OSTRACODES, ROCK FACIES AND MAGNETIC SUSCEPTIBILITY OF THE GIVETIAN / FRASNIAN TRANSITION AT SOURD D'AVE (DINANT SYNCLINORIUM, BELGIUM)

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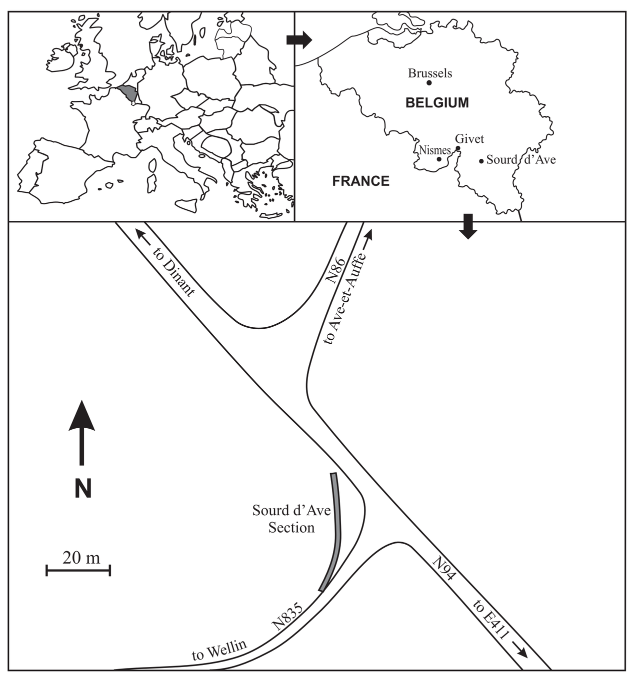
The Sourd d'Ave is a classic reference section in the type region for the definition of the Givetian and Frasnian Stages. This section exposes the Givet Group / Frasnes Group boundary. The Givet Group is represented by the upper part of the Moulin Boreux Member (= Mbr) and by the Fort Hulobiet Mbr belonging both to the Fromelennes Formation (=Fm). The Frasnes Group is represented by the Pont d'Avignon Mbr, by the Sourd d'Ave Mbr and by the base of the La Prée Mbr belonging all to the Nismes Fm.

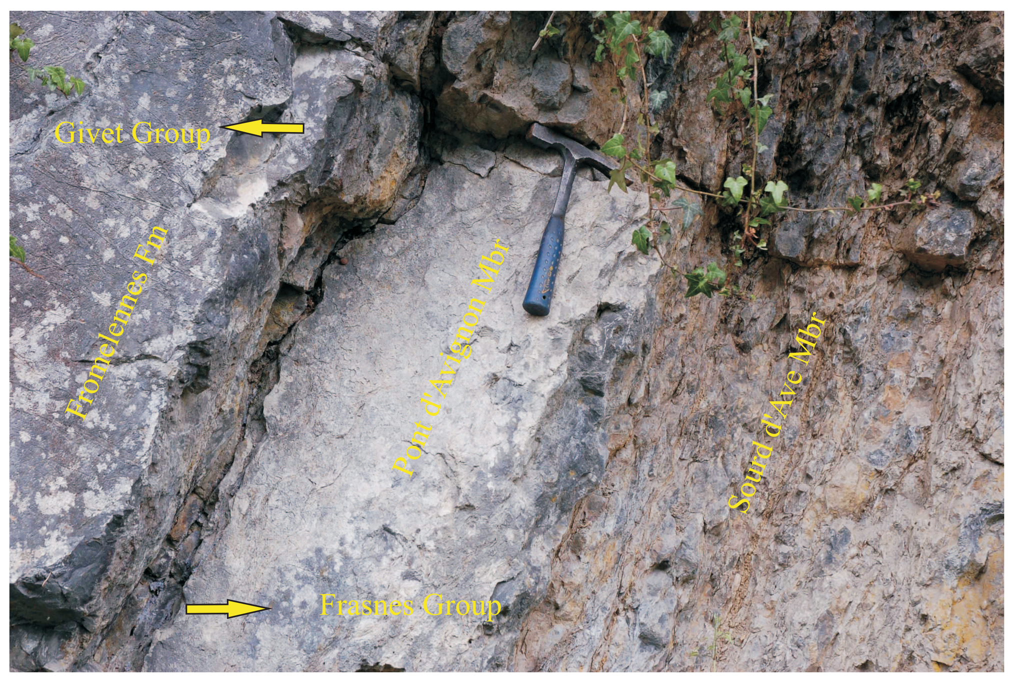
The upper part of the Moulin Boreux Mbr visible in the Sourd d'Ave section is composed of 8 m of built-up limestones with massive and branched stromatoporoids. The Fort Hulobiet Mbr, is composed of 28 m of calcareous shales and argillaceous limestones. The Pont d'Avignon Mbr corresponds to a 45 cm-thick nodular argillaceous limestone. The Sourd d'Ave Mbr is 9.3 m-thick and made up of calcaro-argilaceous nodular shales with rare small argillaceous limestone beds. Finally the base of the La Prée Mbr consists of shales with rare calcaro-argillaceous nodules.

The position of the Givetian / Frasnian boundary in the Dinant Synclinorium is still in debate, and is fixed arbitrarily herein at the Givet Group / Frasnes Group boundary where the first *Ancyrodella* have been recorded by Bultynck (1974), after a 15 m-thick episode without any conodonts.

The study contributes to the IGCP 580 and 596 projects and forms a part of a series on the Middle Devonian ostracodes and their lithological context in the type region for the definition of the Givetian Stage (CASIER *et al.,* 2010, 2011a, b).

