

The base of the Devonian System (also the base of the Lochkovian Stage) is defined immediately below the first appearance of the graptolite species *Monograptus uniformis* in Bed 20 of the Klonk section, Czech Republic (Chlupáč & Kukul 1977).

From the Late Silurian through Early Devonian, continental positions changed slightly. But by the Middle-Late Devonian, continental movement increased, resulting in numerous mountain-building events. By 390 Ma, North America and Europe collided to form a large continent, named Laurentia, which sat near the equator. The supercontinent Gondwana and Laurentia were surrounded by subduction zones. Widespread reef development indicates that the climate was mild and warm, sea levels were high worldwide, and much of the land lay submerged under vast shallow epicontinental seas, where tropical reef organisms lived. A large ocean covered the rest of the planet. In fact, the Devonian has been referred to as a greenhouse age, and global high temperatures allow reefs to develop at unusually high latitudes, reaching 65°N-55°S during the Middle Devonian (Copper 2002a).

Devonian Period (from about 416 to 359 million years) saw profound changes in the evolutionary record, with the first significant colonisation of terrestrial habitats by vascular plants, the rapid expansion of the first aquatic vertebrates, and their emergence onto land. Marine faunas continued to be dominated by bryozoa, diverse and abundant brachiopods and corals. Crinoids were abundant, and trilobites were still fairly common, but less diverse than in earlier periods. The ostracoderms were joined in the mid-Devonian by the first jawed fishes, the great armoured placoderms, as well as the first sharks and ray-finned fish. In the late Devonian, the lobe-finned fish appeared, giving rise to the first tetrapods. The main contributors of the Devonian reefs were calcareous algae, stromatoporoids, and tabulate and rugose corals, displaying a very high biodiversity (Scrutton 1998). Mud mounds were dominated by sponges, calcimicrobes and bryozoans.

The Late Devonian extinction was the second major extinction event during Phanerozoic. A major extinction occurred at the boundary that marks the beginning of the last phase of the Devonian period, the Famennian faunal stage, (the Frasnian-Famennian boundary), about 364 million years ago. A second pulse closed the Devonian period. The mass extinction at the Frasnian-Famennian boundary did not affect land plants, but primarily affected the marine community, and selectively affected warm-water organisms rather than cool-water organisms. Between 50-55 percent of marine invertebrate genera did not survive into the following Carboniferous. The most important group to be affected by this extinction event were the reef-builders of the great Devonian reef-systems, including the stromatoporoids, and the rugose and tabulate corals. The reef system collapse was severe, and may be a contributory factor to the fact that major reef-building did not appear again until the Mesozoic era. A cause of the extinctions may have been an episode of global cooling, following the mild climate of Devonian period. Evidence such as glacial deposits in northern Brazil (located near the south pole) suggests widespread glaciation as a large continental mass covered the polar region. The covering of the planet's continents with photosynthesizing land plants may have reduced carbon dioxide levels in the atmosphere. Since CO₂ is a greenhouse gas, reduced levels might have helped produce a chillier climate. Massive glaciation tends to lower eustatic sea levels, which may have exacerbated the late Devonian crisis. Bolide impacts are dramatic triggers of mass extinctions, but no secure evidence of an extra-terrestrial impact has been identified in this case. Widespread anoxia resulting from ocean turnovers or massive inputs of organic matter is also suggested.

