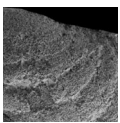


Ostracods and rock facies across the Givetian/Frasnian boundary interval in the Sourd d'Ave section at Ave-et-Auffe (Dinant Synclinorium, Ardenne, Belgium)

JEAN-GEORGES CASIER, XAVIER DEVLEESCHOUWER, SÉBASTIEN MAILLET, ESTELLE PETITCLERC & ALAIN PRÉAT



Ostracods from the Sourd d'Ave section have been collected in the Moulin Boreux and Fort Hulobiet Members (Fromelennes Fm., Givet Group) and in the Pont d'Avignon Member (Nismes Fm., Frasnian Group). Ostracods collected in the Fromelennes Fm. by Milhau (1983a) and in the Nismes Fm. by Casier (1987a) have been also reviewed. Forty-four ostracod species are identified in the Fromelennes Fm. and 25 in the Nismes Fm. They belong exclusively to the Eifelian Mega-Assemblage, and several assemblages indicative of restricted and shallow marine, sometimes agitated, environments are recognized in the Fromelennes Fm. The great rarity of ostracods in the upper part of this formation provides evidence for less favourable lagoonal conditions probably related to increasing aridity at the end of the Givetian. In the Frasnian Group, assemblages are exclusively open marine and indicative of increasing water depth. The majority of ostracod species recognized in the Givet Group are missing in the base of the Frasnian Group as a consequence of the Frasnian Event. A systematic list of ostracods identified in the Fromelennes Fm. at Sourd d'Ave is published as an annex. Systematic sampling has been carried out in order to establish the sedimentological evolution of the environments and to detail the Givetian-Frasnian (G/F) transition. This allowed recognition of 13 microfacies types that replicate the standard sequence of Pr at & Mamet (1989) from open marine shallow subtidal to restricted supratidal near emersion. The Boreux Member and the Fort Hulobiet Member display restricted facies (*Amphipora*, spongiostromid and algal bafflestones and bindstones, loferites with desiccation lumps) with poorly fossiliferous beds interbedded with higher energy peloidal and sometimes oolitic grainstone facies. Laminite horizons, sometimes with small-sized lateral linked hemispheroid stromatolites are uncommon, and are associated with dolomicrites showing pseudomorphs of evaporite minerals. These evaporitic facies become common in the upper part of the Fort Hulobiet Member suggesting the palaeoclimate became more arid at the G/F transition. Metre-scale cyclicality is pervasive throughout the Givetian part of the section. The boundary between the Givet Group and the Frasnian Group is very distinctive in the field, and is characterized by a transition from restricted evaporative lagoonal facies to open marine interbedded marly shales and nodular limestones. The upper part of the Fort Hulobiet Member consists of interbedded biostromes (semi-restricted stromatoporoid boundstones) followed by *Amphipora* floatstones, then fossil-poor units and restricted supratidal laminites with well-developed fenestral fabrics. The Frasnian Pont d'Avignon Member contains a rich faunal assemblage (bryozoans brachiopods, molluscs, nautiloids, tentaculitids) suggesting an abrupt drowning from the marginal Givetian carbonate platform into a Frasnian distal ramp or deep basinal environment below or near storm wave base.

• Key words: ostracods, palaeoecology, sedimentology, Givetian/Frasnian boundary, Fromelennes Formation, Nismes Formation, Dinant Synclinorium, Ardenne, Belgium.

CASIER, J.-G., DEVLEESCHOUWER, X., MAILLET, S., PETITCLERC, E. & PR AT, A. 2013. Ostracods and rock facies across the Givetian/Frasnian boundary interval in the Sourd d'Ave section at Ave-et-Auffe (Dinant Synclinorium, Belgium). *Bulletin of Geosciences* 88(2), 241–264 (10 figures, 2 tables, 1 annex). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received February 3, 2012; accepted in revised form October 18, 2012; published online February 11, 2013; issued June 7, 2013.

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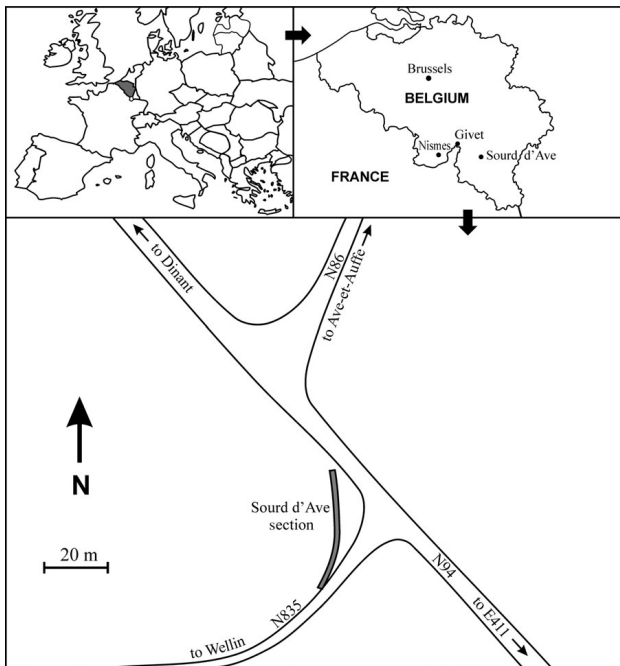


Figure 1. Locality map of the Sourd d'Ave section.

This paper forms part of a series on Devonian ostracods and their lithological context in the type region for the definition of the Givetian and Frasnian Stages (southern part of the Dinant Synclinorium). This new paper concerns the Givet Group/Frasnes Group transition exposed in the Sourd d'Ave section at Ave-et-Auffe (Dinant Synclinorium, Belgium). The transition is particularly well exposed in this classical reference section, and access is very easy.

The Sourd d'Ave section (from 50°05.997' N; 05°07.873' E to 50°06.028' N; 05°07.834' E) is located at the intersection of the Dinant-Neufchâteau road (N48) and Han-sur-Lesse-Wellin road (N35) (Figs 1–3). The Givet Group is represented by the upper part of the Moulin Boreux Member (= Mbr) and the Fort Hulobiet Mbr, both belonging to the Fromelennes Formation (= Fm.). The Frasnian Group is represented by the Pont d'Avignon Mbr, by the Sourd d'Ave Mbr and by the base of the La Prée Mbr, all belonging to the Nimes Fm. (Fig. 4).

In the Sourd d'Ave section, the upper part of the Moulin Boreux Mbr is composed of 8 m of limestones comprising massive and branched stromatoporoids. The Fort Hulobiet Mbr is composed of 28 m of calcareous shales and argillaceous limestones. The Pont d'Avignon Mbr is represented by a 45 cm-thick nodular argillaceous limestone. The Sourd d'Ave Mbr is 9.3 m-thick and made up of calcareo-argillaceous nodular shales with rare small argillaceous limestone beds. Finally the base of the La Prée Mbr consists of shales with rare calcareo-argillaceous nodules (Bultynck 1974, Casier 1987a, Bultynck *et al.* 1991, Boulvain *et al.* 1999).

The level of the Givetian/Frasnian boundary in the Dinant Synclinorium is still in debate. The ostracod study and the sedimentological analysis of the GSSP located at Puech de la Suque (Montagne Noire, France), where the boundary corresponds to the entry of an “early morph” of *Ancyrodella rotundiloba* (Klapper *et al.* 1987), suggests that the G/F transition corresponds to the initiation of a sea-level rise (Casier & Prétat 2007). In fact, the Givetian/Frasnian boundary should be close to the Givet Group/Frasnes Group boundary in the Dinant Synclinorium, and certainly below the boundary designated in 1986 by the Subcommittee on Devonian Stratigraphy, in the auxiliary stratotype at Nimes (Casier & Prétat 2009, 2010). That boundary is based on a “late morph” of *Ancyrodella rotundiloba*. In our paper, the Givetian/Frasnian boundary coincides arbitrarily with the Givet Group/Frasnes Group boundary at the base of the bed where the first *Ancyrodella* have been recorded by Bultynck (1974), after a 15 m-thick episode without any conodonts.

Conodonts from the Sourd d'Ave section have been studied by Bultynck (1974, 1982) and by Narkiewicz & Bultynck (2010). Several ostracod species occurring in the Fromelennes Fm. and Nimes Fm. exposed at Sourd d'Ave have been reported by Casier (1977, 1987a) and Milhau (1983a).

Rock and facies analysis (A. Prétat)

Systematic sampling has been carried out in order to establish the evolution of palaeoenvironments and to detail the Givetian/Frasnian transition. This led to the fabrication of 260 thin sections (*in* Prétat 1984) which allowed recognition of most of the 13 microfacies types that replicate the standard sequence of Prétat & Mamet (1989) from open marine shallow subtidal to restricted supratidal near emersion.

Microfacies description

Open marine near or within the storm wave base

Microfacies type 1 (or MF1). – Definition: shaly, micaceous silty microbioclastic, slightly to heavily burrowed mudstones-wackestones with thin levels of bioclastic wackestones-packstones. Bioclasts (a few hundreds microns in the packstone levels) consist mainly of echinoderms, brachiopods (some with spines), ostracods, molluscs, rare bryozoans, nautiloids and tentaculitids (Fig. 5A–E). Microbioclasts (20–50 µm) are not easily recognizable and very often undeterminable. The matrix is often microsparitized with development of very fine



Figure 2. The Sourd d'Ave section.

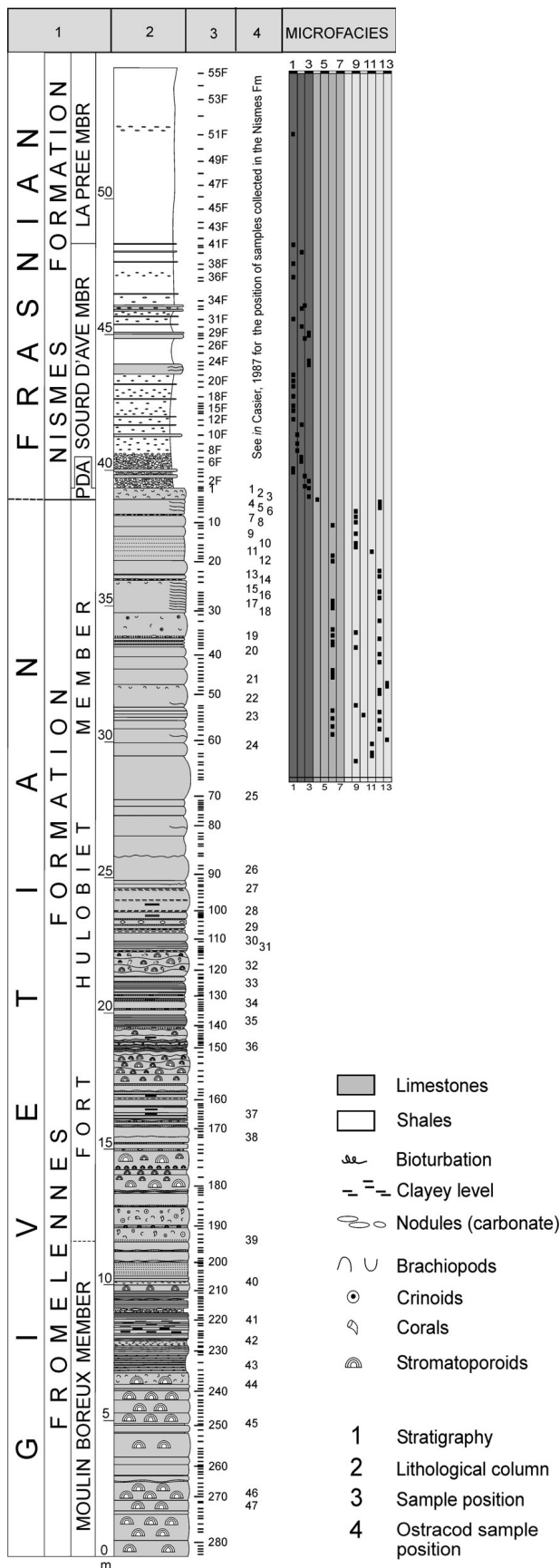


Figure 3. Detail of the Givet Group/Frasnes Group boundary in the Sourd d'Ave section.

grained (5–10 μm , Fig. 5A) or coarse (30–50 μm , Fig. 5C), sometimes “acicular” calcitic microspar (Fig. 5C). The coarsest microspar is associated with the most clay-rich matrix. The matrix is relatively homogeneous in the less microspartitized facies and contains fine-grained pyrite coating molluscs (Fig. 5A), abundant pyritospheres of the same type as those described in Casier *et al.* (2004) and fine-grained fragments of organic matter (around 50–100 μm). Burrowing might be intensive and displaced microbioclasts (Fig. 5B). Silty material consists of subrounded quartz and is not abundant (1 to 5%, Fig. 5D). Pressure solution processes are well expressed in the clayey facies and concentrated pyrite (Fig. 5E).