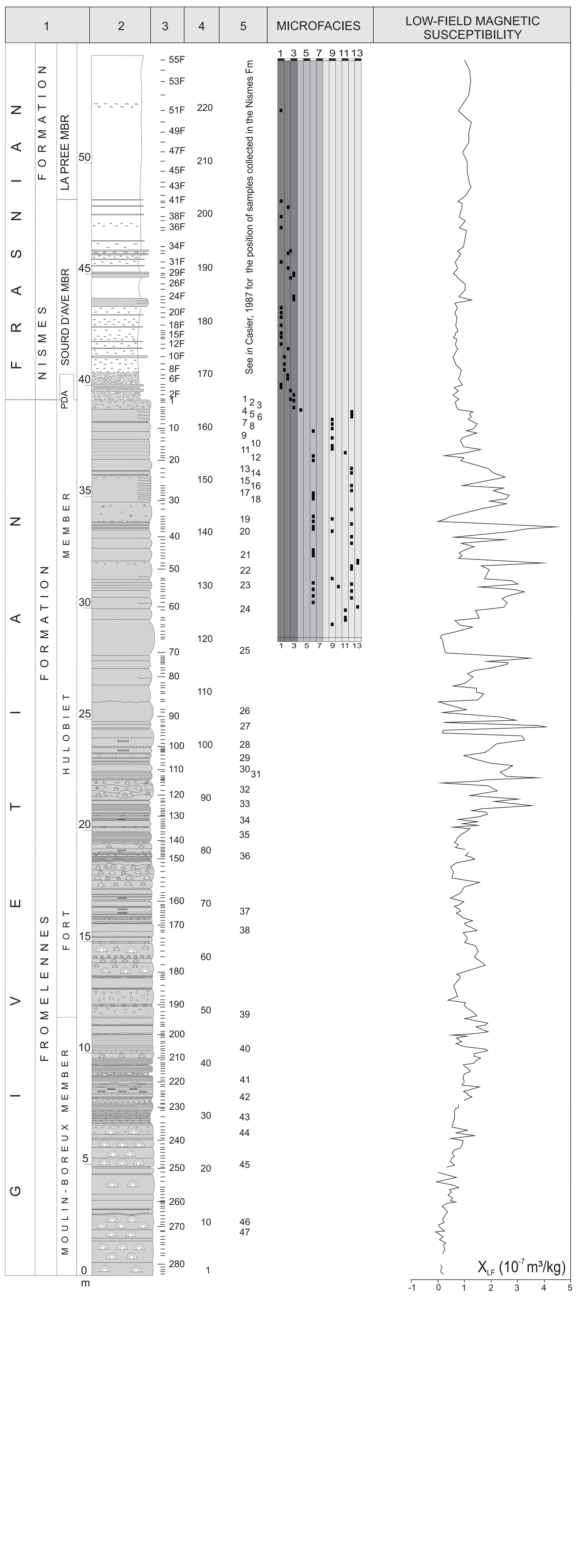


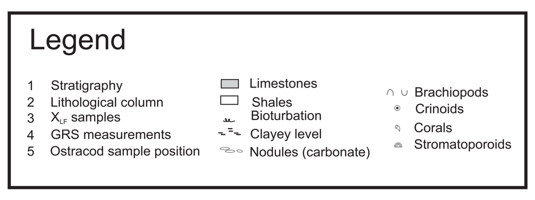
Locality map of the Sourd d'Ave section



The Givet Group / Frasnes Group boundary

The Sourd d' Ave section





Ostracodes

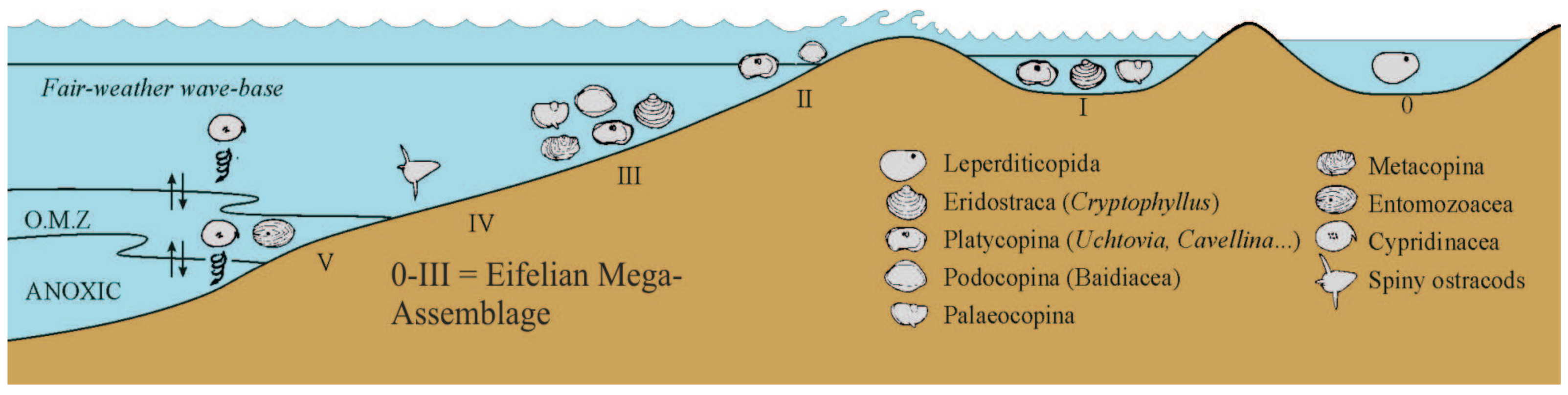
For the study of ostracodes, 47 new samples were collected in the Sourd d'Ave section, and approximately 1,130 carapaces, valves and fragments have been extracted. More than 500 ostracodes collected by CASIER (1977, 1987) and MILHAU (1983) in the Sourd d'Ave section were also reviewed. Forty-five ostracode species are identified in the Fromelennes Fm and 27 in the Nismes Fm, and they belong exclusively to the Eifelian Mega-Assemblage.

