The Red Marble of Baelen, an exceptional mid-Famennian mud mound complex in a carbonate ramp setting from Eastern Belgium

museum
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The Red Marble of Baelen from the Limbourg area (Vesdre Basin, Eastern Belgium) **(Fig. 1)** represents a member of the middle Famennian (late Upper Devonian) Souverain-Pré Formation (Late *marginifera* conodont Zone) **(Fig. 2)**. It corresponds to a short-term transgressive event and eustatic rise during the Famennian, interrupting the regressive megasequence on the Condroz shelf in Belgium. It is the only known or at least the only well-documented mid-Famennian carbonate mud mound complex worldwide (Dreesen *et al.*, 1985, 2013), after the end-Frasnian mass extinction that wiped out numerous invertebrate taxa.

In contrast with the better-known Belgian red-stained Upper Frasnian mud mounds, the Famennian Baelen mud mounds are totally devoid of corals and stromatoporoids. Instead, crinoids, hexactinellid sponges and incertae sedis algae (Algospongia issinellaceans; Vachard & Cózar, 2010) have occupied here the ecological niche left behind. The macrofauna is clearly dominated by crinoids, which are generally represented by large fragments of stems and more rarely by calyxes, but also includes rare brachiopods (Athyridida, Productida and Spiriferida), bryozoans, and oncocerid (?) cephalopods.