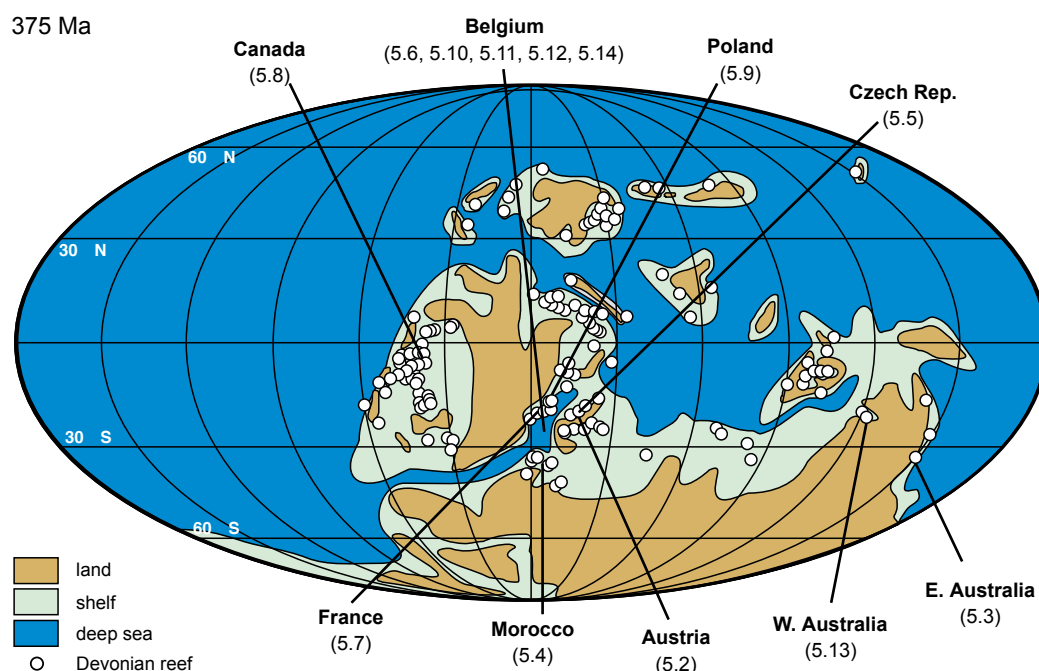


FIG. 1. Palaeogeographic setting of the Devonian case studies discussed below in a Devonian global reconstruction (modified from Kiessling *et al.* 2003).

When considered in more detail, the Devonian Period shows long-term patterns in reef development. During the Lower and Early Middle Devonian, when sea level was still relatively low, reefs were characterized by poor diversity and provinciality. Their growth was reduced, probably related to the low accommodation space. Detrital supply, originating from the erosion of the Caledonian mountain belt hindered reef development in a number of coastal areas (Burchette 1981). In Europe, for example, the earliest Devonian reefs occur in regions where marine sedimentation was continuous from the Lower Palaeozoic through to at least the Middle Devonian: Carnic Alps [chapter 5.2], Bohemia, Armorican Massif and the Cantabrian and Pyreneean mountains. On the periphery of the Caledonian orogen and where the Devonian overlies the Lower Palaeozoic unconformably, reef growth did not begin until Middle Devonian: Ardennes [5.7-5.8], Rhenish Schiefergebirge, Harz, Poland and Moravia [5.6].

Lower to Early Middle Devonian reefs are of limited extension and thickness and show relatively low biodiversity. Mounds and banks are the dominant morphologies [5.2]. Local examples of deeper, hydrothermal-related mounds are observed in North Africa [5.4]. In the Emsian-Givetian, a ‘super greenhouse’ time span, there were six major reef belts with lengths exceeding 2500 km (Copper, 2002b): Western Laurentia, NW Europe, S Europe-N Africa, Urals-Eastern side of Baltica, Siberia, Mongolia and S China. Due to exceptional warm climate, reefs developed in abnormally high latitudes (Kiessling *et al.* 1999). Reef morphologies include barriers, platform reefs [5.5, 5.7], fringing reefs, atolls and mounds [5.6]. During Frasnian, the Canning Basin complexes add another reef belt of over 2000 km long. However, Frasnian reefs are characterized by loss of diversity, cosmopolitanism and collapse of the carbonate factory at the end of the stage (Copper 2002a, b). Frasnian eustatic fluctuations were severe (Sandberg *et al.* 1985) and sea-level variations controlled the reef development [5.8]. Early Frasnian shows reduced episodes of reef building, while Middle Frasnian represents an acme in reef development: nearly all reef morphologies are represented: platform reefs [5.10], barriers, atolls [5.11], and mounds. Late Frasnian reefs are smaller and more restricted and were progressively replaced by mounds [5.12]. After the Frasnian extinction, representing the end of the Silurian-Devonian reef ecosystem, Famennian was characterized by post extinction reefs, in a context of sea level lowstand and major loss of reef habitats. Famennian

reefs are composed of some Lazarus taxa such as labechiid stromatoporoids, lithistid sponges and calcimicrobes; most are mudmound types [5.13], or occur as microbial reef or platform caps in open marine shelf settings (Copper 2002b). Late Famennian mounds are remarkably similar to Waulsortian Carboniferous buildups.