In the Moulin-Boreux Mbr, ostracodes are generally poorly preserved, and frequently coated by the algae activity indicative of shallow environments. In two samples, the monospecificity occurs with the genus *Cryptophyllus,* indicative of semi-restricted water conditions. In the base of the Fort Hulobiet Mbr, ostracodes are very abundant and diversified and they are indicative of marine environments below fair weather wave-base. In the middle and especially in the upper part of the Fort Hulobiet Mbr, ostracodes are absent in several samples. This is probably indicative of more stressfull 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 (monospecific assemblage with the genus *Cavellina*) and even by agitated marine episodes (thick shelled and frequently broken podocopid).

The transition Givet Group / Frasnes Group is abrupt in the Sourd d'Ave section, and the environment became exclusively and durably marine. In the Pont d'Avignon Mbr, the relative proportion of podocopids and metacopids indicates a well oxygenated marine environment a little below fair-weather wave-base level. In the Sourd d'Ave Mbr, the depth increases as showed by the ascendance of metacopids comparatively to podocopids, and in the base of the La Prée Mbr, with the deepening, ostracodes became more rare. Finally in an other section located in the prolongation of the Sourd d'Ave section, entomozoid ostracodes (*Franklinella*) proxy for hypoxic water conditions (CASIER, 2004) have been identified.

The Frasnes Group / Givet Group transition has been recently studied at Nismes, close to Frasnes (CASIER & PREAT, 2009), and at Flohimont, close to Givet (MAILLET, 2010). The only significant change as deduced from the ostracode fauna and the sedimentology in the three sections is the transition from lagoonal and semi-restricted environments 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 corresponding to the entry of *Polyzygia beckmanni beckmanni*, occurred in the upper part of the Fromelennes Fm. In fact, there is a hiatus at the Givet Group / Frasnes Group boundary emphasized by an irregular contact in the Sourd d'Ave section.

Based on the study of the Sourd d'Ave and Nismes sections, only 13 out of 56 species identified in the Givetian survived the Frasnes Event. The important modification of the environment at the Givet Group / Frasnes Group boundary is mostly responsible for this change.



Devonian Ostracode Assemblages

Three mega-assemblages are recognized in the Devonian: 1. The Eifel Mega-Assemblage (0-III) generally characterized by a rich and diversified ostracode fauna is indicative of shallow marine (neritic), semi-restricted or lagoonal environments; 2. The Thuringe Mega-Assemblage (IV) characterized by spiny ostracodes is indicative of deep and (or) cold marine environments; 3. The Myodocopida Mega-Assemblage (V) characterized by entomozoid and (or) cyprinoid ostracodes is indicative of poorly oxygenated water conditions (CASIER, 2008) .

