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

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The Red Marble of Baelen from the Limbourg area (Vesdre Basin, Eastern Belgium) represents a member of the middle Famennian (late Upper Devonian) Souverain-Pré Formation (Late *marginifera* conodont Zone). 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.

Four main laterally and/or vertically carbonate microfacies and corresponding palaeoenvironments succeed: (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 either 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. The co-existence of shallow marine shelf (Paraparchitacean-type) and deep marine shelf (Thuringen-type) ostracods (Dreesen *et al*., 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 kinds 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 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. Both have been used for a large spectrum of building and decorative purposes, mostly within a short radius of the extraction sites in the former Duchy of Limbourg. Its usage was rather rural and vernacular, although it has been exceptionally employed in prestigious buildings such as the 16th century Antwerp town hall. Baelen Marble has been encountered in adjacent regions of the Limbourg area as well, including Aachen (Germany) and Southern Limburg (The Netherlands). 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). The last marble quarries to be active were those of Les Forges in Baelen: they closed shortly after World War II. Red Baelen Marble represents an important and less-known historical but highly valued building stone from Eastern Belgium, adding to the reputation of the better-known Belgian red marbles of Frasnian age. It is a silent witness of the former glory of the Duchy of Limbourg. At least one historical quarry still exists at Limbourg that should urgently be protected as an important Belgian geological heritage site.

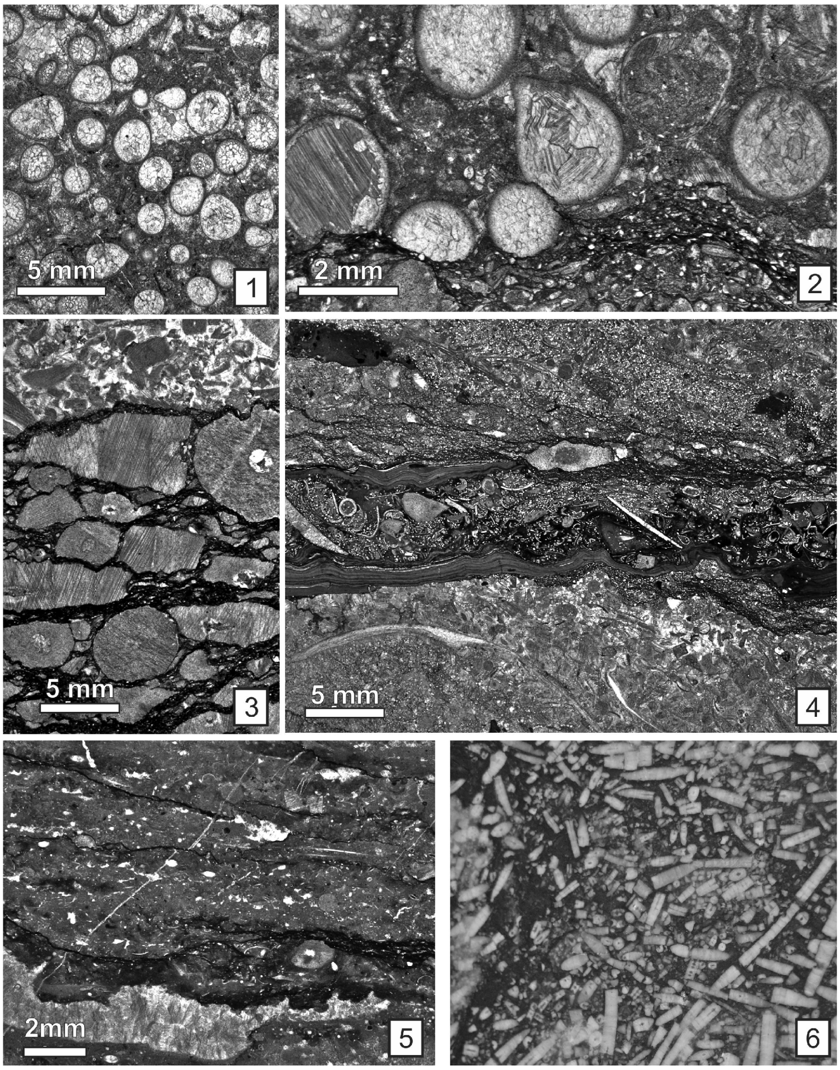

Fig. 1: Characteristic microfacies. (1) Algospongal wackestone/ packstone with numerous sections of *Baculella gemina.* (2) Floatstone with *Baculella* (top) and packstone with *Serrisinella* (bottom). (3) Two types of encrinitic limestone; crinoidal rudstone (top) and stylocumulate crinoidal floatstone (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.

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