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ORIGINAL ARTICLE

An Exceptional Lower Carboniferous Historical Heritage Stone from Belgium, the 'Pierre de Meuse'

Roland Dreesen[1,2] · Edouard Poty[3] · Bernard Mottequin[4] · Jean-Marc Marion[3] · Julien Denayer[3]

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Abstract
Among the many reputed Belgian historical heritage stones, the Dinantian (Lower Carboniferous) 'Pierre de Meuse' is certainly one of the most important. The 'Pierre de Meuse' sensu stricto is a limestone of middle Viséan age (Lower Carboniferous) that is particularly well exposed and well accessible in the Meuse valley, downstream of the city of Namur. The Romans were first to make a wide use of this limestone, both as a building and a decorative stone. Furthermore, during medieval times, it has become the hallmark of Romanesque religious and public buildings, funerary monuments, floor tiles and tombstones. Detailed in situ investigations of historical monuments allowed to define five different macroscopic lithofacies within the 'Pierre de Meuse'. The latter lithofacies or varieties of the 'Pierre de Meuse' have all been successively used as building and/or decorative stone during different time intervals. Their main macroscopic and microscopic (paleontological and petrographical) characteristics are here briefly described and illustrated, as well as their characteristic microfacies and index microfossils. Some of the finest and most famous Belgian black marbles, the 'Marbre noir de Namur', has been derived from particular thinly bedded, black-coloured micritic limestones within the same Lives Formation: its unique chroma and quality have been appreciated at least since Roman times.

Keywords Building stone · Heritage stone · Urban geology · Lower Carboniferous · Belgium

Introduction

The 'Pierre de Meuse' is a grey to black, well-bedded limestone made of the calcite skeletal debris of fossil organisms embedded in a fine-grained matrix of cemented lime mud. It got various names according to different authors at different times (see Groessens 2005 for a complete overview). In a broad sense, it covers all the greyish to blueish limestones that were once extracted in the Meuse valley and some of its tributary valleys, between the towns of Namur and Liège (Berger 1890). Under this definition, it includes quite different lithostratigraphic units of Tournaisian to Viséan age. Hence, we here restrict the definition of the 'Pierre de Meuse' to one single geological unit (both stratigraphically and geographically defined) that was particularly intensively quarried in the vicinity of Namur. It was and still is variously named 'Pierre de Namur', 'Pierre bleue de Namur', 'Pierre bleue de Meuse', 'Naemsche steen', 'blaeu naemsche steen', 'Namense steen', 'Naamse steen', 'kolenkalk' and 'Blaustein'. The variety of name reflects the importance of this stone and its use in a wide area of northern Europe (Belgium, France, the Netherlands, Germany, UK, Scandinavian and Baltic coasts, etc.). Marote (1923) subdivided the quarried succession in three different units: the 'étage inférieur' or 'Pierre des bords de Meuse' (i.e. the lower Viséan Terwagne and Neffe Formations), the 'étage intermédiaire' (middle Viséan Lives Formation) and the 'étage supérieur' or 'Pierre du Val de Samson' (middle-upper Viséan Grands-Malades and Bonne Formations). All those units correspond to distinct rock types that have all been quarried as building stones, displaying different qualities and destined for different applications (Table 1). According to a more restricted and better fitting definition, 'Pierre de Meuse'

✉ Roland Dreesen
roland.dreesen@telenet.be

1 Belgian Geological Survey, Jennerstreet 13, B-1000 Brussels, Belgium

2 Department of Archaeology, Ghent University, Sint-Pietersnieuwstraat 35, B-9000 Ghent, Belgium

3 Evolution and Diversity Lab, Université de Liège, Allée du Six-Août, B18, Sart Tilman, B4000 Liège, Belgium

4 Directorate Earth and History of Life, Royal Belgian Institute of Natural Sciences, rue Vautier 29, B1000 Brussels, Belgium

Table 1 Evolution of the definition of the 'Pierre de Meuse' and its lithostratigraphic affiliation

FORMATION	Berger 1890	Marote 1883	Carte géologique 1930	Van Leckwijck 1947	Groessens 2004
Hoyoux	Pierre de Meuse Étage supérieur	Pierre du vallon du Samson	Pierres de Meuse		
Grande Brèche	Pierre des Grands Malades (ou de Namur)				
Lives	Pierre de Meuse Étage inférieur	Pierre des bords de Meuse		Pierre de Meuse s.s. ou étage inférieur	Pierre de Meuse s.s.ou Pierre des bords de Meuse
Neffe					Pierre de Vinalmont
Terwagne					
Longpré					Calcaire de Longpré

is considered here to be the stone originally quarried in the vicinity of Namur, subsequently in the Meuse valley, between the townships of Spy and Flémalle (Fig. 1).

The 'Pierre de Meuse' shares the overarching name 'pierre bleue' (blue stone or 'blauwe steen') with two other famous Belgian calcareous building stones, the 'Pierre de Tournai' and the 'Petit Granit', both fossiliferous limestones and well-known building stones of Lower Carboniferous age (Groessens 1987, 1996; Pereira et al. 2015). The 'Petit Granit' is traded commercially nowadays as Belgian Blue Stone. Moreover, this designation is a real brand name representing an 'Appelation d'Origine Locale' since 1999. The name 'Petit Granit' is misleading as it is a limestone and not an igneous rock (granite): it refers to the numerous white (calcite) sections of crinoids (and other fossils) that look superficially like feldspar crystals in granites. The designation 'blue' refers to its grey-blue colour (when fresh) resulting from the presence of very finely disseminated organic carbon in the limestone matrix. Due to subsequent mechanical surface treatments, these blue stones display a broad spectrum of colours, ranging from light- to medium-grey over dark-grey to black (when polished). However, over years, these blue stones all develop bright natural patinas when exposed to atmospheric conditions, showing light-grey to ash-grey hues as a result of oxidation of the organic carbon. This light patina is more developed in the finer-grained facies (mudstones and wackestone) of the blue stones. The black facies of the 'Pierre de Meuse' is also known as 'Marbre noir de Namur'. It has often been confused with other Belgian black marbles such as the 'Marbre noir de Theux' and the 'Marbre noir de Dinant', which differ however by their divergent textures, carbonate microfacies and fossil content (see Tourneur 2020, for a recent synopsis).

Due to its cultural history encompassing quite a significant period of time (at least since the Roman period), its broad spectrum of utilisations (dimension stones, sculptures, tombstones, baptismal fonts, floor tiles, various other utilitarian applications, etc.) and its wide geographical distribution (major part of North-Western Europe), the 'Pierre de Meuse' represents a potential Global Heritage Stone Resource, according to the terms of reference approved by the IUGS in 2012 (http://www.globalheritagestone.org/home/ghsr-proposals).

The Pierre de Meuse sensu stricto corresponds lithostratigraphically to the uppermost part of the Haut-le-Wastia Member and the succeeding Corphalie Member of the middle Viséan Lives Formation (Livian, *c.* 335 My, Poty et al. 2002). Within this c. 15-m-thick unit, several limestone types were quarried, each limestone bed or set of limestone beds bearing a different name and suited for distinct uses (floor tiles, rubble stones, ashlars, tombstones, etc.). Despite their apparent lithological differences, they form a really regular set of limestone beds, all developing the same pale-grey patina with contrasting white fossil shells. Their varying lithofacies are described in greater detail in the next chapter.

We here exclude from the 'Pierre de Meuse', several other Viséan limestones also extracted in the Meuse valley, because they either belong to different lithostratigraphic units or because they were not extracted as building/ornamental stones or that they have been used only since the nineteenth century (Table 1). The 'Calcaire de Vinalmont' is a thickly bedded, grey coloured oolitic limestone with characteristic oblique or cross-bedding and with a distinct fossil fauna. It corresponds to the lower Viséan Neffe Formation (Groessens 1982) and was extracted in the Vinalmont village close to the Mehaigne river, a tributary of the Meuse (Fig. 1), from the second part of the nineteenth century onwards (Groessens 1987). The 'Pierre de Longpré', extracted in the same area, is a grey-beige crinoidal limestone that often develops a whitish patina. It corresponds to the upper Tournaisian Flémalle Member of the Longpré Formation (Poty et al. 2002). Its extraction was rather restricted and did not occur before the end of the nineteenth century, as the Longpré quarry does not appear on the 1856 topographic map of Belgium. Besides the type area around Namur, where the 'Pierre de Meuse' was historically quarried, the limestones of the Lives Formation crop also out in the Meuse valley near Dinant upstream of Namur, in the Condroz area