Microfacies type 2 (or MF2). – Definition: clayey, micaceous and silty burrowed microbioclastic wackestones with thin (up to 5 mm-thick) laminar wackestones-packstones containing unmicritized bioclasts (echinoderms, brachiopods – some with spines-, molluscs, ostracods, rare trilobites and bryozoans, Fig. 5F–H). Microbioclasts are of the same type as in the previous facies and not abundant. Millimetric bioturbation features, sometimes with well-defined burrows, are well developed and can obliterate the primary laminations. Organisms are sorted by clast type, echinoderms are partly pyritized and brachiopods perforated with infillings of a silty muddy matrix. Very fine-grained silty material (5–10 μm), consisting of subrounded quartz is slightly more abundant (1 up to 10%) than previously, on the contrary micas are less abundant. The matrix is microspartitized as in the microfacies 1. It is also dolomitized in the pressure solution seams with development of a fine-grained (10–50 μm) pyritized idiotopic dolomite. Pyrite and pyritospheres (Fig. 5G) are present as in microfacies 1.

Microfacies type 3 (or MF3). – Definition: laminar bioclastic wackestones and packstones. The latter contains exceptionally large subrounded microbreccias (up to 1.5 cm) of previous MF1 or MF2 mudstones and wackestones. The



bioclasts of MF3 are more diverse and coarser (from 1 mm to 1 cm, Fig. 6A, B) than in the previous facies. Bryozoans (fenestellids) are particularly well represented and sea urchin spines are regularly observed. The silty and clayey fraction is still present but more commonly absent. The bioclasts are unmicritized or slightly micritized and display high angle oblique stratifications or form elongate lenses. Bioturbation is still present and may destroy the laminations. The matrix is often recrystallized in a heterogeneous fine- to coarse-grained calcitic microspar. The echinoderm fragments can be very abundant and form medium-grained grainstones or encrinities up to 5 mm thick. They are associated with laminar fine- to medium-grained iron oolitic packstones (Fig. 6C, D).

Open marine, peri-reefal environments near or within the fair-weather wave base

Microfacies types 4 and 5 are not observed in the section.

Microfacies type 6 (or MF6). – Definition: stromatoporoid-coral floatstones (Fig. 6F, H). The matrix is a bioclastic wackestone with crinoids, sea urchin spines (Fig. 6H) molluscs, brachiopods, ostracods (Fig. 6F), algae (mainly issinellids) and rare calcispheres. Stromatoporoids are mainly bulbous (dm-sized), sometimes laminar and encrusted by cyanobacteria (*Bevocastria*). This microfacies is often very easy to distinguish in the field, due to its rich faunal assemblage forming several metre-thick biostromes. Reciprocal encrustments between stromatoporoids and corals (mainly Tabulata, *Thamnopora* and *Alveolites*) are common. MF6 displays a variety of textures from floatstones through framestones, the former being the most common. The bioclasts can be aligned and parallel to each other delineating thin packstone levels. Disphyllids (*Rugosa*) are abundant towards the top of the section.

Microfacies type 7 (or MF7) – Definition: burrowed peloidal packstones and oolitic grainstones with erosive discontinuities. The facies is slightly dolomitized. Peloids are subrounded and well-sorted (50–200 µm), a few lumps and small-sized bioclasts are associated. This microfacies is not well represented in the section.

Restricted environments with salinity fluctuations

Microfacies type 8 (or MF8). – Definition: gastropod and *Amphipora* packstone with various micritized bioclasts.

Figure 4. Sourd d'Ave section: lithological column, position of samples for the sedimentological analysis and for the ostracod study, microfacies (Lithologic survey: X. Devleeschouwer & E. Petitclerc).

The matrix is rich in various lumps and displays the appearance of a microbreccia. As for the previous microfacies, this microfacies is rare in the section.

Microfacies type 9 (or MF9). – Definition: burrowed peloidal algal (*Issinella*, *Kamaena*, *Proninella* and ?*Labyrinthoonus* – Mamet & Pr  at 1987, Pr  at & Mamet 1989) cyanobacterial (*Bevocastria*) wackestones with calcispheres, ostracods, *Amphipora*, pelecypods, gastropods, *Bisphaera* (*Incertae sedis*), a few umbellids, and sponge spicules (Fig. 7A). *Amphipora* may be so abundant that they form floatstones and bafflestones as the cyanobacteria forming bindstones. The *Amphipora* branches are well preserved and are often aligned parallel to bedding. The *Amphipora* and gastropods are often encrusted by *Bevocastria* leading to the formation of millimetric oncoids. Irregular lumps are associated with the *Bevocastria* encrustments. A fenestral fabric is present but not well represented and consists of irregular, vertical and sometimes laminoid fenestrae (Tebutt *et al.* 1965). Irregular fenestrae can be confused with various cavities resulting from the partial or complete dissolution of *Amphipora*. The facies is generally dominated by a few groups of these organisms and the matrix ranges from a mudstone to a wackestone. In this case the organisms are not diverse but they are abundant or very abundant. The facies is therefore characterized by impoverished or restricted microfaunas and microfloras. The matrix is a medium to dark grey colour micrite locally heavily bioturbated. It is sometimes argillaceous.

Microfacies type 10 (or MF10). – Definition: spongiostromid packstones and bindstones with abundant irregular peloids and lumps (Fig. 7B). A laminoid fenestral fabric is observed. Serpulids are regularly observed and can be very abundant.

Microfacies type 11 (or MF11). – Definition: loferite and peloidal stromatolitic bindstones with proto-oolites, calcispheres, subrounded and angular cryptalgal chips, subrounded lumps and thin irregular desiccation cracks (Fig. 7C–E). Cryptalgal chips sometimes become so numerous that the sediment becomes an intraformational microbreccia sometimes with thin erosional discontinuities. The chips, lumps and micritic matrix contain very small-sized bipyramidal quartz crystals similar to those described by Pr  at & Mamet (1989) in the Givetian restricted facies of the Dinant Basin. The fauna is very poor, mainly comprised of ostracods and *Amphipora*. *Bisphaera* (*Incertae sedis*) and *Palaeomicrocodium* (Mamet & Pr  at 1985) are also observed. The matrix contains abundant laminoid fenestrae and sponge spicules. The matrix is occasionally slightly recrystallized and displays a very fine-grained calcitic or dolomitic (idiotopic crystals, 20–50 μm) microspar and coarser clear blocky and granular calcite.

Microfacies type 12 (or MF12). – Definition: laminar peloidal packstones and very fine-grained grainstones with disrupted flat laminations similar to those on the modern carbonate tidal flats of the Andros Island (Hardie & Ginsburg 1977). The sediment of the Andros tidal flat belt is mainly a pelleted carbonate mud showing varying degrees of induration. The layering is produced by the alternation of physical sedimentation with the growth of algal mats (mainly *Scytonema*). The millimetric layering of our microfacies 12 is formed by the alternation of thin levels (up to 5 mm thick) of muddy sediments and thicker layers of well-sorted peloidal (from cyanobacterial mats?) microbioclastic (ostracods, molluscs, issinellids, kamaenids, proninellids) packstones and grainstones. Some calcispheres and rare umbellids are also observed. Desiccation and sheet cracks filled with clays are common as tubular and laminoid fenestrae, some of which have geopetal infillings (discmicrite, Fig. 7E). As for the previous facies erosional discontinuities are observed as microsparitization. Large hexagonal quartz crystals with anhydrite inclusions are present in the matrix.

Microfacies type 13 (or MF13). – Definition: very fine-grained peloidal dolopackstones and dolomudstones with rare pelecypods, *Amphipora*, issinellids, kamaenids and calcispheres. The dolomitic crystals are idiotopic and range from 20 to 50 μm in size (Fig. 7H). Filamentous pyrite (Mamet & Pr  at 2005a) is frequently observed in the matrix. Calcite pseudomorphs of rosette-like and acicular crystals are occasionally observed (Fig. 7G) and are of the same types as those reported in the Upper Givetian by Pr  at & Mamet (1989).

Sedimentological and palaeoecological evolutions (Table 1)

Sedimentary model

Microfacies types 1 to 3 display mudstone and wackestone textures with well preserved open-marine faunas deposited near or below the storm wave base. They contain thin coquina packstone levels constituted by reworked, broken-up faunas deposited between the storm wave base and fair-weather wave base (Aigner 1985, Einsele & Ricken 1991). The laminar levels are rare and thin (MF1), of intermediate thicknesses (MF2) and finally thick and abundant (MF3), and they contain similar bioclasts. These microfacies are episodically present in the Fromelennes Fm. and represent the only interbedded carbonate facies in the shaly nodular Nismes Fm. In the field they display highly fossiliferous wackestones and packstones (brachiopods, crinoids with some disphyllids, various solitary corals and rare stromatoporoids). The presence of a fully open marine

Table 1. Summary of microfacies and interpreted environments.

Microfacies	Thickness	Sedimentary structures	Bioclasts	Remarks	Environment
MF1 shales, shaly mdst/wkst	cm–dm	homogeneous, burrows, distal tempestites	microbioclasts: echinoderms, brachiopods, ostracods, bryozoans nautiloids, tentaculitids	acicular calcitic microspar	open marine near SWB
MF2 shales, shaly mdst/wkst	cm–dm	intermediate tempestites	same as MF1		open marine in SWB
MF3 laminar wkst/pkst	dm	proximal tempestites	more diversified, more abundant coarser	rounded microbreccias and iron oolites	open marine SWB near FWWB
MF4 & MF5 *					
MF6 floatstone & (framestone)	dm–m		stromatopores, corals and diversified & abundant bioclasts	algae	peri-reefal photic zone
MF7 peloidal pkst/oolitic gst	cm–(dm)	internal bedding	rare		restricted channels
MF8 gastropod- <i>Amphipora</i> pkst	cm–(dm)	internal bedding	rare (micritized bioclasts)		restricted shoals
MF9 cyanobacterial/algae wkst/bafflestone	dm	abundant fenestrae	calcispheres, <i>Amphipora</i> , mollusks, Umbellids...	endemism of faunas/floras	restricted with salinity variations
MF10 spongiostromide bindstone	cm–dm	irregular laminae	serpulids	calcitic or dolomitic matrix	idem
MF11 loferite-microstromatolitic bindstone	cm–dm	desiccation cracks intraformational breccias	'cryptalgal' chips, calcispheres		idem
MF12 laminar peloidal pkst	cm–dm	disrupted flat laminae millimetre layering	algae, mollusks, ostracods	quartz crystals with anhydrite	supratidal plain
MF13 dolopkst/dolomdst	cm–dm		idem with <i>Amphipora</i>	pseudomorphs	evaporitic

* not observed (see text)

