TRIBUTE TO CHARLES DARWIN AND BERNISSART IGUANODONS:

New Perspectives on Vertebrate Evolution and Early Cretaceous Ecosystems

BRUSSELS 2009

EDITORS: PASCAL GODEFROIT & OLIVIER LAMBERT

TRIBUTE TO CHARLES DARWIN AND BERNISSART IGUANODONS:

New Perspectives on Vertebrate Evolution and Early Cretaceous Ecosystems

BRUSSELS 2009

Programme, Abstracts and Field Trips Guidebook

TAPHONOMY AND SEDIMENTOLOGY OF THE 'BLACK MARBLE' OF DENÉE, A FOSSIL CONSERVATION DEPOSIT FROM THE VISÉAN (MISSISSIPPIAN) OF BELGIUM

Bernard MOTTEQUIN

Unité de Paléontologie animale et humaine, Université de Liège, Bât. B18, Allée du 6 août, B 4000 Liège 1, Belgium, bmottequin@ulg.ac.be

1. Introduction

The localities of Tournai and Visé, respectively the historical type areas of the Tournaisian and Viséan stages (Hance *et al.* 2006a-b), have contributed to the fame of the Lower Carboniferous of the Namur-Dinant Basin [southern Belgium and northern France (Avesnois)] by the great diversity and the abundance of the macrofaunas (see references in Demanet 1958). Nevertheless, their study (except rugose corals and trilobites) has been neglected for many years. In addition to both these well-known fossiliferous localities, the quarries located around the village of Denée (Namur province) (Figure 1) have yielded remarkably preserved but rare fossils (including echinoderms and fishes), which have been collected within the 'black marble' of Denée, a black coloured limestone of early Viséan age.

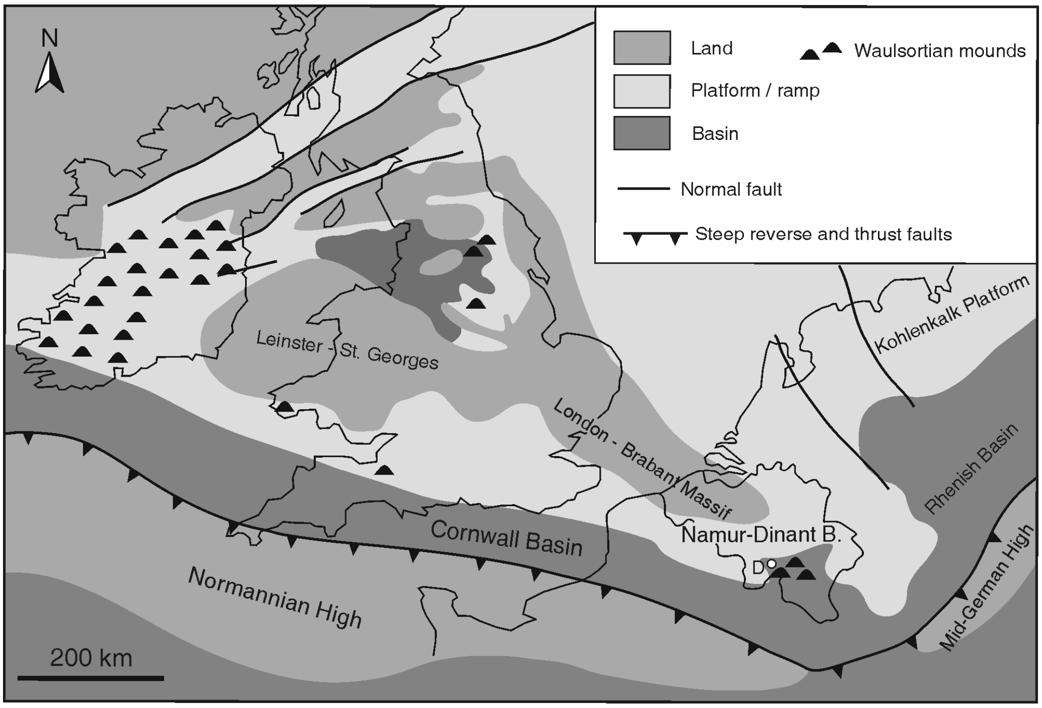

Figure 1. General context of Lower Carboniferous sedimentation in north-western Europe showing the distribution of emergent areas and Waulsortian mounds at the end of the Tournaisian [modified from Ziegler (1990) and Devuyst & Dehantschutter (2007)]. B = Basin; D = Denée.

All the fossils, with few exceptions, were collected at the end of the 19th century and at the beginning of the 20th century by quarrymen when the 'black marble' was intensively and manually quarried. Most of the quarries were subterranean and, nowadays, most of them are disused and flooded. If it had not been worked, the 'black marble' of Denée would have been considered probably as azoic due to the rarity of the fossils. The bulk of the material is deposited at the Maredsous abbey ('Centre Grégoire Fournier'), but additional specimens are housed in the University of Liège, the Royal Belgian Institut of Natural Sciences (Brussels), and the Museum of Comparative Zoology (Harvard). A modern systematic revision is urgently needed for most of the invertebrate phyla; the latest comprehensive list of the faunas dates back to Fournier and Kaisin (1929). As is generally the case with old collections, the origin of the specimens is usually not known with precision, except for some fossils which have a mention of the quarried level ('la Veine', 'les Drîs') on their label. We can suspect that most of the specimens were collected at Denée, from the exploited levels figured by Fournier (*in* Fournier & Pruvost 1928) (Figure 2).

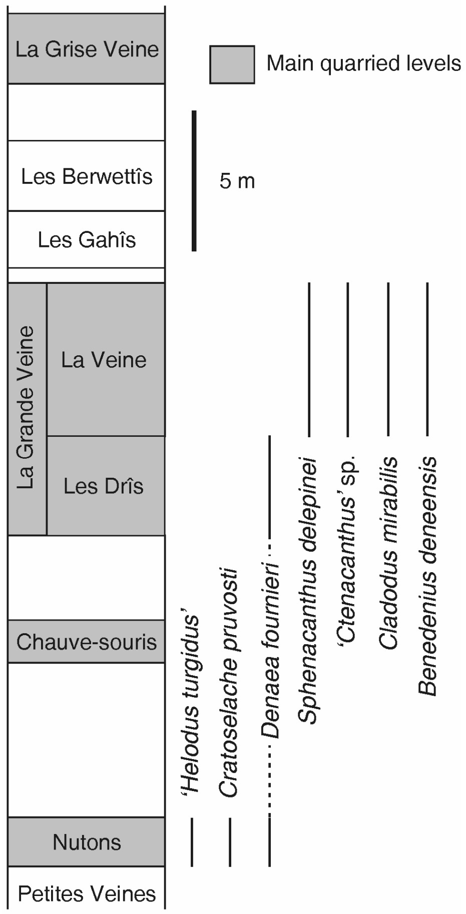

Figure 2. Distribution of fishes within the 'black marble' of Denée (Molignée Formation) as exposed in the quarries of the Denée area [modified from Fournier in Fournier & Pruvost (1928)].