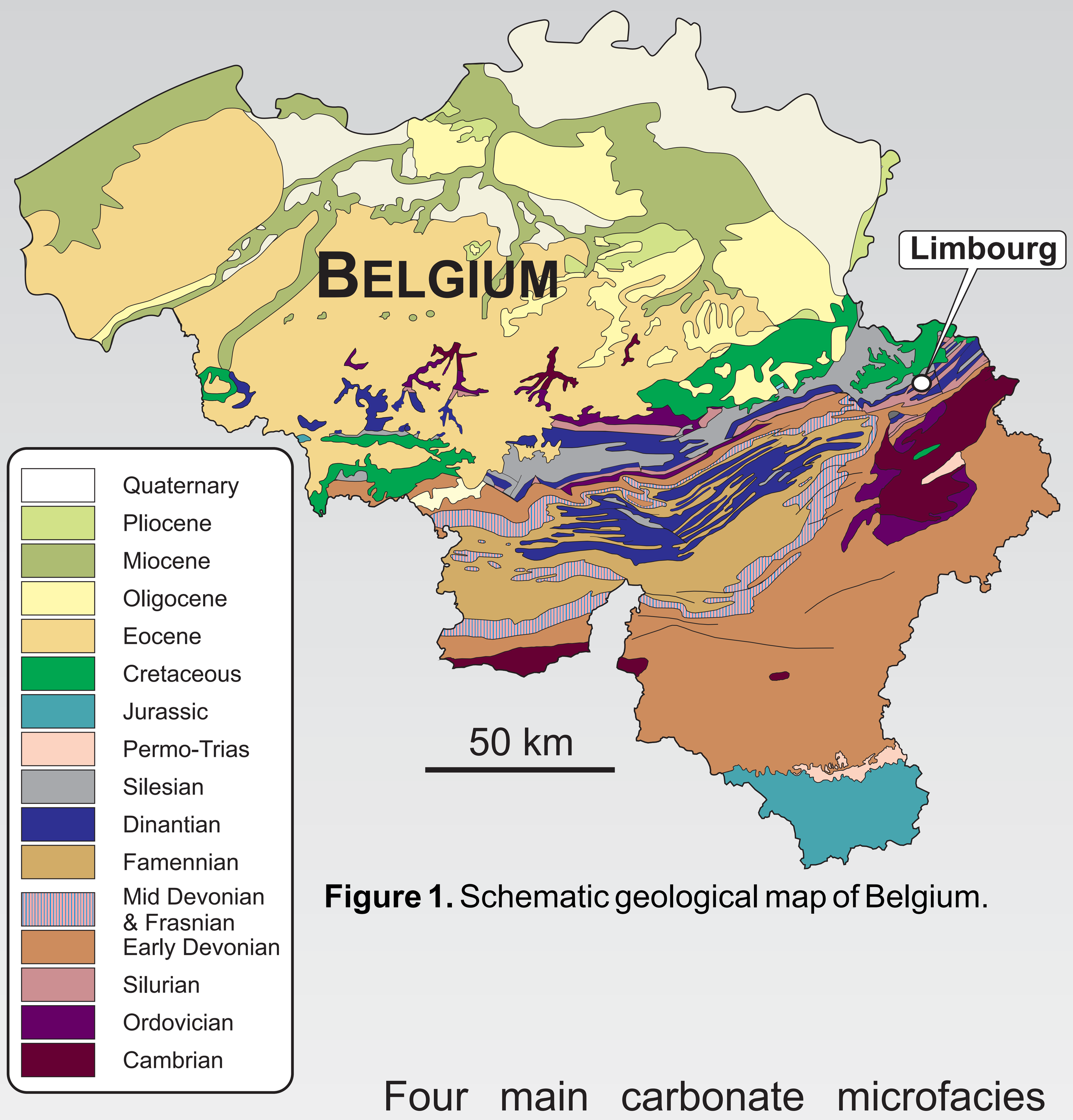

Figure 1. Schematic geological map of Belgium.

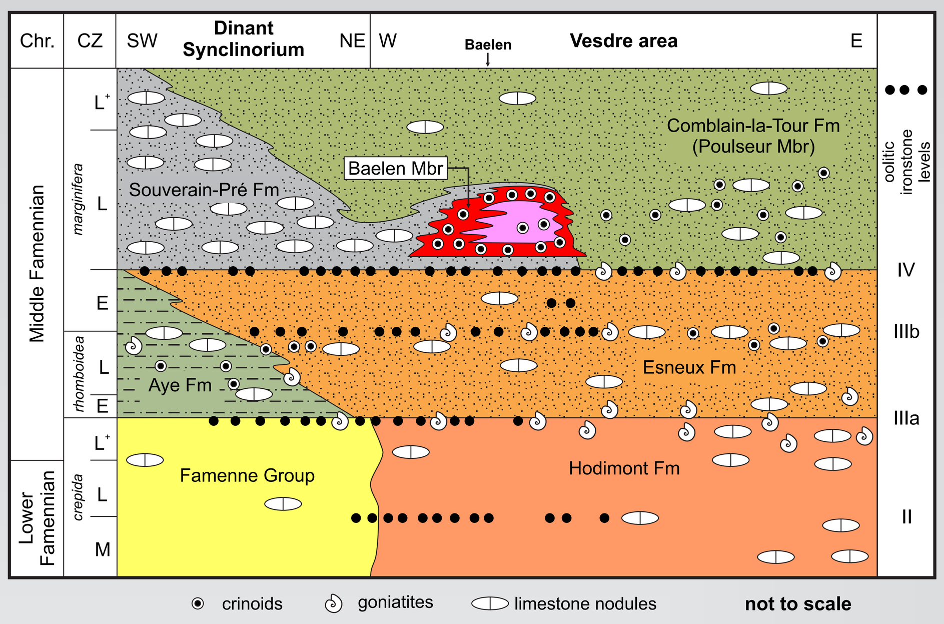

Figure 2. Lithostratigraphical and biostratigraphical framework of the Middle Famennian in the Dinant and Vesdre Synclinoria (modified after Dreesen, 1989). Abbreviations: CZ: conodont zone, E = early, L = Late, L+ = Latest, Fm = Formation; Mb = Member.