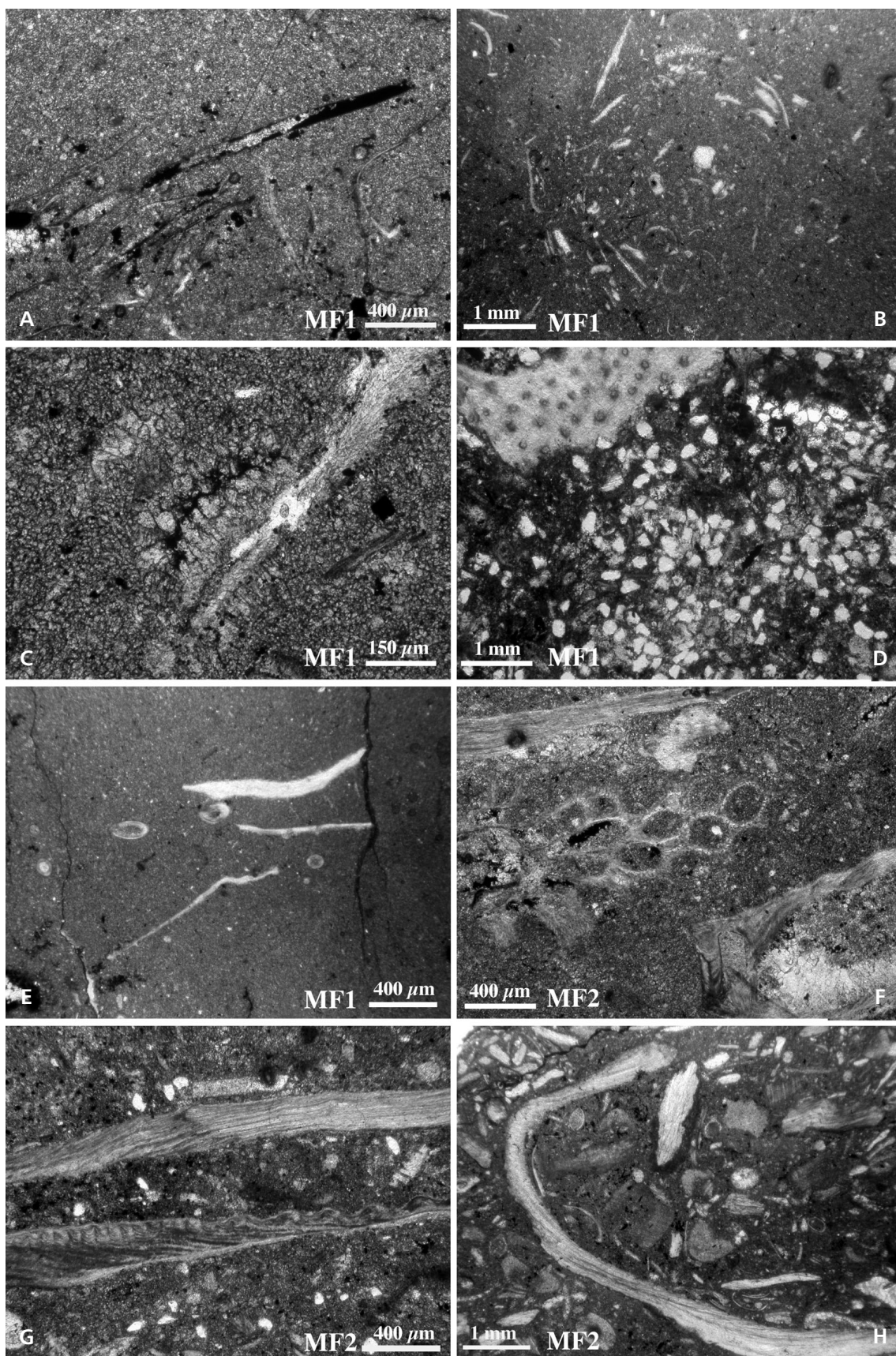
mdst = mudstone, wkst = wackestone, pkst = packstone, gst = grainstone, SB = storm wave base, FWWB = fair weather wave base

assemblage is suggestive of a general distal open marine depositional environment below normal wave base. Storms occasionally impinged into this environment, therefore an environment at (MF2 and MF3), or just below (MF1) storm wave base is suggested. The significant facies change at the Givetian/Frasnian boundary, that records similar microfacies to those described by Pr at & Kasimi (1995) suggests that carbonate and shale deposition was initiated in a homoclinal ramp where a slight slope (absence of turbidites) existed with no true barrier or topographic differentiation. Casier & Pr at (2009) have shown in the Nismes G/F parastratotype, close to Frasn es (southern border of Dinant Basin) that the Givetian carbonate platform was drowned and dismantled prior its definitive drowning. This major

sedimentary change also reported in the Sourd d'Ave section might be attributed to a sedimentary evolution of a "Givetian" carbonate platform to a Lower Frasnian mixed ramp system.

Microfacies 6 and 7 are observed only in the Fromelennes Fm. Microfacies 6 consists of stromatoporoid-coral floatstones and is easy to identify in the field due to the presence of recognizable large macrofaunas. Strata are generally well bedded, with beds between a few dm to one meter in thickness, but commonly being about 40 to 50 cm thick. Stromatoporoids are variable in size (around 10 cm in diameter) and do not construct recognizable bioherms. They appear as well- to poorly-bedded biostromes with a bioclastic matrix variably composed of bulbous, globular

Figure 5. Thin sections are deposited in the Department of Earth Sciences and Environment of the University of Brussels (ulb/sed ...). SF- and SG- = sample number (see Fig. 4 for the stratigraphic position). Open marine environment. • A – bioclastic (molluscs, ostracods) wackestone with a slightly recrystallized fine-grained calcitic microspar. Blackish zones covering bioclasts are small-sized pyrite. Open-marine environment near the storm wave base-level. MF1, ulb/sed 9036-11, sample SG-4, Fromelennes Fm. • B, C – burrowed bioclastic (echinoderms, molluscs, ostracods). Blackish zones are spheroidal pyrite dispersed in the micrite (B). Irregular zones with very coarse grained calcitic microspar and associated pyrite around brachiopods are present in C. Open-marine environment near the storm wave base-level. MF1, ulb/sed 9041-11 (B) and 9044-11 (C), sample SF-10, Nismes Fm. • D – Bioclastic (brachiopod) burrowed silty wackestone. Open-marine environment near the storm wave base-level. MF1, ulb/sed 9053-11, sample SF-4, Nismes Fm. • E – bioclastic mudstone with brachiopod shells and spines. Irregular pyritic and calcitic pressure solution seams and dendritic pyrite microtufts developed later in the matrix. Open-marine environment near the storm wave base-level. MF1, ulb/sed 9059-11, sample SF-15, Nismes Fm. • F, G – bioclastic (bryozoans and brachiopods in F and only brachiopods in G) silty packstone forming a thin layer in a fine-grained wackestone. The zoecia of the bryozoans are filled with very small-sized pyrite spheres. Open-marine environment in the storm wave base-level (distal tempestite). MF2, ulb/sed 9047-11 (F) and 9049-11 (G), sample SF-7, Nismes Fm. • H – bioclastic (brachiopods, echinoderms, ostracods) packstone forming a thin burrowed layer in a fine-grained wackestone. Open-marine environment near the storm wave base-level (distal tempestite). MF2, ulb/sed 9030-11, sample SF-3, Nismes Fm.



and rare laminar stromatoporoids, corals (Tabulata – thamnoporoids, alveolitids – and solitary Rugosa), crinoids, and brachiopods. Bioconstructors are rarely preserved in their life position (framestone), but they are not very broken-up, pointing to only minor transportation in moderate energy environments except during storm events, which episodically dislodged the macrofaunas. No large scale cross bedding has been identified suggesting that higher-energy conditions were not encountered in this shallow (presence of algae in thin sections) marine environment. Oolitic packstones and grainstones of microfacies 7 are not well represented and suggest moderate to high-energy conditions with constant wave action in subtidal-intertidal channels. Modern-day ooids form in shoals, tidal deltas, lakes and foreshore zones with water as deep as 15 m but usually less than 5 m (Westphal *et al.* 2010). Microfacies 7 formed thin oolitic accumulations (less than one dm) and probably represent small temporary sand banks with the moderate-energy slightly restricted subtidal zone as also suggested by the abundance of peloids (Préat & Mamet 1989, Flügel 2004, Tucker & Garland 2010). The absence of microfacies 4 and 5 indicates that no true or important reefal barrier or biohermal lenses (Mamet & Préat 2005b, Préat *et al.* 2007) were developed in the sedimentation area.

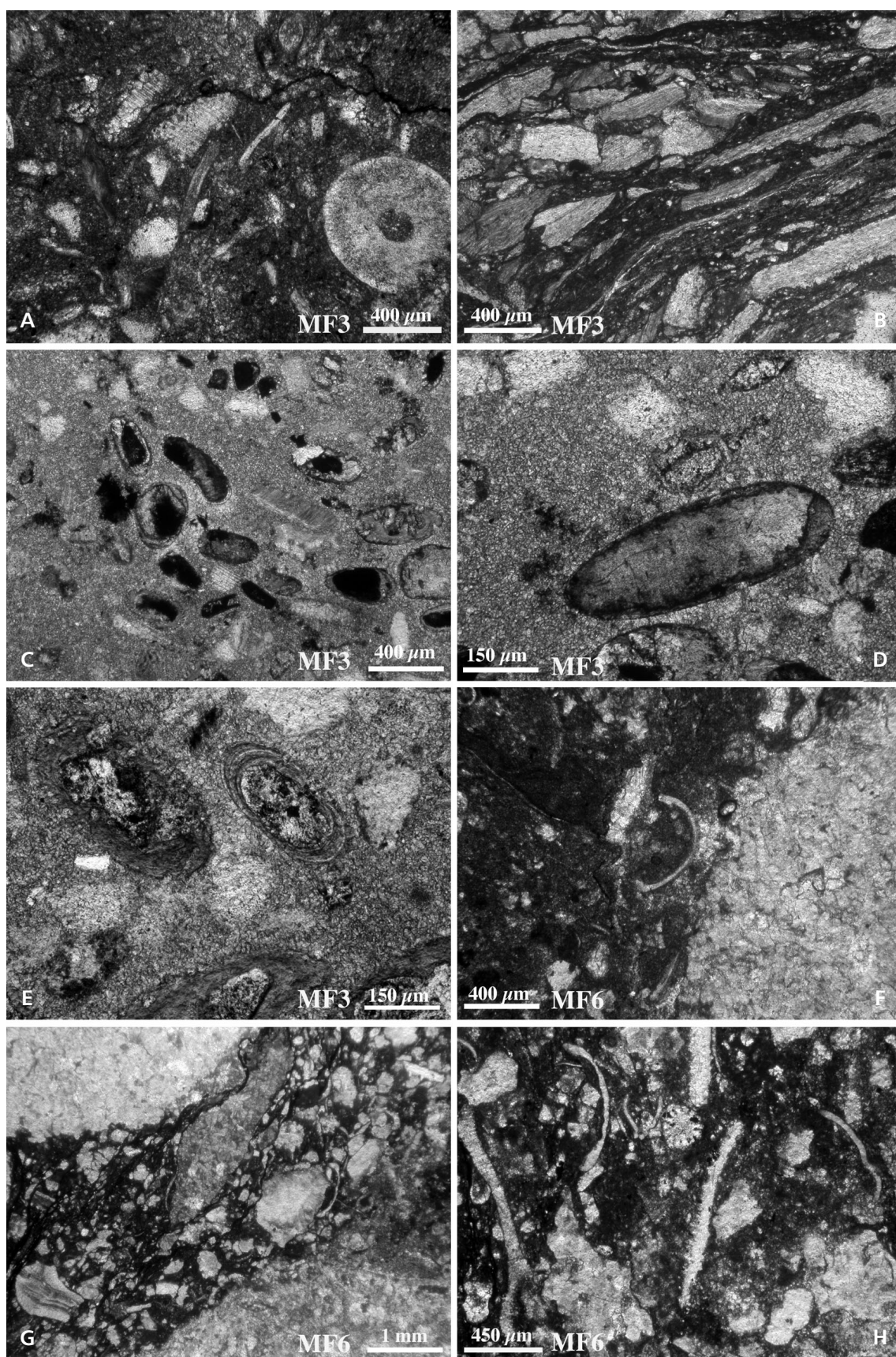
Microfacies 8 to 13 are only observed in the Fromelennes Fm. (as for MF6 and 7) and are extremely common in the studied section. The previous open marine fauna (of MF1-3) is absent or very rare and deposition was at very shallow depths or near emersion. Most organisms of the open marine facies are replaced by endemic faunas (ostracods, *Amphipora*, molluscs, sponges), floras (algae, calcispheres) and microbial mats (cyanobacteria, “spongiostromids”, “stromatolites”). The facies are well-bedded, and the bedding is mostly planar and ranges from a few cm to a few dm in thickness, commonly being 5 cm to 7 cm thick. This set of microfacies is characterized by macrofossil-poor muddy sediments, or by monospecific (micro)fossil assemblages. Microfacies 9 and 11 are also well represented, but the others are not common. They include *Amphipora* floatstones (MF8), algal wackestones and bindstones (MF9), spongiostromid packstones and bindstones (MF10), stromatolitic bindstones (MF11), peloidal laminar packstones (MF12) and dolomudstones (MF13). *Amphipora* is extremely common in the Sourd

d’Ave section and is considered to indicate warm temperatures in a restricted quiet environment (Flügel 2004). The presence of the dense accumulation (bafflestone) of this organism and the sometimes uniform orientation of their well preserved delicate branches suggest that these accumulations were deposited close to their living site. The optimum depths of the amphiporids are less than 10 m, sometimes around 1 m (Racki 1993). They were deposited in back-reef environments in calm water, shallow lagoon characterized by abundant calcispheres, algae and cyanobacteria present in microfacies 9. These facies assemblages (microfacies 9–12) are partly associated with intertidal to supratidal zones as suggested by the occasional fenestral laminoid fabric. These fenestrae are thought to have formed through desiccation processes in subaerial zones (Tebbutt *et al.* 1965) as a result of early diagenetic alteration of cyanobacterial mats. This is equivalent to the MF9a defined by Préat & Mamet (1989) in the broad Givetian shelf lagoon of the southern Ardennes. High intertidal and supratidal facies are characterized by the development of spongiostromids and lateral linked hemispheroid (= LLH) stromatolites in microfacies 10 and 11. Intraformational breccias and mudcracks characterize these facies. Mudchips and subangular lumps resulted from the probable destruction of mud polygons. The faunas and floras (algae) are rare and the development of a laminoid fenestral fabric highlights the stressful conditions of the environment. Supratidal laminites (MF12) and very fine-grained dolomudstones (MF13) capping this standard sequence record a shallow, calm, highly restricted environment that was subject to evaporitic, subaerial conditions (MF13). Episodic hurricanes or particular strong tidal currents tides affected the cyanobacterial mats, which colonized the supratidal surface or littoral plain where cyanobacteria either agglutinated or baffled the sediment. The repetition of this process leads to the formation of these supratidal laminites (Boulvain & Préat 1987).

