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# POTENTIAL DISCRIMINATION OF BELGIAN BLACK MARBLES USING PETROGRAPHY, MAGNETIC SUSCEPTIBILITY AND GEOCHEMISTRY*

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*Five varieties of Belgian black marbles are investigated in order to discriminate them. Their age ranges from Frasnian (Golzinne) to Visean (Dinant, Theux, Basècle, Lives). Three methods were used: petrography, magnetic susceptibility and geochemistry of major elements and Rare Earth Elements (REE). The petrographic analyze reveals 16 microfacies reflecting very quiet environments, sporadically perturbed by more energetic phenomena like turbidites or storms. These microfacies are integrated in two depositional models: a quiet offshore setting, below or close to the storm wave base (Salet, Basècles) and a shallow but very restricted zone, protected from waves and currents (Lives and Golzinne). The magnetic susceptibility results show that all the black marbles are characterized by very low, even slightly negative values, except the Golzinne one which shows higher values. Geochemical data allow to discriminate between the Theux black marble (low $SiO_2$ content), and the Basècles samples (low $Al_2O_3$, $K_2O$ and REE contents). These methods could be useful to determine/refine the origin of archaeological stones, even if all these analyses are destructive. Two archeologic samples were investigated in order to identify their possible origin.*

*KEYWORDS:* GOLZINNE, DINANT, THEUX, BASÈCLE, LIVES, FRASNIAN, VISEAN

## INTRODUCTION

The world famous black marbles of Belgium are not marbles in a petrographic meaning. Actually, this concept corresponds to fine-grained, well-cemented Paleozoic limestones, without dots, veins or fossils: this gives as a matter of fact a uniform pure black color, high resistance and makes these rocks finely polishable ("calcaires à grain extrêmement fin, prenant un beau poli et présentant, après cette opération, une teinte uniforme d'un noir profond, sans taches ni veinage d'aucune sorte"; Kaisin, 1934). The black marbles of Belgium never reached higher metamorphic conditions than the anchizone (Fielitz & Mansy, 1999).

The first sedimentological studies dedicated to the black marble facies were completed in the Dinant area by geologists like e.g. Renier (1909) and specially Kaisin (1910, 1928,1934), which

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devoted later several detailed papers on the different varieties of these black marbles. Several generations of geologists further generalized the petrography and depositional history of this particular stone to all the black marbles of Belgium, introducing a certain degree of confusion (Dumon, 1982). To avoid this, in the present paper, the term "black marble" will always be followed by its geographical and geological origin. Specifically, the black marble facies is present in a lot of Belgian Paleozoic limestones, the most worked and known being Dinant (and the close Molignée valley), Namur (with other localities along the Meuse river), Theux, Golzinne and Basècles, stratigraphically ranging between the Frasnian and the Viséan (Groessens, 1981, De Ceukelaire et al., 2014). We shall not consider here the stones of the Tournai region, among them some levels being called "black beds", because they present a rather distinct aspect, specifically when they are weathered, and they followed other historical roads of distribution, along the Schelde valley to the North Sea (Tourneur & Groessens, 2018).

The present paper follows two main objectives. First we aim to synthesize the geological data already bibliographically available for the different Belgian black marbles. Actually, several modern works dedicated to the geology and petrology of these stones were proposed, e.g. by Overlau (Basècles, 1966), Mottequin (Dinant, 2004, 2008, 2015) and Dusar *et al.* (2009 a, b), but however, none of these studies addressed the similarities and/or differences between petrography, geochemistry and depositional environment of the different stones. Second, we provide new accurate geological data (and for the first time geochemistry of REE of the various black marbles) in order to compare/discriminate them, and finally, we propose an identification for two archeological samples.

## HISTORICAL USE

Belgian black marbles are used since the Roman Antiquity, among others for mosaics in black and white, or as decorative material for bathrooms. A recent survey of these Roman uses was presented by Dreesen *et al.* (2018), with a short synthetic petrographic atlas (Dreesen *et al.*, 2018, fig.2) and a synthesis of petrographic characteristics of the main varieties (Dreesen *et al.*, 2018, table 2). According to these authors, "The Romans were the first to extract and use 'Belgian black marbles' for decorative purposes, e.g. in floor decorations, funerary objects, etc. "Indeed, around Namur, funeral stones with carefully carved inscriptions are rather frequently found in excavations. Their smooth surfaces, today of grey color, were probably originally polished

Table 1 *Content (%) of major elements in the Belgian black marbles. LOI = lost of ignition*

| *Site* | | *$SiO_2$* | *$Al_2O_3$* | *$Fe_2O_3$* | *MgO* | *CaO* | *$K_2O$* | *LOI* |
|---|---|---|---|---|---|---|---|---|
| Basècles | average | 4.34 | 0.35 | 0.13 | 1.19 | 52.62 | 0.06 | 40.87 |
| | std dev. | 0.86 | 0.10 | 0.04 | 0.55 | 1.23 | 0.02 | 0.23 |
| Golzinne | average | 3.58 | 1.00 | 0.42 | 1.56 | 51.38 | 0.35 | 40.78 |
| | std dev. | 0.44 | 0.17 | 0.04 | 1.07 | 1.46 | 0.05 | 0.35 |
| Lives | average | 4.38 | 0.92 | 0.24 | 0.55 | 51.95 | 0.16 | 41.12 |
| | std dev. | 1.02 | 0.38 | 0.08 | 0.15 | 0.98 | 0.06 | 0.44 |
| Salet | average | 5.26 | 0.92 | 0.38 | 0.67 | 52.16 | 0.28 | 39.64 |
| | std dev. | 3.25 | 0.90 | 0.35 | 0.14 | 2.73 | 0.28 | 2.33 |
| Theux | average | 0.81 | 0.31 | 0.15 | 0.33 | 54.77 | 0.04 | 42.54 |
| | std dev. | 0.25 | 0.21 | 0.06 | 0.14 | 1.12 | 0.01 | 0.76 |

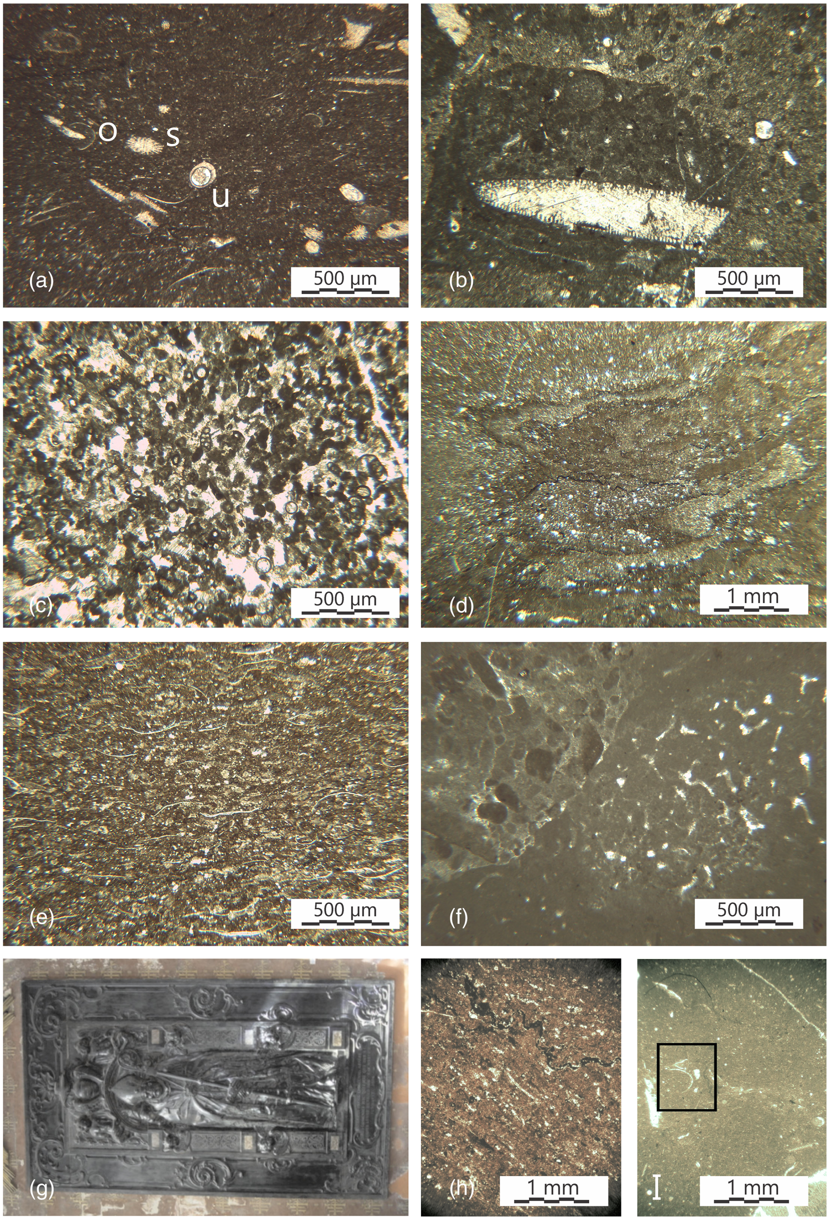


Plate 1 *A: mudstone with Umbella (u), echinid spines (s) and ostracods (o) (Golzinne, MFG1, sample GOL61d). B: wackestone with lithoclasts and peloids; the 1 mm large lithoclast includes an echinid fragment (Salet, MFS2, sample SAL195). C: laminated grainstone with calcispheres, peloids, foraminifers and paleosiphonocladales (Salet, MFS4, sample SAL226). D: laminated argillaceous mudstone with micro-folded slump structures (Basècles, MFB1, sample POE397). E: argillaceous packstone with ostracods, radiolarians and bioclasts (Theux, MFT1, sample THX14). F: left: wackestone with rounded lithoclasts and peloids; right: mudstone with vermicular structures (Lives, MFL4, sample LIV7b). G: funeral monument for Emeric Schillinck, eulogist of the former cathedral Saint-Lambert of Liège. H: argillaceous mudstone with bioclasts, sample ML101. I: mudstone-wackestone with brachiopods (squared) and Umbella, sample RF560. All the pictures were taken on a Zeiss photomicroscope, with a Moticam 10MP camera (natural light). [Colour figure can be viewed at wileyonlinelibrary.com]*

into a shining black. From the early Middle Ages, not many objects remained in this kind of stone, with one major exception: the epitaph of Adrian the First in Rome. Preserved in the portico of the Saint-Pieter basilica but in a rather high position, it was recently studied in detail (Story *et al*., 2005). Different geological analyses confirmed that this large black stone, with exquisite epigraphy, was coming from the Meuse region, which also constitutes the birthplace of the Carolingian family. This famous epitaph was indeed offered by Charlemagne himself after the death of the pope in 798.