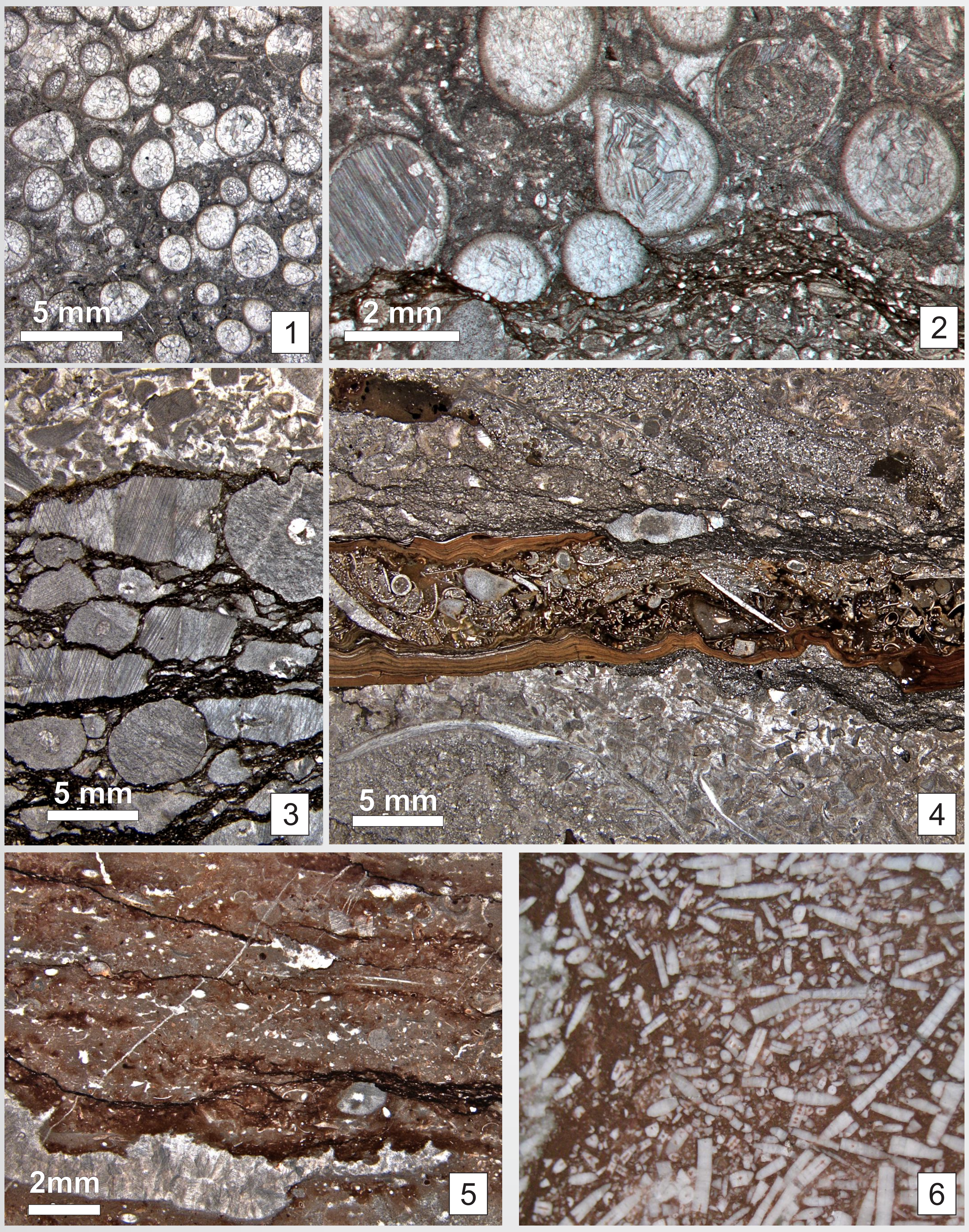

Figure 3. Characteristic microfacies. (1) Algospongal wackestone/ packstone with numerous sections of *Baculella gemina*. (2) Floatstone with *Baculella* (top) and packstone with *Serrisinella* (bottom). (3) Two types of encrinitic limestone; crinoidal rudstone (top) and stylocumulate crinoidal floatstone (bottom). (4) Silty bioclastic packstone/grainstone with important bioaccumulations (tempestites and/or contourites) separated by bacterial endostromatolites. (5) Red wackestone with stromatactis, sponge spicules, crinoids, and ostracods. (6) Polished slab of red argillaceous limestone ("peastone" variety), with numerous crinoid stems (width of crinoid stems: 5 mm). All figures are micrographs of thin sections in transmitted light, except 6.