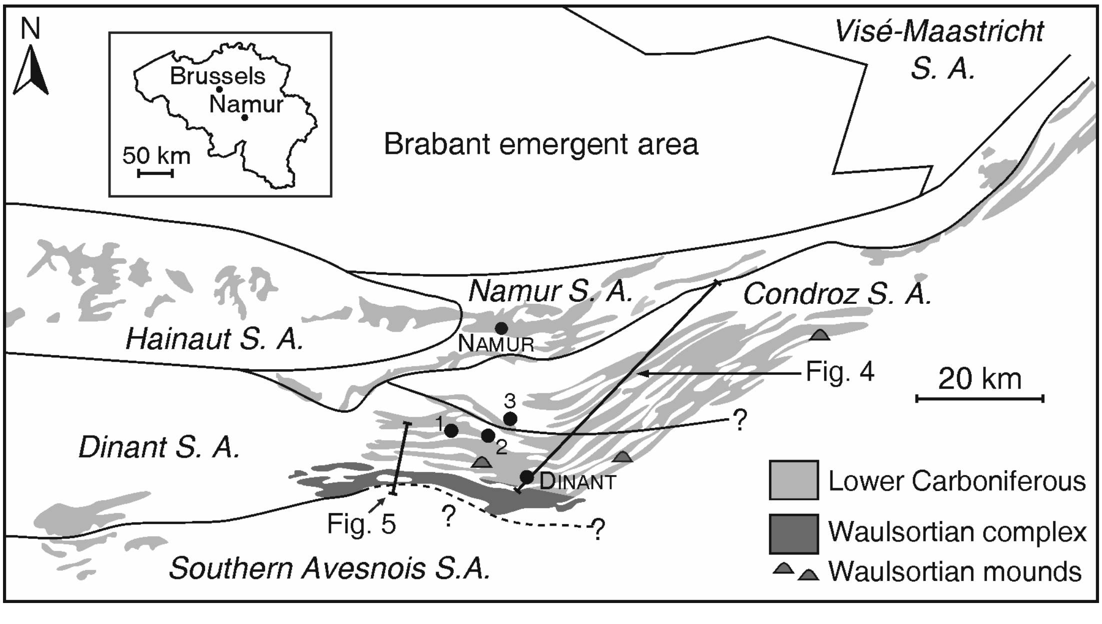

Figure 3. Late Tournaisian sedimentation areas in the Namur-Dinant Basin (not palinspastic) (modified from Poty *et al.* 2006). 1. Denée; 2. Salet; 3. Sovet. S.A. = sedimentation area.

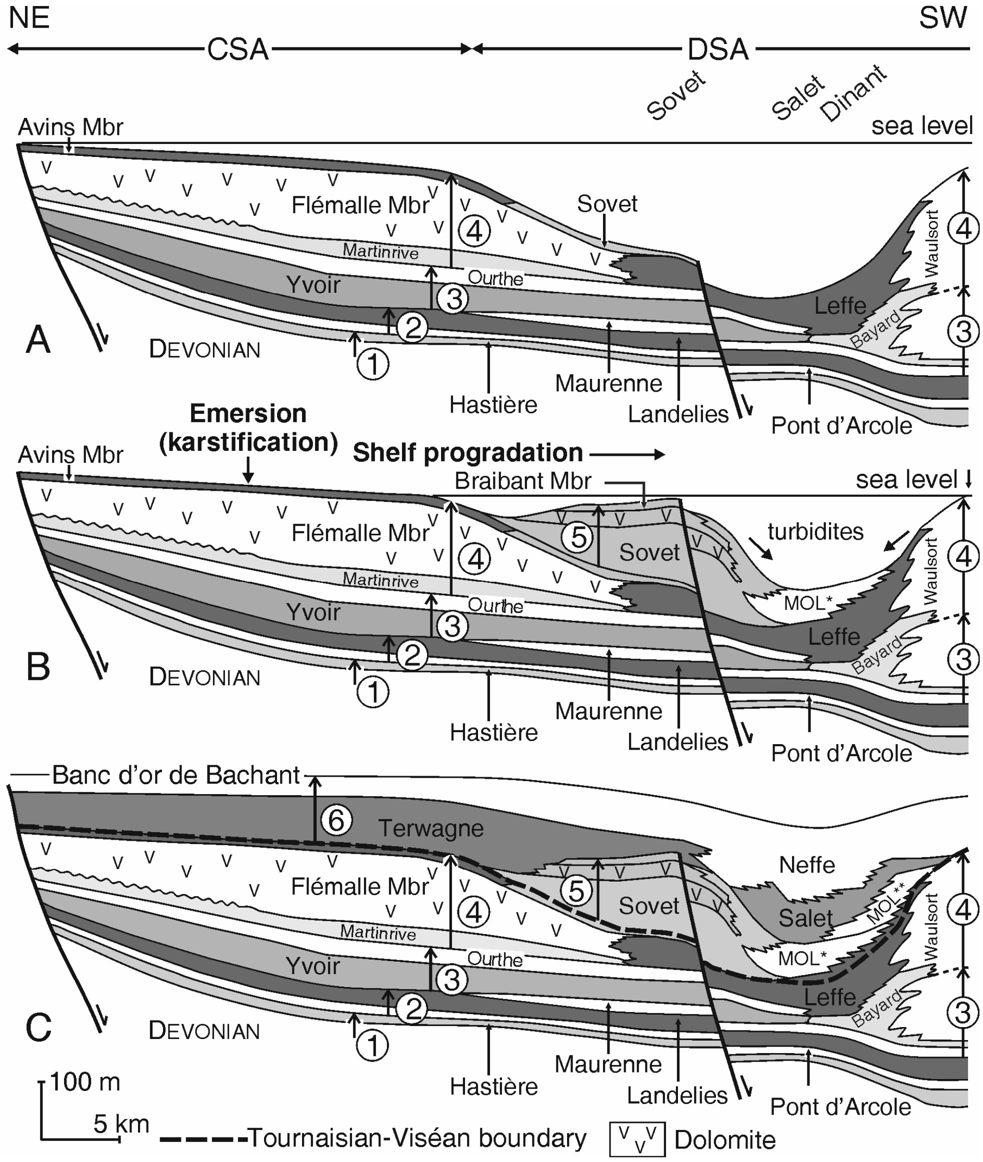

Figure 4. Evolution of the Condroz sedimentation area (CSA) and the Dinant sedimentation area (DSA) during the third-order sequences 4 (**A**), 5 (**B**) and 6 (**C**) (numbered black arrows) [Tournaisian (Ivorian) to Lower Viséan (Moliniacian)] (modified from Hance *et al.* 2001); see also Figure 3. The Banc d'Or de Bachant is a bentonite, locally transformed into a palaeosol (Delcambre 1989). The Longpré Formation includes, from base to top, the Flémalle and the Avins members; the Braibant Member corresponds to the top of the Sovet Formation (Poty *et al.* 2002). Mbr: Member; MOL*: Molignée Formation ('black marble' of Denée); MOL**: Molignée Formation ('black marble' of Dinant).