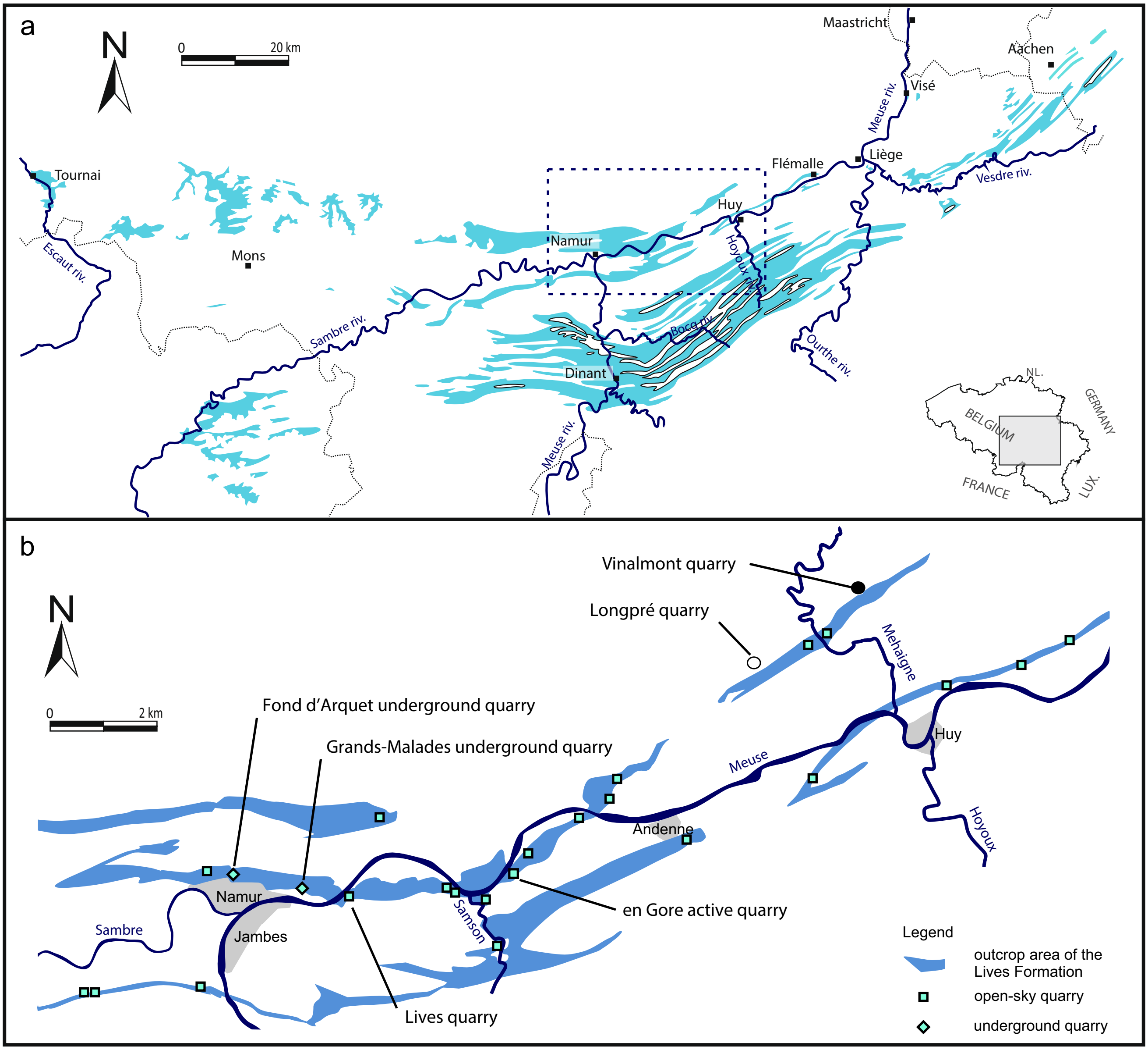


Fig. 1 Simplified geological maps. **a** Outcrop zones of the Lower Carboniferous strata in southern Belgium and neighbouring areas (modified, after de Béthune 1954). **b** Outcrop zones of the Lives Formation and location of the best known quarries

and more eastwards in the Vesdre valley (Fig. 1). However, the limestone beds are folded and faulted in the latter areas, hampering their extraction as suitable ornamental stones (Groessens 1996).

Moreover, their lithological facies are quite different from those observed in the historical Namur area (see further). In the Aachen area (Northwestern Germany), macroscopically analogous limestones are often designated under the name 'Aachener Blaustein'. Yet, this name is ambiguous because it refers to dark-grey or black fossiliferous limestones of both late Devonian (Frasnian) and early Carboniferous (Viséan) age (Kasig 1980; Walter 2015). Note also that stratigraphically coeval limestones of the 'Pierre de Meuse' were quarried for ornamental stones (so-called marbles) in the Boulogne-sur-Mer area (Northern France), more especially from the 'Calcaire du Haut-Banc' formation (Brice and Colbeaux 1985; Robaszynski and Guyétant 2010). The latter formation is 50m thick and underlies the so-called Marbres du Boulonnais (e.g. Marbre Napoléon and other varieties). Even so, their typical beige to pinkish colours makes it quite easy to distinguish them from their Belgian counterpart (Groessens 2005).

In conclusion, this new definition of the 'Pierre de Meuse' bears both a genetic component linked to its lithostratigraphical origin and a geographical limitation, as the typical facies are only present within the Meuse valley area between the towns of Namur and Flémalle. This limestone was preferentially quarried as a building/ornamental stone in the Meuse valley because of (1) its sub-horizontal or slightly dipping bedding, (2) the presence of thin argillaceous joints and stylolites between the limestone beds allowing an easy extraction and (3) the presence of natural outcrops in both flanks of the Meuse valley close to the river, which allowed its easy extraction and subsequent fluvial transport. Indeed, from the Middle Ages onwards or even since Antiquity, the Meuse has been a major transport route for the stones extracted in its vicinity (e.g. Suttor 2006; Jansma et al. 2017).

Lithostratigraphy and Geological Age

From a purely lithostratigraphic point of view, the 'Pierre de Meuse' is restricted to a small part of the Lives Formation (Livian substage of middle Viséan age, Lower Carboniferous, about 335 My). The Lives Formation (Fig. 2) corresponds to a succession of well-bedded limestones, rhythmically arranged in thin shallowing-upward sequences, starting with a coarse-grained bioclastic grainstone to packstone rich in marine fossil faunas. Each of these sequences grades into finer-grained and more restricted marine carbonate facies, ending with a stromatolitic facies often capped by an emersion surface (Michot et al. 1963). Individual limestone sequences are 2 to 6 m thick and consist of a series of limestone beds that can be easily traced laterally from one quarry to the other. Some of these sequences can even be traced over several hundreds of kilometre, from Boulogne-sur-Mer (Northern France) through the Vesdre area (Eastern Belgium) (Poty et al. 2002). Furthermore, each sequence is identified by a specific number, originally introduced by Michot et al. (1963) and still used nowadays. The basal sequence 0 is very thick (16 to 18m) and it is lithostratigraphically positioned in the central part of the Lives Formation. The sequences below sequence 0 bear negative numbers (−1, −2, −3, etc.), whereas those above bear positive numbers (+1, +2, +3, etc.). The sequences −7 to −11 are dominated by stromatolitic facies and form the Haut-le-Wastia Member (Fig. 2). Sequence 0 corresponds on its own to the Corphalie Member. Sequences +1 to +9, displaying a predominant bioclastic facies, represent the Les Awirs Member (Groessens 1987; Fig. 2).

Most of the historically quarried 'Pierre de Meuse' corresponds to the sequences 0 and −1. Later on, during the nineteenth century, the extraction has been expanded towards the Awirs and Haut-le-Wastia Members. The 'Marbre Noir de Namur' corresponds to the thinly bedded upper part of the Corphalie Member (sequence 0) but does not include the upper sequences of the Les Awirs Member, as suggested earlier by Groessens (1987).

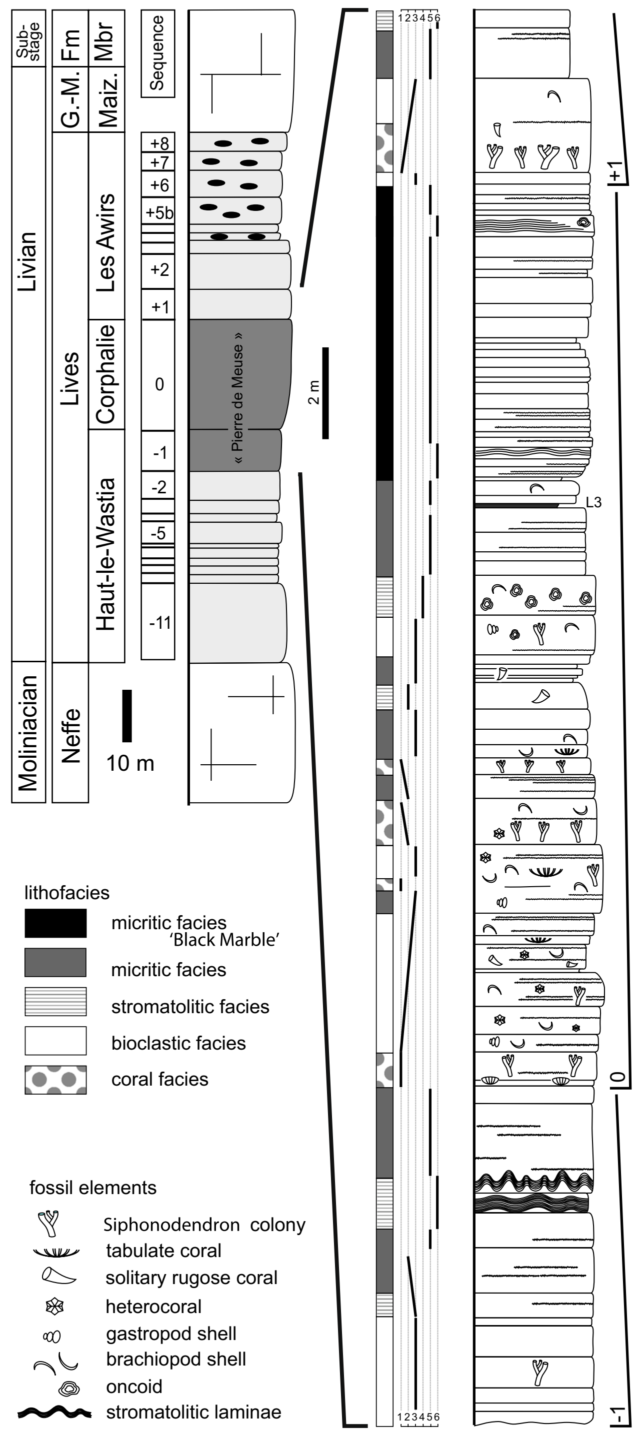


Fig. 2 Lithostratigraphic log of the 'Pierre de Meuse' with the denominations of the successive lithological units, characteristic sequences litho- and microfacies within the quarried part of the Lives Formation (unpublished personal data). Abbreviations: Fm Formation; G.-M. Grands-Malades; Maiz. Maizeret; Mbr Member; Seq. sequence

Main Lithological and Palaeontological Characteristics

The ‘Pierre de Meuse’ displays five major lithofacies that can be easily recognised macroscopically, not only in outcrop but also in historical buildings or monuments and in archaeological lithic materials. These lithofacies differ in grain size of the rock particles, overall colour, sedimentary structures, texture and enclosed fossils. The colour of the ‘Pierre de Meuse’ is always dark-grey to black, when fresh or polished, but it rapidly turns to light-grey—or even whitish—when weathered under atmospheric conditions. Interestingly, the colour of this patina varies with the grain size of the limestone, the finest-grained (mudstone–wackestone) facies displaying an ash-grey to almost white patina, the coarser grained (packstone–grainstone) facies displaying a darker (more greyish) patina. The colour of the patina also clearly differs from that of the ‘Petit Granit’, which is darker grey, further from that of the ‘Pierre de Longré’, which is yellowish and from that of the ‘Pierre de Vinalmont’ which is light-grey as well, but where numerous white millimetric ooids can be observed (Dusar et al. 2009; Dreesen et al. 2019).