Palaeoecological evolution at the G/F boundary

The Moulin Boreux Mbr and Fort Hulobiet Mbr display restricted facies (*Amphipora*, spongiostromid and algal bafflestones and bindstones, loferites with desiccation lumps or cryptalgal chips) and poorly fossiliferous beds interbedded

Figure 6. Open marine and fore-shoal environments. • A, B – partly burrowed bioclastic (brachiopods, echinoderms) packstone with a slightly recrystallized fine-grained calcitic microspar. Blackish zones covering some bioclasts are small-sized pyrite. Pyritic pressure solution seams are abundant between the bioclasts. Open marine fore-shoal near the fair-weather wave base-level. MF3, ulb/sed 9025-11 (A) and 9027-11 (B), sample SG-4, Fromelennes Fm. • C, D, E – laminar partly pyritized oolitic and bioclastic (altered echinoderms) packstone. The matrix is a medium-grained calcite microsparite. Open marine fore-shoal near the fair-weather wave base-level. MF3, ulb/sed 9066-11 (C), 9068-11 (D) and 9069-11 (E), sample SF-23, Nismes Fm. • F – stromatoporoid floatstone with ostracod and molluscan bioclasts in a wackestone matrix. Slightly agitated peri-reefal environment near a bioconstruction. MF6, ulb/sed 8980-sample SG-52, Fromelennes Fm. • G, H – stromatoporoid floatstone with ostracod, coral, echinodermal (sea urchin spine, H) and molluscan bioclasts in a packstone matrix. Agitated peri-reefal environment near a bioconstruction. MF6, ulb/sed 9009-11 (G) and 9010-11 (H), sample SG-35, Fromelennes Fm.



with higher energy peloidal and sometimes oolitic grainstone facies. Laminite horizons, sometimes with small-sized LLH-stromatolites are uncommon, and they are associated with dolomicrites containing pseudomorphs of evaporite minerals. These evaporitic facies become common in the upper part of the Fort Hulobiet Mbr suggesting the palaeoclimate became more arid during the Givetian/Frasnian transition. The boundary between the Givetian and the Frasnian, which is very distinctive in the field, is characterized by a transition from semi-restricted peri-reefal environments (MF6–7) and restricted evaporative lagoonal facies (MF8–13) to open marine interbedded marly shales and nodular limestones (MF1–3). This evolution could reflect the transition of a restricted carbonate platform (Préat & Mamet 1989) to a mixed siliciclastic ramp system similar to the one observed in the Eifelian of Belgium and France (Préat & Kasimi 1995).

Metre-scale cyclicality is very pervasive throughout the Givetian part of the section. Cyclicality was determined by assessing the vertical stacking of facies, the base of a cycle being identified by the initial backstepping of less restricted facies-type over a restricted facies-type. Cycles have open or semi-restricted subtidal bases with stromatoporoids, crinoids, corals and restricted supratidal tops with common “algal chips”. They record a decrease in circulation, a decrease in diversity of organisms, which are endemic (cyanobacteria, stromatolites, ostracods, gastropods, umbellids), and an increase in salinity upwards through the cycles. Horizons rich in ostracods are commonly seen representing the impingement of storms in the low energy restricted lagoons. Oncoids are locally abundant in specific horizons. The upper part of the Fort Hulobiet Mbr consists of interbedded biostromes (semi-restricted stromatoporoid boundstones) overlain by *Amphipora* floatstones, then fossil-poor units and restricted supratidal laminites with well-developed fenestral fabrics. The Frasnian Nismes Fm. shows a rich faunal assemblage (bryozoans, brachiopods, molluscs, nautiloids, tentaculitids) suggesting a deepening of the Frasnian from the marginal Givetian carbonate platform to a deeper distal ramp or basinal environment below or near the storm wave base.

Ostracods (J.-G. Casier & S. Maillet)

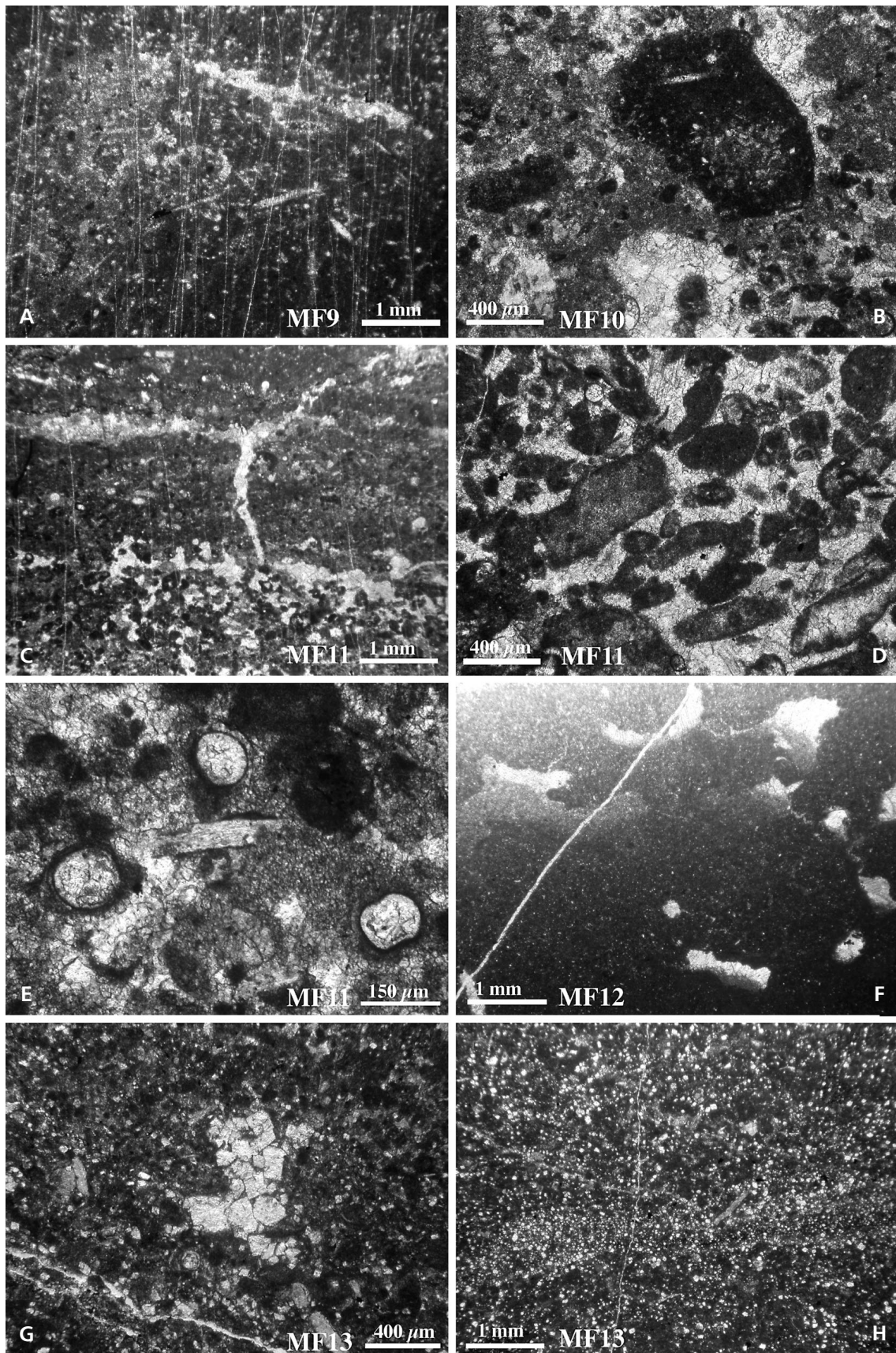
Previous studies

In 1977, Casier discussed ostracods from the lower part of the Nismes Fm. at Sourd d’Ave, and later (1987a), he published a paper on ostracods from the Frasnian Group exposed in this section, and in another lateral, but slightly higher section. Those two sections were separated by a hiatus of 20 m. The list of ostracods recognized by Casier (1977, 1987a) is also reported in Bultynck *et al.* (1988).

In a paper on the biostratigraphic and palaeoecological values of ostracods in the type-region for the Upper Givetian, Milhau (1983a) identified ostracods from the Sourd d’Ave section. His study, based on 5 samples collected in the Fromelennes Fm. recognized the following 30 ostracod species, of which 27 are in open nomenclature: *Bairdiocypris* cf. *Bairdia* (*B.*) sp. nov. Groos, 1969, Quasillitacea gen. indet. sp. A, *Healdianella* sp. 1, *Bythocypris*? sp. G1’ Magne, 1964, *Birdsallella*? sp. indet., *Microcheilinella* cf. *clava* (Kegel, 1932), *Cryptophyllus* sp. 3 Magne, 1964, *Acratia* sp. 1, *Bairdiocypris* cf. *rauffi* Krömmelbein, 1952, *Cavellina* sp. 1, *Cytherellina* cf. sp. 1, *Cytherellina* cf. *perlonga* (Kummerow, 1953), *Cytherellina* sp. 2, *Eridonconcha*? sp. 1, *Knoxiella* sp. 1, *Polyzygia neodevonica* (Matern, 1929), *Uchtovia*? sp. 1, *Sulcella* (*P.*) *abundans* (Pokorný, 1950), *Samarella* aff. *crassa* Polenova, 1952, *Cavellina* cf. sp. II Groos, 1969, *Bairdia* (*R.*) sp. 1, *Evlanella* sp. 1, *Evlanella* cf. *sulcellina*? Becker, 1964, *Macrocypris*? sp. G Magne, 1964, *Sulcella*? sp. 3, *Sulcella* (*S.*) *speculaea* Becker, 1965, *Evlanella* sp. 2, *Nodella* sp. 1, *Quasillitacea* gen. indet. sp. B, and probably *Silenites*? sp. G Magne, 1964.

In the same section, Milhau (*Ibid.*) mentioned the presence of Paraparchitidae gen. and sp. indet., *Jenningsina* sp. indet. and *Polyzygia beckmanni* Krömmelbein, 1954, in the Pont d’Avignon Mbr, and of *Jenningsina* sp. indet., *Polyzygia beckmanni* Krömmelbein, 1954, *Plagionephrodes* sp. indet., *Ponderodictya* sp. C3 Magne, 1964 and *Punctomosea weyanti* Becker, 1971, in the base of the Sourd d’Ave Mbr.

