus</i> <i>Paraarchaediscus</i>	MFZ11B <i>Glomodiscus</i> <i>Archaediscus</i> <i>Paraarchaediscus</i>	MFZ11B <i>Pojarkovella</i>
	Cf4 γ		Cfm1a	MFZ11A		MFZ11A
	Cf4 β	V1b	<i>Uralodiscus rotundus</i>	<i>Uralodiscus rotundus</i>	<i>Uralodiscus rotundus</i>	<i>Uralodiscus rotundus</i>
	Cf4 α 2	V1a p.p.	not defined	MFZ10 <i>Planoarchaediscus</i> - <i>Ammarchaediscus</i>		
				MFZ9 <i>Eoparastaffella simplex</i>		

	lower Viséan	middle Viséan	
Moliniacian			Livian
	Arundnian		Holkerian
	Bobrikian	Tulan	
Cf4δ	Cf5α	Cf5β	
MFZ11	MFZ12 _α	MFZ12 _β	
V2a		V2b	
Belgium	<i>Poarkovella nibelis</i>		
	<i>Koskinotextularia</i>		
	<i>Archaeidiscus at concavus st.</i>		
	<i>Endothyranopsis compressa</i>		
	<i>"Millerella"</i>		
	<i>Archaeidiscus at concavus st.</i>		
	<i>Poarkovella sp.</i>		
England	<i>Endothyranopsis compressa</i>		
	<i>Poarkovella nibelis</i>		
	<i>Koskinotextularia</i>		
	<i>Archaeidiscus trans. angulatus st.</i>		
	<i>Archaeidiscus at concavus st.</i>		
	<i>Poarkovella sp.</i>		
S France	<i>Endothyranopsis compressa</i>		
	<i>Poarkovella nibelis</i>		
	<i>Koskinotextularia</i>		
	<i>Archaeidiscus trans. angulatus st.</i>		
	<i>"Millerella"</i>		
	<i>Archaeidiscus at concavus st.</i>		
Morocco	<i>Endothyranopsis compressa</i>		
	<i>Koskinotextularia</i>		
	<i>Poarkovella sp.</i>		
	<i>Endothyranopsis compressa</i>		
S China	<i>Archaeidiscus at concavus st.</i>		
	<i>Koskinotextularia</i>		
	<i>Poarkovella nibelis</i>		
	<i>Archaeidiscus trans. angulatus st.</i>		
	<i>Archaeidiscus at concavus st.</i>		
	<i>Endothyranopsis compressa</i>		
Iran	<i>Poarkovella nibelis</i>		
	<i>Poarkovella sp.</i>		
	<i>Archaeidiscus trans. angulatus st.</i>		

			Morocco	Turkey	Iran	China	this study
middle Viséan	Cf5 β	V3a	Cfm3 <i>Koskinotextularia</i>	MFZ12 β <i>Pojarkovella nibelis</i> - <i>Koskinotextularia</i>			MFZ12 β <i>Pojarkovella nibelis</i> <i>Koskinotextularia</i>
		V2b	Cfm2 <i>Conilidiscus</i> <i>Endothyranopsis compressa</i>				
	Cf5 α	///	Cfm1b <i>Archaediscus convexus</i>	///	MFZ12 α <i>Archaediscus at concavus</i> st.	MFZ12 α <i>Pojarkovella</i>	MFZ12 α <i>Pojarkovella</i> <i>Archaediscus at concavus</i> st.
lower Viséan	Cf4 δ	V2a	Cfm1a	MFZ11B <i>Conilidiscus</i> <i>Paraarchaediscus</i>	MFZ11B <i>Glomodiscus</i> <i>Archaediscus</i> <i>Paraarchaediscus</i>	MFZ11	MFZ11 γ <i>Nodosarchaediscus</i> <i>Consobrinellopsis</i>
	Cf4 γ						MFZ11 β <i>Conilidiscus</i> <i>Archaediscus at involutus</i> st.
	Cf4 β	V1b	<i>Uralodiscus rotundus</i>	MFZ11A <i>Uralodiscus rotundus</i>	MFZ11A <i>Uralodiscus rotundus</i>		MFZ11 α <i>Uralodiscus rotundus</i>
	///		MFZ10 <i>Planoarchaediscus</i> - <i>Ammarchaediscus</i>				
	Cf4 α 2	V1a p.p.	///	MFZ9 <i>Eoparastaffella simplex</i>			