2. Geological setting

The Namur-Dinant Basin developed on the SSE margin of the London-Brabant Massif (Figures 1 and 3) in a back-arc extensional setting (Hance *et al.* 2001), north of the Ligerian Arc (e.g. Leeder 1988). In the course of late Tournaisian and early Viséan time, the ramp setting that has prevailed since the early Tournaisian progressively evolved to a rimmed-shelf and to a broad flat-topped platform of regional extent during the middle and late Viséan (Hance *et al.* 2006b). On the basis of their lithostratigraphic character, several sedimentation areas have been defined within the Namur-Dinant Basin by Poty (1997) and Hance *et al.* (2001). These are (Figures 3 and 4): 1) the Hainaut sedimentation area was an area in which subsidence allowed accumulation of about 2500 m of Lower Carboniferous rocks, including several thick evaporitic intercalations; 2) the Namur sedimentation area (NSA) characterized by the more proximal facies and the less complete lithostratigraphic succession; 3) the Condroz sedimentation area (CSA) with relatively proximal facies and some sedimentary breaks – it displays southward and southwestwards a transition with the Dinant sedimentation area; 4) the Dinant sedimentation area (DSA) displaying the deepest water facies with the development of carbonate mounds characterised by microbially mediated muds (= Waulsortian mounds; see references in Lees 2006), as well as an almost complete stratigraphic succession; 5) the southern Avesnois sedimentation area (ASA) showing a similar situation to that of the CSA, but with a markedly different lithostratigraphy (shallower water facies); 6) the Visé-Maastricht sedimentation area suffered block faulting during the Devonian and Mississippian. It was connected with the NSA during the Upper Devonian and Tournaisian and evolved to a graben that was open to the Campine Basin during the Viséan (Poty 1997). In Belgium, the absence of Lower Carboniferous exposures south of the DSA, due to post-Variscan erosion, does not allow the precise delineation of the eastern extension of the ASA. However, according to recent investigations of Pirotte (2006), it seems, at least, that the ASA borders the southern margin of the DSA, south of the Waulsortian complex (Figure 5).

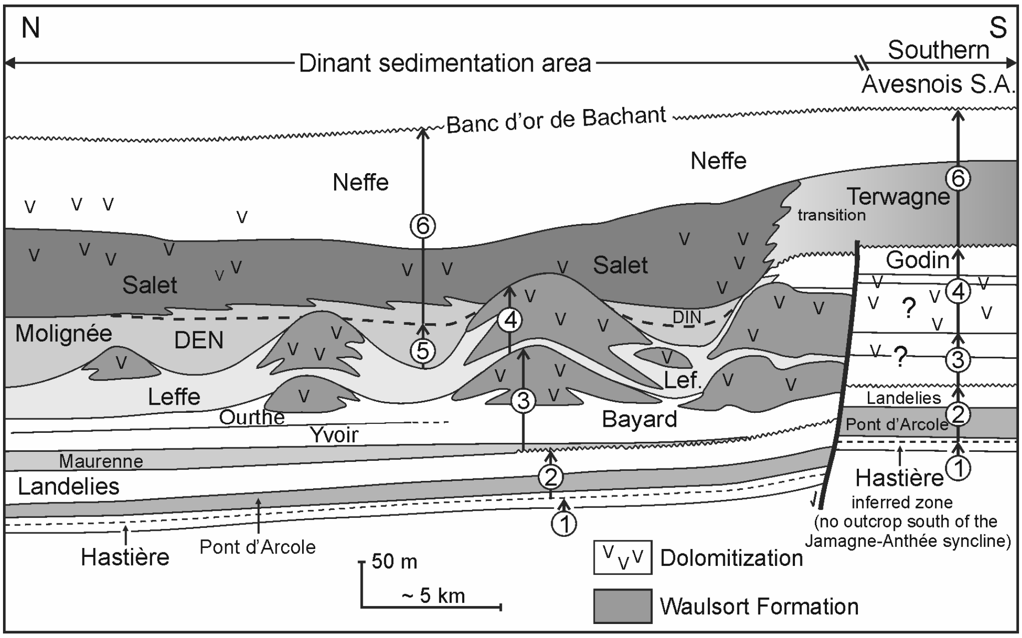

Figure 5. Pirotte's (2006) modified model of stacking of the third-order sequences (numbered black arrows) in the southern part of the Dinant sedimentation area and in the southern Avesnois sedimentation area, from the Lower Tournaisian to Lower Viséan; see also Figure 1. DEN = 'black marble' of Denée; DIN = 'black marble' of Dinant; Lef. = Leffe.

The 'black marble' of Denée was formerly included in the 'black marble' of Dinant ('V1a' of the Belgian authors), but according to Conil (1967), it precedes this latter unit, strictly speaking, on the basis of the foraminifer associations (Figures 4 and 5). Now, both former units are included in the diachronic Molignée Formation (*sensu* Poty *et al.* 2002) of early Viséan age [regional Moliniacian Substage (e.g. Devuyst *et al.* 2006)]. This formation is developed only in the central part of the DSA between the prograding platform and the Waulsortian complex (Hance *et al.* 2001) running along the border between the DSA and the ASA (Figures 3–5). The Molignée Formation consists of a succession of thin-bedded (less than one metre to several metres thick), commonly laminated black limestones which alternate with thick-bedded, dark-grey limestones ('thick beds') (Figure 6). These alternations correspond to the 'polysequences' and 'monosequences' of Mamet (1964). The contacts between both lithotypes are always clear-cut.

The range of the 'black marble' of Denée, in terms of Mississippian Foraminifer Zone (MFZ), spans the interval of the MFZ 9 (upper part) to the MFZ10 according to Devuyst and Hance (*in* Poty *et al*. 2006). In the Salet road section (stratotype of the Molignée Formation), the 'black marble' of Denée begins at bed 191 and ends at bed 273 (Figure 6A); 39 m thick (see Hance (1988), Devuyst *et al.* (2006) and Poty *et al.* (2006) for detailed logs of this section). Thus, it does not correspond completely to the Molignée Formation (from bed 169 to the top of bed 294; *c.* 58 m thick) as redefined by Poty *et al.* (2002).

3. The 'black marble' of Denée, a fossil conservation deposit

Besides numerous ichnofossils (crawling and grazing traces), the 'black marble' of Denée has yielded the following biota: chondrostean and elasmobranch fishes (e.g. Traquair *in* de Koninck 1878; Pruvost *in* Fournier & Pruvost 1922, 1928; Woodward 1924; Derycke *et al.* 1995, Maisey 2007) (Figures 2, 7A–B), echinoids (e.g. Jackson 1929) (Figure 7C–D), ophiuroids (Fraipont 1904) (Figure 7E), crinoids (Fraipont 1904) (Figure 7F), holothuroids (?), dendroid graptolites (e.g. Ubaghs 1941) (Figure 7G–H), rugose (Figure 7I) and tabulate corals, sponges, conulariids, bryozoans, brachiopods (Delépine 1928) (Figure 7J), phyllocarids, trilobites, bivalves (Demanet 1929) (Figure 7K), gastropods, goniatites (Delépine 1940), nautiloids, and floated plant remains. Most of the fossils belong to the autochthonous epibenthos (Mottequin 2004). The echinoid fauna, including the largest and most remarkable Palaeozoic specimens, as well as the fishes, have contributed largely to its fame. Nowadays, it is not possible to sample all the fauna anymore because of the poor exposures of the Molignée Formation. Palaeoecology and taphonomy were studied by Mottequin (2004).