Lithofacies

Five major lithofacies can be distinguished within the broad lithological spectrum of the ‘Pierre de Meuse’: each lithofacies has its own characteristic components and has a particular macroscopic look. Furthermore, each of the lithofacies corresponds to a distinct lithostratigraphic level within the formal sequences 0 and +1. From the coarsest- to the finest-grained facies, we can distinguish a bioclastic lithofacies (Fig. 3e), a coral lithofacies (Fig. 3a), an oncolitic lithofacies, a stromatolitic lithofacies (Fig. 3b–c) and a micritic lithofacies (Fig. 3d). These lithofacies occur in rhythmically arranged sequences within the Lives Formation: they were commonly extracted together; hence, they usually occur jointly within the historical monuments. More than the presence of a particular and individual facies, it is clearly the assemblage of all those different but closely associated lithofacies, in combination with characteristic macrofossils that allows a proper identification of the limestone as ‘Pierre de Meuse’.

The Bioclastic Lithofacies

This carbonate facies is rather coarse-grained, and is composed of numerous bioclasts or fossil skeletal debris that commonly exceed 1 cm in size, floating in a finer-grained carbonate matrix, which is often darker in colour (Fig. 3e). Once weathered, the bioclasts become white, as they are chiefly composed of calcite. Many of the bioclasts can be identified with confidence as various taxa of gastropod and brachiopod shells, coral skeletons, green algae, etc. Within the group of corals, some taxa are quite indicative of the ’Pierre de Meuse’ and these are briefly described below. The bioclasts occur either scattered in the limestone or they tend to be concentrated into fossil-rich horizons. Both broken and unbroken elements occur together within the same beds.

The Coral Lithofacies

In the Meuse valley, a particular level of the Lives Formation is particularly rich in coral colonies belonging to the species *Siphonodendron martini* (Milne-Edwards and Haime 1851) (Aretz and Chevalier 2007). A single colony is made of several tens to hundreds of individual corallites. The latter corallites are cylindrical; hence, they appear as either circular (transversal), elliptical (oblique) or elongated (longitudinal) sections. The carbonate matrix in between the corallites is commonly bioclastic or micritic, which contrasts well with the corals due to its darker colour (Fig. 3a).

The Oncolitic Lithofacies

As for the banded or finely laminated stromatolites (see 3b), oncolites are the result of a microbial-driven (cyanobacterial) precipitation of calcium carbonate. Contrary to the laminated stromatolites, oncoids are formed by concentric carbonate crusts around free-rolling elements, hence their round, subspherical or often irregular forms of the cortex (Fig. 3g). In the Lives Formation, the nuclei of the oncoids are often composed of a single brachiopod shell of the genus *Composita* Brown 1849 (Fig. 4i). The complete oncoid averages 0.5–2 cm in diameter. This oncolitic facies is quite distinctive of the middle part of the Corphalie Member (sequence 0) (Fig. 2).

The Stromatolitic Lithofacies

Microbialites are sedimentary structures produced by physiological activity of micro-organisms (mostly Archaea and bacteria) triggering the precipitation of calcium carbonate from the sea-water, resulting in piles of very thin layers or laminae. The stromatolites are quite common in the ‘Pierre de Meuse’ and form thinly laminated beds up to 50 cm thick. The stromatolites are either laminar (planar, Fig. 3b–c) or irregular (wavy, columnar, conical and cauliflower-shaped, ‘en bouffées de pipes*’* as described in older literature). When they become dried out, the microbial mats often retract and curve, forming tepee structures, and they even become reworked (detached, then re-accumulated) producing centimetre-sized ripped-up stromatolitic chips.

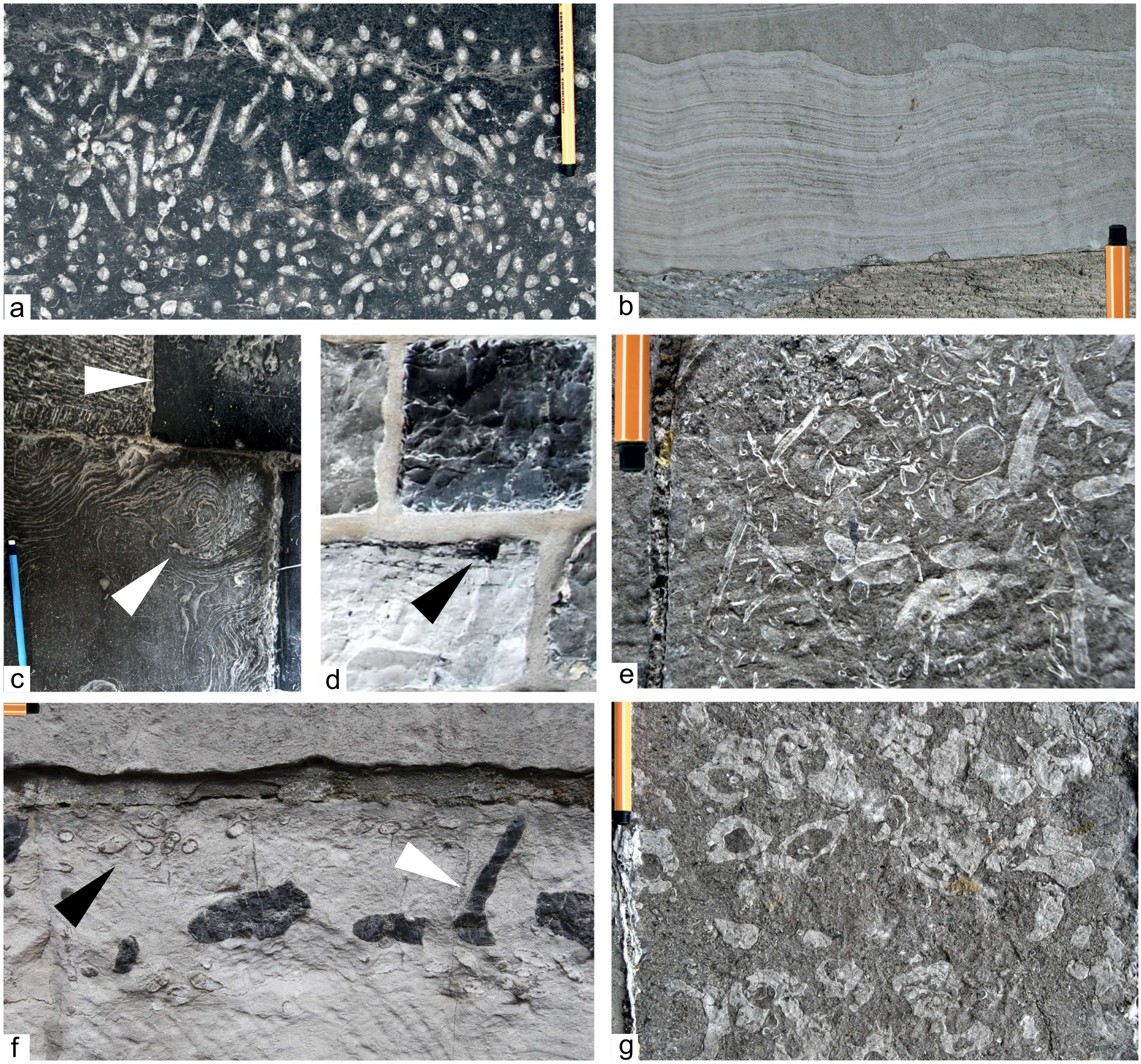


Fig. 3 Photographs of characteristic lithofacies of the 'Pierre de Meuse' observed in building stones of monuments. **a** Bioclastic lithofacies with abundant coral fragments (Namur, Château des Comtes). **b** Stromatolitic lithofacies, cut perpendicular to the bedding (Alken, St. Aldegondis church). **c** Stromatolitic lithofacies cut parallel to the bedding (Maastricht, pavement inside Church of Our Lady). **d** Micritic lithofacies 'Marbre noir de Namur' (Namur, Porte de Médiane). **e** Bioclastic lithofacies (Liège, sixteenth century defending wall, Quai Sainte-Barbe). **f** Chert nodules (white arrow) and silicified corals (black arrow), Hasselt (Herkenrode kazerne); **g** oncoidal facies (Namur, Porte de Médiane)

The Micritic Lithofacies

The lithification of micrite (lime mudstone) resulting from the abrasion and disintegration of calcitic skeletons produces a smooth and homogeneous limestone, dark-grey or black in colour when fresh but often pale when weathered (Fig. 3d). Fossils are quite rare, with the notable exception of small gastropod and ostracods shells. This micritic facies occurs in thin beds called 'plaquettes' (thin slabs) that were once quarried as ornamental stones displaying a pleasant homogeneous pitch-black colour, especially after a mirror-like polished finish. This particular black fine-grained limestone corresponds to the famous 'Marbre Noir de Namur', one of the so-called Belgian black marbles, considered a global heritage stone (Tourneur 2020).

Macrofossils Among the numerous fossils that can be observed in 'Pierre de Meuse', some are quite easy to identify and they provide good tools (index fossils) to differentiate it from other macroscopically analogous building stones. The most common and easily identifiable fossils in limestone samples, without involving microscopical techniques, are described and illustrated below.

Corals

The rugose coral *Siphonodendron martini* (Milne-Edwards and Haime 1851) appears as a cluster of tubes (Fig. 4a–c) displaying a regular internal structure made of radial elements (septa), an axial (columella) and horizontal (tabulae). The diameter of the tube varies from 6 to 10 mm and there are 23 to 28 septa. In longitudinal section, the corallites appear as a ladder, with 10–15 tabulae per centimetre (Fig. 4b). Where the longitudinal section cuts the axis, the tabulae are cut by the axial structure, and appear as vertical laths. *Siphonodendron martini* is most common in the bioclastic lithofacies and is a key component of the coral lithofacies. *Lithostrotion araneum* (McCoy 1844) displays the same internal structure but it has polygonal corallites forming massive colonies. This species is typical of the argillaceous lower bed of the Corphalie Member (Poty 1981). The tabulate corals *Syringopora* sp. and *Cladochonus* sp. appear also as clusters of small (1–2 mm) tubes lacking any radial and axial structures (Fig. 4j, n). Solitary rugose corals, such as *Axophyllum nanum* Poty 1981, and *Clisiophyllum garwoodi* Salée 1913, occur occasionally. In transverse section, they appear as regular circles with numerous septa joining the axis of the corallites, where a complex columella is present. *Axophyllum nanum* rarely reaches 1 cm in diameter (Fig. 4d), but *Clisiophyllum garwoodi* commonly reaches 3 cm (Fig. 4g–h). In longitudinal section, they both display tabulae that are strongly upturned towards the axial structure. Larger solitary corals (up to 5 cm in diameter) with long septa and no axial structure belong to the species *Caninophyllum archiaci* (Milne-Edwards and Haime 1851) (Fig. 4f). These corals are a typical component of the Lives Formation (Denayer et al. 2011). *Heterophyllia ornata* McCoy 1849, and the smaller *Hexaphyllia mirabilis* Duncan 1867, are heterocorals, appearing as white strips up to 4 cm long and 1–3 mm in diameter (Fig. 4e). Their unusual abundance, compared to that of other Lower Carboniferous limestones, is most characteristic of the lower part of the Corphalie Member of the Lives Formation (sequence 0) (Poty 1981).