Four main carbonate microfacies and corresponding palaeoenvironments laterally and/or vertically succeed **(Figs 3-4)**: (1) Wackestones/packstones with cyanobacteria *(Girvanella* sp.), algosponges *(Serrisinella* ex gr. *melekessensis* (Kulik)), kamaenaceans, plurilocular foraminifera *(Septabrunsiina baeleni* Conil) and primitive heterocorallia (*Oligophylloides* sp.). This microfacies is interpreted as being deposited in the lowermost part of an inner ramp, just above fair weather wave base (FWB); (2) Wackestones/packstones with closely associated *Serrisinella* ex gr. *melekessensis* and *Baculella* (or *Dreesenulella* Vachard) *gemina* Conil & Dreesen, evolving into packstones/boundstones. The former two algosponges either correspond to two different genera, or they represent different generations of a same organism: actually sterile (*Serrisinella*) and fertile (*Baculella*) stages. This assemblage probably thrives in the upper part of a mid-ramp, below the FWB, in a disphotic zone; (3) Encrinitic grainstones/rudstones, probably corresponding to tempestites that accumulated in the lower part of the mid-ramp in the aphotic zone. Locally, this microfacies becomes more bioclastic containing brachiopods and conodonts. (4) Red spiculitic microbial mudstones/wackestones with stromatactis locally displaying zebra structures: these represent outer ramp deposits above storm weather wave base (SWWB), whereas coeval more pelitic and silty deposits occur in the deeper shelf area.

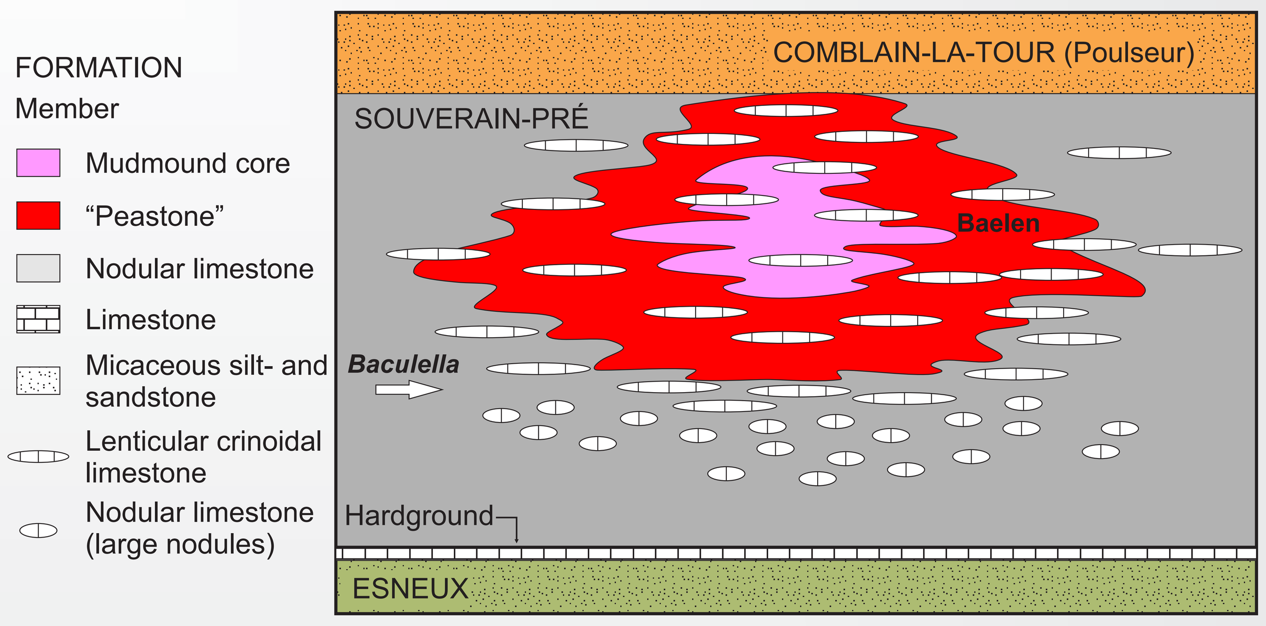

Figure 4. Cartoon with the new model (not to scale) for the Baelen Member showing the temporal-spatial relationships (lithofacies framework) of the different lithologies observed in the field (Dreesen *et al.*, 2013).