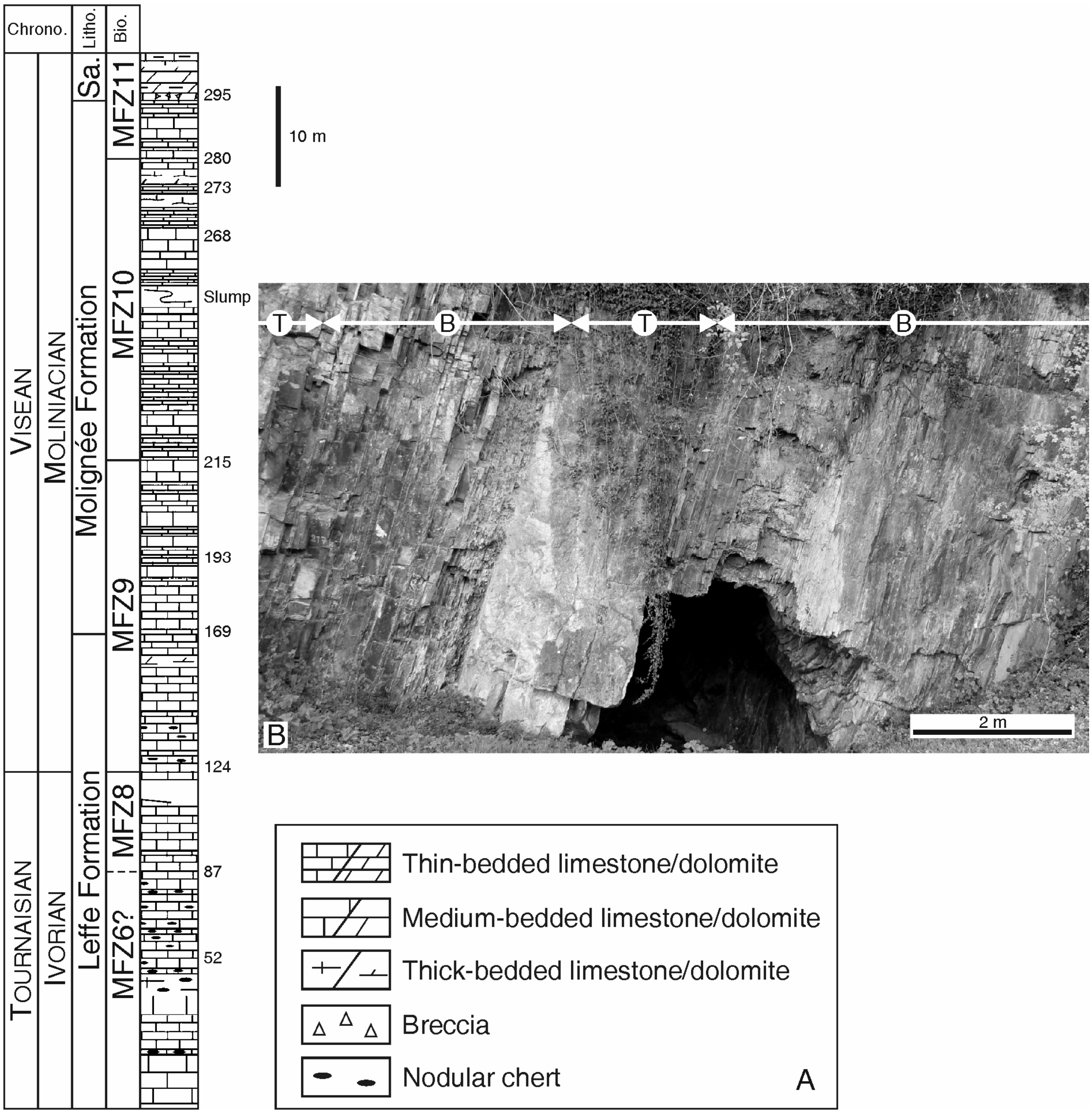

Figure 6. A. Partial log of the Salet road section (stratotype of the Molignée and Salet formations) (modified from Poty *et al.* 2006). Bio. = Biostratigraphy; Chrono. = chronostratigraphy; Litho. = lithostratigraphy; MFZ = Mississippian Foraminifer Zones of Devuyst & Hance (in Poty *et al.* 2006). **B**. Molignée Formation in its stratotype showing the alternating thicker bedded and thinner bedded units. Bed numbers are those of Overlau (1966). B = 'black marble' facies; T = 'thick beds' facies.

During the Moliniacian, the colonization of the sea floor of the central part of the DSA by the benthos and the diversity of the latter were strongly influenced by oxygen concentration. Only some organisms were able to develop in this particular environment. Most of the bivalves belong to the 'paper pecten' morphotype (Figure 7K) which is diagnostic of dysaerobic environments according to Allison *et al.* (1995). Echinoderms, especially the echinoids, seem to have been well adapted to face this poorly oxygenated environment, as indicated by their relative abundance in the collection and their preservation *in situ* (complete tests with spines in anatomical connection). This is not surprising because these organisms are known in upper dysaerobic facies of modern oxygen deficient basins; Savrda *et al.* (1984) reported also ophiuroids, holothuroids, polychaetes, crabs and gastropods in their lower dysaerobic facies. Among brachiopods, representatives of the suborder Productidina predominate in the collection. Some of them have spines of much greater length than the shell bearing them (Delépine 1928) (Figure 7J). These long spines were most probably for support (Brunton & Mundy 1988) and acted as a stabilizing snowshoe to prevent shells from sinking in the muddy substrate (Bowen *et al.* 1974). Their preservation attests to the absence of or only minor transport. Productidina would indicate better oxygenated conditions than those prevailing during the colonization by bivalves and echinoids.