Gastropods and Other Molluscs

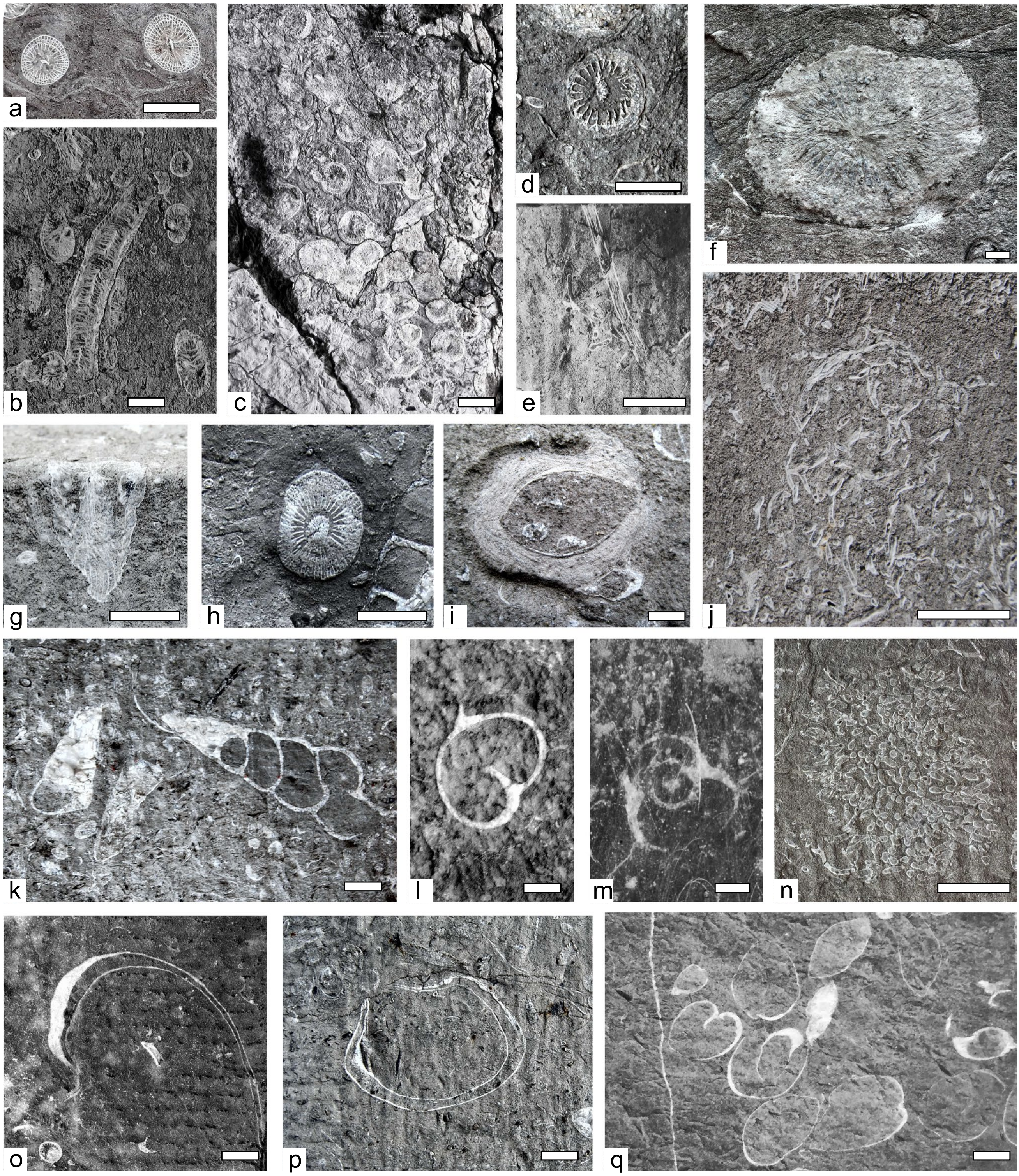
Among the gastropods that are frequently present in the micritic and bioclastic lithofacies, the turriform (<1 to 5 cm long) and thick-walled murchisonids occur (Fig. 4k–l) as well as the rarer discoid straparollids. Bellerophontids, with their involute sub-spherical thick shell, are not so frequent (Fig. 4m).

Brachiopods

Brachiopods are quite common in the bioclastic lithofacies, where different genera sensu lato can easily be recognised. Their calcitic shells appear white on weathered rock surfaces. Specimens of productidines have concavo-convex, thinly ribbed shells with two valves fitting into each other, with a small space in between them. When cut transversely, they are easily recognisable, but when cut parallel to the edge of the valve, they commonly appear as thick concentric white or grey circles (Fig. 4o–p). The width of the shell varies from 2–3 cm up to 10–12 cm for the largest specimens. The genus *Composita* Brown 1849, displays small (1–2 cm wide), biconvex and smooth shells. These brachiopods are rather common in the oncolite lithofacies where they occur as nuclei of the oncoids (Fig. 4i, q).

Other Non-biogenic Macro-elements Cherts are siliceous concretions that grow during or after the deposition of the sediment. They appear as black nodules, lenses or irregular beds of 2–3 cm up to 10 cm in thickness. Cherts commonly fracture perpendicularly to the bedding plane, along narrow white calcite veins. Fossils and sedimentary structures are occasionally preserved within the silica matrix. The chert being harder and more resistant to weathering (dissolution) than the limestone, it often protrudes from the stone (Fig. 3f). The Les Awirs Member of the Lives Formation is particularly rich in chert beds and nodules, but it has not been quarried as a building material, most probably because of the presence of these cherts. Furthermore, cherts are quite rare in the limestones of the Corphalie Member. Another type of silicification occasionally affects all the lithofacies of the 'Pierre de Meuse': a pervasive silicification of the rock often occurs along natural fracture planes (diaclases) and affects the limestone over a few millimetres to some centimetres, on both sides of the fracture, particularly affecting fossils and carbonate particles such as oncoids (Fig. 3f). As natural fractures often facilitated the cleaving of the rock in the quarries, these silicified surfaces are often visible in the building stones.

Stylolites (also called 'terrasses' or 'déssères' in French and 'zwarte voegen' or 'brandlagen' in Dutch) are zig-zag-shaped joints darkened by insoluble organic and clayish material that traverses the limestone. They result from diagenetic (post-deposition) compression and dissolution (pressure solution) of the limestone.



Microscopical Characteristics

Carbonate Microfacies

As mentioned earlier, the Lives Formation is characterised by rhythmically arranged shallowing-upward and thinning-upward sequences. A large set of microfacies recording various stages of water depth and hydrodynamic conditions are present. However, six main microfacies are recognised within the sequences −1, 0 and +1, i.e. the units quarried as 'Pierre de Meuse'. These carbonate microfacies resemble those in the other sequences,

◂**Fig. 4** Photographs of selected macrofossils found in the 'Pierre de Meuse', as observed in building stones of historical monuments. Scale bar equals 1 cm for all. **a** Corallites of the colonial rugose coral *Siphonodendron martini* (Milne-Edwards and Haime 1851) in transverse section (Liège, column at the entrance of the Palais des Princes-Evêques). **b** Same species in longitudinal section (Namur, Château des Comtes). **c** Colony of *Siphonodendron martini* (Milne-Edwards and Haime 1851) in transverse section (Alden Biesen Castle). **d** Solitary rugose coral *Axophyllum nanum* Poty 1981 (Liège, Cours des Mineurs); **e** Solitary heterocoral *Hexaphyllia mirabilis* McCoy 1849 (Huy, Notre-Dame collegiate church). **f** Solitary rugose coral *Caninophyllum archiaci* (Milne-Edwards and Haime 1851) (Liège, Récolets Church). **g** Solitary rugose coral *Clisiophyllum garwoodi* Salée 1913 in longitudinal section (Tongeren, Beguinage Church). **h** Same species in transverse section (Tongeren, Beguinage Church). **i** Athyridide brachiopod (*Composita* sp.) in an oncoid (Hasselt, Sint Rochus Church). **j** Colonial cladochonid tabulate coral (Liège, old defensive wall along the Quai Sainte-Barbe). **k–l** Murchisonid gastropod shells cut under two orthogonal directions (Tongeren, Beguinage church). **m** Bellerophontid mollusc shell (Namur, Bonnet de Prêtre). **n** Colonial syringoporid tabulate coral (Liège, Récolets Church). **o–p** Productidine brachiopod with articulated valves cut under two orthogonal directions (Namur, Porte de Médiane). **q** *Composita* brachiopod (Liège, Cour des Mineurs)

however with minor differences but they are not discussed here: more details can be found in Michot et al. (1963).

***Bioclastic Rudstone with Corals, Brachiopods and Small Oncoids* (Fig. 5g)** This microfacies is dominated by a rudstone facies (the matrix is a coarse-grained bioclastic grainstone with patches of packstone) where the colonies of the rugose coral *Siphonodendron martini* are broken but the corallites are usually well preserved (not crushed or fragmented) and commonly coated by a thin microbial layer (cortoids). Other allochems include small (5 mm) oncoids, brachiopods, gastropods, foraminifers (endothyrids), calcareous algae (koninckoporids) and mud-coated grains. This microfacies is most common in the coral lithofacies (Fig. 3a). Fragments of tabulate corals (syringoporids, cladochonids) and heterocorals replace the rugose corals in the bioclastic rudstone. This coarse-grained facies typically occurs at the base of the above-mentioned sequences.