The co-existence of shallow marine shelf (Paraparchitacean-type) and deep marine shelf (Thuringen-type) ostracods (Dreesen, 1985) confirms this lateral zonation of palaeoenvironments. Pressure solution strongly affected most of the above microfacies, producing conspicuous stylocumulate and stylonodular fabrics.

Furthermore, the sudden occurrence of these particular kind of carbonate deposits within an otherwise overall siliciclastic shelf depositional environment (micaceous silt- and sandstones of the Condroz Sandstones Group), the preferential or pre-destinated location of the mounds on supposedly deep-seated faults (Marion, 1985), the occurrence of unusual biota and the presence of zebra-like stromatactis structures, could all point to "cold seep carbonates" or "methane-derived carbonates" produced near former methane leaks at the sea-bottom (Peckman & Thiel, 2004; Krause *et al*., 2004). Unfortunately, due to strong tectonic disturbances (faulting), a complex diagenetic history and hydrothermal overprinting, the stable C- and O-isotopic signature of the Baelen microbial carbonates is not yet supporting this hypothesis and needs to be investigated further.

Besides its geological importance, the Red Marble of Baelen is also a famous building stone **(Fig. 5)** from the Limbourg area (Vesdre Basin, Eastern Belgium), where it has been quarried probably since Roman times. Two varieties exist: a cherry-red crinoidal limestone displaying numerous white crinoid ossicles (so-called "peastone") and a grey, pink to red stromatactis limestone. Its earliest usage dates back from Roman times, as proven by the occurrence of marble slabs in decorations of the harbor temple in Xanten, Germany (Ruppiene, 2015).

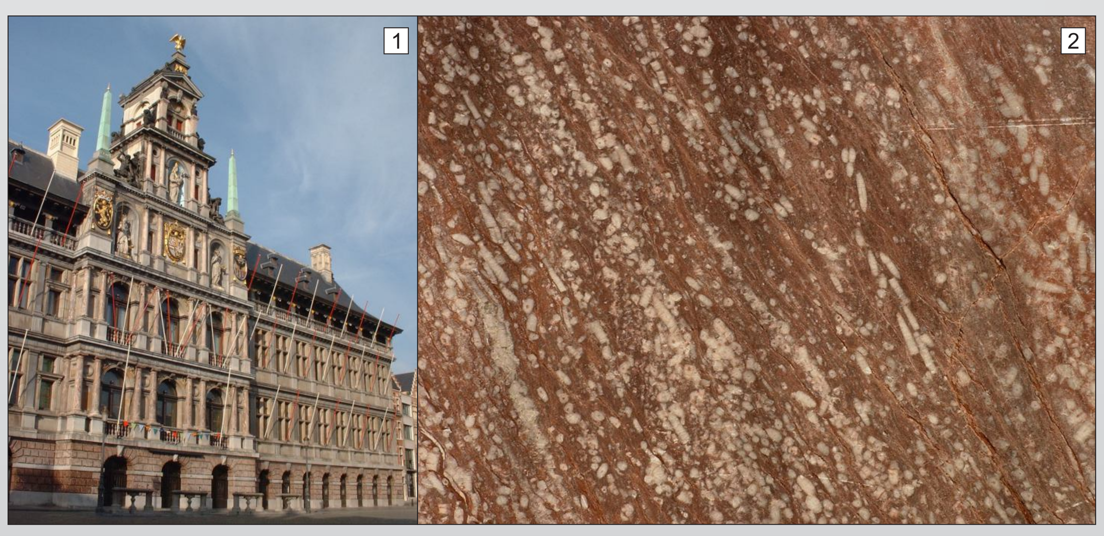

Figure 5. Antwerp town hall, substructures made of red Belgian marbles (1). Detail of cladding made of polished slabs in red marble, originally Red Marble of Baelen (2).