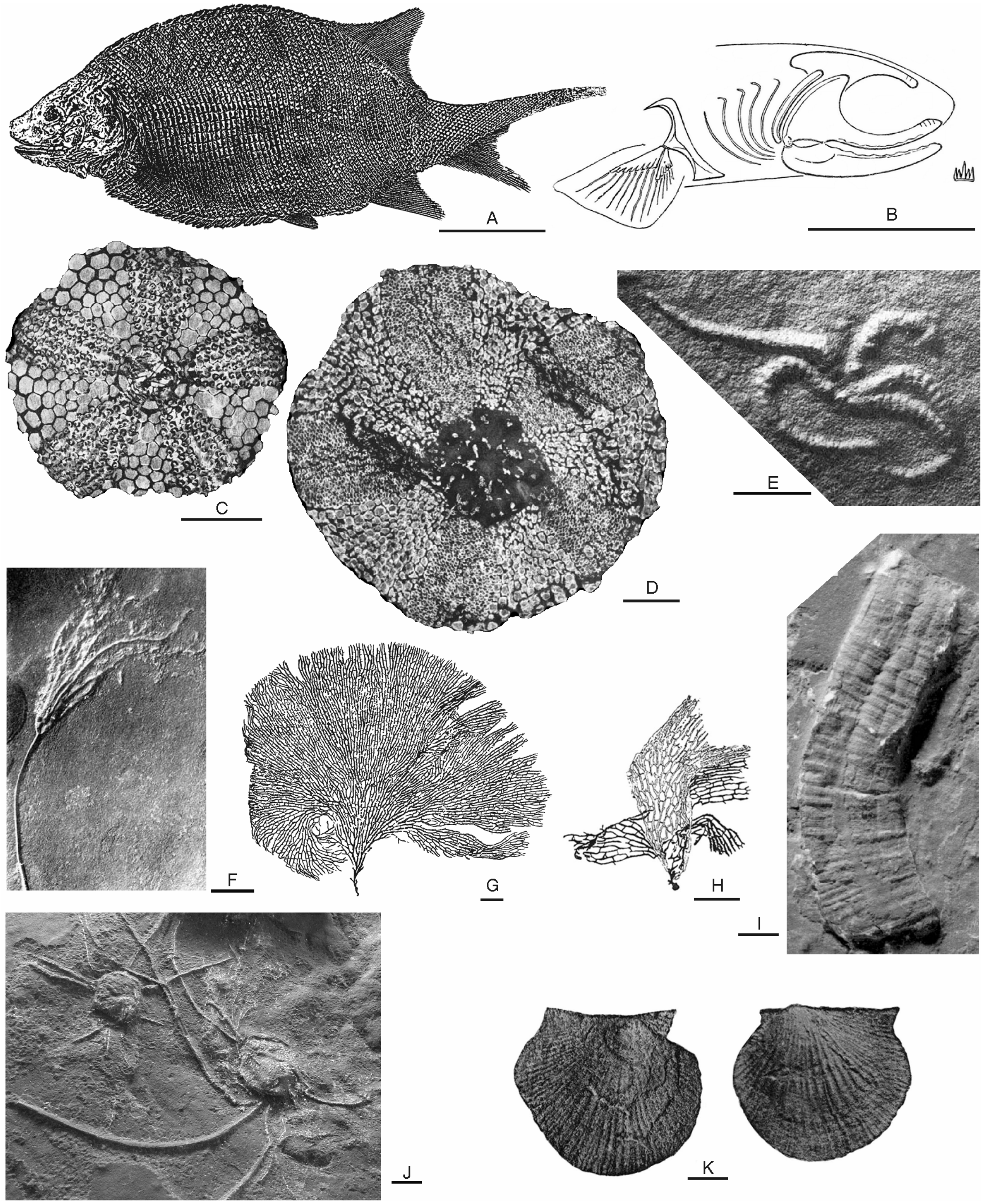

Figure 7. Fossils of the early Viséan-aged 'black marble' of Denée (Molignée Formation). **A.** *Benedenius deneensis* Traquair; **B.** *Denaea fournieri* Pruvost; **C.** *Proterocidaris giganteus* de Koninck; **D.** *Fournierechinus deneensis* Jackson; **E**. *Taeniaster? fournieri* Fraipont; **F.** *Graphiocrinus longicaudatus* (Fraipont); **G.** *Ptiograptus fournieri* Ubaghs; **H.** *Dictyonema fraiponti* Ubaghs; **I.** *Caninophyllum* sp.; **J.** unidentified productid brachiopods; **K.** *'Pterinopecten' dumontianus* (de Koninck). Scale bars are 5 cm for A–D and 1 cm for E–K.

The ‘black marble’ of Denée is a fossil conservation deposit (‘fossil Lagerstätte’; see discussion in Shields 1998), i.e. the skeletons and the tests of organisms are preserved in their entirety. However, soft parts have not really been highlighted with certainty although Van Straelen (1926) described an enigmatic fossil under the name of *Medusina boulengeri* that he interpreted as the mould of the exombrella of a jellyfish. It has been assigned to the Medusae *incertae sedis* by Harrington & Moore (1956), but Mottequin (2004) reinterpreted it as a probable burrow. This hypothesis must be confirmed by X-rays analysis. Exceptional burrows have been recognized within the ‘black marble’ facies such as *Zoophycos*. Rapid burial is considered here as one of the major factor of preservation [‘obrution deposits’ of Seilacher *et al.* (1985)]. It is well exemplified by the excellent preservation of most of the echinoderms. Low oxygen concentrations prevailing within the substrate slowed down the disarticulation of the tests and excluded the eventual predators.

Carpentier (1913) and Jackson (1929) have compared the ‘black marble’ of Dinant with the lithographic limestone of Portlandian age from the Solnhofen area in Germany which is the type of the ‘taphofacies IF: dysoxic/anoxic basin’ of Brett *et al.* (1997) based on echinoderm taphonomy. However, in the case of Denée, the organisms are essentially benthic and generally autochthonous, contrary to the lagoon of Solnhofen, where the benthos was imported during storms and only survived for some days before the re-establishment of hypersaline conditions. The ‘black marble’ is close also to the to obrution deposit typified by the Hunsrück Slate of Emsian age (Brett & Seilacher 1991) and more especially by the locality of Budenbach. Although the faunas of the ‘black marble’ of Denée are not pyritized, the burial of the organisms in the Belgian conservation fossil deposit is approximately the same as in the German locality (Sutcliffe *et al.* 1999). Nevertheless, the environment in Denée may have been less oxygenated as indicated by the presence of bivalves of the ‘paper pecten’ morphotype and the very rare to absent trilobites.

4. Sedimentation in the central part of the part of the Dinant sedimentation during the early Moliniacian

4.1. General context

An important factor that influenced the sedimentation and the palaeoenvironment of the Molignée Formation was the topographic context inherited from the upper part of the Tournaisian. During the Ivorian (Tournaisian), the DSA was characterized by the build-up of large Waulsortian mounds whose maximal development gave rise to a discontinuous barrier in its south-western part (Waulsortian complex) (Lees 1997). At the same time, the ASA recorded a subsidence rate lower than the one of the DSA, from which it was separated by a synsedimentary fault (Pirotte 2006). The end of the Tournaisian, i.e. at the end of the third-order sequence 4 of Hance *et al.* (2001), is marked by a major sea-level drop which induced the emersion of the shallower areas of the Namur-Dinant Basin (karstification of the top of the Avins Member) and the southward progradation of the shelf during the next sequence (sequence 5) (Figure 4B). In the early Viséan (sequence 5) that corresponds to the period of deposition of the Molignée Formation, the central part of the DSA evolved as a residual intra-platform basin bounded by the prograding shelf to the north and the Waulsortian complex built against a major synsedimentary fault to the south. The eustatic magnitude of this sequence was probably low, because, in the Namur-Dinant Basin, it is only recorded in the DSA. In the ASA, the Terwagne Formation (sequence 6) lies directly on the Godin Formation (sequence 4) whereas in the CSA and the NSA, the former caps the Avins Member of the Longpré Formation (Hance *et al.* 2001) that indicates clearly a sedimentary gap (Figure 3). According to Devuyst (2006), it is probable that the top of the Waulsortian complex emerged also, because it was growing in very shallow water at the end of the Tournaisian (Lees 1997), although no trace of such emersion has, however, yet been found. According to Devuyst (2006), this may be the result of the monotonous facies which hinder the recognition of facies variations.