***Grainstone-Packstone with Peloids and Intraclasts* (Fig. 5e)** The dominant texture is that of a grainstone, but patches or layers of packstone are present as well. Intraclasts (up to 1 mm) and peloids, most probably of microbial origin, are the most characteristic allochems of this biofacies but bioclasts (corals, brachiopods, gastropods) are common, as well as microfossils, including plurilocular foraminifers (see further) and moravamminid microproblematica. Small peloids occur in the matrix of the packstone patches. This facies is characteristic of the sequences −1 to +1, in combination with the previous and succeeding ones. The latter microfacies is the real hallmark of the bioclastic lithofacies.

***Bioclastic Packstone-Wackestone with Calcispheres* (Fig. 5e)** The dominant texture is that of a packstone, but patchers of grainstone and wackestone are present as well. Calcispheres are abundant, next to foraminifers, moravamminids and large bioclasts of tabulate corals, brachiopods and gastropods. Peloids and small mud-coated grains occur within the matrix. This microfacies, commonly associated with the previous one, is characteristic of the bioclastic lithofacies.

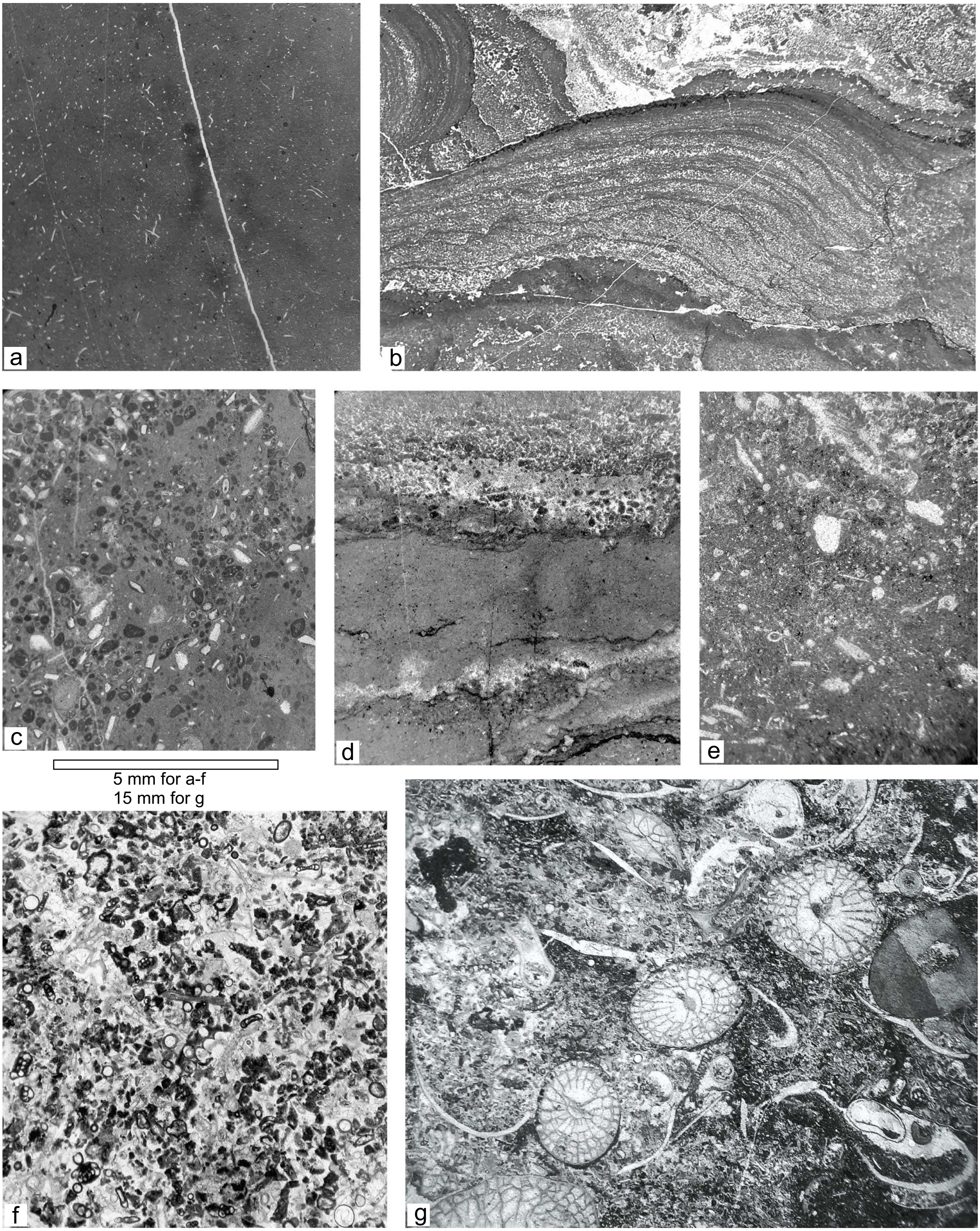
***Lime Mudstone with Peloids* (Fig. 5a, c)** This microfacies is a homogeneous mudstone, locally grading into wackestone, with small bioclasts and peloids. Unfragmented ostracods, calcispheres and foraminifers are accessory allochems. Sponge spicules and very thin shell fragments of gastropods may be present. Locally, the mudstone contains micrograinstone layers or burrows filled with peloidal grainstone. This lime mudstone microfacies is the chief component of the 'Marbre Noir de Namur', corresponding to the upper half of sequence 0, but occurring also in the top layers of sequences −1 and +1.

***Laminated Mudstone-Wackestone with Stromatolitic Laminae* (Fig. 5b, d)** This microfacies is composed of alternating micritic layers (with rare small microbial tubes) and peloidal wackestone, trapped in between stromatolitic laminae. The stromatolites are planar, domal or columnal. In the latter case, the sediment between the stromatolite columns is a laminated peloidal grainstone. This stromatolitic microfacies of course dominates the stromatolitic lithofacies and occurs in beds capping the sequences in association with the mudstone microfacies.

***Wackestone-Packstone with Large Oncoids* (Fig. 3g)** The oncoids are millimetre to centimetre large and contain often a single small brachiopod as nucleus. They occur either in fine-grained bioclastic wackestone and packstone or peloidal wackestone facies, containing mud-coated grains and encrusted bioclasts. This microfacies is only found in the oncolitic lithofacies.

Microfossils

Besides the index macrofossils described above, different microfossils are characteristic or diagnostic for the Pierre de Meuse, mainly foraminifera and calcareous algae (Poty et al. 2002). Following the biostratigraphical scheme proposed by Conil et al. (1977, 1991) and emended by Poty et al. (2006), the Lives Formation is almost entirely included in the foraminiferal biozone MFZ12 (former Cf5), which usually starts above the base of the formation. In Lives, the stratotype of the eponymous formation, the entry of the foraminifer *Pojarkovella nibelis* (Durkhina 1959) (Fig. 6a–b)


a
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g

◂**Fig. 5** Microfacies from the sequence 0 (Corphalie Member) of the Lives Formation and Livian substage stratotypic section in Lives, in the Meuse valley downstream of Namur; bed numbers are those of Michot et al. (1963). **a** Homogeneous mudstone with peloids (bed 79 of Michot et al. 1963). **b** Stromatolitic mudstone (bed 67b). **c** Mudstone with peloids (bed 68). **d** Laminated mudstone with grainstone horizons (bed 77). **e** Bioclastic wackestone-packstone (bed 67a). **f** Bioclastic grainstone with foraminifers (bed 48). **g** Bioclastic grainstone-packstone with corals (bed 56)

and guide for the MFZ12, occurs only 14 m above the base of the formation because of the predominance of restricted environmental conditions. The foraminiferal diversity increases upwards, with the entry in the Haut-le-Wastia Member, of *Koskinotextularia* spp. (Fig. 6h) and the increasing abundance of the following taxa characteristic of an open marine facies: *Lituotubella* spp., *Brunsina* spp. (Fig. 6j), *Rhodesinella* spp., *Omphalotus* spp. (Fig. 6c), *Endothyra* spp., *Eostafella* spp. (Fig. 6i) and several archaediscids (Fig. 6d–f). Calcispheres (Fig. 6k) are also locally abundant in the more restricted marine facies. Dasycladacean green algae such as *Koninckopora* spp. are locally abundant in the grainstone lithofacies (Fig. 6g).