During the Middle Ages, black marbles were used to produce objects of high added value, like monumental sculpture, baptismal fonts, tombs of different typologies and columns of diverse dimensions, with a round or octagonal profile (Tourneur, 2012). The production is traditionally supposed to come from two different extractive basins, close to important rivers, transportation of heavy material like stone being then operated mainly by boat. The Scaldian basin around Tournai was a major center for stony products, but it is not considered here, because the Lower Carboniferous rocks of Tournai are easy to distinguish in petrography and geochemistry (with high content of insoluble material) and also because the dark beds of Tournai do not take a shining polish and remain of dark grey, anthracite color. The Mosan production is of equivalent importance, but quarries were active both in Namur and in Dinant, so in different marble types, as demonstrated by the few petrographic analyses of these museum objects (Tourneur, 2007). Art historians frequently use stylistic arguments to distinguish Escaut and Meuse but these latter mentioned that geological data are frequently lacking and samples impossible to collect. Calcimetric methods were tried to make difference between the two main regions but results remained somewhat approximate (Tollenaere, 1957).

Since the $16^{th}$ c., exportation became even wider, reaching Mediterranean basin but also countries around the Baltic, following the Hanseatic network, as Dinant was the southernmost Hanse town (Tourneur, 2017). The great Flemish designer Cornelis Floris imposed a mixture of three colors for liturgical or secular furnishing – black, red and white, the two firsts being “Belgian black and red marbles”, the last white crystalline marble from Carrara, pale alabaster or white chalky limestone from Northern France. This “trichromy” was very frequent until the end of $18^{th}$ c. In the same time, black marbles were always used for funeral objects and also very frequently as floor elements, alone or in checkerboard with other materials.

In $19^{th}$ c., progress in engineering allowed to find solution for the water problem, most of the deposits being in aquifer situation, dewatering was very difficult before introduction of steam engines and later of electricity (Doperé, 2015). Many quarries, both open air and underground, were consequently strongly developed, the production technology being itself highly improved, notably sawing machines allowing thin slabs of marble. Transportation methods were also developed, what increased exportation, even to distant countries like North and South America. The market crash of 1929, following the Great War, somewhat decreased this important flow, as introduction of new artificial materials, some of them imitating black marble. Today, in Belgium, only one underground quarry is still active in Golzinne, with a limited but high-valued production of a pure black marble, unique in the world by its silky darkness.

## METHODS

Three methods were used in this study: petrography (microfacies analysis), magnetic susceptibility (MS) and geochemistry of major elements and REE by FUS-MS (Fusion Mass Spectrometry).

Microfacies analysis came from the detailed bed-by-bed study of five outcrops (Basècles, Salet, Golzinne, Lives and Theux) and 190 thin sections. The maximum interval between two samples is 1 m. For each sample, the microfacies was determined and magnetic susceptibility measurements were performed. The textural classification used to characterize microfacies follows Dunham (1962) and Embry and Kolvan (1971).

Magnetic susceptibility (MS) is a measure of the material response to an applied magnetic field (Borradaile, 1988). Volume magnetic susceptibility (k) is defined as the ratio of induced magnetization intensity (M) per unit volume of a substance, to strength of the applied magnetic field (H) inducing the magnetisation: $k = M/H$. It is important to note that what we measure here is induced magnetization as opposed to residual (or fossil) magnetization related to Earth magnetic field. Magnetic susceptibility of a rock depends on the mineralogical composition of the rock and proportion of each mineral. There are three main magnetic behaviours: diamagnetic minerals show extremely weak negative values of MS (carbonates and quartz), paramagnetic minerals show weak positive values (clay minerals, pyrite), and ferromagnetic minerals show high and positive values (mainly magnetite) (Walden et al., 1999). The MS signal in marine sedimentary rocks is carried mainly by detrital minerals (mainly ferromagnetic and paramagnetic minerals) whose concentration is related to the lithogenic fraction (continental contribution) that are related to eustatic, climatic and tectonic variations (Ellwood et al., 1999). The measurements performed in our lab correspond to mass-specific magnetic susceptibility expressed in $m^3/kg$. Measurements were performed on the KLY-3S Kappabridge of the University of Liège. Three measurements were made on each sample weighed with a precision of 0.01 g.

Samples for geochemical analyses were prepared at the University of Namur and analyses were carried out at the Activation Laboratories Ltd (Actlabs, Ontario, Canada). Samples were crushed with a RETSCH PM 100 planetary ball mills (University of Namur) in order to obtain the maximum 125 µm grain size. Major elements ($SiO_2$, $Al_2O_3$, $Fe_2O_3$, MnO, MgO, CaO, $Na_2O$, $K_2O$, $TiO_2$, $P_2O_5$) and Lost of Ignition (LOI) were analyzed by Fusion Inductively Coupled Plasma Optical Emission Spectrometry (FUS-ICP) using Varian Vista 735 ICP. REE were analyzed by Fusion Mass Spectrometry (FUS-MS) using Perkin Elmer Sciex Elan 9000 ICP-MS. REE contents were normalized to those of the PAAS (Post Archean Australian Shale; Taylor and McLennan, 1985). Cerium anomaly (Ce*) is calculated following the recommendations of Akagi & Masuda (1998).

## GEOLOGICAL CONTEXT AND PREVIOUS WORKS

The Belgian black marbles stratigraphically range from the Frasnian (Upper Devonian) to the Visean (Middle Mississippian). During this period, the regional seascape follows the east–west trending southern coast of the Old Red Continent, which was bathed by the northern Rheic Ocean (Boulvain & Vandenberghe, 2017). The spectacular development of carbonates was probably related to a warmer climate at this time (Belgium was situated between the Equator and the Capricorn tropic). During the Frasnian, the black marble of Golzinne was deposited in the northernmost part of the sedimentation area, resting on the Lower Paleozoic Brabant massif (Fig. 1). During the end of the Upper Devonian (Famennian), carbonates were temporarily replaced by detrital sediments. The Lower and Middle Mississippian sedimentation (Tournaisian-Viséan) marks a return to marine carbonate sedimentation. A dramatic decrease of detrital supply favored the resumption of the carbonate factory, and a large carbonate platform subsequently developed south of the Brabant massif (Fig. 1). This platform was divided into several sedimentation areas (Condroz, Dinant,

Table 2 *Content (ppm) and normalization to PAAS (Post Archean Australian Shales) of REE in the Belgian black marbles*