Figure 7. Restricted lagoonal environments. • A – spiculitic (sponge) wackestone. The calcitic spicules are partly dissolved. Restricted lagoon. MF9, ulb/sed 9018-11, sample SG-23, Fromelennes Fm. • B – peloidal packstone with a very fine-grained microsparitized calcitic matrix. A subrounded micritic microbreccia containing a sponge spicule is present. Intertidal channel in a restricted environment. MF10, ulb/sed 8971-11, sample SG-54, Fromelennes Fm. • C – peloidal laminar packstone with curved mudcrack and poorly developed fenestral fabric. Supratidal levee associated with an intertidal channel bordering a restricted environment. MF11, ulb/sed 8964-11, sample SG-56, Fromelennes Fm. • D – peloidal laminar loferitic packstone with well sorted subrounded lumps and coated grains. Supratidal-intertidal levee-channel in a restricted environment. MF11, ulb/sed 8990-11, sample SG-49, Fromelennes Fm. • E – calcispherid peloidal microsparitized wackestone with small-sized unrecognizable bioclasts. Restricted lagoonal environment. MF11, ulb/sed 8950-11, sample SF62, Fromelennes Fm. • F – “dismicrite” with irregular geopetal loferitic cavities in a homogeneous mudstone. Restricted lagoonal environment. MF12, ulb/sed 9015-11, sample SG-23, Fromelennes Fm. • G – peloidal dolopackstone with dolomite pseudomorph after a former sulphate mineral? MF13, ulb/sed 8954-11, sample SG-60, Fromelennes Fm. • H – dolomudstone with idiomorphic 20–50 µm dolomite rhombs. Restricted lagoonal evaporitic environment. MF13, ulb/sed 8991-11, sample SG-48, Fromelennes Fm.



Some of these specimens have been figured by Milhau (1982, 1983a, b) from the Sourd d'Ave section.

The Givet Group/Frasnes Group transition has been recently investigated for ostracods in the Dinant Synclinorium by Casier & Pr eat (2009) at Nismes, 42 km west of the Sourd d'Ave, and by Maillet (2010) in the Flohimont section at Fromelennes, 22 km west of the Sourd d'Ave. The great abundance of ostracods in the upper part of the Fromelennes Fm. in these two sections prompted us to undertake the study of ostracods present in this formation at Sourd d'Ave.

Material and methods

For our study, 47 new samples of approximately 500 g each were collected in the Sourd d'Ave section, 8 in the Moulin Boreux Mbr, 36 in the Fort Hulobiet Mbr, and 3 in the Pont d'Avignon Mbr. All the samples were crushed by a hydraulic press and about 200 g of each sample (except SA-38 and SA-39: 300 g; SA-35 and SA-36: 400 g) were processed with 99.8% glacial acetic acid, at nearly 90°C, for four days at a rate of eight hours a day. This mode of extraction, called the hot acetolysis method, was described by Lethiers & Crasquin-Soleau (1988). The residues were sieved on 250 µm and 1,600 µm mesh screens. About 1,130 carapaces, valves and fragments of ostracods identifiable at any taxonomic level were thus extracted, 50 in the Moulin Boreux Mbr, 915 in the Fort Hulobiet Mbr, and 165 in the Pont d'Avignon Mbr. The stratigraphic positions of these new ostracod samples are shown on Fig. 4.

About 500 ostracods collected by Milhau (1983a) in the Fromelennes Fm. at Sourd d'Ave, and stored in the collection of the Facult e Libre des Sciences et Technologies de Lille, were also reviewed. The approximate location of the samples of Milhau is the following: Sc119 is slightly below the new sample SA-45 (Fig. 4); Sc120 corresponds approximately to SA-43; Sc121 is between SA-40 and SA-39; Sc123 corresponds approximately to SA-22, and Sc124 to SA-15.

Paleoecology of ostracods in the Sourd d'Ave section

The distribution of ostracods is extremely variable in the Sourd d'Ave section. Sixteen samples out of the 44 recently collected in the Fromelennes Fm. are unproductive (SA-42, 31, 29, 25–23, 20, 18, 17, 13, 10, 9, 7–4). In this formation, ostracods are rare or even very rare in all the other samples with the exception of the very rich samples SA-39 to SA-35. Ostracods are present but indeterminable in samples SA-46, 30, 26, 14, and from sample SA-46 to sample SA-41 ostracods are coated.

Ostracods are abundant in the samples collected in the Pont d'Avignon Mbr, and relatively rare in the other members belonging to the Nismes Fm. Their distribution in the Fromelennes Fm. at Sourd d'Ave is reported in Table 2. For the Nismes Fm., see Fig. 2 in Casier (1987a).

Ostracods in the Sourd d'Ave section belong exclusively to the Eifelian Mega-Assemblage, which corresponds to the incorrectly named "Eifelian ecotype" of Becker (in Bandel & Becker 1975; see Casier 2004). Several assemblages are recognized in the Eifelian Mega-Assemblage, and they are indicative of lagoonal, semi-restricted, agitated marine environments above fair-weather wave base, and marine environments below fair-weather wave base or below storm wave base (see Casier 1987b, fig. 1 in Casier 2008, fig. 3 in Casier & Pr eat 2003). In this last assemblage, the abundance of alleged filter-feeding metacopids (Adamczak 1969, Lethiers & Whatley 1995) comparative to deposit-feeding podocopids is related to the oxygen content of the bottom waters and consequently to the water depth. In deeper settings, only metacopid and palaeocopid ostracods are present, and in this case the ostracod assemblage corresponds to the Malvinokaffric "ecotype" of Lethiers *et al.* (2001) as demonstrated by the recent study of ostracods from the Belen Fm. at Pisacavina, in Bolivia (Casier in Racheboeuf *et al.* 2012).

In the Fromelennes Fm. (Givet Group) (Table 2, Figs 8–10, Annex 1), 44 species are identified in the Fromelennes Fm.: 13 belong to the Palaeocopina, 2 to the Paraparchiticopina, 10 to the Platycopina, 5 to the

Figure 8. Palaeocopina and Parachiticopina present in the Fromelennes Fm. at Sourd d'Ave. The types are deposited in the collections of the Department of Paleontology (section Micropaleontology) of the Royal Belgian Institute of natural Sciences (IRScNB No. b 64...). • A – *Amphissites* sp. indet. SA-37, IRScNB No. b 6443, right valve, × 80. • B – *Kozłowskiella plana* (Kummerow, 1953). SA-28, IRScNB No. b 6444, right valve, × 50. • C – *Aparchitellina irgizlensis* Rozhdestvenskaya, 1962. SA-43, IRScNB No. b 6445, right lateral view of a carapace, × 60. • D – *Aparchitellina* aff. *glabra* Rozhdestvenskaya, 1962. SA-35, IRScNB No. b 6446, right valve, × 85. • E – *Kozłowskiella* sp. indet. SA-41, IRScNB No. b 6447, broken left valve, × 40. • F – *Nodella faceta* Rozhdestvenskaya, 1972. SA-124, IRScNB No. b 6448, right valve, × 85. • G – *Fellerites* sp. indet. SA-35, IRScNB No. b 6449, broken valve, × 50. • H – *Parapribylites* cf. *cingulatus* (Kummerow, 1953). SA-35, IRScNB No. b 6450, right lateral view of a carapace, × 110. • I – *Kielciella fastigans* (Becker, 1964). SA-35, IRScNB No. b 6451, right lateral view of a carapace, × 60. • J – *Gravia?* sp. indet. SA-37, IRScNB No. b 6452, left lateral view of a carapace, × 90. • K – *Coryellina?* sp. indet. SA-37, IRScNB No. b 6453, right lateral view of a carapace, × 70. • L – *Buregia ovata* (Kummerow, 1953). SA-16, IRScNB No. b 6454, right lateral view of a carapace, × 50. • M – *Youngiella* sp. indet. SA-11, IRScNB No. b 6455, right lateral view of a poorly preserved carapace, × 60. • N – *Coeloenellina optata* (Polenova, 1955). SA-47, IRScNB No. b 6456, right lateral view of a carapace, × 65. • O – *Coeloenellina* sp. indet. SA-35, IRScNB No. b 6457, right lateral view of a carapace, × 85.

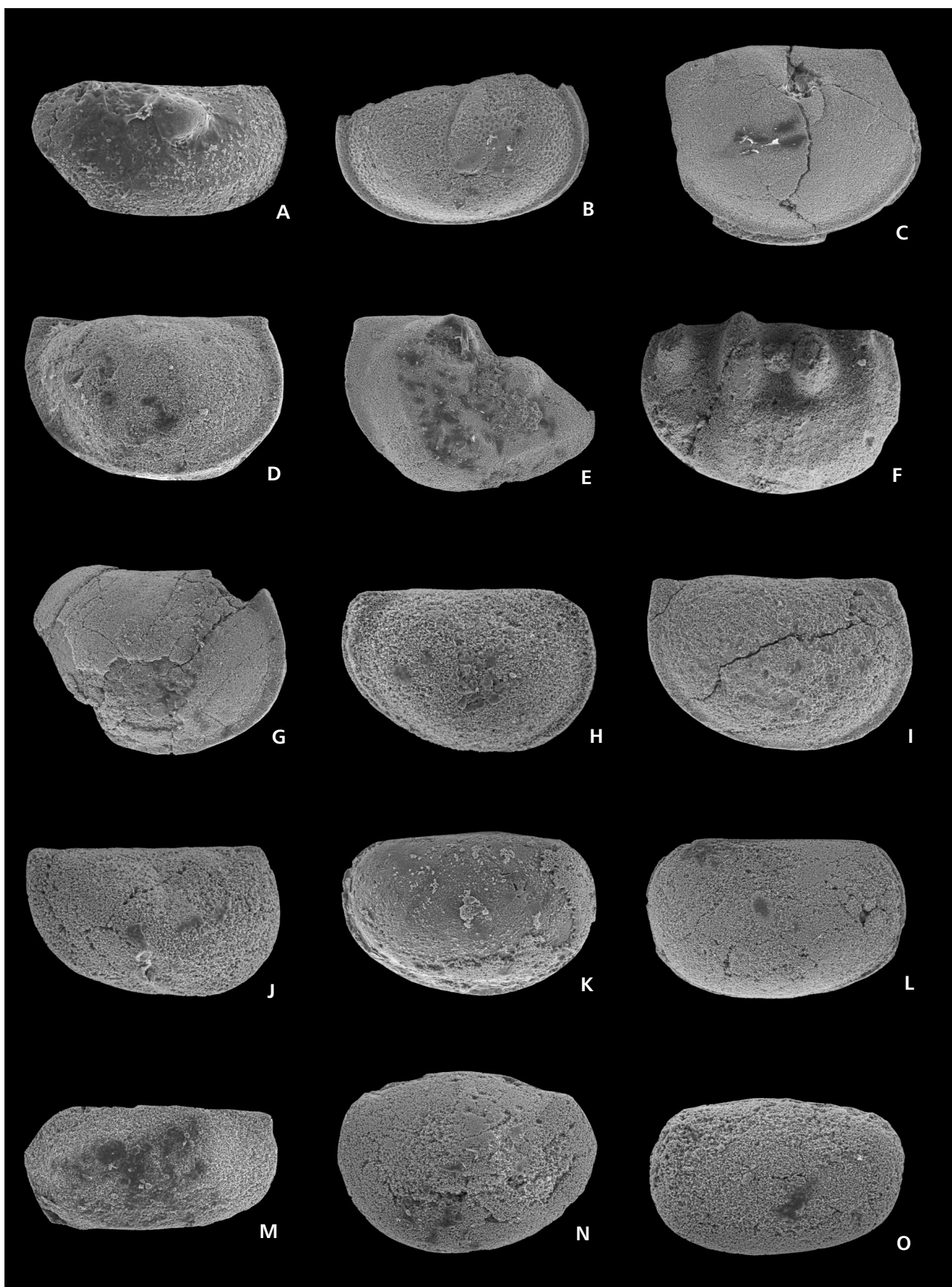


Table 2. Distribution of ostracods in the Fromelennes Fm. exposed in the Sourd d’Ave section at Ave-et-Auffe. Samples 119–124 from Milhau (1983).