Historical Use and Geographical Distribution

The 'Pierre de Meuse' was first used by the Romans (second century AD), for the manufacturing of milestones, funerary monuments, floor tiles and for various building and decorative applications (sculptured wall decorations and mouldings) within the former *civitas Tungrorum* (Dreesen et al. 2015; Dreesen and Vanderhoeven 2017; Coquelet et al. 2018). Its capital Tongeren (*Atuatuca Tungrorum*) was the major destination of Roman stone trade. Moreover, variously coloured Belgian 'marbles' and 'Pierre de Meuse' were exported to different Roman settlements outside the actual *civitas*, such as Coriovallum (Roman bathhouse, Heerlen), Xanten, pavements and revetmens in baths of Roman villae as well as other Roman constructions of Wasserliesch Konz, Pfazel, Cologne and Trier (Dreesen and Vanderhoeven 2017; Dreesen 2018, Ruppiené 2015, 2021 and Ruppiené, pers. com.). Fragments of Meuse limestones have also been found in the Roman villa of Echternach in Luxemburg (Bintz et al. 1981) and were used as tiles bordering the mosaics found in Vichten (Luxemburg; Krier and Reinert 1995). Stone trade and supplies were possible due to the supposed existence of transshipment facilities in the nearby fluvial agglomeration of Maastricht (*Mosa trajectum*) in the Netherlands. In the above *civitas Tungrorum*, the 'Pierre de Meuse' and a particular variety of Frasnian Belgian grey marble (called 'Gris des Ardennes') represent the most popular local decorative stones cherished by the Romans (Dreesen et al. 2015, 2018; Vanderhoeven 2018). Moreover, the black 'Marbre noir de Namur' has also been used for the manufacturing of small cubiform tiles in Roman mosaics, as seen in Tongeren (Dreesen et al. 2015) and that of a *labrum* (large water-filled vessel), found in the Romans baths of *Coriovallum* (Heerlen, the Netherlands; Dreesen et al. 2018). Furthermore, a series of Roman votive altars dedicated to the goddess Nehalennia carved in 'Pierre de Meuse' (Fig. 7e) were found near the Roman sanctuary of Colijnsplaat (*Ganuenta*) (Anderson and Groessens 1996). From the fourth century onwards, spolia of 'Pierre de Meuse' were frequently recycled. Subsequently, the recycling of Roman building and decorative materials became a real hallmark of early medieval constructions. Only the coral, bioclastic and micritic lithofacies (Fig. 7f) have been used by the Romans, presumably because of their easy extraction (obviously due to the presence of thicker beds, their sub-horizontal bedding and the location of their outcrops close to the river). After the decline of the Roman Empire, the architecture and construction of structures with stone fell into disuse. From the twelfth and thirteenth centuries onwards, there is a revival of the stone industry in the Namur area, in response to the booming export of tombstones, columns and baptismal fonts made of the competing Lower Carboniferous Tournai Limestone, along the Scheldt to the Netherlands and England (Groessens 2005). In the Niederrhein area (Western Germany), 70 Romanesque baptismal fonts made in 'Pierre de Meuse' have been inventoried by G. Pudelko (1932). Other examples (dating from the thirteenth century) are also known farther north, such as in the churches of Waddewaarden and Westrum in German Ostfriesland (Petersen 1997). From this period onwards, other varieties of 'Pierre de Meuse' were used, more especially the stromatolitic lithofacies (Fig. 7a, g), together with the reuse of blocks of bioclastic limestone from destroyed Roman buildings (Fig. 7d). From the fourteenth and fifteenth centuries onwards, the oncolitic lithofacies appears in historical monuments and in several funerary objects (e.g. burial crosses and tombstones). Numerous great examples of their use can still be observed at many places in the Principality of Liège, notably within the Belgian province of Limburg (Dusar et al. 2009; Dreesen et al. 2019): here, various applications can be admired, including building stones, floor tiles (e.g. Figs. 3c, 7b), cornices, columns, capitals, burial crosses, incised tomb slabs, baptismal fonts and coats of arms. Interestingly, Mosan gothic is the name of a gothic building style in the Principality of Liège that prevailed during the thirteenth to sixteenth century. The presence of the so-called Mosan capitals (sculptured capitals with stylised leaves) on top of columns, all made in 'Pierre de Meuse', is its discriminating element. Dutch builders imported the 'Pierre de Meuse' for plinths, door and window frames, sills, cornices, stairs and pavements, from the beginning of the fifteenth century onwards, in larger constructions such as churches and houses in Utrecht (Janse and De Vries 1991),

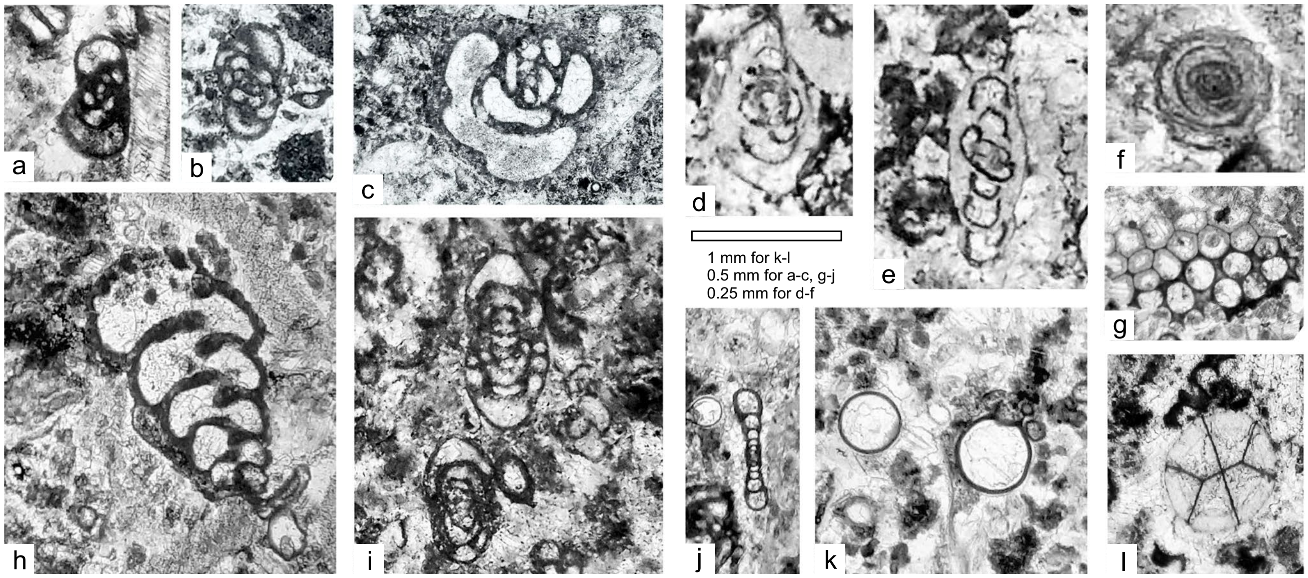

Fig. 6 Microfossils, from the sequence 0 (Corphalie Member) and sequence −1 (Haut-le-Wastia Member) from the Lives Formation and Livian substage stratotypic section in Lives, in the Meuse valley downstream of Namur; bed numbers are those of Michot et al. (1963). **a**–**b** *Pojarkovella nibelis* (Durkhina 1959) (foraminifer marker of biozone MFZ12) (bed 51). **c** *Omphalitis* sp. (foraminifer characteristic of the Lives Formation) (bed 49). **d**–**e** Archaediscid foraminifer (axial section) (bed 57). **f** Archaediscid foraminifer (equatorial section) (bed 48). **g** *Koninckopora* sp. (green algae) (bed 48). **h** *Koskinotextularia* sp. (foraminifer characteristic of the Lives Formation) (bed 53). **i** *Eostafella* sp. (foraminifer abundant in the Lives Formation) (bed 38). **j** *Brunsina* sp. (foraminifer) (bed 53). **k** Calcispheres (incertae sedis, abundant in some beds of the Lives Formation) (bed 51). **l** *Hexaphyllia* sp. (heterocoral, common in sequences 0 and −1) (bed 60)

defence works (Dordrecht) and bridges (e.g. the Koppelpoort, Amersfoort) (T. Nijland, pers. com.). This export was especially important during the sixteenth century because of the imperialistic behaviour of Namur and Liège. Stone traders became also structurally active on the northern Low Countries market, since a number of them settled down in Dordrecht and Amsterdam in 1585 (Van Tussenbroek 2001, 2010). As a result, the 'Pierre de Meuse' reached Dutch regions north of the Meuse belt, including the cities of Alkmaar, Amsterdam, Zutphen, Gouda, Vianen (e.g. front facade of the townhall) and Zaandam (e.g. used for the construction of locks). Fluvial transport of 'Pierre de Meuse' extracted from the quarries located near the river was common practice from the thirteenth century onwards (Suttor 2006). Therefore, the oldest applications of 'Pierre de Meuse' in the Netherlands are to be found in the adjacent province of Limburg. Nevertheless, 'Pierre de Meuse' was already reported in earlier buildings of the large fluvial area in the Netherlands, such as in the tenth century churches of Andelst and Alphen a/d Maas (Slinger et al. 1980). 'Pierre de Meuse' was also shipped upstream in the early fifteenth century to Dinant or even further southward, to Mézières in France (Suttor 2006).

Within the Principality of Liège and its surroundings, a particular regional architectural style was introduced during the sixteenth century, the so-called Mosan renaissance or Mosan style (Timmers 1980). This style has been applied predominantly in the Principality of Liège (seventeenth to eighteenth century) in present-day Belgium and the Netherlands, mainly in the city of Liège, the Herve region and the provinces of Belgian Limburg and Dutch South Limburg. Stone-framed windows, decorated architraves and alternating layers of brick and stone (alternating stone bands) are its most distinctive features. The utilised materials were endemic to the regions where the style prevailed, including grey 'Pierre de Meuse', red bricks and yellow (Upper Cretaceous) Maastricht limestone. Beautifully incised and signed sixteenth to seventeenth century tomb slabs made of 'Pierre de Meuse' were discovered in the province of Friesland in the northern Netherlands and described in detail by Brink (2016) (Fig. 7c), as well as in other northern Dutch provinces (e.g. in Groningen, Nijland, pers. com.), in German Ostfriesland (Petersen 1997) and along the German Baltic coast (Mecklenburg-Vorpommern, e.g. Wismar and Bad Doberan, Nijland, pers. com.). Interestingly, the related oolitic Vinalmont stone and the crinoidal Longpré stone do not appear in our historical monuments before the start of the nineteenth century (see Table 2).

The 'Pierre de Meuse' has been intensively quarried until the beginning of the twentieth century. However, since the end of the nineteenth century, the production of 'Pierre de Meuse' strongly declined in favour of that of Petit Granit, a widespread more homogenous Tournaisian crinoidal limestone (Groessens 2005; Dusar et al. 2009).

Fig. 7 Examples of use of the 'Pierre de Meuse'. **a** Western wall of the fifteenth century cloister in stromatolitic facies, Saint Paul Cathedral, Liège. **b** Pavement of the courtyard of the Palais des Princes-Evêques, Liège in stromatolitic facies and 'Marbre noir de Namur'. **c** seventeenth century incised tombstone in Schettens, Friesland, by P. Claes (courtesy of T. Brink). **d** Reuse of large Roman blocks of 'Pierre de Meuse', twelfth century Church of Our Lady, Maastricht. **e** Roman altar dedicated to the goddess Nehalennia in 'Marbre noir de Namur', Rijksmuseum voor Oudheden, Leiden. **f** Pedestal of a pillar in bioclastic facies, portal of eleventh century Romanesque Saint Etienne Church, Seilles. **g** Pedestal of a column in stromatolitic facies, cloister of the twelfth century monastery, Tongeren

Table 2 Overview of the evolution in time of the different lithofacies of the 'Pierre de Meuse', based on observations in historical monuments

LITHOFACIES	1st-4th	5th-11th	12th-13th	14th-15th	17th-18th	19th-20th
Coral	■	Re-use	■	■	■	■
Bioclastic	■	Re-use	■	■	■	■
Stromatolitic			■	■	■	■
Oncolitic				■	■	■
Micritic	■		■	■	■	■
Vinalmont					■	■
Longpré						■

In Belgium, more than 1100 historical buildings, dating from the tenth century through the early twentieth century, are at least partly built in 'Pierre de Meuse' (Belgian Geological Survey unpublished inventory, De Ceukelaire & Dusar, pers. com.), whereas more than 250 buildings of the same type were reported from the Netherlands (Nijland, pers. com.). Among these buildings, many are recognised and protected by national or international (e.g. UNESCO) heritage programs. This is the case, for instance, for the belfry of Namur (UNESCO World Heritage #943bis). The Palace of the Prince-Bishop in Liège, also partly build in 'Pierre de Meuse', is candidate since 2008 for recognition as a World Heritage site. Moreover, more than 100 sites are actually protected as 'Patrimoine exceptionnel de Wallonie', including numerous religious, military and civilian buildings and sites.