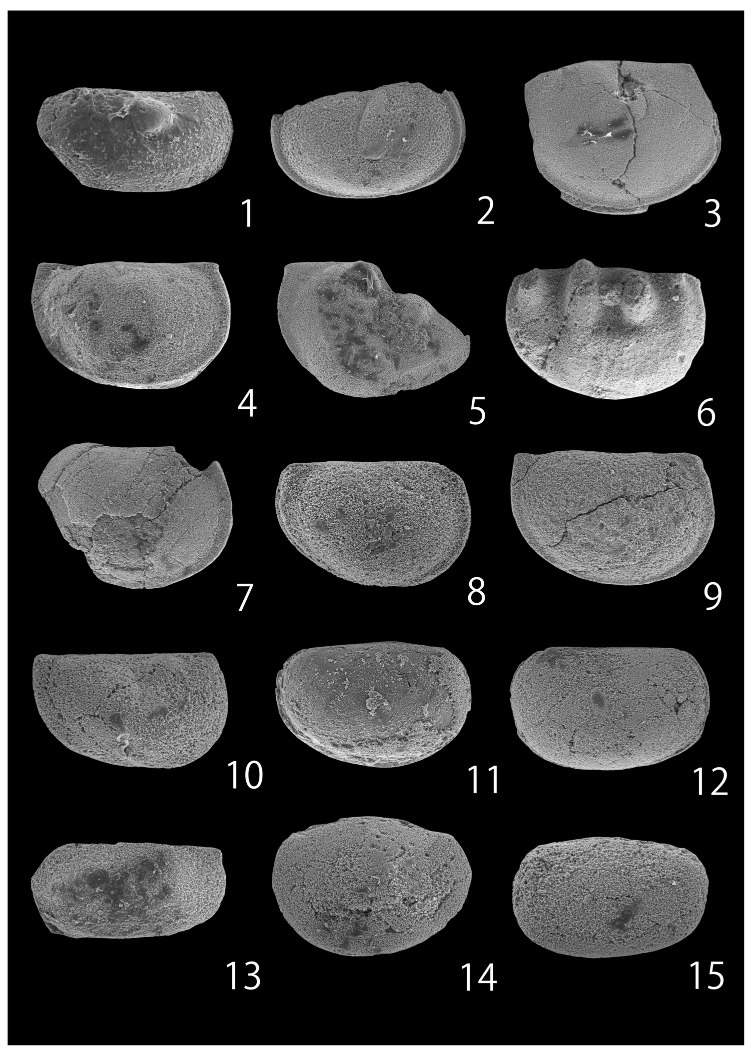


PLATE 1

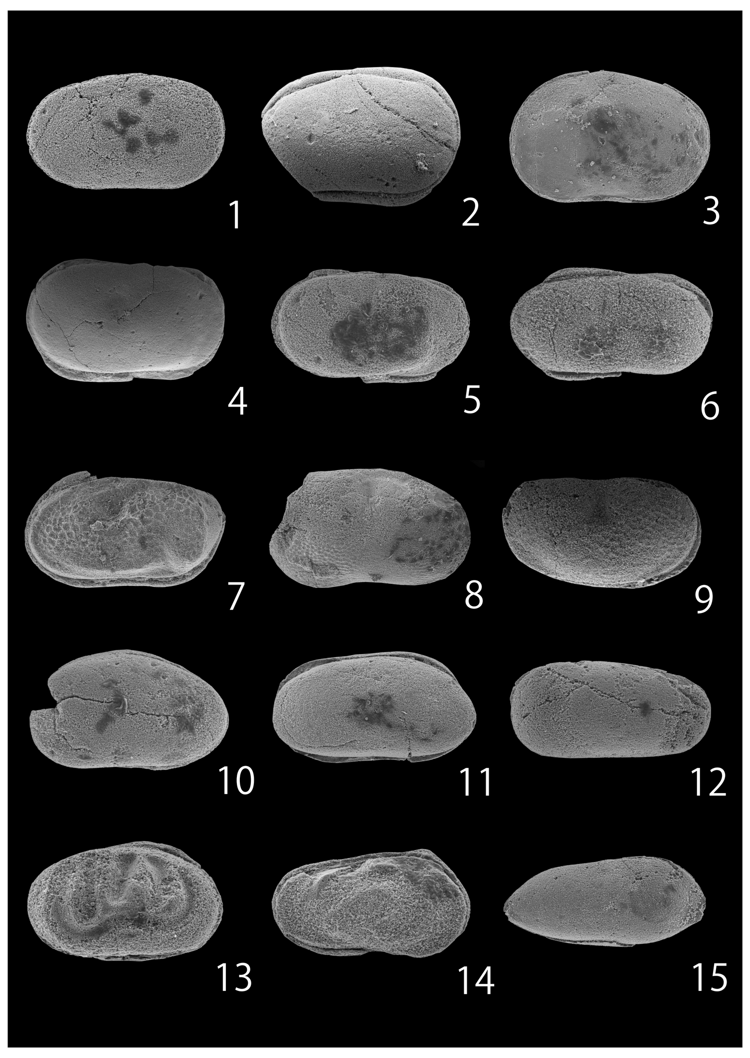


PLATE 2

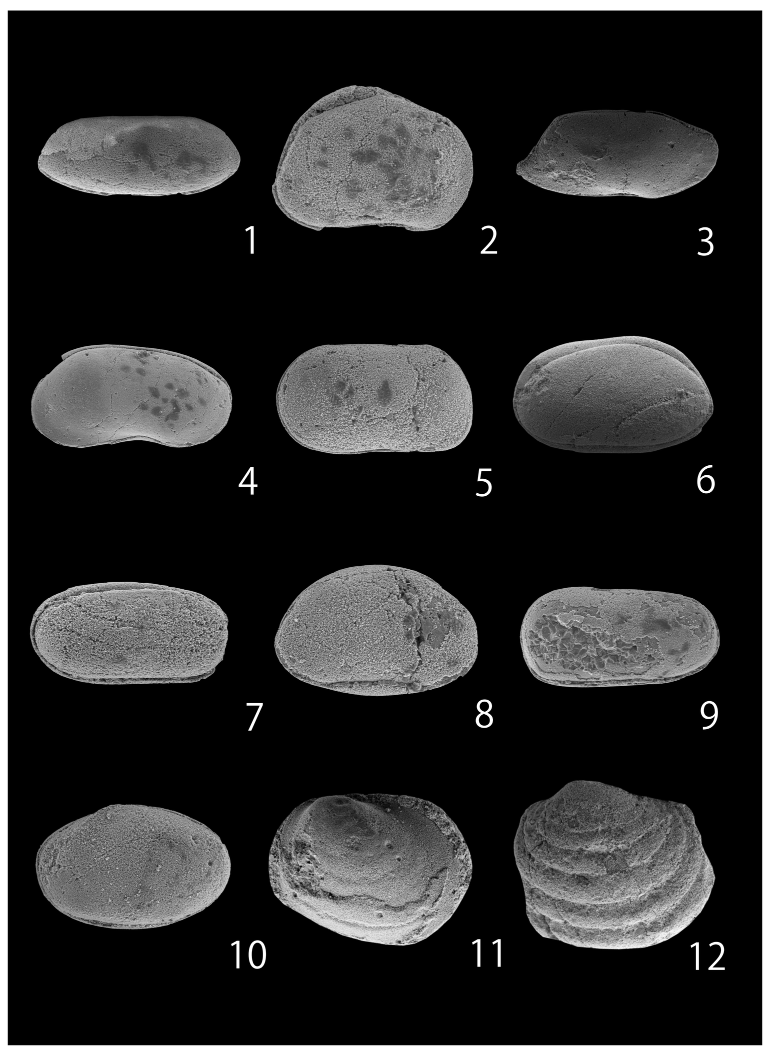


PLATE 3

Plates 1-3: ostracodes from the Fromelennes Fm (Givet Group)

PLATE 1 - 1. *Amphissites* sp. indet. SA-37, x80; 2. *Kozlowskiella plana* (KUMMEROW, 1953). SA-28, x50; **3.** *Aparchitellina irgizlensis* ROHDESTVENSKAJA, 1962. SA-43, x60; **4.** *Aparchitellina* aff. glabra ROHDESTVENSKAJA, 1962. SA-35, x85; 5. *Kozlowskiella* sp. indet. SA-41, x40; **6.** *Nodella faceta* ROZHDESTVENSKAJA, 1972. SA-124, x85; **7.** *Fellerites* sp. indet. SA-35, x50; **8.** *Parapribylites* cf. *cingulatus* (KUMMEROW, 1953). SA-35, x110; **9.** *Kielciella fastigans* (BECKER, 1964). SA-35, x60; **10.** *Gravia?* sp. indet. SA-37, x90; X**11.** *Coryellina?* sp. indet. SA-37, x70; **12.** *Buregia ovata* (KUMMEROW, 1953). SA-16, X50; **13.** *Youngiella* sp. indet. SA-11, x60; **14.** *Coeloenellina optata* (POLENOVA, 1955). SA-47, x65; **15.** *Coeloenellina* sp. indet. SA-35, x85.