*NORMALIZED DATA*

| *PAAS value (ppm)* | | *38* | *80* | *8.9* | *32* | *5.6* | *1.1* | *4.7* | *0.77* | *4.4* | *1* | *2.9* | *0.41* | *2.8* | *0.43* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Analyse Symbol* | *Site* | *La* | *Ce* | *Pr* | *Nd* | *Sm* | *Eu* | *Gd* | *Tb* | *Dy* | *Ho* | *Er* | *Tm* | *Yb* | *Lu* | *La/Yb* | *Ce/Ce** |
| BAS 379 | Basècles | 0.04 | 0.03 | 0.03 | 0.04 | 0.07 | 0.05 | 0.06 | 0.06 | 0.07 | 0.06 | 0.06 | 0.08 | 0.08 | 0.07 | 0.48 | 0.80 |
| BAS 409 | Basècles | 0.03 | 0.02 | 0.02 | 0.03 | 0.04 | 0.06 | 0.05 | 0.04 | 0.03 | 0.03 | 0.03 | 0.05 | 0.05 | 0.05 | 0.47 | 0.97 |
| BAS 410 | Basècles | 0.04 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.08 | 0.07 | 0.59 | 0.77 |
| BAS 431 | Basècles | 0.03 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.07 | 0.06 | 0.05 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.74 | 0.76 |
| BAS POE 322 | Basècles | 0.03 | 0.02 | 0.02 | 0.03 | 0.04 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.71 | 0.59 |
| GOL 25 | Golzinne | 0.07 | 0.07 | 0.07 | 0.08 | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 | 0.07 | 0.07 | 0.08 | 0.07 | 0.05 | 1.05 | 0.92 |
| GOL 36 | Golzinne | 0.08 | 0.08 | 0.08 | 0.08 | 0.11 | 0.14 | 0.09 | 0.09 | 0.08 | 0.06 | 0.07 | 0.08 | 0.08 | 0.08 | 1.02 | 0.96 |
| GOL 53 | Golzinne | 0.07 | 0.07 | 0.06 | 0.08 | 0.10 | 0.11 | 0.08 | 0.08 | 0.08 | 0.06 | 0.06 | 0.08 | 0.07 | 0.07 | 1.03 | 0.98 |
| GOL 61D | Golzinne | 0.10 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.09 | 0.12 | 0.12 | 0.10 | 0.09 | 0.11 | 0.11 | 0.09 | 0.87 | 0.95 |
| GOL 71B | Golzinne | 0.09 | 0.06 | 0.09 | 0.10 | 0.11 | 0.13 | 0.12 | 0.09 | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 | 0.07 | 1.18 | 0.66 |
| LIV 03 | Lives | 0.05 | 0.04 | 0.05 | 0.05 | 0.08 | 0.08 | 0.07 | 0.08 | 0.08 | 0.07 | 0.07 | 0.08 | 0.06 | 0.06 | 0.76 | 0.93 |
| LIV 07B | Lives | 0.06 | 0.04 | 0.06 | 0.06 | 0.09 | 0.12 | 0.13 | 0.13 | 0.12 | 0.10 | 0.10 | 0.12 | 0.12 | 0.10 | 0.49 | 0.72 |
| LIV 11A | Lives | 0.19 | 0.16 | 0.15 | 0.16 | 0.18 | 0.14 | 0.25 | 0.23 | 0.25 | 0.22 | 0.23 | 0.23 | 0.21 | 0.22 | 0.90 | 0.90 |
| LIV 21A | Lives | 0.04 | 0.04 | 0.04 | 0.04 | 0.06 | 0.08 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.05 | 0.71 | 0.91 |
| LIV 26 | Lives | 0.07 | 0.07 | 0.07 | 0.08 | 0.10 | 0.10 | 0.10 | 0.08 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.09 | 0.69 | 0.97 |
| SAL 198 | Salet | 0.10 | 0.03 | 0.07 | 0.09 | 0.12 | 0.17 | 0.18 | 0.14 | 0.15 | 0.15 | 0.18 | 0.19 | 0.15 | 0.14 | 0.65 | 0.38 |
| SAL 205 | Salet | 0.08 | 0.07 | 0.08 | 0.09 | 0.11 | 0.15 | 0.12 | 0.12 | 0.12 | 0.10 | 0.10 | 0.12 | 0.12 | 0.10 | 0.71 | 0.86 |
| SAL 213 | Salet | 0.14 | 0.04 | 0.10 | 0.13 | 0.14 | 0.15 | 0.22 | 0.23 | 0.26 | 0.24 | 0.26 | 0.27 | 0.25 | 0.24 | 0.56 | 0.33 |
| SAL 218 | Salet | 0.16 | 0.14 | 0.15 | 0.16 | 0.19 | 0.16 | 0.23 | 0.21 | 0.23 | 0.20 | 0.21 | 0.22 | 0.20 | 0.18 | 0.79 | 0.91 |
| SAL 220 | Salet | 0.20 | 0.18 | 0.19 | 0.20 | 0.25 | 0.18 | 0.28 | 0.29 | 0.29 | 0.26 | 0.30 | 0.32 | 0.28 | 0.27 | 0.70 | 0.95 |
| THX 02 | Theux | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.94 | 0.76 |
| THX 05 | Theux | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.79 | 0.72 |
| THX 136 | Theux | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.71 | 0.93 |
| THX 14 | Theux | 0.06 | 0.05 | 0.05 | 0.06 | 0.05 | 0.05 | 0.07 | 0.06 | 0.07 | 0.06 | 0.07 | 0.08 | 0.08 | 0.07 | 0.73 | 0.91 |
| THX 19 | Theux | 0.08 | 0.07 | 0.07 | 0.08 | 0.08 | 0.08 | 0.10 | 0.09 | 0.10 | 0.08 | 0.08 | 0.10 | 0.10 | 0.08 | 0.81 | 0.94 |

Hainaut, Namur, Visé, cf. Hance et al., 2001) with different types of limestones and various thicknesses. The Basècles, Dinant, Lives and Theux black marbles are part of this series. In the next paragraphs, previous works and refined geological context will be supplied for the different types of marbles, according to their stratigraphic position.

### *The black marble of Golzinne*

Limestones were exploited around the Orneau valley and the village of Mazy since at least the Middle Ages, for building elements, such as rubble stone (observed among others in the ruins of the Villers abbey). Already known as decoration material in the $17^{th}$ c., the black marble of Golzinne (or Mazy) started to be exploited intensively at the beginning of $19^{th}$ c. and expanded at about 1850, as a consequence of underground mining of very regular beds, first with galleries than with wells. From this date, tens of exploitations opened but many were subsequently abandoned because of difficulties with evacuation of fatal water. Nowadays, only the Merbes-Sprimont company is still active close to the small village of Golzinne, between Bossière and the Orneau valley (Fig. 2A).

The black marble of Golzinne is the stratigraphically oldest worked in Belgium (Netels, 1989). It belongs to the Frasnian Rhisnes Formation (60–90 m thick), dominated by nodular limestone whose Golzinne Member represents a dark limestone unit mainly observed in the Orneau area (northwestern part of the Brabant parautochton). The Rhisnes Formation pass laterally eastwards to the Huccorgne Formation. The lateral extension of the Golzinne Member is not known but seems to be close to 20 km (between Emines and Tongrinnes). Very few macrofossils are known from this black marble: Dumon (1933) reported very uncommon colonial corals.

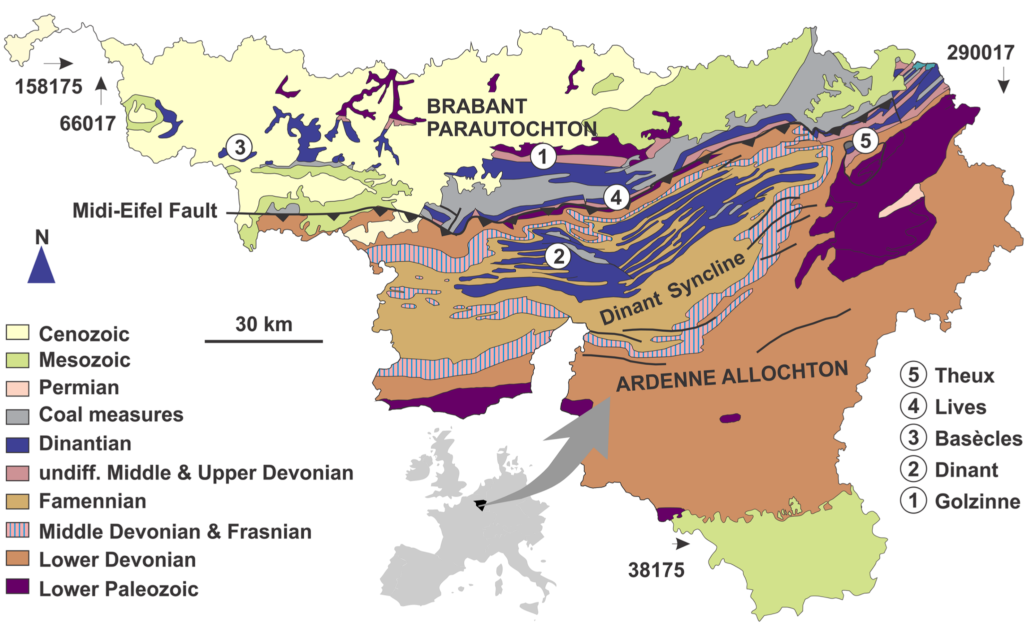


Figure 1 *Geological context and location of the black marble outcrops on the geological map of Wallonia. XY = Belgian Lambert coordinates [Colour figure can be viewed at wileyonlinelibrary.com]*

Table 3 *Main petrographical characteristics of the black marbles. M = mudstone, W = wackestone, P= packstone and G= grainstone*

| | *Textures* | *Main sedimentary structures* | *Main indigenous fossils* | *Main transported fossils* |
|---|---|---|---|---|
| Golzinne | M, W, P, G | Vertical burrows, lithoclasts | Gastropods, echinoderms, ostracods, algae, bivalves | Bryozoans, trilobites, crinoids |
| Dinant | M, W, P, G | Turbidites, lithoclasts | Sponges, ostracods, brachiopods, foraminifers, crinoids, bivalves, bryozoans | Calcispheres, algae, oncoids, corals, gastropods |
| Basècles | M, W, P, G | Turbidites, lithoclasts, slumps, breccia | Radiolarians, brachiopods, ostracods, foraminifers | Calcispheres, algae, bivalves |
| Theux | M, W | Slumps, laminae, storm deposits | Radiolarians, ostracods, brachiopods, sponges | Algae |
| Lives | M, W, P, G | Fenestrae, lithoclasts | Algae, oncoids, calcispheres, microbial mats, sponges | Corals, foraminifers, ostracods, trilobites, crinoids, bivalves |

The first sedimentological model was published by Dumon (1933), after the pioneer works of Kaisin. He proposed that the lime mud at the origin of the black marble settled in an embayment, close to the Brabant massif. According to Mamet (1964) who studied the different outcrops, the black marble unit is 22-m-thick. This author assigned the confined character of the sedimentation to a rapid subsidence, balanced by an active shallow sedimentation.