SOURD D’AVE	47	119	45	44	43	120	41	40	121	39	38	37	36	35	34	33	32	28	27	123	21	19	16	15	124	12	11	8
<i>Kozłowskiella</i> sp. indet.	*						*																					
<i>Coeloenellina optata</i> (Polenova, 1955)	*	?							*	*		*	*	*				?										
<i>Cavellina</i> nov. sp. A, aff. <i>clara</i> Polenova, 1955	?								*		*			*									?					
<i>Microcheilinella</i> cf. <i>affinis</i> Polenova, 1955	?								*											*	*					*	*	
<i>Bairdiacypris antiqua</i> (Pokorný, 1950)	*											?	?							*	*						*	
<i>Evlanella</i> cf. <i>mitis</i> Adamczak, 1968	?		*					?			*	?	*	*			?			*	*			?		?		?
<i>Cytherellina obliqua</i> (Kummerow, 1953)		*							*	*																		
“ <i>Schneideria</i> ” <i>groosae</i> (Becker, 1971)	*								*		*		*							*	*							
<i>Uchtovia abundans</i> (Pokorný, 1950)	*								*	*	*	*	*	*						*	?					*		
<i>Cryptophyllus</i> sp. 3 in Magne (1964)			*	*		*	*	*	*	*	*				*													
<i>Aparchitellina irgizlensis</i> Rohdestvenskaya, 1962						*																						
Quasillitidae gen. and sp. indet.									*																			
<i>Cryptophyllus</i> sp., aff. <i>materni</i> Becker, 1971									*																			
<i>Acratia lucea</i> Maillet nom. nud.									*			*																
<i>Polyzygia neodevonica</i> (Matern, 1929)									*			*	*															
<i>Cytherellina</i> sp. A, aff. <i>perlonga</i> (Kummerow, 1953)									*	*	*	*		*													?	
<i>Orthocypris kummerowi</i> Zbikowska, 1983?									?	*											?					*		
<i>Knoxiella?</i> sp. A									*																		*	
<i>Bairdia paffrathensis</i> Kummerow, 1953									*	*	*	*	?	*				*		*						*		
<i>Bairdia</i> cf. <i>siliklensis</i> Rozhdestvenskaya, 1962									*												*						*	
<i>Uchtovia refrathensis</i> (Krömmelbein, 1954)									*		*	*	*							*	*					*	*	
<i>Cavellina macella</i> Kummerow, 1953										*																		
<i>Orthocypris?</i> <i>bicarinata</i> Maillet nom. nud.										*																		
<i>Nodella faceta</i> Rozhdestvenskaya, 1972										*																	*	
<i>Evlanella germanica</i> Becker, 1964										*			*	*						*		*				*		
<i>Poloniella</i> sp. indet.											*		*							*								
<i>Acratia</i> sp. A, aff. sp. G II in Magne (1964)											*																	
<i>Gravia?</i> sp. indet.												*																
<i>Amphissites</i> sp. indet.												*																

Table 2. continued

SOURD D'AVE	47	119	45	44	43	120	41	40	121	39	38	37	36	35	34	33	32	28	27	123	21	19	16	15	124	12	11	8
<i>Coryellina?</i> sp. indet.												*		?														
<i>Uchtovia</i> cf. <i>kloedenellides</i> (Adamczak, 1968)													*															
<i>Bairdiocypris</i> cf. <i>breuxensis</i> Casier & Olemp., 2008													*															
<i>Bairdiocypris</i> sp. indet.													*															
<i>Euglyphella europaea</i> Coen, 1985													*		?													
<i>Bairdiocypris</i> sp. indet.													*			*												*
<i>Aparchitellina</i> aff. <i>glabra</i> Rohdestvenskaya, 1962														*														
<i>Fellerites</i> sp. indet.														*														
<i>Kielciella fastigans</i> (Becker, 1964)														*														
<i>Coeloenellina</i> sp. indet.														*														
<i>Kozłowskiella plana</i> (Kummerow, 1953)														*			*											
<i>Parapribylites</i> cf. <i>cingulatus</i> (Kummerow, 1953)														*		*		*	*									
<i>Bairdiocypris corniger</i> Rohdestvenskaya, 1962?																												*
<i>Cytherellina</i> sp. II in Groos (1969)																												?
<i>Buregia ovata</i> (Kummerow, 1953)																								*				
<i>Cavellina rhenana</i> Krömmelbein, 1954																												*
<i>Tubulibairdia?</i> sp. A																												*
<i>Youngiella</i> sp. indet.																												*

Metacopina, 12 to the Podocopina and 2 to the Eridostraca. In the Moulin Boreux Mbr, ostracods are generally poorly preserved and frequently coated by algae (particularly from samples SA-46 to SA-44). This is indicative of a relatively agitated shallow marine environment (oolitic facies). Ostracods in sample SA-46 are indeterminable, but in samples SA-45 and SA-44, the monospecificity indicative of semi-restricted water conditions predominates with the genus *Cryptophyllus*. In the base of the Fort Hulobiet Mbr (from sample SA-121 to SA-35), a more diversified rich fauna and the presence among others of *Bairdia paffrathensis* Kummerow, 1953, and *Polyzygia neodevonica* (Matern 1929), are indicative of open marine water conditions below fair-weather wave base. In the middle and especially in the upper part of the Fort Hulobiet Mbr, ostracods are absent in several samples (SA-18, 17, 10, 9, 7 to 4). This is probably indicative of more stressful lagoonal conditions related to an increase of the aridity of the climate in the Late Givetian. Nevertheless these lagoonal

conditions are sometimes interrupted by semi-restricted water conditions (SA-34, 32) and even by agitated marine episodes (SA-33, 123, 21).

The Givet Group/Frasnes Group transition is abrupt in the Sourd d'Ave section: the environment becomes exclusively marine. Twenty-nine species are identified in the Nismes Fm. (fig. 2 in Casier 1987a, and plates 1, 2, *ibid.*), 5 belong to the Palaeocopina, 5 to the Platycopina, 8 to the Metacopina, 9 to the Podocopina and 2 to the Eridostraca.

In the Pont d'Avignon Mbr we have identified: *Roundyella patagiata* (Becker, 1964), *Uchtovia refrathensis* (Krömmelbein, 1954), *Cavellina* sp. A, aff. *clara* Polenova, 1955, *Samarella?* sp. A, *Quasillites* cf. *nismesensis* Casier, 2009, *Jenningsina paffrathensis* Krömmelbein, 1954, *Polyzygia beckmanni beckmanni* Krömmelbein, 1954, *Cytherellina* sp. A, aff. *perlonga* (Kummerow, 1953), *Orthocypris kummerowi* Zbikowska, 1983, *Bairdiocypris* cf. *breuxensis* Casier & Olempska, 2008, *Acratia* sp., aff. GII in Magne, 1964, *Bairdia paffrathensis*,

Kummerow, 1953, *Bairdia* cf. *carinata* Polenova, 1960, *Bairdia singularis* Krömmelbein, 1954, *Cryptophyllus* sp. nov., aff. *granulifera* (Adamczak, 1961). This ostracod assemblage corresponds to a well oxygenated marine environment below fair-weather wave base.

In the Sourd d'Ave Mbr, Casier (fig. 2 in Casier 1987a) recorded the presence of *Nodella hamata* Becker, 1971, *Nodella* sp. indet., *Balantoides minimus* (Lethiers, 1970), *Refrathella* sp. indet., *Scrobicula?* sp. indet., *Uchtovia refrathensis* (Krömmelbein, 1954), *Uchtovia materni* Becker, 1971?, *Cavellina* sp. A, aff. *clara* (Polenova, 1955), *Cavellina* cf. *caduca* Mc Gill, 1963, *Cavellina* sp., *Polyzygia beckmanni beckmanni* Krömmelbein, 1954, *Ponderodictya belliloci* Casier, 1986, *Jenningsina paffrathensis* Krömmelbein, 1954, *Favulella lecomptei* Becker, 1971, *Asturiella blessi* Becker, 1971?, *Bairdiocypris* sp., *Baschkirina?* sp. and *Cryptophyllus* sp. indet. This ostracod assemblage is also indicative of an open marine environment, but of greater depth as displayed by the abundance of metacopids comparative to podocopids.

In the base of the La Prée Mbr ostracods became rarer, associated with deepening. Casier (1987a) reported the presence of *Amphissites* sp., *Adelphobolbina europaea* Becker, 1971, *Uchtovia materni* Becker, 1971, *Favulella lecomptei* Becker, 1971, *Ponderodictya belliloci* Casier, 1986, *Jenningsina lethiersi* Becker, 1971 vel *J. paffrathensis* Krömmelbein, 1954, *Bairdia* sp. and *Cryptophyllus* sp.

Finally in the section lateral but higher extension of the Sourd d'Ave section, Casier (fig. 3 in Casier 1987a) recorded several ostracods and among them entomozoid ostracods (*Franklinella*) belonging to the Mydocopid Mega-Assemblage, a proxy for hypoxic water conditions (Casier 2004). However the exact dating of this section is controversial. Casier (1987a) suggests that this section exposes the boundary between the Nismes Fm. and the overlying Moulin Liénaux Fm., but Bultynck & Coen in Boulvain *et al.* (1999) assigned this section to the Ermitage Mbr, the second member in the Moulin Liénaux Fm. The presence of *Franklinella latesulcata* Paeckelmann, 1921, in the base of this section should indicate that the *torleyi* Zone of the biostratigraphic zonation established on

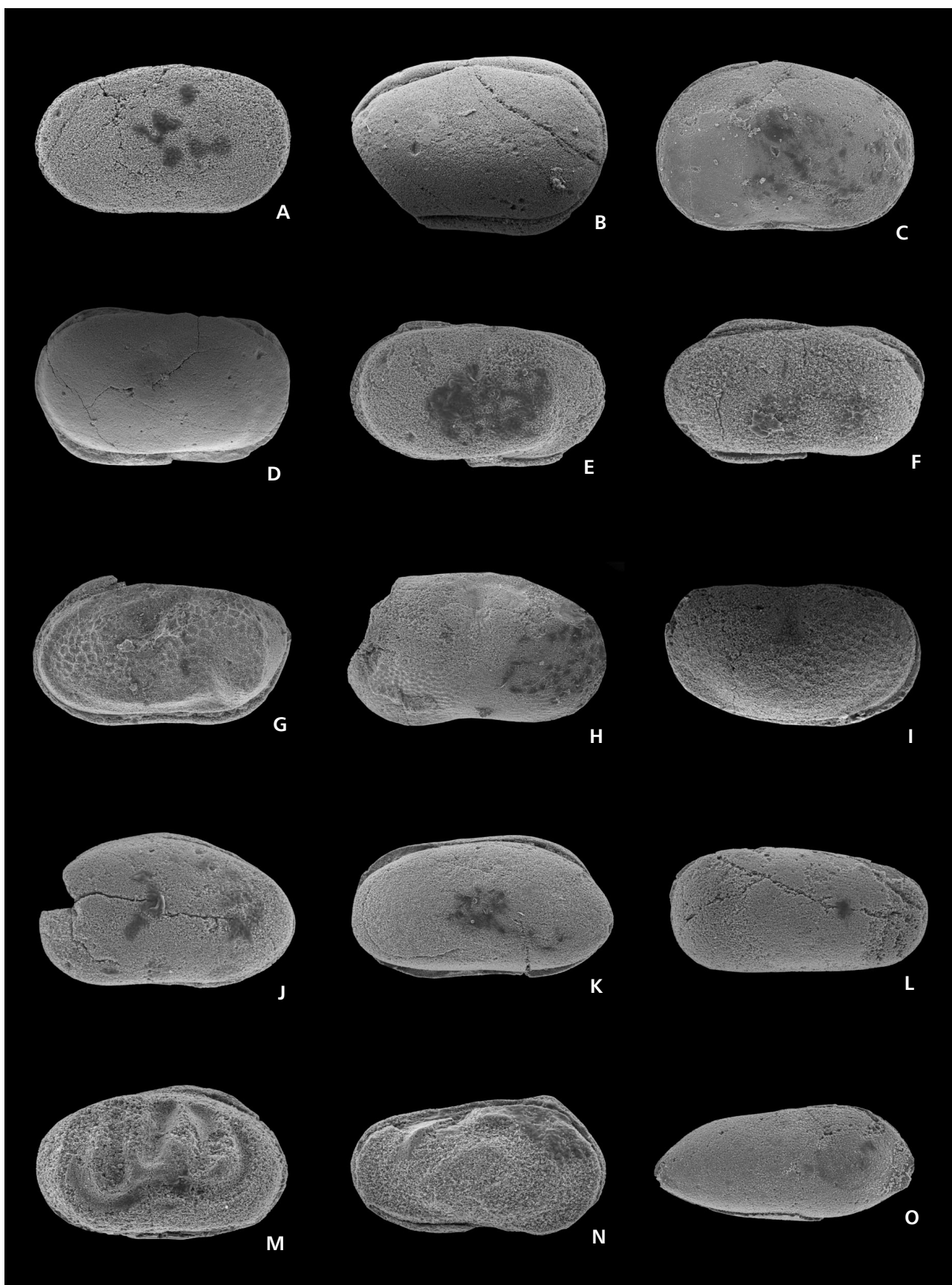
entomozoid ostracods by Rabien (1954), and corresponding to the Lower *Polygnathus asymmetricus* conodont Zone (Groos-Uffenorde & Wang 1989), is recognized at Sourd d'Ave. Consequently, we can surmise that in reality the top of the Chalon Mbr (15 m of shales), the first member belonging to the Moulin Liénaux Fm., the Arche Mbr (reduced to 6 m of limestones, nodular limestones and shales with calcaro-argilaceous nodules in which Bouharrak (1984) has collected conodonts characteristic of the *Polygnathus asymmetricus* Zone), and the base of the Ermitage Mbr (31 m of shales), are exposed in this second section.