PLATE 2 - 1. *Cavellina* sp. A, aff. *clara* POLENOVA, 1955. SA-35, x65; **2.** *Cavellina rhenana* KRÖMMELBEIN, 1954. SA-124, x75; **3.** *Cavellina macella* KUMMEROW, 1953. SA-39, X45; **4.** *Uchtovia abundans* (POKORNY, 1950). SA-123, x50; **5.** *Uchtovia refrathensis* (KRÖMMELBEIN, 1954). SA-38, x60; **6.** *Uchtovia* cf. *kloedenellides* (ADAMCZAK, 1968). SA-6, X50; **7.** *Evlanella germanica* BECKER, 1964. SA-35, x55; **8.** *Evlanella* cf. *mitis* ADAMCZAK, 1968. SA-45, X40; **9.** *Knoxiella?* sp. A. SA-121, x85; **10.** *Cytherellina obliqua* (KUMMEROW, 1953). SA-39, x90; **11.** *Cytherellina* sp. II *in* GROOS (1969)? SA-21, X35; **12.** *Cytherellina* sp. A, aff. *perlonga* (KUMMEROW, 1953). SA-39, x70; **13.** *Polyzygia neodevonica* (MATERN, 1929). SA-36, x65; **14.** *Euglyphella europaea* COEN, 1985. SA-36, X65; **15.** *Acratia lucea* MAILLET, *nom. nud.* SA-39, x60.

PLATE 3 - 1. *Acratia* sp. A, aff. sp. G II *in* MAGNE (1964). SA-38, x65; **2.** *Bairdia* cf. *siliklensis* ROZHDESTVENSKAJA, 1962. SA-11, x65; **3.** *Bairdia paffrathensis* KUMMEROW, 1953. SA-121, x50; **4.** *Bairdiacypris antiqua* (POKORNY, 1950). SA-47, X45; **5.** *"Schneideria" groosae* (BECKER, 1971). SA-35, X80; **6.** *Tubulibairdia?* sp. A. SA-124, x80; **7.** *Microcheilinella* cf. *affinis* POLENOVA, 1955. SA-21, x85; **8.** *Bairdiocypris* cf. *breuxensis* CASIER & OLEMPSKA, 2008. SA-36, x90; **9.** *Orthocypris kummerowi* ZBIKOWSKA, 1983? SA-39, x70; **10.** *Orthocypris? bicarinata* MAILLET *nom. nud*. SA-39, x85; **11.** *Cryptophyllus* sp. 3 *in* MAGNE (1964). SA-120, X90; **12.** *Cryptophyllus* sp., aff. *materni* BECKER, 1971. SA-121, X80.

Plates 4, 5: ostracodes from the Nismes Fm (Frasnes Group)

PLATE 4 - 1. *Amphissites* sp. indet. SA-83-48, x70; **2.** *Adelphobolbina europaea* BECKER & BLESS, 1971. SA-83-43, X55; **3.** *Roudyella patagiata* (BECKER, 1964). SA-2, x55; **4.** *Scrobicula?* sp. indet. SA-83-14, x90; **5.** *Balantoides minimus* (LETHIERS, 1970). SA-83-13, x125; **6.** *Nodella hamata* BECKER, 1971. SA-83-13, x75; **7.** *Refrathella* sp. indet. SA-83-13, x75; **8.** *Samarella?* sp. A. SA-2, x80; **9.** *Cavellina* cf. *caduca* MC GILL, 1963. SA-83-34, x85; **10.** *Cavellina* sp. A, aff. *clara* POLENOVA, 1955. SA-1, x75; **11.** *Uchtovia materni* BECKER, 1971, SA-83-19, x40; **12.** *Uchtovia refrathensis* (KRÖMMELBEIN, 1954). SA-3, x50; **13.** *Cytherellina* sp. A, aff. *perlonga* (KUMMEROW, 1953). SA-2, x65; **14.** *Polyzygia beckmanni beckmanni* KRÖMMELBEIN, 1954. SA-1, x70; **15.** *Ponderodictya belliloci* CASIER, 1986. SA-83-14, x60.

PLATE 5 - 1. *Jenningsina paffrathensis* KUMMEROW, 1954. SA-83-13, x75; **2.** *Quasillites* cf. *nismesensis* CASIER, 2009. SA-83-12, x60; **3.** *Favulella lecomptei* BECKER, 1971. SA-83-4, x60; **4.** *Orthocypris kummerowi* ZBIKOWSKA, 1983. SA-2, x75; **5.** *Bairdiocypris* cf. *breuxensis* CASIER & OLEMPSKA, 2008. SA-2, x80; **6.** *Acratia* sp., aff. GII *in* MAGNE, 1964. SA-2, x75; **7.** *Bairdia* cf. *carinata* POLENOVA, 1960. SA-2, x70; **8.** *Baschkirina* sp. indet. SA-83-32, x650; **9.** *Bairdia paffrathensis* KUMMEROW, 1953. SA-2, x45; **10.** *Bairdia singularis* KRÖMMELBEIN, 1953. SA-83-12, x65; **11.** *Polenovia?* sp. indet. SA-83-43, x75; **12.** *Cryptophyllus* n. sp., aff. *granulifera* (ADAMCZAK, 1961) *in* CASIER (1987). SA-83-13, x90.