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PRAGIAN-EMSIAN CRINOIDAL SAND BANKS
AND STROMATOPOROID-HYDROZOAN BUILDUPS, CARNIC ALPS, AUSTRIA

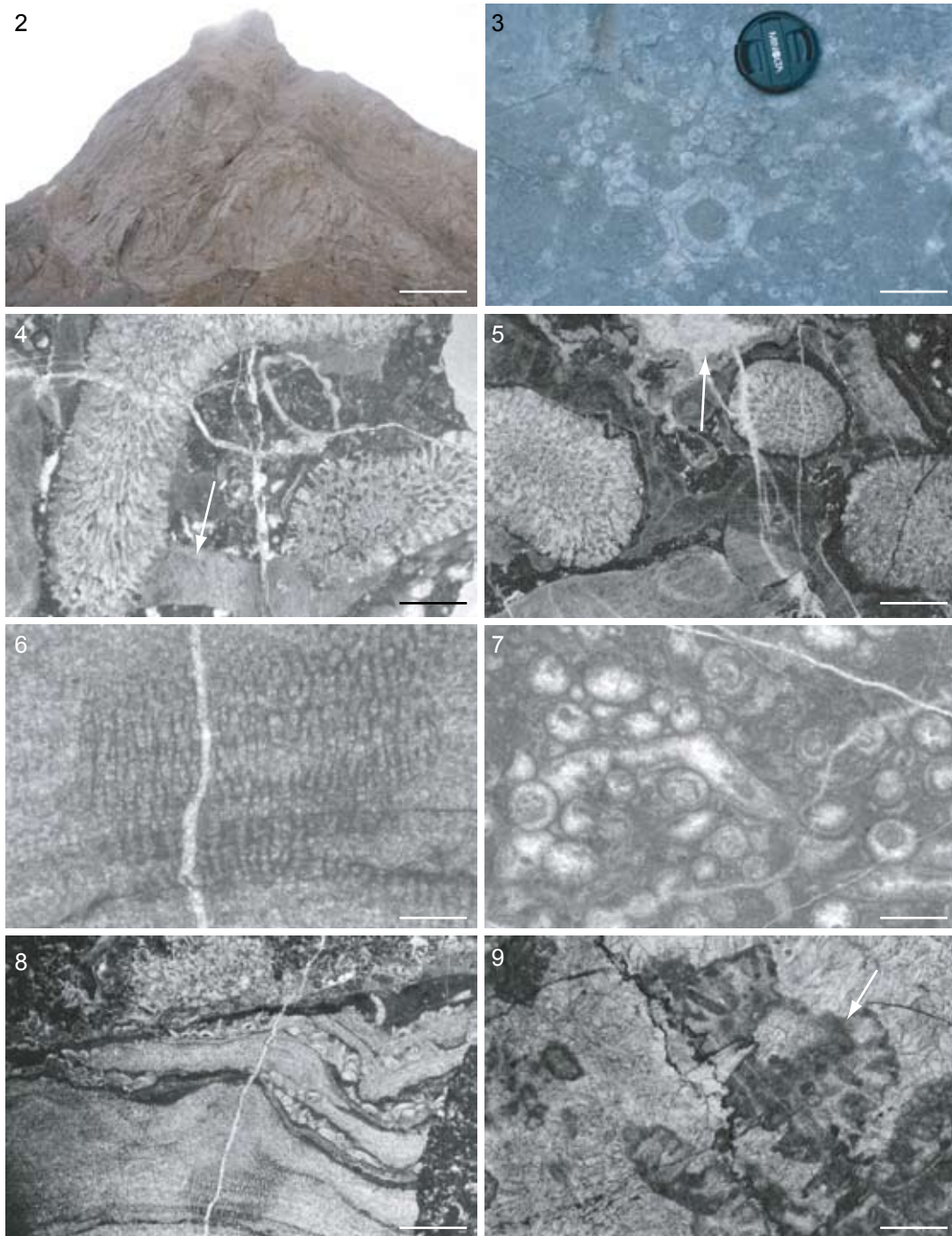
LOCALITY. – Pragian/Emsian subtropical shelf edge, Carnic Alps Platform, adjacent to northern margin of Gondwana (Schönlaub 1992).