The gorgeous black micritic variety of the 'Pierre de Meuse', the 'Marbre noir de Namur', belongs to the outstanding group of prestigious Belgian black marbles, now considered Global Heritage Stones (Tourneur 2020). This latter appellation usually designates dark fine-grained limestones present in the Palaeozoic substrate (Upper Devonian through Lower Carboniferous) of south Belgium. Many different historical uses were made of these prestigious fine-grained black limestones for architecture, decoration or sculpture, in different religious and civil contexts. The 'Pierre de Meuse' has been exported well beyond the limits of the Meuse region, as stated by Groessens (2005): i.e. it has been exported in the sixteenth century to Roskilde (Denmark) for the manufacturing of the royal graves of King Cristian IV and to Poland and Lithuania in the seventeenth century, as ordered by King Sigmund III for the construction of castles.

Quarries and Extraction Areas

Historical Extraction Sites

At the end of the nineteenth century, Berger (1890) inventoried a total number of 31 active quarries, where the 'Pierre de Meuse' was still extracted. Besides a detailed description of each limestone bed, he listed also their qualities and defaults if or when used in a monument. Today, only one single quarry in the Meuse valley still extracts the 'Pierre de Meuse' (see below). Both the famous historical underground and open-air quarries of Les Grands-Malades (this particular name refers to an old leprosy located at the foot of the cliffs) are located on the eastern exit of Namur towards Beez (Fig. 1), on the left side of the Meuse. The 'Falises en Herbatte' quarry (situated on the hills of Bouge and belonging to the hospice or almshouse of Les Grands-Malades) was first mentioned in 1229, when the Abbey of Val-Dieu handed over this quarry to the Val-Saint-Lambert monastery (Ruwet 1955; Suttor 2006). Cauchy (1825) described in great detail how the black marble beds were extracted at this particular quarrying site. Van der Maelen (1832) identified 16 individual limestone beds in the same underground quarry, among which several beds of black marble quality, all identified by a particular name and specific thickness. During the second half of the nineteenth century, the underground extraction of limestone stopped in favour of another open-air quarry that produced limestone for feeding lime kilns erected between 1872 and 1882 in its direct vicinity (Doperé 2014). Another underground quarry, the quarry of 'the Fond d'Arquet' (Fig. 8b), was located in the Bomel quarter of Bouge, a submunicipality located directly north of Namur. Initially, building stone has been extracted from here, but the quarry is best known for the production of limestone for lime burning. It seems that the underground quarries in the northern flank of the Meuse valley in Namur were the exclusive providers of the 'Pierre de Meuse' (so-called 'Pierre de Namur') before the nineteenth century, as no other quarries were mentioned on the official topographic maps before this period. From the nineteenth century onwards, open-air quarries developed in the Meuse valley, most of them producing both building stones and limestone for the lime industry (Goemaere 2010; Mottequin et al. 2012). Some open-air quarries gradually developed underground for the extraction of the 'Pierre de Meuse' such as the Lives quarry (Fig. 8a). These underground quarries have been exploited according to the roof-and-pillar method: these quarries contain several large cavities (or chambers) of plurimetric to decametric dimensions. In the Namur quarries, the latter chambers are 20 m wide and 20 m high (Fig. 8b), some of which reach 55 m in length, 20 m in width and 10 m in height (Service

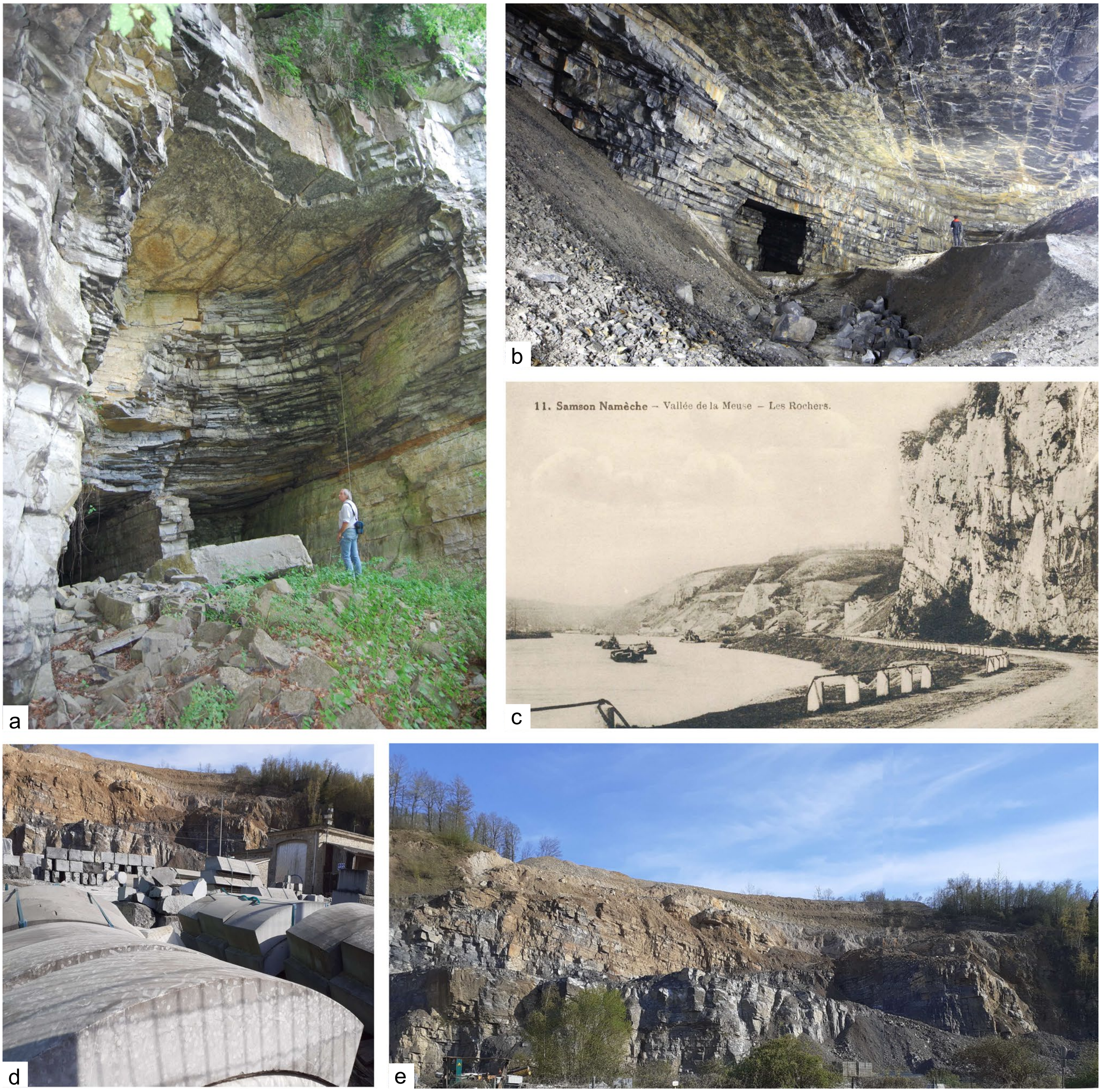

Fig. 8 Examples of 'Pierre de Meuse' quarries. **a** Lives quarry (Namur) with exposure of thin-bedded limestones of black marble quality ('Marbre Noir de Namur'). **b** underground quarry of the Fond d'Arquet; note that the quarry has been partially filled with stone debris deriving from limestone production and lime burning (courtesy of Vincent Duseigne). **c** The En Gore quarry, Namêche in the 1910s and the Thon cliff along the Meuse valley (courtesy of Yves Sorée). **d** The En Gore quarry in 2020, the last open-air quarry still extracting the 'Pierre de Meuse'. **e** Workshop at the En Gore quarry showing stones prepared for the restoration of historical buildings

Géologique de Wallonie). Sometimes, the bottom of some of these chambers is located at depths of less than 20 m below the inhabited districts. Some of the underground quarries most probably extracted the limestone beds belonging to sequences −1 and 0 first, before caving the roof for limestone for the manufacturing of lime, as was the case for the above-mentioned Fond d'Arquet quarry.

Most of the former underground quarries should be rescued and protected as important historical and geoheritage sites. Unfortunately, several of those quarries are no longer accessible. A few have been protected in the meantime though, as biotopes, especially for bats.

Operating Quarries and Alternative Extraction Sites

Today, only one open-air quarry is still active: the quarry of En Gore or Gore (different spellings occur), located in between the bridges of Namêche and Sclayn downstream of the town of Namur (Fig. 8c–e). It is owned by the Walloon Region and its annual production amounts 3000 m^3 of limestone (2010) of which 300 m^3 represent finished products. This production is important for the restoration of historical monuments and for the design and refurbishment of public sites (Goemaere 2010). Several quarries extracting the lower Viséan Neffe Formation (e.g. at Seilles, Moha, Anton, etc.) also mine the limestones of the Lives Formation for aggregates. These quarries could also be used as alternative sites for the production of the 'Pierre de Meuse', like the Moha quarry which temporarily supplied this stone to a building stone producer. Similarly, several quarries situated in the historical extraction area of the stone (in Asty-Moulin, Lives, Maizeret, Ben-Ahin, etc.; see Fig. 1) still constitute important stone resources and might be strategic sites for the supply of 'Pierre de Meuse' in the near future.

Geoheritage and Geotouristic Initiatives

Well-bedded and sub-horizontal limestones featuring the 'Pierre de Meuse' form conspicuous and spectacular rocky outcrops or sceneries, representing great geotouristic attractions in the Meuse valley, such as the 70-m-high Rochers de Samson in Thon: this cliff stretches across more than 700 m south, east and east-north-east of the bridge of Namêche (Figs. 8c, 9a). The Chokier Castle in Flémalle, upstream of Liège in the Meuse valley, is built on top of a cliff made of strongly dipping and overturned beds of the Lives Formation, resulting in a blowing scenic view (Fig. 9d).