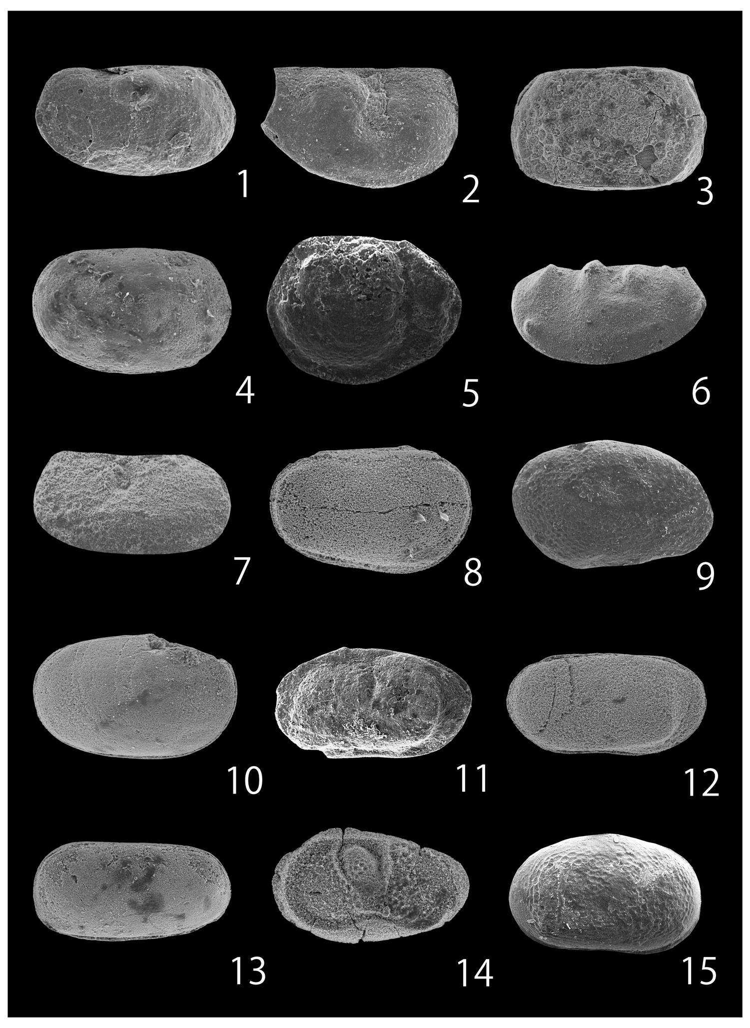


PLATE 4

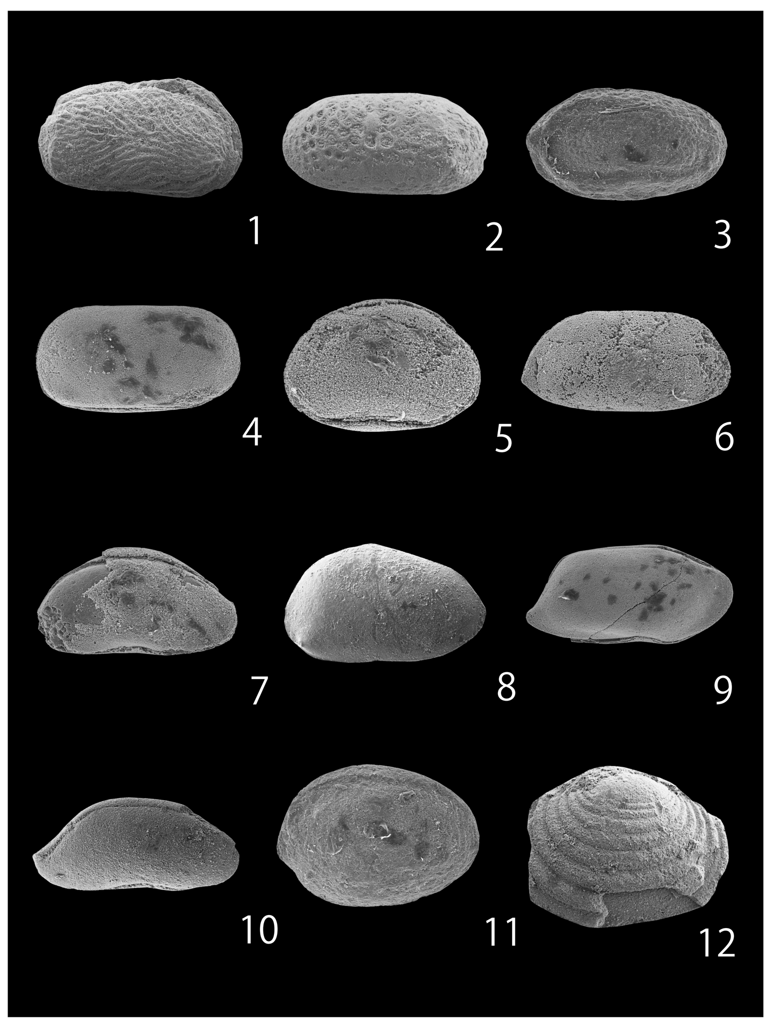
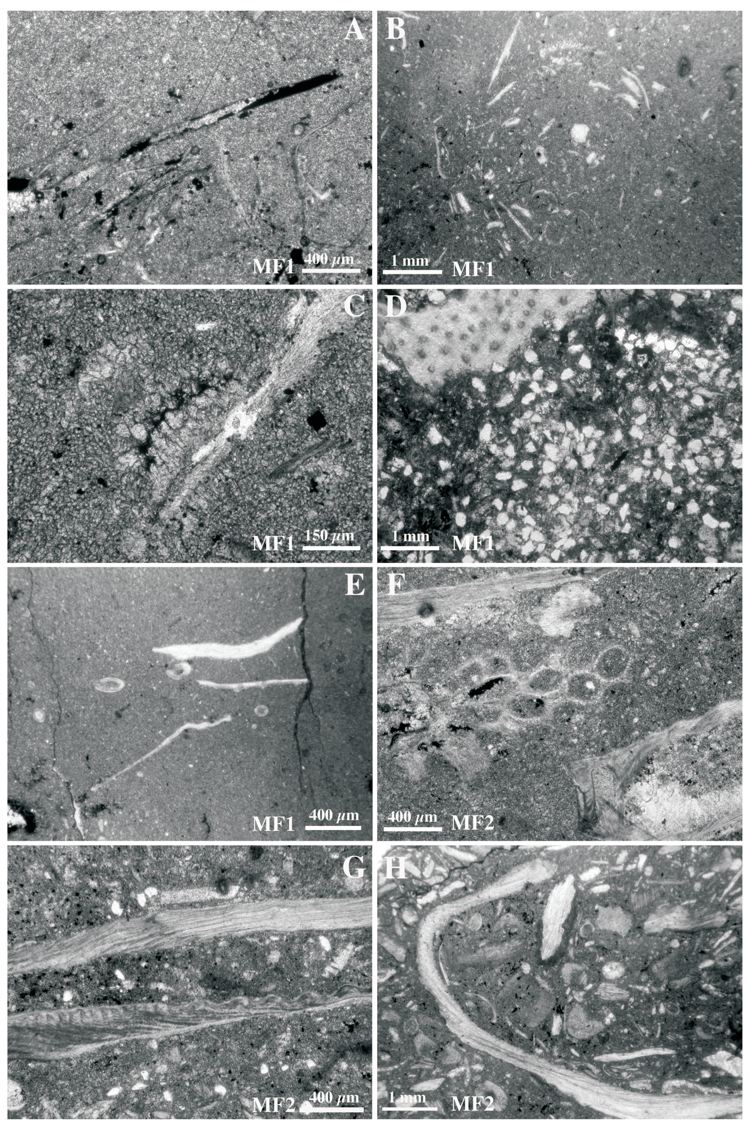