### *The black marble of Dinant*

The black marble of Dinant (or Salet, Denée) has probably been exploited for the longest time. Historiography of this remarkable material was recently established (Dubois, 2018) and its economic and artistic history is rather well known, in comparison with others. This marble crops out in the Dinant Synclinorium (Ardenne allochton) and belongs to the 10 m to-100 m-thick Visean Molignée Formation (sub-stage Moliniacian). The Molignée Formation was deposited in the Dinant sedimentation area. The key exploitations were located first around the town of Dinant, then in Salet and Denée, in the Molignée valley (Fig. 2B). Fossils are scarce but remarkable by their very good preservation and diversity (fishes, arthropods, mollusks, bryozoans, echinoderms, corals, brachiopods, sponges, fragments of terrestrial plants, algae). Actually, the black marble of Dinant is a fossil conservation deposit, that is the skeletons and the tests of organisms are preserved in their entirety. A large collections of fossils is preserved in the Benedictine abbey

Table 4 *Discriminating main petrographical, MS and geochemical differences between the five Belgian black marbles*

| | |
|---|---|
| Golzinne | Restricted shallow fossil community, highest MS |
| Salet | Offshore fossil community, turbidites, relatively high $Al_2O_3$, $K_2O$ and REE contents |
| Basècle | Offshore fossil community, turbidites, relatively low $Al_2O_3$, $K_2O$ and REE contents |
| Theux | Offshore fossil community, relatively low $SiO_2$ content |
| Lives | Restricted shallow fossil community, low MS |

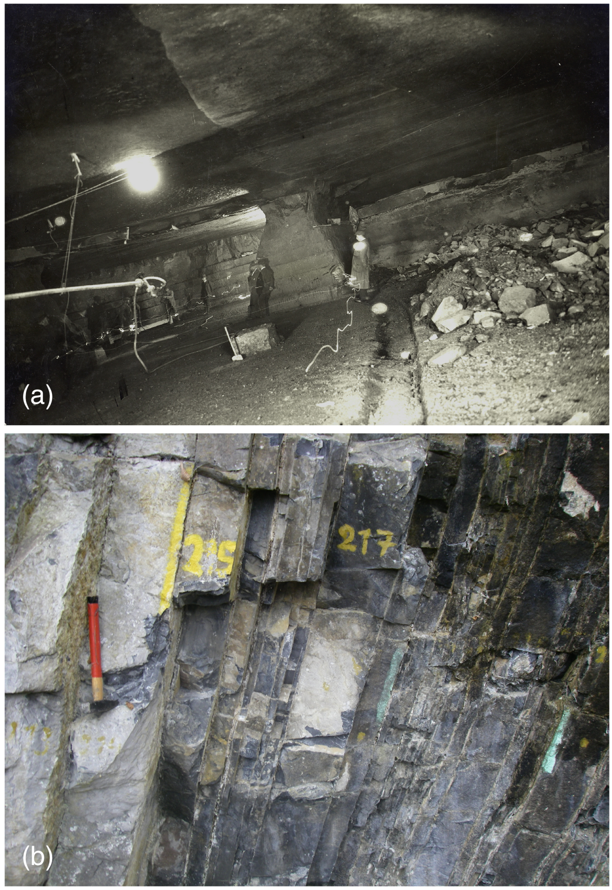


Figure 2 *A: the underground black marble quarry in Mazy (1929). B: Field picture of the black marble of Dinant in the Salet road section. Hammer for scale [Colour figure can be viewed at wileyonlinelibrary.com]*

of Maredsous (Mottequin *et al.,* 2015). The most common accessory minerals include fluorine and pyrite (Fournier, 1928).

As the most known black marble, the Dinant black marble has fed many sedimentological models. Renier (1909), after discovering fossil plants in the black marble, proposed a very quiet, organic rich (sapropelic) littoral environment. This model was confirmed by Kaisin (1910) who found organic rich clay seams and breccia levels in the black marble unit and Salée (1911) who focused on coral fossils crushed by compaction. For de Dorlodot (1911), the depositional environment should have been very quiet but far from the littoral zone. He generalized later his theory to all the Belgian black marbles. In 1934, Kaisin came back on the environmental interpretation and suggested that the black marble settled in neritic, shallow and reducing waters. Mamet (1964) interested to the sequences observed in the black marble and argued that this limestone is not sapropelic because it contains not more than 0.2% carbon. The black color should then be related to the fine-grained matrix. Mamet also proposed a reducing lagoon as depositional palaeoenvironment. Recently, Mottequin (2004) interpreted the black marble of Denée as distal calcareous turbidites originating from a southward prograding shelf in a confined intra-platform basin. He observed alternations of laminated beds and bioturbated ones and assigned it to anoxic to dysoxic periods alternating with more oxygenated ones due to sea-level fluctuations.

*The black marble of Basècles*

Although still mentioned in older archives, the black marble of Basècles knew its main exploitation in the 19th c. and the first half of 20th c., with an important production of floor tiles. Its esthetic quality was always supposed to be worse than those of its Dinant, Mazy and Namur equivalents.

The black marble of Basècles is thought to be nearly contemporaneous of the black marble of Dinant (Visean, sub-stage Moliniacian), but deposited in the Hainaut sedimentation area (Brabant parautochton) (Groessens et al., 1982; Poty et al., 2001). The Basècles Formation is 250 m thick and includes various facies. The black marble facies is divided in two units ("Grande Veine" and "Petite Veine", separated by argillaceous limestone beds, cf. Bouckaert et al., 1961). Although less rich in fauna than the classical Dinant black marble, it contains fossils (crinoids, corals and brachiopods, cf. Overlau, 1966).

Mamet (1958), in his stratigraphic study of the Basècles area, interpreted the depositional palaeoenvironment of the Basècles black marble as shallow, without further precision. Overlau (1966) described slumps and convolute bedding, suggesting a deep slope environment with a turbiditic dominated sedimentation. Algae are present but are reworked from shallower areas. The lack of bioturbation is due to fast deposition or to toxic sea bottom conditions.

*The black marble of Theux*

The Theux marble was supposed to have been already largely exploited in the Antiquity, although recent archaeological researches through some doubts about this very ancient origin (Dreesen *et al*., 2018, p.33). Historical data from 16th c. and 17th c. confirm that the quarries were then used by great sculptors from Liège for their works, in Renaissance and Baroque styles (Den Dooven, 1966). Later, it was employed for small objects like clocks, because it was supposed to be carved and sculpted easier than its other equivalents "black marbles", being "softer" according to artists and craftmen.

The black marble of Theux crops out in the Theux tectonic window and is part of the eastern part of the Brabant parautochton. The main quarries, which remained always of limited extension, mostly because of tectonic complexity, were located in a small valley, called "ravin de Hodbomont". The stratigraphic age of the black marble of Theux was more questioned than the other marbles, because of the tectonic context and of the scarcity of fossils. Formerly thought to be upper Visean, it was dated Moliniacian by Coen et al. (1982) and is thought to be a particular facies of the Terwagne Formation. This 20–30 m thick formation is mainly characterized by stromatolites and brecciated paleosoils, suggesting a shallow and restricted environment. No sedimentological model was proposed yet for the Theux black marble.

*The black marble of Lives*

Black marbles from Namur were renowned since the Antiquity, with quarries established around the Northern suburbs of the town (see Dreesen *et al*., 2018, fig.3, for a schematic map), but also downstream on both sides of the Meuse river. The exploitation since the Middle Ages to the 20th c. is still rather good known (for a recent historiography, see Dubois, 2018) and also the distribution of the production through the Meuse to Netherlands and, from there, to the North Sea,