4.2. Microfacies of the Molignée Formation

Among the thin beds (‘black marble’ facies), the dominant microfacies consists of well-sorted and laminar packstones to grainstones composed of calcispherids, peloids, moravamminids, plurilocular foraminifers, algal fragments and other allochems of similar size (Figure 8B–C). By their characteristics (flat parallel laminations, allochems of small dimensions), they have been interpreted previously as distal turbidites by Overlau (1966), which poured out on the marine floor and were intercalated with mudstones with calcispherids and radiolarians (Figure 8A). The packstones-grainstones shift laterally to wackestones-packstones due to the progressive decrease of the turbidity currents. Moreover, the rugose and tabulate corals recovered in the ‘black marble’ are always as reworked fragments which are transported into the basin via the turbidity currents. Numerous skip marks produced by broken shells of gastropods and cephalopods also confirm the existence of bottom currents. The burrows are exceptional (*Zoophycos* sp.; see also section 3). The ‘thick beds’ are mainly composed of bioturbated wackestones to packstones with a high diversity of allochems, among which include as major components: bryozoans, echinoderms, gastropods, ostracods, trilobites, and foraminifers (especially *Tetrataxis*) (Figure 8E). Sponge spicules, algae, *Rectangulina*, *Globochaete*, cephalopods, solitary rugose corals (*Cyathaxonia* sp.), brachiopods, and calcispherids have been also recognized (see section 4.3 for their interpretation). Rudstones (Figure 8D) and grainstones occur at the base of some beds. The microfacies of the 'thick beds' occurring in the Molignée Formation are reminiscent of those of the underlying Leffe Formation (Noël *in* Groessens & Noël 1975), though coated clasts and oncoids are less abundant. According to Lees *et al.* (1977), the carbonate mud of the Leffe Formation is probably derived from the Waulsortian mounds developed in the DSA. However, the Leffe facies has never been identified with certainty in other areas with Waulsortian mounds (Lees 1997). Devuyst (2006) suggested that a large part of the lime mud of the upper part of the Leffe Formation was exported from the mounds when they reached depths at which the accommodation space for aggradation was reduced.

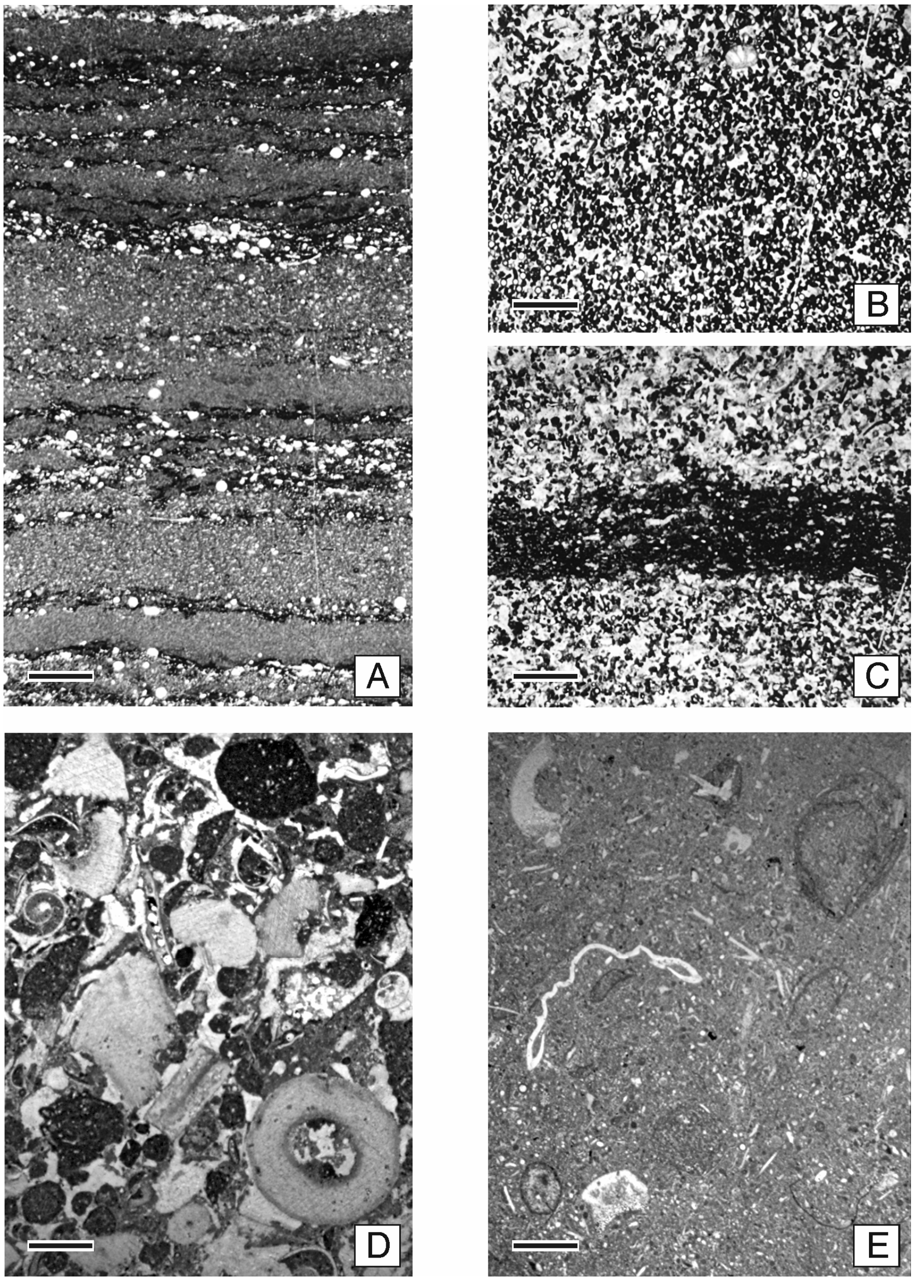

Figure 8. Microfacies of the Molignée Formation in the Denée area; the bed numbers are those of Mottequin (2004). A–C, 'black marble' facies. **A.** Alternation of mudstone, wackestone and packstone with radiolarians, En Gilotia locality in Maredret (bed 8a). **B.** Well-sorted, laminated grainstone with peloids and calcispherids, Debras quarry in Salet (bed 49). **C.** Grainstone with peloids and calcispherids, and packstone with bioclasts, Debras quarry in Salet (bed 2e). D–E, 'thick beds' facies. **D.** Rudstone with lithoclasts, crinoids, bryozoans and peloids, Debras quarry in Salet (bed 27a). **E.** Wackestone with peloids, trilobites, crinoids, bryozoans and mud balls, En Gilotia locality in Maredret (bed 24). All scale bars are 10 mm.

4.3. Palaeoenvironmental interpretation of the Molignée Formation in the Denée-Salet area

The origin of the alternations of ‘black marble’ and ‘thick beds’ facies has been previously interpreted by Mottequin (2004) as shallowing-upwards parasequences with the ‘thick beds’ at their base and the ‘black marble’ facies at their top (Figure 6B); their origin would have been linked to the periodic confinement of the DSA due to sea-level fluctuations. Low oxygen concentrations are suggested by the remarkable preservation of the fauna and the existence of dysaerobic organisms such as the bivalves of the ‘paper pecten’ morphotype. Because of the required depth conditions for the expansion of anoxia in Recent confined basins (Murray *et al.* 1989), Mottequin (2004) suggested that the ‘black marble’ facies would have been developed between 100 and 150 m water depth, whereas the ‘thick beds’ would have been deposited between 150 and 200 m depth. This last estimation used the presence of the plurilocular foraminifer *Tetrataxis* within the ‘thick beds’ which would indicate a depth less than 200 m, according to Lees (1997), as well as the reconstruction of the Namur-Dinant Basin by Hance *et al.* (2001).