PLATE 5

Rock facies

Systematic sampling has been carried out in order to establish the evolution of the environments and to detail the G/F transition. This lead to the examination of 254 thin sections which allowed recognition of 13 microfacies types paralleling the standard sequence of MAMET & PREAT (1989) from open marine shallow subtidal to restricted supratidal near emersion. The Boreux Mbr and the Fort Hulobiet Mbr 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 LLH-stromatolites are uncommon, and they are associated with dolomicrites showing pseudomorphs of evaporite minerals. These evaporitic facies become common in the upper part of the Fort Hulobiet Mbr suggesting the palaeoclimate may be becoming more arid at the G/F transition. The boundary between the Givet Group and the Frasnes Group which is very distinctive on the field, is therefore characterized by a transition from restricted evaporative lagoonal facies to open marine interbedded marly shales and nodular limestones. A meter-scale cyclicity is very pervasive throughout the Givetian part of the section. Cyclicity 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 stromatopores, 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, ostracodes, gastropods, umbellids), and increase in salinity upwards through the cycles. Horizons rich in ostracodes 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) 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) suggesting an abrupt deepening of the Frasnian from the marginal Givetian carbonate platform to a deep basinal environment below or near the storm wave base.



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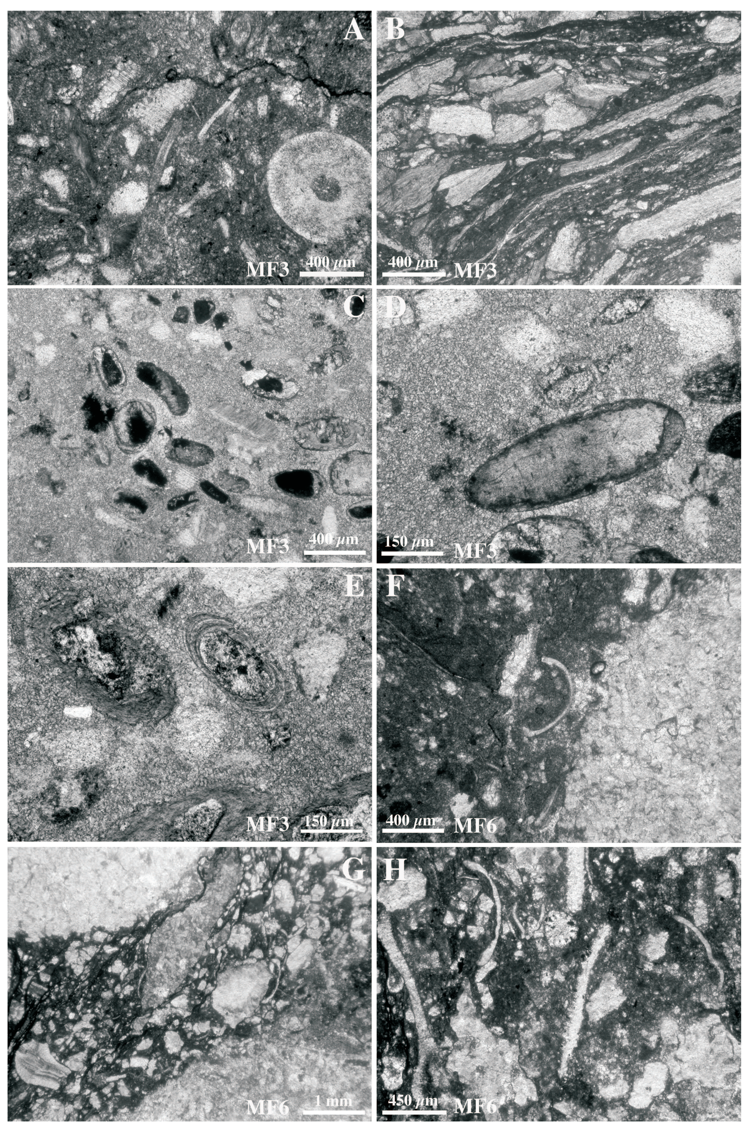