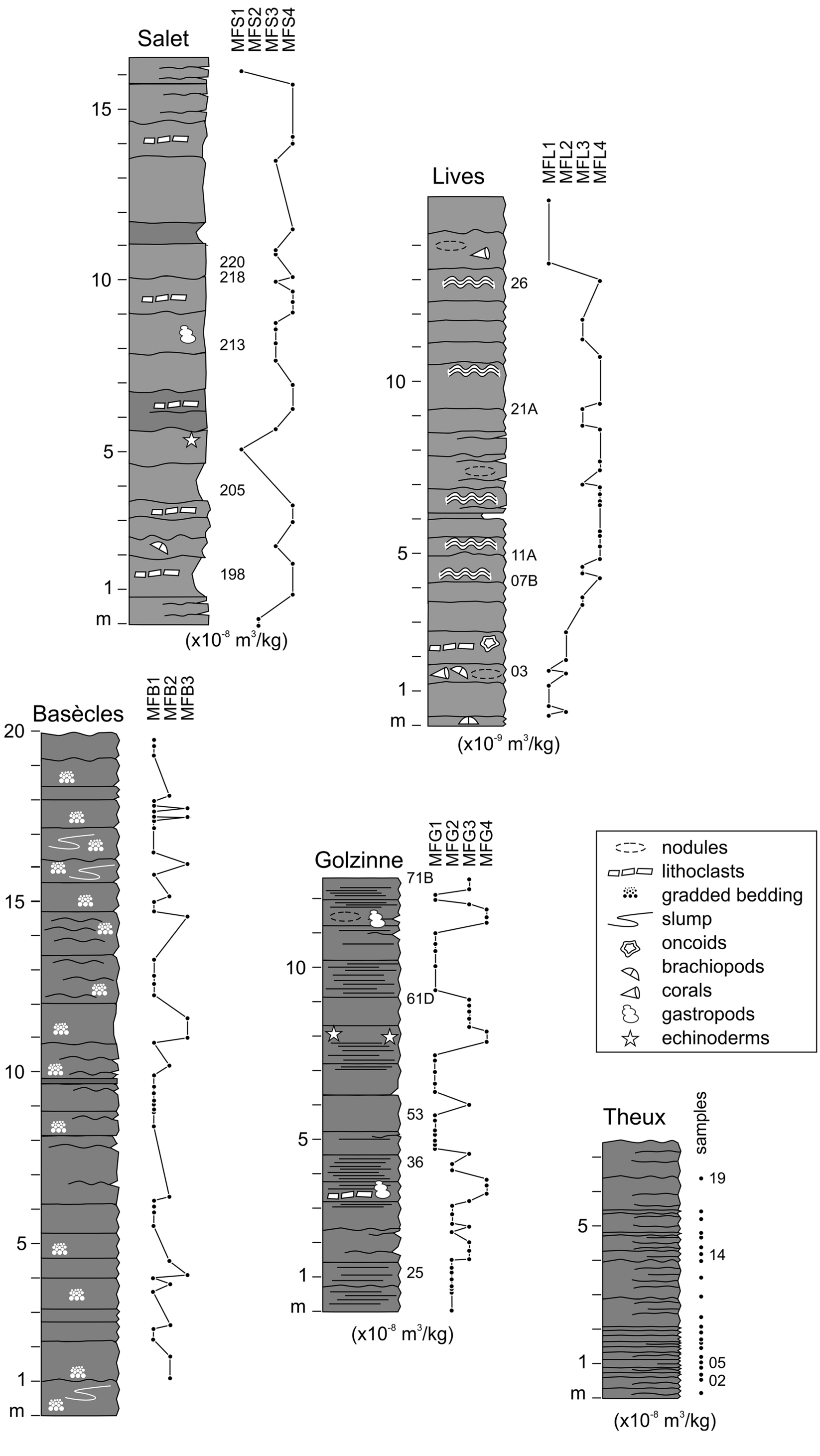


Figure 3 *Logs of the Golzinne, Dinant, Basècles, Theux and Lives black marble units, with microfacies curves (MF) and location of geochemical samples. Legend of symbols*

with a very wide area of diffusion, until the Baltic States or the Southern hemisphere (São Tomé or Indonesia).

Although Visean, the black marble of Lives is younger (sub-stage Livian) than the Dinant, Basècles and Theux ones. This facies is included in the 80 m thick Lives Formation and belongs to the Namur sedimentation area (middle part of the Brabant parautochton). The key exploitations were located near the town of Namur, on both sides of the Meuse river between Namur and Andenne, for example at the "Piton de Lives" (Fig. 1). They took frequently the form of underground galleries. No sedimentological model was proposed yet for the Lives black marble.

## RESULTS: PETROGRAPHY

The black marble of Golzinne.

This 13 m-thick section partly corresponds to the Golzinne Member and was surveyed and sampled in the Golzinne underground quarry (Figs 1, 2A), actively worked by the Merbes-Sprimont company. The lower part of the section (Fig. 3) was measured in a disused mine drift and the upper part in the access ramp. Four microfacies were observed.

MFG1: mudstone with ostracods (Plate 1, A). Few bioclasts and fossils are present: ostracods, echinoids, sponge spicules, small fragments of trilobites, brachiopods or gastropods and locally, *Umbella* (an alga). Bioturbation is uncommon but locally represented by vertical burrows.

MFG2: dolomitic laminated bioclastic mudstone-wackestone. Fossils are similar as in MFG1 but are associated with unrecognizable small bioclasts. The lamination (0.1–5 mm) is due to variations in bioclasts abundance.

MFG3: microbioclastic wackestone-packstone. Lots of fossil debris are unrecognizable, due to transport. Some bigger fossils include ostracods, bivalves, worm tubes and echinoderm spines. Lamination, locally present, is often disturbed by horizontal burrows, filled up with lime mud.

MFG4: dolomitic grainstone-packstone with lithoclasts (reworked fragments of lithified sediment), gastropods and ostracods. Plurimillimetric lithoclasts and smaller peloids (rounded micritic little pellets, often of fecal origin) together with ostracods and bivalves account for the bulk of the grains. These grains are often concentrated in mm-thick laminations. Transported crinoids and well-preserved gastropods are also present.

Pyrite (cubes and framboids) is present in every microfacies as well as numerous small dolomite crystals (20–50 μm). Detrital quartz (20–100 μm) is uncommon.

MFG1–4 reflects an increase in water agitation, from a very quiet to a moderately agitated environment, influenced by storms (cf. lithoclasts). Two types of fossils are present: open marine (echinoderms, brachiopods) and restricted (gastropods, *Umbella*) (Mamet, 1970). However, the better preservation of the latter suggests a partially restricted quiet lagoon, with periodic supply of storm-transported bioclasts. The presence of pyrite and locally preserved lamination or bioturbation would be proof that the sediment was at the boundary between an anoxic and a well-oxygenated bottom. As suggested by Da Silva (2004), the area where Golzinne is located corresponds to a deep lagoon, between the continent (Brabant Massif) and the shallower Dinant shoal.

### *The black marble of Dinant*

The studied section is located along the N971 road, in the Molignée valley, 1 km far from the Salet village (Fig. 2B). The black marble facies is part of the Molignée Formation (Conil *et al.,* 1977; Hance *et al.,* 2001) and the 16 m surveyed partly corresponds to an old disused underground quarry (Fig. 3). Four microfacies were observed.

MFS1: mudstone with sponge spicules. This microfacies is dominated by sponge spicules and associated structures (vermicular structure *sensu* Miller, 1986). Rare ostracods and brachiopods fragments, calcispheres and phosphatic debris are observed. This microfacies shows locally a faint lamination.

MFS2: wackestone-packstone with lithoclasts and ostracods (Plate 1, B). Lithoclasts are up to 2–3 mm, angular or smoothed. Ostracods are less abundant than the formers and are accompanied by bioclasts (fragments of brachiopods, crinoids, bryozoans, gastropods, microbial mats, algae, calcispheres, foraminifers …).

MFS3: bioturbated bioclastic packstone-wackestone. Fragments of bivalves, crinoids, gastropods, sponge spicules and lithoclasts are the most abundant grains in this microfacies. Uncommon algae (*Umbella*), ursin spines, microbial mats, gastropods, foraminifers, bryozoans, coral fragments, phosphatic debris and calcispheres are locally observed. Horizontal burrows (1–4 mm in diameter) are present and are filled up by micrite or small dolomite crystals.

MFS4: laminated bioclastic grainstone-packstone with lithoclasts (50 µm-0.5 mm), peloids, calcispheres and paleosiphonocladales (a green alga). The three types of grains listed above are common and are accompanied by less abundant foraminifers, *Girvanella* (an alga), ostracods, sponge spicules and fragments of brachiopods and crinoids. No bioturbation was observed and a regular mm-thick lamination is present, due to variations in the grains abundance (Plate 1, C).

Quartz grains (20–75 µm), pyrite (20–50 µm) and dolomite crystals (10–70 µm) are locally observed in all microfacies.

Like in the Golzinne series of microfacies, two types of grains are present: open marine (foraminifers, bryozoans, coral fragments, phosphatic debris, brachiopods, sponges and echinoderms) and grains derived from a shallower environment: algae (*Umbella* and *Girvanella*, paleosiphonocladale algae, microbial mats, calcispheres, gastropods). The algae are mainly reported from lagoonal environments (Mamet & Préat, 1992) and obviously grew in the photic zone. Unlike in the Golzinne section, the shallowest grains show the longest transport. Lamination was interpreted by Mottequin (2004) as distal turbidites, reworking sediment originating from shallower parts of the platform. Slumps were already mentioned by Overlau (1966), strengthening this model. The depositional environment of the Dinant black marble is therefore a relatively small but deep intra-platform basin, with an anoxic bottom (Allison *et al.,* 1995) and episodic supplies of material coming from shallower parts of the platform during periods of low sea-level.

### *The black marble of Basècles*

This 20 m-thick section was surveyed and sampled in the Basècles quarry, south of the village, known as the "ancienne carrière Bernard" (Figs 1 & 3). The black marble facies is observed at different levels of the Basècles Formation. Three microfacies were observed.

MFB1: locally laminated argillaceous mudstone-wackestone with radiolarians, brachiopods and sponge spicules. Grains are relatively well-sorted, about 100 µm in size and consist of radiolarians, spicules, fragments of brachiopods, echinoderms and small bioclasts. Locally, some algae (*Umbella*, paleosiphonocladales, calcispheres), ostracods, peloids and lithoclasts are observed. Laminae vary in thickness, from 200 µm to 2 cm, are flat to undulating and show a normal grading.

MFB2: bioturbated packstone with lithoclasts, brachiopods and calcispheres. The poorly sorted aspect of this packstone is due to 1–2 mm thick burrows, often filled up with calcitic cement. The main constituents are 100–200 µm lithoclasts, radiolarians, fragments of brachiopods and calcispheres. Paleosiphonocladale algae, ostracods, crinoids, ursin spines and foraminifers are locally present.

MFB3: grainstone-packstone with lithoclasts and calcispheres. A micritic to microsparitic matrix characterizes the packstone while the grainstone shows a sparitic cement. Grains are relatively well-sorted in two populations: 50–500 µm and 500 µm-1 mm. Lithoclasts (50–200 µm) dominate, with calcispheres. Other grains are less frequent and consist in sponge spicules, bivalves, foraminifers, crinoids, brachiopods, peloids, ostracods and paleosiphonocladale algae.