The confinement of the central part of the DSA was probably due to minimal sea-level fluctuations, partly induced by glacio-eustasy (see discussion in Mottequin 2008). ‘Spasmodic’ synsedimentary tectonics of the basin may have also influenced the palaeoenvironment. Indeed, two major synsedimentary faults have been inferred previously on the basis of thickness variations of some formations, as well as on sudden facies changes. The first one would have been located in the Sovet area (Figure 4B), but it is believed to have been active at least after the sedimentation of the Braibant Member forming the cap beds of the Sovet Formation (Hance 1988; Hance *et al*. 2001; Devuyst 2006; Poty *et al.* 2006). The second fault delimited the southern part of the DSA and the northern part of the ASA (Pirotte 2006; Figure 5); it appeared probably at the end of the Hastarian when the ASA began to differentiate from the DSA with the appearance of shallower water facies in the former. If both were active during the deposition of the Molignée Formation, the DSA would have thus evolved as a subsiding zone.

Devuyst (2006) recognized three large-scale shallowing-upwards cycles in the stratotype of the Sovet Formation (the lateral equivalent of the Molignée Formation) which he interpreted as reflecting the southwards progradation of the platform margin as successive mega-clinoforms. So, most of the turbidites occurring within the ‘black marble’ facies would originate from the northern part of the DSA, as previously suggested by Hance *et al.* (2001), on the basis of the allochems present in the packstones-grainstones. The turbidites would result from violent storms, earthquakes or clinoform instability due to an oversteepened slope.

The persistence within the Molignée Formation of facies similar to those observed in the Leffe Formation can be partly explained by the fact that the abrasion of the Waulsortian mounds continued after their decay – they stopped growing in the late Tournaisian – and also by the fact that the topography inherited from these buildups remained for a while. Waulsortian mounds are recognized in the Denée-Salet area (e.g. Delcambre & Pingot 2004).

Because of the random mode of dispersion of the turbidites, it is very difficult to correlate the various sections exposing the Molignée Formation in the Denée-Salet area. The microfacies recognized in Denée and Salet are different because Salet occupied a more proximal position. So the wackestones-packstones occurring mainly in Denée have been interpreted as the distal equivalents of the packstones-grainstones that dominated in Salet.

5. Conclusions

The ‘black marble’ of Denée, included within the Molignée Formation of Moliniacian age and developed in the central part of the Dinant sedimentation area (corresponding to an intra-platform basin), is a fossil conservation deposit and belongs more particularly to the ‘obrution deposits’ of Seilacher *et al.* (1985). The turbiditic sedimentation with smothering effect combined with deficient oxygenation of the bottom waters favoured the exceptional preservation of the faunas (e.g. echinoderms, fishes) by inhibiting the development of the necrophagous and saprophagous organisms during the deposition of the ‘black marble’ facies *sensu stricto*. The periodic confinement of the central part of the Dinant sedimentation area was induced by sea-level fluctuations of low magnitude and took place during a third-order sequence characterized by a low sea-level, namely the sequence 5 of Hance *et al.* (2001).

6. References

ALLISON, P.E., WIGNALL, P.B. & BRETT C.E. 1995. Palaeo-oxygenation: effects and recognition. In *Marine Palaeoenvironmental Analysis from Fossils*, BOSENCE, D.W.J. & Allison, P.E. (eds). *Geological Society Special Publication*, 83: 97-112.

BOWEN, Z.P., RHOADS, D.C. & MCALESTER, A.L., 1974. Marine benthic communities in the Upper Devonian of New York. *Lethaia*, 7: 93-120.

BRETT, C.E. & SEILACHER, A., 1991. Fossil Lagerstätten: a taphonomic consequence of event sedimentation. In *Cycles and Events in Stratigraphy*, EINSELE, G., RICKEN, W. & SEILACHER, A. (eds). Springer-Verlag: Berlin; 283-297.

BRETT, C.E., MOFFAT, H.A. & TAYLOR, W.L., 1997. Echinoderm taphonomy, taphofacies, and Lagerstätten. In *Geobiology of Echinoderms*, WATERS, J.A. & MAPLES, C.G. (eds). *The Paleontological Society Papers*, 3: 147-190.

BRUNTON, C.H.C. & MUNDY D.J.C. 1988. Strophalosiacean and aulostegacean productoids (Brachiopoda) from the Craven Reef Belt (late Viséan) of North Yorkshire. *Proceedings of the Yorkshire Geological Society*, 47: 55-88.

CARPENTIER, A., 1913. Contribution à l'étude du Carbonifère du Nord de la France. *Mémoires de la Société géologique du Nord*, 7 (2): 1-434.

CONIL, R., 1967. Problèmes du Viséen inférieur dans le Condroz. *Annales de la Société géologique de Belgique*, 90: B413-B429.

DELCAMBRE, B., 1989. Marqueurs téphrostratigraphiques au passage des calcaires de Neffe vers ceux de Lives. *Bulletin de la Société belge de Géologie*, 98: 163-170.

DELCAMBRE, B. & PINGOT, J.L., 2004. Carte géologique de Wallonie à 1/25.000. Biesme-Mettet 53/1-2 (+ notice explicative). Ministère de la Région Wallonne, Namur.

DELEPINE, G., 1928. Les Brachiopodes du Marbre noir de Dinant (Viséen inférieur). *Mémoires du Musée royal d'Histoire naturelle de Belgique*, 37: 1-39.

DELEPINE, G., 1940. Les Goniatites du Dinantien de la Belgique. *Mémoires du Musée royal d'Histoire naturelle de Belgique*, 91: 1-91.

DEMANET, F., 1929. Les Lamellibranches du Marbre noir de Dinant. *Mémoires du Musée royal d'Histoire naturelle de Belgique*, 40: 1-80.

DEMANET, F., 1958. Contribution à l'étude du Dinantien de la Belgique. *Mémoires du Musée royal d'Histoire naturelle de Belgique*, 141: 1-152.

DERYCKE, C., CLOUTIER, R. & CANDILIER, A.M., 1995. Palaeozoic vertebrates of northern France and Belgium: Part II - Chondrichthyes, Acanthodii, Actinopterygii (uppermost Silurian to Carboniferous). *Geobios*, *Mémoire special*, 19: 343-350.

DEVUYST, F.X., 2006. *The Tournaisian-Viséan boundary in Eurasia. Definition, biostratigraphy, sedimentology and early evolution of the genus Eoparastaffella (foraminifer)*. PhD Thesis, Catholic University of Louvain.

DEVUYST, F.X. & DEHANTSCHUTTER, J.A.E., 2007. Waulsortian carbonate mud-banks, Belgium. In *Facies from Palaeozoic reefs and bioaccumulations*, VENNIN, E., ARETZ, M., BOULVAIN, F. & MUNNECKE, A. (eds). *Mémoires du Muséum national d'Histoire naturelle*, 195: 235-238.

DEVUYST, F.X., HANCE, L. & POTY, E., 2006. Moliniacian. In *Current status of chronostratigraphic units named from Belgium and adjacent areas*, DEJONGHE, L. (ed). *Geologica Belgica*, 9: 123-131.

FOURNIER, G. & KAISIN, F., 1929. Compte rendu de la session extraordinaire de la Société belge de Géologie, de Paléontologie et d'Hydrologie tenue à Yvoir les 19, 20 et 21 septembre 1927. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, 38: 15-45.

FOURNIER, G. & PRUVOST, P., 1922. Découverte d'un Poisson nouveau dans le Marbre noir de Denée. *Bulletin de la Classe des Sciences de l'Académie royale de Belgique* (5ème série), 8: 210-218.