PLATE 7

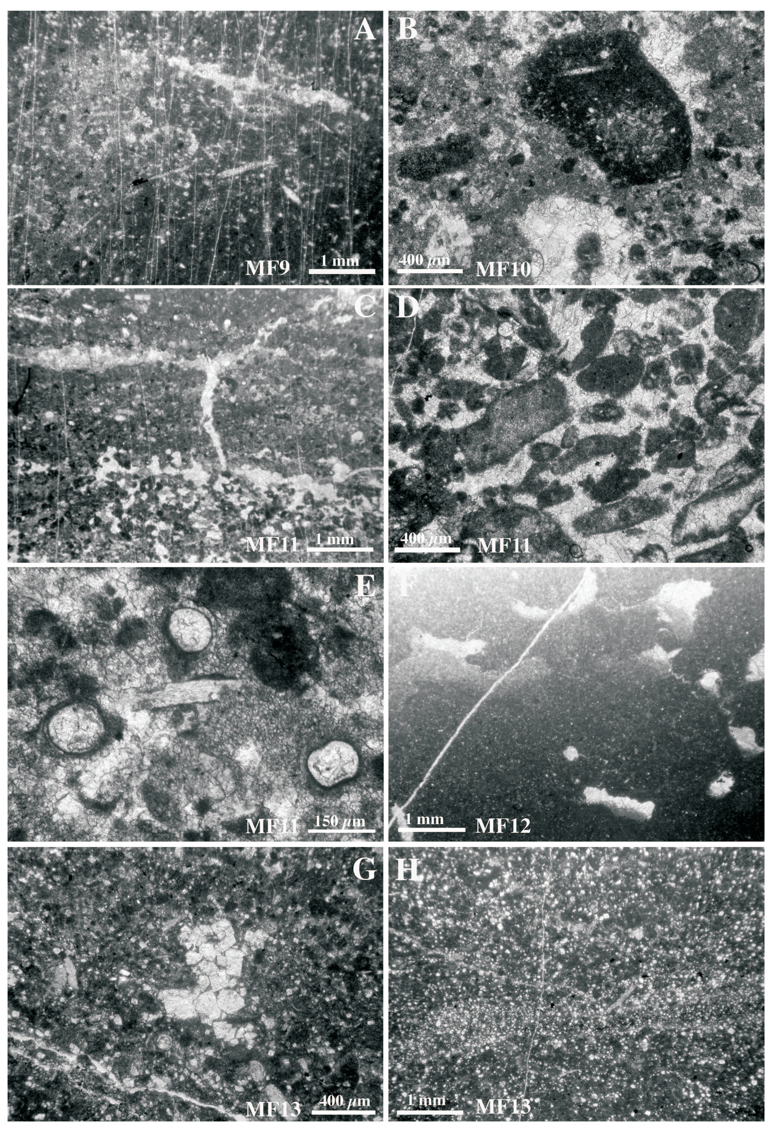

PLATE 8

Plate 6 - Open marine environment. A. Bioclastic (molluscs, ostracodes) 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. Fromelennes Fm. **B, C.** Burrowed bioclastic (echinoderms, molluscs, ostracodes). Blackish zones are spheroidal pyrite dispersed in the micrite (Fig. B). Irregular zones with very coarse grained calcitic microspar and associated pyrite around brachiopods are present (Fig. C). Open-marine environment near the storm-wave base-level. MF1, Nismes Fm. **D.** Bioclastic (brachiopod) burrowed silty wackestone. Open-marine environment near the storm-wave base-level. 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. Nismes Fm. **F, G.** Bioclastic (bryozoans and brachiopods in Fig. F and only brachiopods in Fig. 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. Nismes Fm. **H.** Bioclastic (brachiopods, echinoderms, ostracodes) packstone forming a thin burrowed layer in a fine-grained wackestone. Open-marine environment near the storm-wave base-level (distal tempestite). MF2. Nismes Fm.

Plate 7 - 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. Pyrtic pressure solution seams are abundant between the bioclasts. Open marine fore-shoal near the fair-weather wave-base level. 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. Nismes Fm. **F.** Stromatoporoid floatstone with ostracode and molluscan bioclasts in a wackestone matrix. Slightly agitated peri-reefal environment near a bioconstruction. MF6. Fromelennes Fm. **G, H.** Stromatoporoid floatstone with ostracod, coral, echinodermal (sea urchin spine, Fig. H) and molluscan bioclasts in a packstone matrix. Agitated peri-reefal environment near a bioconstruction. MF6. Fromelennes Fm.

Plate 8 - Restricted lagoonal environments. A. Spiculitic (sponge) wackestone. The calcitic spicules are partly dissolved. Restricted lagoon. MF9. 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. 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. Fromelennes Fm. **D.** Peloidal laminar loferitic packstone with well sorted subrounded lumps and coated grains. Supratidal-intertidal levee-channel in a restricted environment. MF11. Fromelennes Fm. **E.** Calcispherid peloidal microsparitized wackestone with small-sized unrecognizable bioclasts. Restricted lagoonal environment. MF11. Fromelennes Fm. **F.** "Dismicrite" with irregular geopetal loferitc cavities in a homogeneous mudstone. Restricted lagoonal environment. MF12. Fromelennes Fm. **G.** Peloidal dolopackstone with dolomite pseudomorph pobably after a former sulphate mineral. MF13. Fromelennes Fm. **H.** Dolomudstone with idiotopic 20-50 µm dolomite rhombs. Restricted lagoonal evaporitic environment. MF13. Fromelennes Fm.

Magnetic susceptibility

A total of 339 samples were collected for the study of low-field magnetic susceptibility (X_{LF}) in the Sourd d'Ave section. The MS values were measured with a Kappabridge MFK1-A with a CS-3 furnace and CS-L cryogenic apparatus. The MS values range between 6.0 x 10^{-10} m^3/kg and 4.52 x 10^{-7} m^3/kg. The highest X_{LF} values are present in the Fort Hulobiet Mbr and observed at the top of magnetic susceptibility evolutions. A clear decreasing trend of the X_{LF} is discernable at the end of the Fort Hulobiet Mbr and the X_{LF} values remain weaker in the sediments at the base of the Frasnian. Nevertheless, the X_{LF} are quite high and remain around 1 x 10^{-7} m^3/kg throughout the Frasnian. To better constrain and understand the origin of the signal, magnetic mineralogical analyses have been launched through hysteresis measurements and thermomagnetic curves revealing the presence of ferromagnetic *s.l.* and paramagnetic minerals controlling the X_{LF} signal.

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