Two zones of the zonal sequence established on metacopid ostracods by Casier (1979, see also 2008) and following those of Lethiers (1974a), are recognized in the Nismes Fm. at Sourd d'Ave: The *Polyzygia beckmanni beckmanni* Zone and the *Favulella lecomptei* Zone (Casier 1987a), but the rarity of ostracods in the middle part of the Sourd d'Ave Mbr does not permit the precise placement of the base of this last zone.

Comparison with the Nismes and Flohimont sections

The Givet Group/Frasnes Group transition has been recently studied at Nismes, close to Frasnes, by Casier & Prétat (2009), and at Flohimont, close to Givet, by Maillet (2010). The only significant difference based on the ostracod fauna and the sedimentology in the three sections is the transition from lagoonal to open-marine environments close to the Givet Group/Frasnes Group boundary. But at Sourd d'Ave, this change is abrupt and takes place exactly at this boundary. On the contrary in the Nismes and Flohimont sections, this change corresponds to the entry of *Polyzygia beckmanni beckmanni* Krömmelbein, 1954, and occurred in the upper part of the Fromelennes Fm. In reality there is a hiatus emphasized by an irregular contact at the Givet Group/Frasnes Group boundary in the Sourd d'Ave section (Bultynck & Coen in Boulvain *et al.* 1999).

Figure 9. Platycoquina, Metacoquina and Podocoquina present in the Fromelennes Fm. at Sourd d'Ave. • A – *Cavellina* sp. A, aff. *clara* Polenova, 1955. SA-35, IRScNB No. b 6458, left lateral view of a carapace, × 65. • B – *Cavellina rhenana* Krömmelbein, 1954. SA-124, IRScNB No. b 6459, left lateral view of a broken carapace, × 75. • C – *Cavellina macella* Kummerow, 1953. SA-39, IRScNB No. b 6460, left lateral view of a carapace, × 45. • D – *Uchtovia abundans* (Pokorný, 1950). SA-123, IRScNB No. b 6461, left lateral view of a carapace, × 50. • E – *Uchtovia refrathensis* (Krömmelbein, 1954). SA-38, IRScNB No. b 6462, left lateral view of a carapace, × 60. • F – *Uchtovia* cf. *kloedenellides* (Adamczak, 1968). SA-6, IRScNB No. b 6463, left lateral view of a carapace, × 50. • G – *Evlanella germanica* Becker, 1964. SA-35, IRScNB No. b 6464, left lateral view of a carapace, × 55. • H – *Evlanella* cf. *mitis* Adamczak, 1968. SA-45, IRScNB No. b 6465, left lateral view of a broken carapace, × 40. • I – *Knoxiella?* sp. A. SA-121, IRScNB No. b 6466, left lateral view of a carapace, × 85. • J – *Cytherellina obliqua* (Kummerow, 1953). SA-39, IRScNB No. b 6467, right lateral view of a carapace, × 90. • K – *Cytherellina* sp. II in Groos (1969)? SA-21, IRScNB No. b 6468, right lateral view of a carapace, × 35. • L – *Cytherellina* sp. A, aff. *perlonga* (Kummerow, 1953). SA-39, IRScNB No. b 6469, right lateral view of a carapace, × 70. • M – *Polyzygia neodevonica* (Matern, 1929). SA-36, IRScNB No. b 6470, right lateral view of a carapace, × 65. • N – *Euglyphella europaea* Coen, 1985. SA-36, IRScNB No. b 6471, right lateral view of a carapace, × 65. • O – *Acratia lucea* Maillet, *nom. nud.* SA-39, IRScNB No. b 6472, right lateral view of a carapace, × 60.



Geographic distribution of species recognized close to the G/F transition at Sourd d'Ave

Shared relationships between the Ardenne and North America are restricted to generic level (Coen 1985) and are found mainly amongst the cosmopolitan Thlipsuroidea (*Polyzygia*, *Jenningsina*...).

Relationships between the Ardenne and North Africa are more important. Numerous genera of palaeocopid, platycopid, metacopid and podocopid ostracods are common in both regions but only rarely are species observed in the Frasnian of the Sourd d'Ave section recognized in Algeria (Magne 1964, Lefèvre 1971, Casier 1985) and in Morocco (Milhau 1996; Casier *et al.* 1997, 2010). They belong mainly to the Thlipsuroidea (*Polyzygia neodevonica*, *P. beckmanni beckmanni*, *Favulella lecomptei*, *Uchtovia abundans*).

Relationships with Asia are also restricted to genera except for the Eastern Taurides (Turkey) where studies in progress by Nazik (Nazik & Becker 2008, Nazik *et al.* 2012) show important similarities. Several species present in the Frasnian of the Sourd d'Ave section (*Adelphobolbina europaea*, *Uchtovia refrathensis*, *U. materni*, *Polyzygia neodevonica*, *P. beckmanni beckmanni* and *Bairdia paffrathensis*) are common with that region.

Relationships with Spain and the southern part of France that was united with Gondwana during the Devonian are also restricted to the generic level, except for rare species belonging to Thlipsuroidea: *Favulella lecomptei* and *Polyzygia neodevonica* are recognized in Spain by Gozalo (1994) and this last species is also present in the G/F GSSP at Puech de la Suque (Montagne Noire). However ostracods are generally represented by instars difficult to identify in the G/F GSSP, which is largely composed of storm deposits (Casier & Pr eat 2007).

The European sections studied from Boulonnais (France) to the Holy Cross Mountains (Poland) form a province in which the fauna present maximum affinities (Coen, 1985). This province corresponds to the ancient Rhenohercynian carbonate platform. Numerous papers have been published on these sections, among others by Kummerow (1953), Kr ommelbein (1954), Magne (1964), Becker (1964, 1965a, b), Adamczak (1968, 1976), Groos (1969), Lethiers (1970, 1982, 1984), Olempska (1979), Zbikowska (1983), Milhau (1982, 1983a, 1983b, 1988). In this province, relationships with the Boulonnais (France), and with the Eifel and the Bergisches Land (Germany) are the most important. Twenty-three species recognized in the Sourd d'Ave section are known from the Boulonnais, 17 from the Eifel and the Bergisches Land (Germany), and 12 from the Holy Cross Mountains (Poland).

The species common with the Boulonnais are the following: *Adelphobolbina europaea*, *Balantoides minimus*, *Roundyella patagiata*, *Kielciella fastigans*, *Buregia ovata*, *Cavellina rhenana*, *Uchtovia abundans*, *U. materni*, *Evla-*

nella germanica, *Cytherellina obliqua*, *Asturiella blessi*, *Favulella lecomptei*, *Jenningsina lethiersi*, *J. paffrathensis*, *Polyzygia neodevonica*, *P. beckmanni beckmanni*, *Ponderodictya belliloci*, *Microcheilinella cf. affinis*, *Orthocypris? bicarinata*, *Acratia lucea*, *Bairdia paffrathensis*, *Bairdiacypris antiqua* and *Cryptophyllus* sp. 3.

The species common with Germany are the following: *Kozłowskiella plana*, *Roundyella patagiata*, *Nodella hamata*, *Kielciella fastigans*, *Buregia ovata*, *Cavellina rhenana*, *C. macella*, *Uchtovia abundans*, *U. refrathensis*, *U. materni*, *Evlanella germanica*, *Cytherellina obliqua*, *Polyzygia neodevonica*, *P. beckmanni beckmanni*, *Jenningsina paffrathensis*, *Bairdia paffrathensis* and *Bairdia singularis*.

The species common with the Holy Cross Mountains are the following: *Adelphobolbina europaea*, *Kielciella fastigans*, *Cavellina macella*, *Uchtovia refrathensis*, *U. abundans*, *U. materni*, *Orthocypris kummerowi*, *Bairdia paffrathensis*, *Bairdiacypris antiqua*, *Favulella lecomptei*, *Asturiella blessi* and *Jenningsina lethiersi*.

Several genera present in the Sourd d'Ave section are recognized in Moravia (Czech Republic) but only *Uchtovia abundans* and *Bairdiacypris antiqua* are common (Pokorn y 1950). The relationship to the Russian Platform is also limited to *Aparchitellina irgizlensis*, *Nodella faceta* and *Coeloenellina optata* described by Rozhdestvenskaya (1962) and Polenova (1955) from the Volga and Ural districts.

The Frasnian Event and the ostracod fauna in Europe

Conversely to Frasnian ostracods, Givetian ostracods have been the theme of numerous papers, mostly reflecting the predominant lithologies of the two stages, which is generally carbonaceous in the Givetian, and shaly in the Frasnian in most European sections. Ostracods are more abundant and well preserved in limestones where they can be extracted by the hot acetolysis method (Lethiers & Crasquin-Soleau 1988), and more rare and poorly preserved in shales. Studies of ostracods present in sections straddling the G/F boundary are also rare. Nevertheless a clear faunal change among the benthic ostracod communities is distinguishable close to the G/F boundary in several European countries. Ostracods from the Boulonnais, in the western extension of the Namur Synclinorium of the Ardenne, have been studied by Magne (1964), Lethiers (1982) and Milhau (1983a, 1983b, 1988). Although the G/F interval is faulted in this area, Milhau (1983b) reported 47 ostracod species in the Givetian Blacourt Fm. (Middle *P. varcus* conodont Zone) and 9 in the Frasnian Beaulieu Fm. (Lower *L. asymmetricus* conodont Zone), of which only 1 straddles the G/F boundary. In the Rheinische Schiefergebirge, where ostracods have been studied *e.g.* by Groos (1969)