Abandoned limestone quarries where limestones of the Lives formation used to be extracted for the feeding of lime kilns, such as the one in Ampsin (Amay), have been redesigned now into attractive geosites by geologists of the Liège University (Mottequin et al. 2012; see Fig. 9f–g). Here, a geological path with 13 explanatory panels shows the highlights of the local and regional geology, as well as that of the fauna and flora that colonised the quarry since its abandonment in 2007. The exposed rocks display a continuous stratigraphic section including the marine limestones of the Lives and Grands-Malades Formations (Livian, mid-Viséan) and their sudden transition to the continental siliciclastic deposits of the Namurian Chokier formation. The quarry sits next to a museum space, called 'Les Maîtres du Feu' (the masters of fire), that retraces the history of the extraction industry in the Meuse basin (limestone, iron ore, etc.).

Besides their scenic view (Fig. 9b), the disused Lives-sur-Meuse quarry and rock exposures along the Meuse represent stratotype sections of both the Lives Formation and the Livian substage (middle Viséan, Lower Carboniferous) (Poty and Hance 2006). Today, this particular site is abandoned but its intrinsic scientific value and geoheritage potential would certainly deserve to be further highlighted and developed.

The spectacular abandoned underground quarry of Les Grands-Malades in Beez (Namur, Fig. 9c) was initially used in the twentieth century as a brewery storage and as a mushroom farm. Since then and after years of illegal visits through aeration chimneys, speleologists discovered new and safer access routes to the underground quarry. The latter has now become a magnificent playground for speleologists under the supervision of the Société Spéléologique de Namur, as well as an important winter refuge for bats. The site is now considered a Site of Great Biological Importance (SGIB).

Different paleontological walks in the historical towns of Wallonia ('Fossiles en ville'—fossils in the city) offer the possibility of discovering fossils in a fun way: they are scattered in the indigenous building stones, paving stones and various street furniture. Several itineraries, maps and fossil guides (booklets including identification keys) can be downloaded for free (rejouisciences.uliege.be\FeV). The booklets allow the discovery and recognition of more than 60 (mostly invertebrate) fossils that can easily be observed and photographed in various building stones, including abundant examples of the various lithofacies of the 'Pierre de Meuse'. This nice example of urban geology and fossil hunting, designed for a wide public and supported by the Fédération Wallonie-Bruxelles government, has been rewarded by the Belgian National Fund for Scientific Research for its innovative way of popularising geology and palaeontology in particular. Twelve itineraries are available yet in six towns and the project is still expanding to other Belgian towns (see Fig. 9e). The booklets are associated with virtual itineraries available on several online walking applications such as Cirkwi (https://www.cirkwi.com).

Conclusions

'Pierre de Meuse' is an important building and decorative stone used already since Roman times, in a large part of the *civitas Tungrorum* and subsequently in the Principality of Liège (during medieval through modern times). Since medieval times, it has been widely exported beyond the actual borders of Belgium. It is now geologically and stratigraphically well-defined and it has been given a rather restricted historical-geographical provenance area. As a result, we constrain its definition now to all stones originally quarried in the direct vicinity of the town of Namur (and to all stones extracted from the same stratigraphic level close to

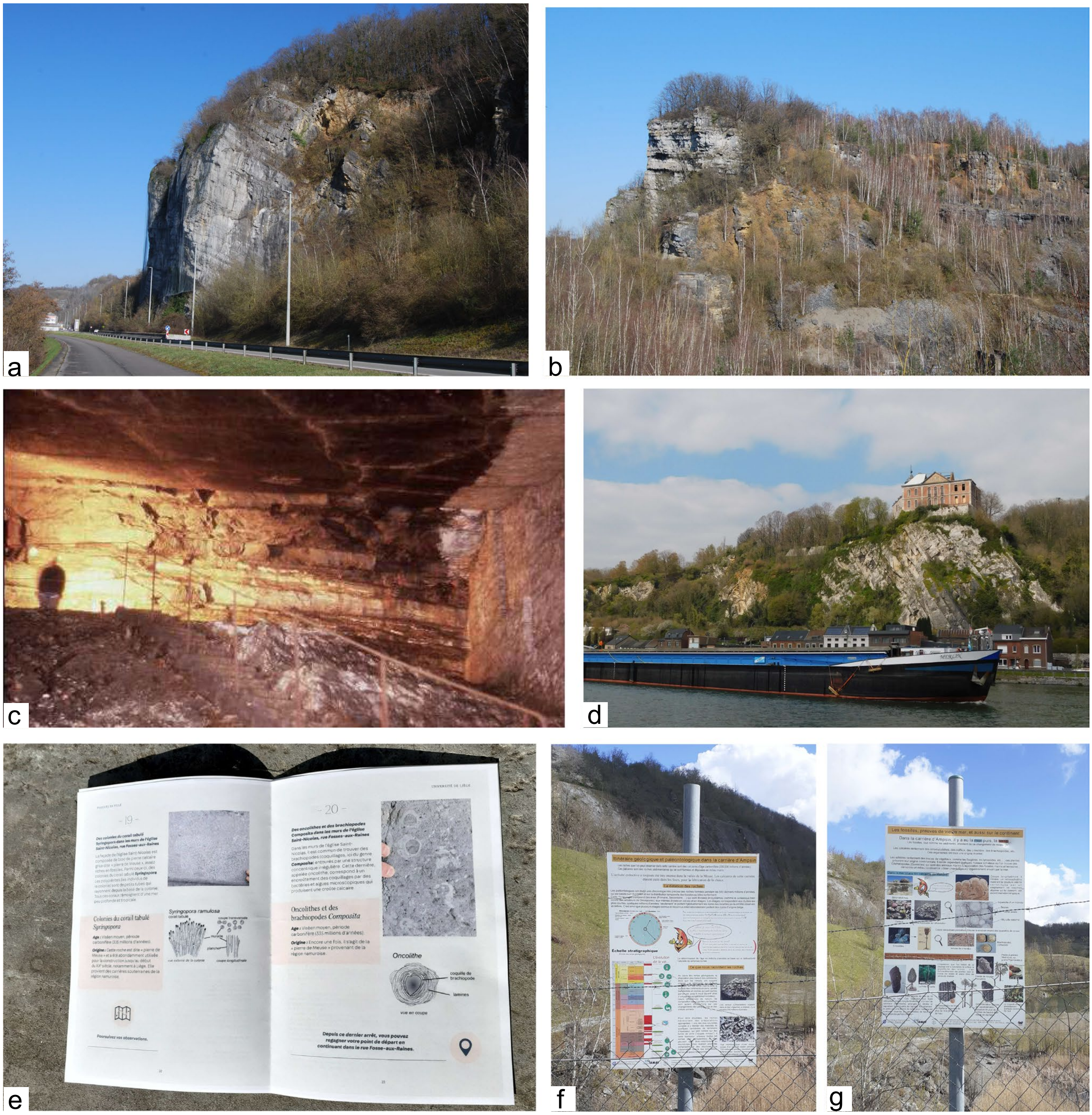

Fig. 9 Examples geosites and urban geology, related to the 'Pierre de Meuse'. **a** Scenic view of the Thon cliffs in the Meuse valley, exposing well-bedded limestones of the Lives Formation. **b** Scenic view of the stratotype of the Lives Formation in Lives-sur-Meuse. **c** Underground quarry of the Grands-Malades, Namur, one of the best-preserved historical extraction sites of the 'Pierre de Meuse' (courtesy of Vincent Duseigne). **d** Chokier Castle resting on top of a cliff composed of overturned beds of the Lives Formation. **e** Fossil coral from the 'Pierre de Meuse' as shown in the booklet 'Fossiles en Ville' dealing with Liège city old centre. **f–g** Explanative panels at the Ampsin quarry geosite

that river), subsequently in the Meuse valley between Spy and Flémalle, bearing a specific lithostratigraphic and sedimentological hallmark: it corresponds lithostratigraphically to the extreme top of the Haut-le-Wastia Member and the following Corphalie Member, both belonging to the middle Viséan Lives Formation. For historical and geological reasons, we exclude from this definition all other Lower Carboniferous rock types in the Meuse area and adjacent Condroz and Vesdre areas that have a somewhat analogous macroscopical appearance (the so-called blue stone or 'pierre bleue'). Indeed, either they have a different stratigraphical age (e.g. the Vinalmont and Longpré stones; the Aachener Blaustein), they display different lithofacies (e.g. the 'Marbre noir de Dinant') or they have been tectonically too deformed for proper extraction (e.g. all time-equivalent limestones in the Vesdre area). Characteristic lithofacies, carbonate microfacies and distinctive fossil guides are described and figured in this paper, in order to help archaeologists, building historians, restoration architects and all colleagues interested in stone sourcing, with the identification of the various varieties (lithofacies) of the 'Pierre de Meuse'. This particular stone has been used for a broad spectrum of building or decorative applications, for which various varieties or particular lithofacies have been applied, at different time intervals. The 'Pierre de Meuse' displays also quite a large geographical distribution of which nice examples are known both upstream and downstream of Namur and even beyond the catchment basin of the Meuse (e.g. north of the great river belt in the Netherlands). The Meuse acted as its major historical fluvial transport route in Belgium and the Netherlands, although sometimes the Scheldt has been used as well. Most famous are the baptismal fonts and the incised tombstones manufactured in 'Pierre de Meuse', whereas particular architectural trends in the Meuse valley are dominated by the use of this stone, such as the Mosan gothic and Mosan renaissance styles. Not much is known about the earliest (Roman) extraction, probably because of younger quarrying activities that destroyed all former traces. However, a number of abandoned historical quarries (both underground and open-air) still exist, most of which are located in the direct vicinity of Namur. Some of these have now become important biotopes and/or geosites, whereas others represent most wanted speleological attraction sites. A particular fine-grained (micritic) and pitch-black lithofacies is known as the 'Marbre noir de Namur'. Together with the other Belgian black marbles, it recently received the status of Global Heritage Stone. Its first use dates back to the first and second century AD as Roman votive altars and mosaic tesserae. The 'Pierre de Meuse' is particularly rich in invertebrate fossils: geological walks in historical city centres of Wallonia, focusing on Lower Carboniferous fossils in building stones and those typical of the 'Pierre de Meuse', represent original and playful urban geological initiatives, promoting palaeontology and earth sciences through various digital applications and social media supports.

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Declarations

Conflict of Interest The authors declare no competing interests.

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