FOURNIER, G. & PRUVOST, P., 1928. Description des Poissons Elasmobranches du Marbre noir de Denée. *Mémoires de la Société géologique du Nord*, 9 (2): 1-21.

FRAIPONT, J., 1904. Echinodermes du Marbre noir de Dinant. *Annales de la Société géologique de Belgique*, Mémoires in-4°, 2: 5-21.

GROESSENS, E. & NOËL, B., 1975. Etude litho- et biostratigraphique du Rocher du Bastion et du Rocher Bayard à Dinant. *International Symposium on Belgian micropaleontological limits from Emsian to Viséan, Namur 1974*, Geological Survey of Belgium, Publication n°15: 1-17.

HANCE L. 1988. Le Moliniacien du Synclinorium de Dinant (Belgique) depuis la région dinantaise jusqu'à la vallée de l'Ourthe. *Mémoires de l'Institut Géologique de l'Université de Louvain*, 34: 1-90.

HANCE, L., POTY, E. & DEVUYST, F.X., 2001. Stratigraphie séquentielle du Dinantien type (Belgique) et corrélation avec le Nord de la France (Boulonnais, Avesnois). *Bulletin de la Société géologique de France*, 172: 411-426.

HANCE, L., POTY, E. & DEVUYST, F.X., 2006a. Tournaisian. In *Current status of chronostratigraphic units named from Belgium and adjacent areas*, DEJONGHE, L. (ed). *Geologica Belgica*, 9: 47-53.

HANCE, L., POTY, E. & DEVUYST, F.X., 2006b. Viséan. In *Current status of chronostratigraphic units named from Belgium and adjacent areas*, DEJONGHE, L. (ed). *Geologica Belgica*, 9: 55-62.

HARRINGTON, B.J. & MOORE, R.C., 1956. Medusae incertae sedis and unrecognizable forms. In *Treatise on Invertebrate Paleontology, Part F, Coelenterata*, MOORE, R.C. (ed). Geological Society of America and Kansas University Press, New York and Lawrence, Kansas: F153-F161.

JACKSON, R.T., 1929. Palaeozoic Echini of Belgium. *Mémoires du Musée royal d'Histoire naturelle de Belgique*, 38: 1-74.

KONINCK, L.G. (de), 1878. Faune du calcaire carbonifère de Belgique. Poissons. *Annales du Musée royal d'Histoire naturelle de Belgique*, 2: 1-152.

LEEDER, M.R., 1988. Recent developments in Carboniferous geology: a critical review with implications for the British Isles and N.W. Europe. *Proceedings of the Geologists' Association*, 99: 73-100.

LEES, A., 1997. Biostratigraphy, sedimentology and palaeobathymetry of Waulsortian buildups and peri-Waulsortian rocks during the late Tournaisian regression, Dinant area, Belgium. *Geological Journal*, 32: 1-36.

LEES, A., 2006. Waulsortian. In *Current status of chronostratigraphic units named from Belgium and adjacent areas*, DEJONGHE L. (ed.). *Geologica Belgica*, 9: 151-155.

LEES, L., NOËL, B. & BOUW, P., 1977. The Waulsortian 'reefs' of Belgium: a progress report. *Mémoires de l'Institut Géologique de l'Université de Louvain*, 29: 289-315.

MAMET, B., 1964. Sédimentologie des faciès 'Marbres noirs' du Paléozoïque franco-belge. *Mémoires du Musée royal d'Histoire naturelle de Belgique*, 151: 1-131.

MAISEY, J.G., 2007. The braincase in Paleozoic symmoriiform and cladoselachian sharks. *Bulletin of the American Museum of Natural History*, 307: 1-122.

MOTTEQUIN, B., 2004. Paléoécologie et interprétation sédimentologique du 'marbre noir' de Denée (Viséen inférieur, Belgique). *Geologica Belgica*, 7: 3-19.

MOTTEQUIN, B., 2008. The 'black marble' of Denée, a fossil conservation deposit from the Lower Carboniferous (Viséan) of southern Belgium. *Geological Journal*, 43: 197-208.

MURRAY, J.W., JANNASCH, H.W. *et al.*, 1989. Unexpected changes in the oxic/anoxic interface in the Black Sea. *Nature*, 338: 411-413.

OVERLAU, P., 1966. *La sédimentation viséenne dans l'Ouest du Hainaut belge*. PhD Thesis, University of Louvain.

PIROTTE, N., 2006. *Etude de la transition entre l''Auge dinantaise' et la 'Ride d'Avesnes' au Dinantien, au bord sud du Synclinorium de Dinant et en Avesnois*. DEA Thesis, University of Liège.

POTY, E., 1997. Devonian and Carboniferous tectonics in the eastern and southern part of the Brabant Massif (Belgium). *Aardkundige Mededelingen, Leuven University Press*, 8: 143-144.

POTY, E., DEVUYST, F.X. & HANCE, L., 2006. Late Devonian and Mississippian foraminiferal and rugose coral zonations of Belgium and Northern France, a tool for Eurasian correlations. *Geological Magazine*, 143: 829-857.

POTY, E., HANCE, L., LEES, A. & HENNEBERT, M., 2002. Dinantian lithostratigraphic units (Belgium). In *Guide to a revised lithostratigraphic scale of Belgium*, BULTYNCK, P. & DEJONGHE, L. (eds). *Geologica Belgica*, 4: 69-94.

SAVRDA, C.E., BOTTJER, D.J. & GORSLINE, D.S., 1984. Development of a comprehensive oxygen-deficient marine biofacies model: evidence from Santa Monica, San Pedro and Santa Barbara Basins, California Continental Borderlands. *American Association of Petroleum Geologists Bulletin*, 68: 1179-1192.

SEILACHER, A., REIF, W.E. & WETSPHAL, F., 1985. Sedimentological, ecological and temporal patterns of fossil-Lagerstätten. In *Extraordinary biotas: their ecological and evolutionary significance*, WHITTINGTON, H.B. & CONWAY MORRIS, S. (eds). *Philosophical Transactions of the Royal Society of London*, 311: 5-23.

SHIELDS G. 1998. What are Lagerstätten? *Lethaia*, 31: 124.

SUTCLIFFE, O.W., BRIGGS, D.E.G. & BARTELS, C., 1999. Ichnological evidence for the environmental setting of the Fossil-Lagerstätten in the Devonian Hunsrück Slate, Germany. *Geology*, 27: 275-278.

UBAGHS, G., 1941. Les Graptolithes dendroïdes du Marbre noir de Denée (Viséen inférieur). *Bulletin de l'Institut royal des Sciences naturelles de Belgique*, 17 (2): 1-30.

VAN STRAELEN, V., 1926. Sur les premiers restes de Méduses trouvés dans le Calcaire carbonifère de la Belgique. *Bulletin de la Classe des Sciences de l'Académie royale de Belgique*, 12: 952-956.

WOODWARD, A.S., 1924. Un nouvel Elasmobranche (*Cratoselache Pruvosti* gen. et sp. nov.) du Calcaire carbonifère inférieur de Denée. Livre jubilaire de la Société Géologique de Belgique, 1: 59-62.

ZIEGLER, P.A., 1990. *Geological atlas of Western and Central Europe (2nd edition)*. Shell Internationale Petroleum Maatschappij B.V., Den Haag, 239 pp.