All these microfacies may include clay seams, stylolithes, cubic or framboidal pyrite (0–8%), detrital quartz grains (0–7%, 10–200 µm), automorphic quartz crystals (~100 µm), phosphatic debris, and automorphic dolomite crystals (0–5%, 50–100 µm). Breccia levels (with 1–3 mm mudstone fragments) and convolute or slump structures are observed (Plate 1, D).

Like in the Salet section (Dinant black marble), two populations of grains are present: radiolarians, brachiopods and echinoderms suggest an open marine environment, while calcispheres and algae should be derived from a shallower zone. Obviously, the latter show evidences of transport and the presence of slumps, convolute structures, normal grading point to a quiet, deep environment, periodically exposed to turbiditic flows, reworking material coming from a shallow platform. The lithoclasts are probably fragments of sediment eroded by the turbidites. This is globally the same model as the Salet section.

### *The black marble of Theux*

One of the very last accessible section in this black marble is located in a private property in Theux (avenue Reine Astrid) and is known as the “ancienne carrière Dethier”. Beds are slumped and folded and the 7 m thick section was surveyed in the less disturbed zone (Fig. 3). One microfacies was observed.

MFT1: argillaceous mudstone-packstone with radiolarians and ostracods (Plate 1, E). Well-preserved ostracods and radiolarians are the main fossils. Locally, brachiopods, bioclasts, broken paleosiphonocladale algae and sponge spicules are observed. Detrital quartz (1–10%; 10–50 µm), dolomite crystals (20 µm), phosphatic debris, framboidal pyrite and clay seams are present. A faint lamination, consisting in mm-thick alternation of wackestones and packstones is visible in some thin sections.

The fine-grained texture of this microfacies reflects a quiet environment, below or close to the storm wave base. Well-preserved brachiopods and radiolarians, together with phosphatic debris point to an open-marine platform. It should be noted that this interpretation questions the lithostratigraphic attribution of the Theux marble to the Terwagne Formation (Coen *et al.,* 1982), which is known to be characterized by very shallow and restricted facies (Hance, 1988).

### *The black marble of Lives*

The chosen section (Piton de Lives) is located in the disused Sagrex quarry, on the right bank of the Meuse river, 1 km east of the Beez viaduct (Fig. 1). The Lives Formation is subdivided in 3 members, the Haut-le-Wastia, Corphalie and Les Awirs members. The black marble unit is included in the Corphalie Member (Fig. 3). Three microfacies are defined.

MFL1: packstone with paleosiphonocladale algae and peloids. This poorly sorted packstone includes bioclasts, paleosiphonocladale algae, peloids, crinoids and less often, broken trilobites, brachiopods and corals, ostracods and foraminifers.

MFL2: packstone-grainstone with lithoclasts, brachiopods and oncoids. This poorly sorted microfacies is characterized by lithoclasts (0.5–3 mm), brachiopods, bioclasts, relatively large (4–5 mm in diameter) oncoids (these structures are microbially coated grains), calcispheres, codiaceae, paleosiphonocladales and porostromata algae. Locally, sponges, coral fragments, crinoids, ursin spines and ostracods are present.

MFL3: mudstone-wackestone with ostracods, rounded lithoclasts and peloids. This microfacies is locally laminated or slightly bioturbated. Main fossils are ostracods, peloids, lithoclasts, and rare ursin spines, crinoids, fragments of brachiopods.

MFL4: mudstone with sponges and rounded lithoclasts or peloids (Plate 1, F). Locally laminated and sorted, this mudstone is characterized by vermicular structures due to sponges or algal filaments, and peloids. Thin (0.1–1 mm) lenses of peloidal grainstone are observed.

These microfacies may include clay seams and stylolithes, small pyrite crystals or framboids, 50–100 μm quartz grains, silicification, and small fenestrae (0.1–0.6 mm) cemented by a yellowish fibrous calcite.

This series of microfacies is characterized by a restricted fauna and flora, dominated by algae and microbial mats. Other fossils are rare and show evidences of transport from a more open part

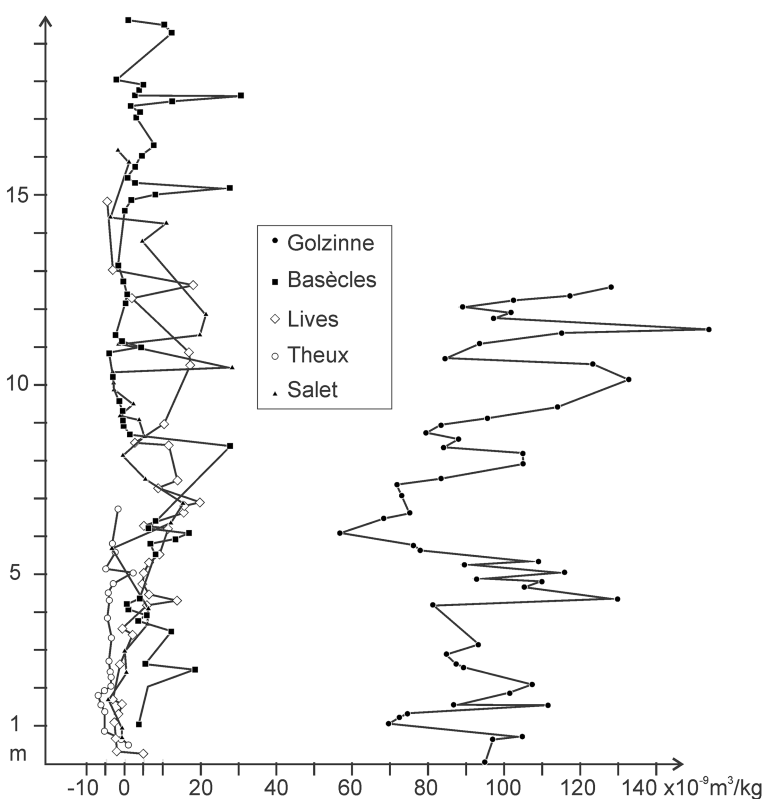


Figure 4 *MS curves from the Golzinne, Basècles, Lives, Theux and Salet sections*

of the platform. Peloids and lithoclasts are abundant and may be related to erosion of sediment by storms or tidal channels. All these characteristics suggest a very quiet and restricted shallow lagoon environment.

## RESULTS: MAGNETIC SUSCEPTIBILITY

Nearly 200 MS measurements were made on all the black marble types. The results are synthesized in Fig. 4.

All the sections are characterized by very low, even slightly negative values, except the Golzinne section which shows relatively high values. More precisely, the mean MS value increases from Theux ($-3.2$ x$10^{-9}$ $m^3$/kg), Salet and Basècles (4.6 x$10^{-9}$ $m^3$/kg), Lives (6.3 x$10^{-9}$ $m^3$/kg) up to Golzinne (96.5 x$10^{-9}$ $m^3$/kg).

## RESULTS: GEOCHEMISTRY

The geochemical data of major elements are shown in Table 1 and Fig. 5. The geochemical data of Rare Earth Elements (REE) are shown in Table 2 and Fig. 6.