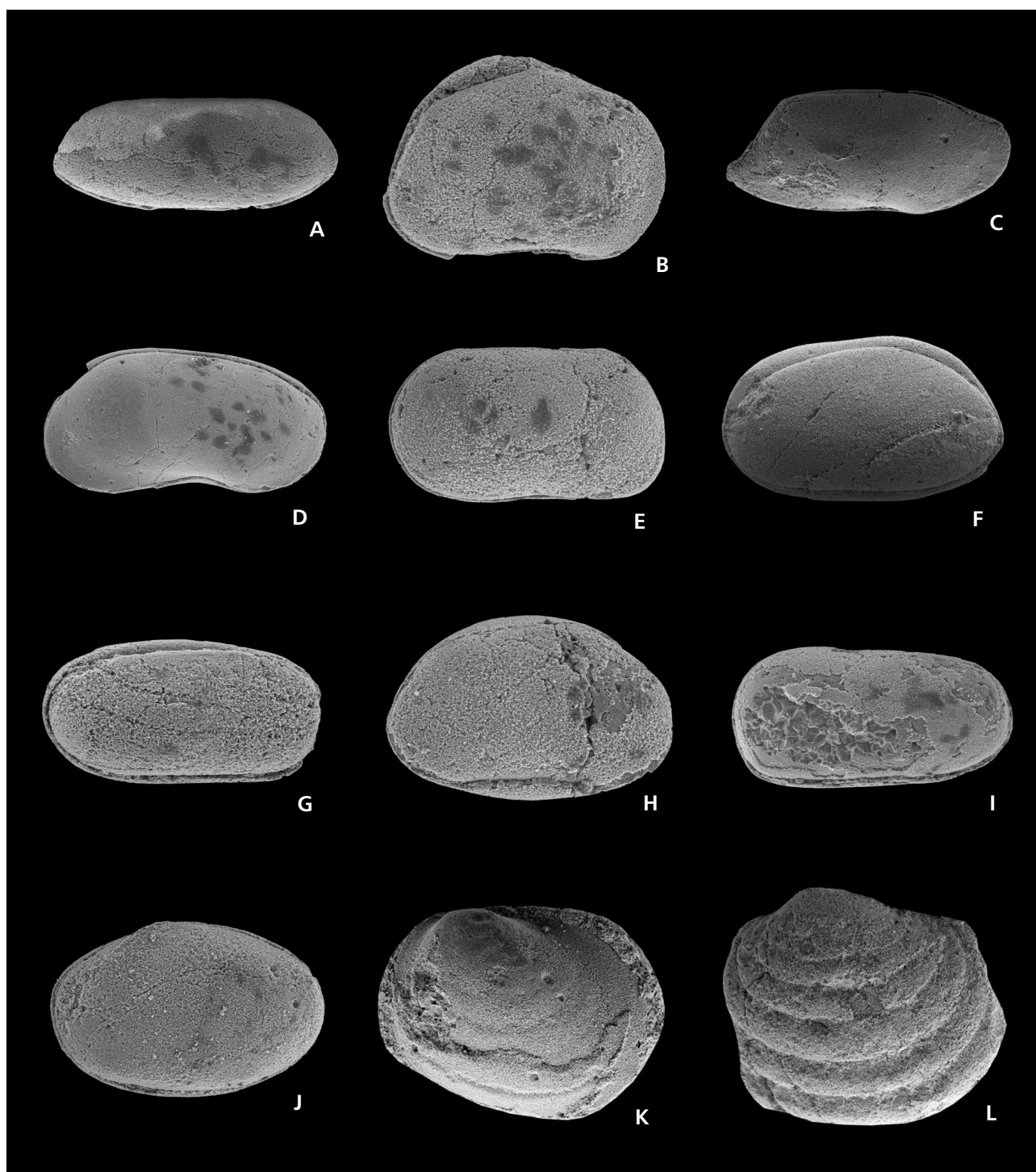


Figure 10. Podocopina (continuation) and Eridostraca present in the Fromelennes Fm. at Sourd d'Ave. • A – *Acratia* sp. A, aff. sp. G II in Magne (1964). SA-38, IRScNB No. b 6473, right lateral view of a carapace, × 65. • B – *Bairdia* cf. *siliklensis* Rozhddestvenskaya, 1962. SA-11, IRScNB No. b 6474, right lateral view of a carapace, × 65. • C – *Bairdia paffrathensis* Kummerow, 1953. SA-121, IRScNB No. b 6475, right lateral view of a carapace, × 50. • D – *Bairdiacypris antiqua* (Pokorný, 1950). SA-47, IRScNB No. b 6476, right lateral view of a carapace, × 45. • E – “*Schneideria*” *groosae* (Becker, 1971). SA-35, IRScNB No. b 6477, right lateral view of a carapace, × 80. • F – *Tubulibairdia?* sp. A. SA-124, IRScNB No. b 6478, right lateral view of a carapace, × 80. • G – *Microcheilinella* cf. *affinis* Polenova, 1955. SA-21, IRScNB No. b 6479, right lateral view of a carapace, × 85. • H – *Bairdiocypris* cf. *breuxensis* Casier & Olempska, 2008. SA-36, IRScNB No. b 6480, right lateral view of a carapace, × 90. • I – *Orthocypris kummerowi* Zbikowska, 1983?. SA-39, IRScNB No. b 6481, right lateral view of a carapace, × 70. • J – *Orthocypris?* *bicarinata* Maillet *nom. nud.* SA-39, IRScNB No. b 6482, right lateral view of a carapace, × 85. • K – *Cryptophyllus* sp. 3 in Magne (1964). SA-120, IRScNB No. b 6483, left lateral view of a carapace, × 90. • L – *Cryptophyllus* sp., aff. *materni* Becker, 1971. SA-121, IRScNB No. b 6484, left valve, × 80.

and Becker (1971a, 1971b), the number of species straddling the G/F boundary is also insignificant. In the southern part of the Holy Cross Mountains, Malec & Racki (1993) reported only 2 species straddling the G/F boundary.

The widespread faunal change around the Middle/Upper Devonian boundary is related to the Frasnian event (House 1985). The benthic ostracod communities of the Rhenohercynian platform are significantly affected by this event, with the installation of a Frasnian cosmopolitan fauna dominated by metacopid and palaeocopid ostracods replacing the endemic faunas of the Givetian that are dominated by platycopid and podocopid ostracods. This change is coupled with an important sea-level rise and a climatic change. The climate becomes warmer and more arid from the end of the Givetian onwards (Joachimski *et al.* 2009, Marshall *et al.* 2011), inducing continental erosion responsible for a higher detrital influx in the marine realm. In the same way, a major transgressive phase at the G/F boundary (Boulvain *et al.* 2009) leads to the flooding of the Givetian carbonate platform (Préat & Mamet 1989) and to the disappearance of the Givetian large reef barriers.

Conclusions

Ostracods belong exclusively to the Eifelian Mega-Assemblage in the Sourd d'Ave section. Forty-four species have been identified in the Givet Group and 25 in the Frasnian Group. These ostracods are successively indicative of semi-restricted water conditions in the upper part of the Moulin Boreux Mbr, of marine environments below fair-weather wave base in the base of the Fort Hulobiet Mbr, and of lagoonal environments interrupted by brief semi-restricted or marine agitated episodes in the middle and upper part of this last member. The Givet Group/Frasnian Group transition is abrupt at Sourd d'Ave: the environment became open marine and the relative proportion of podocopids and metacopids indicates increasing water depth in the Early Frasnian. This change corresponds to the entry of *Polyzygia beckmanni beckmanni*, and occurred in the top of the Fromelles Fm. in other sections of the Dinant Synclinorium.

Based on the study of Sourd d'Ave and Nismes sections (Casier & Préat 2009), only 12 (13?) out of 56 species identified in the Late Givetian survived the Frasnian Event (House 1985) in the studied section. The change in environmental conditions at the Givet Group/Frasnian Group boundary from semi-restricted to open marine water conditions is mostly responsible for this transformation. The surviving species belong principally to metacopids and palaeocopids.

Sedimentological and ostracod analyses are in agreement, with greater ostracod diversity found in more open facies (MF1–3) in the shaly intervals of the Fort Hulobiet Mbr and in the whole of the Nismes Fm., while only rare ostracods have been observed in the most stressful environments

(MF9–13) in most of the Givetian succession. Typical ostracods of semi-restricted environments (MF6) and of higher energy settings (MF7) have also been observed in the Givetian succession. The boundary between the Givet Group and the Frasnian Group is characterized by a dramatic deepening from restricted evaporative lagoonal facies (microfacies 6–13) to open marine interbedded marly shales and nodular limestones (microfacies 1–3). The upper part of the Fort Hulobiet Mbr consists of interbedded biostromes (semi-restricted stromatoporoid boundstones) followed by *Amphipora* floatstones, then of fossil-poor units and restricted supratidal laminites with well-developed fenestral fabrics. The Frasnian Pont d'Avignon Mbr shows a rich faunal assemblage (bryozoans brachiopods, molluscs, nautiloids, tentaculitids, ostracods) suggesting an abrupt drowning from the marginal Givetian carbonate platform into a Frasnian distal ramp setting or deep basinal environment below or near the storm wave base. This transgressive event at the G/F boundary is highlighted by argillaceous shales, marly shales and tempestites with open-marine interbedded nodular limestones, and the development of a rich fauna succeeding the endemic communities that prevailed during Givetian times.

Acknowledgments

The research is a contribution to the IGCP 596 project. We thank especially Bruno Milhau (Faculté Libre des Sciences et Technologies, Université Catholique de Lille), who reviewed our manuscript and allowed us to re-examine the ostracods collected by him in the Sourd d'Ave section. We are also very grateful to David Bond (University of Leeds) who improved substantially the spelling of our manuscript and for his constructive remarks.

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Annex 1: Systematic position of ostracod species identified in the Fromelennes Formation at Sourd d'Ave

Order Palaeocopida

Suborder Palaeocopina

Superfamily Kirkbyoidea

Family Amphissitidae Knight, 1928

Amphissites sp. indet. Figure 8A

Superfamily Beyrichioidea

Family Beyrichiidae Matthew, 1886

Kozłowskiella plana (Kummerow, 1953). Figure 8B

Aparchitellina irgizlensis Rozhdestvenskaya, 1962. Figure 8C

Aparchitellina aff. *glabra* Rozhdestvenskaya, 1962. Figure 8D

Kozłowskiella sp. indet. Figure 8E

Superfamily Nodelloidea

Family Nodellidae Zaspelova, 1952

Nodella faceta Rozhdestvenskaya, 1972. Figure 8F

Superfamily Aparchitoidea

Family Rozhdestvenskayitidae Mc Gill, 1966

Fellerites sp. indet. Figure 8G.

Superfamily Primitiopsoida

Family Pribylites Pokorný, 1958

Parapribylites cf. *cingulatus* (Kummerow, 1953). Figure 8H

Kielciella fastigans (Becker, 1964). Figure 8I

Gravia? sp. indet. Figure 8J

Family Primitiopsidae Swartz, 1936

Coryellina? sp. indet. Figure 8K

?Family Buregiidae Polenova, 1953

Buregia ovata (Kummerow, 1953). Figure 8L

Superfamily Youngiellacea

Youngiella sp. indet. Figure 8M.

Suborder Paraparchitocopina

Superfamily Paraparchitoidea

Family Paraparchitidae Scott, 1959

Coeloenellina optata (Polenova, 1955). Figure 8N

Coeloenellina sp. indet. Figure 8O

Suborder Platycopina

Superfamily Cytherelloidea

Family Cavellinidae Egorov, 1950

Cavellina sp. A, aff. *clara* Polenova, 1955. Figure 9A

Cavellina rhenana Krömmelbein, 1954. Figure 9B

Cavellina macella Kummerow, 1953. Figure 9C

Superfamily Kloedenelloidea

Family Kloedenellidae Ulrich & Bassler, 1908

Poloniella sp. indet.

Uchtovia abundans (Pokorný, 1950). Figure 9D

Uchtovia refrathensis (Krömmelbein, 1954). Figure 9E

Uchtovia cf. *kloedenellides* (Adamczak, 1968). Figure 9F

Evlanella germanica Becker, 1964. Figure 9G

Evlanella cf. *mitis* Adamczak, 1968. Figure 9H

Family Knoxitidae Egorov, 1950

Knoxella? sp. A. Figure 9I

Order Podocopida

Suborder Metacopina

Superfamily Healdioidea

Family Healdiidae Harlton, 1933

Cytherellina obliqua (Kummerow, 1953). Figure 9J

Cytherellina sp. II in Groos (1969)? Figure 9K

Cytherellina sp. A, aff. *perlonga* (Kummerow, 1953). Figure 9L

Superfamily Thlipsuroidea

Family Thlipsuridae Ulrich, 1894

Polyzygia neodevonica (Matern, 1929). Figure 9M

Family Ropolonellidae Coryell & Malkin, 1936

Euglyphella europaea Coen, 1985. Figure 9N

Family Quasillitidae Coryell & Malkin, 1936

Quasillitidae gen. and sp. indet.

Suborder Podocopina

Superfamily Bairdioidea

Family Acratiidae Gründel, 1962

Acratia lucea Maillet *nom. nud.* Figure 9O

Acratia sp. A, aff. sp. G II in Magne (1964). Figure 10A

Family Bairdiidae Sars, 1888

Bairdia cf. *siliklensis* Rozhdestvenskaya, 1962. Figure 10B.

Bairdia paffrathensis Kummerow, 1953. Figure 10C

Bairdiacypris antiqua (Pokorný, 1950). Figure 10D

Bairdiacypris sp. indet.

“*Schneideria*” *groosae* (Becker, 1971). Figure 10E

Superfamily Bairdiocypridoidea

Family Pachydomellidae Berdan & Sohn, 1961

Tubulibairdia? sp. A. Figure 10F

Microcheilinella cf. *affinis* Polenova, 1955 = *Microcheilinella* sp. *sensu* Coen, 1985. Figure 10G

Family Bairdiocyprididae Shaver, 1961

Bairdiocypris cf. *breuxensis* Casier & Olempska, 2008. Figure 10H

Bairdiocypris corniger Rozhdestvenskaya, 1962?

Bairdiocypris sp. indet.

Orthocypris kummerowi Zbikowska, 1983? Figure 10I

Orthocypris? *bicarinata* Maillet *nom. nud.* Figure 10J

Order Eridostraca

Family Cryptophyllidae Adamczak, 1961

Cryptophyllus sp. 3 in Magne (1964). Figure 10K

Cryptophyllus sp., aff. *materni* Becker, 1971. Figure 10L