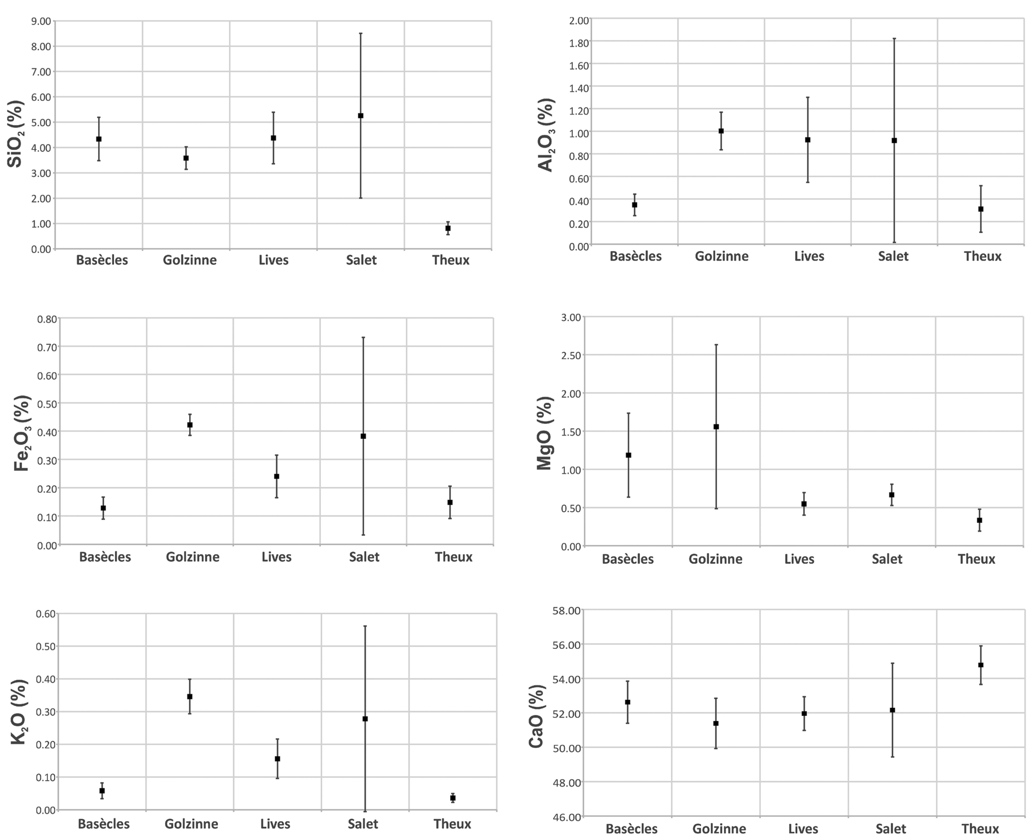


Figure 5 *Content (%) of major elements in Belgian black marbles*

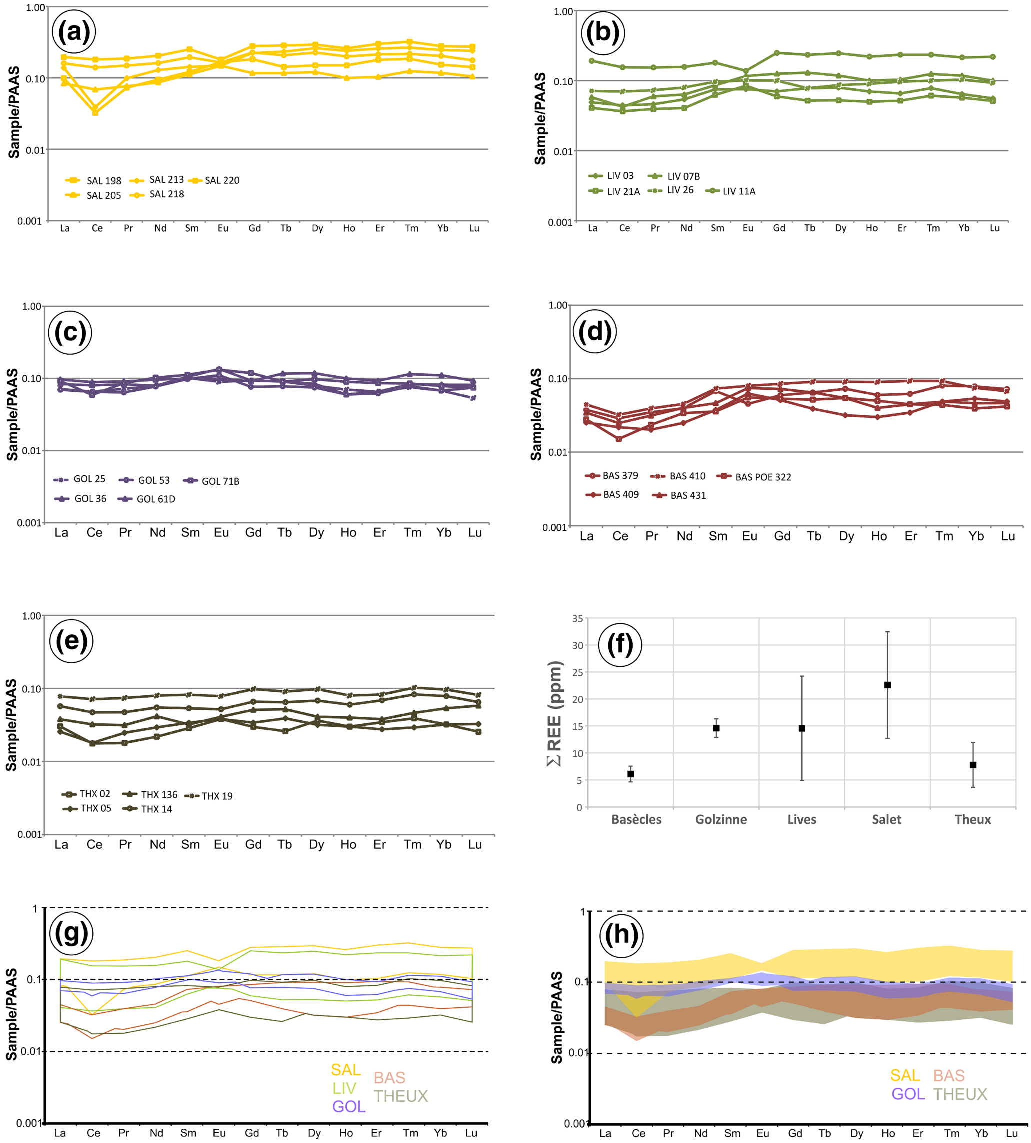


Figure 6 *A-E. REE patterns of the Salet, Lives, Golzinne, Basècles and Theux sites. F. Sum of REE in the Belgian black marbles. G. Lower and upper limits of the REE patterns normalized to PAAS, for each site. H. REE patterns normalized to PAAS for 4 sites (excluding Lives site showing various patterns) illustrating i) the low variability in the Golzinne samples, ii) the low contents of Basècles and Theux sites [Colour figure can be viewed at wileyonlinelibrary.com]*

We develop below the main features of the contents of the major elements. The Basècles samples have relatively low and significant contents of $Al_2O_3$ (average 0.35%) and $K_2O$ (average 0.06%). The Golzinne samples show relatively high and significant contents of $Fe_2O_3$ (average 0.42%) and $K_2O$ (average 0.35%). The Lives samples show no significant content compared to those of the other localities. The Salet samples have high standard deviations for all the major elements except MgO. The Theux samples show relatively low and significant contents of

$SiO_2$, $Al_2O_3$ and $K_2O$, and relatively high content in CaO. The Basècles and Golzinne samples have relatively high contents and large standard deviations in MgO (samples GOL 25 and GOL 36 have MgO content of 2.64% and 2.82% respectively; samples BAS 379 and BAS 431 have MgO content of 1.91% and 1.5% respectively), most probably associated to various dolomite content, as observed in thin sections.

We develop below the main features of the REE patterns. Normalized to PAAS (Post Archean Australian Shales), all the REE patterns are relatively flat, with low La/Yb ratios, ranging from 0.47 to 1.18. All the REE patterns are below 1. The Ce anomalies are negative for all the samples of black marbles. Two samples of the Salet site show relatively high Ce anomalies (0.33 for sample SAL 213 and 0.38 for sample SAL 198). The sum of REE contents are relatively low for Basècles and Theux samples, and show large standard deviation for Lives and Salet samples. The REE of the Golzinne samples show very similar pattern.

## GENERAL DISCUSSION: POTENTIAL IDENTIFICATION OF BLACK MARBLES USING PETROGRAPHY, MS AND GEOCHEMISTRY

We synthesize all the data in order to potentially discriminate the various types of Belgian black marbles. From a petrographic point of view, two schematic models are proposed to account for the palaeoenvironmental diversity of the five types of black marbles (Fig. 7).

All facies reflect relatively quiet environments, sporadically perturbed by more energetic phenomena like turbidites (Salet, Basècles) or storms (Golzinne, Lives), leading to the

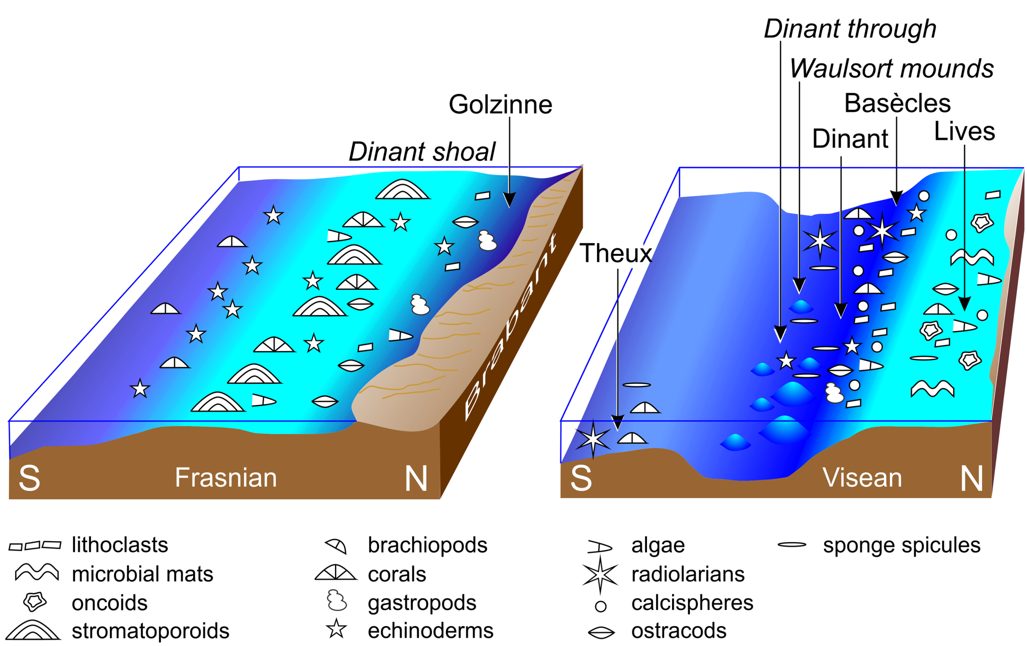


Figure 7 *Schematic palaeoenvironmental models for the Frasnian (left) and the Visean (right) black marbles. Please note that the Visean black marbles are not strictly contemporaneous [Colour figure can be viewed at wileyonlinelibrary.com]*

deposition of thin to relatively coarse levels or laminae in fine-grained sediments. It is known that in the marine realm, quiet environments are present in offshore settings, below or close to the storm wave base (like in Salet, Theux, and Basècles) and in shallow but very restricted zones, protected from waves and currents (in Lives and Golzinne). These very various environments are characterized by different fossil communities: open marine with echinoderms, brachiopods, radiolarians, trilobites, bryozoans and restricted shallow with algae, microbial mats, calcispheres, gastropods. These two fossil communities may be partially mixed by storms and by gravity flows. For example, in Salet, shallow grains are reworked from the platform and deposited in deeper environments by turbidites while in Lives, open-marine fossils are brought in the shallow lagoon by storms. Fortunately, even if the two kinds of fossil are mixed, their abrasion index still allows to differentiate transported from indigenous communities. So, the Salet, Theux, and Basècles black marbles are characterized by an open-marine fossil community, while the Golzinne and Live ones are characterized by a restricted fossil community. Algal-microbial structures are typical in the Lives limestone.

Sedimentary structures and non-fossil grains like lithoclasts are also discriminating: the latter are not present in Theux for example; vertical burrows are typical from Golzinne and slumps are present in Basècles, Theux and Salet. Table 3 summarizes the main petrographic characteristics of the five black marble types.

The results of MS clearly distinguish the Frasnian black marble from its Visean equivalents. However, MS does not distinguish between the various Visean black marbles (Fig. 4). Several hypothesis can be envisaged to explain the difference between the Visean and Frasnian MS levels. Remembering that MS is predominantly ruled by detrital ferromagnetic minerals (Ellwood et al., 1999), the closer vicinity of the continent (Brabant Massif) during the end of the Frasnian must be considered. We observe the transition to a detrital sedimentation at the end of the Frasnian and during the Famennian, while Visean is characterized by an arid climate with local precipitation of evaporites. Moreover, the more humid climate during the end of the Frasnian provided more detrital grains to the platform. During Visean times, the general marine transgression brought the shores of the Brabant-London Massif several tens of kilometers farther to the North (Ziegler, 1982). An alternative explanation is provided by the high $Fe_2O_3$ content of the Golzinne samples, probably related to disseminate pyrite crystals.

Discrimination of marbles/rocks using geochemistry has been successfully applied in various cases, such as REE geochemistry in the Lorraine ochre limestones (e.g. Lecuit et al., 2018). Our geochemical data allow us to discriminate:

- the Theux site, using its relatively low $SiO_2$ content ($< 1.0\%$), most probably related to low detritic supplies;
- the Theux and Basècles samples from the other sites, using their low $Al_2O_3$ ($< 0.6\%$ for Theux and $< 0.5\%$ for Basècles), $K_2O$ ($< 0,1\%$ for both the sites) and REE contents ($< 10$ ppm for Basècles and $< 15$ ppm for Theux – note that two samples from Lives also show REE content $<10$ ppm), most probably also related to low detritic supplies;
- the Golzinne site, using its high $Fe_2O_3$ content $>0.4\%$ (note that 2 samples from Salet also show $Fe_2O_3$ content $>0.4\%$), most probably associated to the high pyrite content.

The geochemical results do not allow us to characterize the samples from Lives and Salet. The samples of both the latter sites have relatively high standard deviations in many major elements. Their REE patterns are not significant.

CaO contents are quite similar for all the Belgian black marbles used in this study. The MgO contents most probably reflect the dolomitisation in samples from Basècles and Golzinne sites. For the other sites, the MgO contents are low ($< 0.9\%$) but not discriminant.

## CASE STUDIES

### *Origin*

As the capital of an ecclesiastic principality for eight centuries, the city of Liège was a major center of artistic creation. During the $16^{th}$ c., a group of sculptures significant for the introduction of Renaissance style in the region used a special material, the black marble (see among other Lefftz, 2008, for a recent synthesis). Since the $19^{th}$ c., historians mentioned the renting of black marble quarries in Theux by the most famous artists from the $16^{th}$ c. to the $18^{th}$ c., among them the Baroque sculptor Jean Delcour. It was thus quite tempting to gather together all these pieces under the common label "black marble of Theux", without other criteria than the fine grain and the dark color of the rock. Later, these historians introduced the concept of workshops, among them the famous Palardin-Fiacre workshop, known as "italo-liégeois" (Palardino/Palardini coming from Italy and associated with the Fiacre family from Liège). No petrographic analysis was tempted on these objects, their artistic value preventing any sampling. But a careful examination to the naked eye allowed the observation of fossils like fasciculate colonies of Tetracorallia (of the genus *Siphonodendron*), indicating without doubt other geographical and stratigraphic origins – the "Meuse limestones" of Middle Viséan age, exploited between Namur and Liège. This is, among others, the case of funeral monuments by Jean Delcour (Tourneur in Lefftz, 1996).

During the elaboration of a new detailed catalogue of the European sculptures collections of the Louvre museum in Paris (Bresc-Bautier, 2006), some 20 years ago, the request of precise material identification allowed sampling of important Renaissance objects from Liège, preserved in Paris (where they were moved after the French Revolution). The first one is a monumental funeral slab, big (2.9 x 1.7 x 0.2 m) and heavy (more than 2600 kg), coming from the former Saint-Jacques abbey and devoted to the abbot Jean de Coronmeuse de Cordemois, dead in 1525. The work of highly refined quality was already described by many researchers, who proposed very different stylistic analyses and interpretations, attributing the work to the Palardin-Fiacre workshop or to the Swabian artist Daniel Mauch – but never questioning the "black marble of Theux" materiality. The other work, very distinct in conception and also supposed of "black marble of Theux", consists of five fragments of a funeral monument for Emeric Schillinck, eulogist of the former cathedral Saint-Lambert of Liège, completely destroyed after the French Revolution (Plate 1, G). The black marble structural elements are encrusted with four alabaster reliefs, everything being exquisitely carved. The monument bears the date of 1561.

### *Analyses*

Six samples were available, one from the slab of Cordemois (RF560), five from each of the elements of the Schillinck memorial (ML101). Petrographic thin sections and MS results were available for all samples. ML101 is an argillaceous mudstone with brachiopods and trilobites fragments, radiolarians, sponge spicules, framboidal pyrite and detrital quartz (Plate 1, H). This microfacies is very similar to MFT1 (see above), strongly suggesting Theux as a possible origin. The second sample, RF560 is a well-sorted mudstone-wackestone with brachiopods, ostracods, crinoids, sponge spicules, calcispheres and *Umbella* (Plate 1, I). Detrital content (quartz grains and clay) is very low. The MS value is low, close to $5 \times 10^{-9}$ $m^3$/kg, 20 times lower than Golzinne values. Calcispheres and *Umbella* were not observed in Theux, thus eliminating these two origins. Lives (MFL3) is also eliminated because the archeological sample RF560 does not show any peloids. It therefore remains Basècles (MFB1) and Dinant (MFS1). The latter is preferred because no radiolarians (typical for Basècles) are observed in RF560.

## CONCLUSION

The black marbles of Belgium are used since the Roman Antiquity. These rocks are not marbles in a petrographic meaning; instead they correspond to several varieties of fine-grained, well-cemented Paleozoic limestones, without dots, veins or fossils. However, these marbles are difficult to distinguish from each other.

Five marbles were investigated in this study. The oldest, the Frasnian black marble of Golzinne was deposited in the northernmost part of the sedimentation area, resting on the Lower Paleozoic Brabant massif. During the end of the Upper Devonian, carbonates were temporarily replaced in Belgium by detrital sediments. The Lower and Middle Mississippian sedimentation marks a return to marine carbonate sedimentation. A dramatic decrease of detrital supply favored the resumption of the carbonate factory, leading to the deposition of the younger Viséan Dinant, Theux, Basècle and Lives black marbles.

The present paper followed two main objectives: (1) to synthesize the geological data already bibliographically available for the different Belgian black marbles and (2) to provide new accurate geological data in order to compare/discriminate them. Three methods were used: petrography (microfacies analysis), magnetic susceptibility (MS) and geochemistry of major elements and Rare Earth Elements (REE) by FUS-MS (Fusion Mass Spectrometry).

Petrographically, all facies reflect quiet environments, sporadically perturbed by more energetic phenomena like turbidites (Salet, Basècles) or storms (Golzinne, Lives), leading to the deposition of thin to relatively coarse levels or laminae in very fine-grained sediments. Salet, Theux and Basècles sediments were deposited in quiet offshore settings, below or close to the storm wave base. Lives and Golzinne sediments correspond to shallow but very restricted zones, protected from waves and currents. The fossils are very different: in Salet, Theux and Basècles, black marbles are characterized by an open-marine fossil community, while the Golzinne and Live ones are characterized by a restricted fossil community.

MS results show that all the black marbles are characterized by very low, even slightly negative values, except the Golzinne one which shows relatively high values. This should be preferentially attributed to the closer vicinity of the continent (Brabant massif) during the deposition of the Golzinne sediments, leading to the supply of higher amounts of high-MS detritic grains. Geochemical data allow to discriminate between the Theux black marble with a relatively low $SiO_2$ content, and the Basècles samples using their low $Al_2O_3$, $K_2O$ and REE contents. This may be synthesized by Table 4, which enhances the main differences between the five black marbles.

Our results confirm that discriminating the different Belgian black marbles is not straightforward and needs a combination of very different techniques, ranging from petrography to geochemical analysis. However, all these techniques are destructive and request a sampling, which the size ranges from ~1 g (geochemical analyses), ~10 g for MS and to the confection of a thin section for petrography.

Two archeological black marble samples were investigated in order to determine their geological origin. The first one is undoubtedly attributed to the Theux marble, following its characteristic microfacies while the second probably corresponds to the Dinant one, based on both microfacies and MS value.

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