STRATIGRAPHY. – Hohe Warte Limestone is a formation of the southern shallow water facies preserved in the Kellerwand Nappe of the Central Carnic Alps (Kreutzer 1990, 1992a, b). Hohe Warte Limestone is 350 m thick and preceded by Lochkovian crinoid limestone (neritic Rauchkofel Limestone) and succeeded by Seewarte Limestone (early Emsian?), a lagoonal facies with *Hercynella* (Fig. 2). Crinoidal sand mounds occur in the lower part of the section and are characterized by coarse carbonate sand with partially preserved crinoids surrounded by finer-grained crinoidal sand. Stromatoporoid-hydrozoan buildups occur in the upper part of the section and form patchily distributed bioherms of unknown thickness and extent surrounded by crinoidal debris (Bandel 1969).

FACIES AND MICROFACIES (Figs 2-9). – Above a crinoidal sand substrate (neritic Rauchkofel Limestone), the first crinoidal bank facies progrades basinward in the late Lochkovian to early Pragian. Facies consists of crinoidal rudstone with spar-filled open space structures and large crosssections of crinoid calyces (Fig. 3). The amount of early marine cements lining open space structures suggests that a framework existed which provided attachment sites for crinoids (Figs 4, 5). Higher up in the section framestones with tabulate and rugose corals, stromatoporoids and hydrozoans become abundant. They are accompanied by crinoidal grainstones with numerous calcareous algae.

BIODIVERSITY AND TAPHONOMY. – Heritsch (1943) listed 4 species of crinoids which were found in boulders at the base of Mount Seewarte: *Cyathocrinus carnicus* Charlesworth, *Megistocrinus devonicus* Charlesw., *Melocrinus prostellaris* Frech, and *Rhipidocrinus praecursor* Frech. The large cross-section (Fig. 3) maybe *Pernerocrinus*, a common Lower Devonian crinoid that also occurs in the Pragian Koneprusy reefs (J. Dzik, written comm., 2005). The floating bulbs (loboliths) are very common in Silurian/Lochkovian boundary interval beds in the deeper water successions. The good preservation of the crinoids indicates that they were deposited close to their area of origin. Crinoids produced the large amounts of carbonate sand encountered in the lower Hohe Warte Limestone.

Stromatoporoids, tabulate and rugose corals and hydrozoans are the dominant reef builders in the upper Hohe Warte Limestone. *Plectostroma latens* (Počta) (Fig. 6) is the most common stromatoporoid in the Hohe Warte together with *Actinostroma?* Ex gr. *clathratum* Nicholson, both were previously described from Koneprusy (May 2002). *Schistodictyon?* sp. is also present. The problematic hydrozoan *Fistulella undosa* Shuysky is very common and acts as binder and encruster in the reef community (Figs 7, 8). Among the tabulate corals the ramose *Scoliopora* (*Protoscoliopora*) *puberulus* (Janet) represents a baffling reef dweller (Fig. 4). Heliolitids are present with *Heliolites* aff. *wernerii* Oekentorp & Brühl, and *Helioplasma* aff. *aliena* Galle and favositids are represented by *Favosites styriacus* Penecke. All three form small bulbous colonies. Two small encrusting species occur: *Platyaxum* (*Roseoporella*) *altechedatense* (Dubatolov) and *Aulopora* (*Mastopora*) sp. They are accompanied by a small ramose form *Coenites falsus* Dubatolov. Two significant



FIGS 2-9. All pictures are from the Hohe Warte Limestone, base of Mount Seewarte, Central Carnic Alps, Austria. **2,** Exposure of the 350 m thick Hohe Warte Limestone at the flank of Mount Seewarte; scale = 100 m. **3,** Preservation of abundant large calyces of crinoids indicates deposition at or very close to, the live position of the animals (boulder at north western base of Mount Hohe Warte); scale = 5 cm. **4,** *Scoliopora (Protoscoliopora) puberulus* (Janet) offers a holdfast for crinoidal cirri (arrow); scale = 1 mm. **5,** Thin-section of *Scoliopora* surrounded by crinoidal cirri, visible above is a cavity lined with fibrous calcite cement and filled with calcite spar (arrow); scale = 1 mm. **6,** Thin-section photograph of *Plectostroma latens* (Počta), scale = 2 mm. **7,** Thin-section photograph of the problematic hydrozoan *Fistulella undosa* Shuysky; scale = 2 mm. **8,** *Fistulella undosa* Shuysky encrusting consecutive layers of stromatoporoid, scale = 3 mm. **9,** Udoteacean alga (arrow) in a sparry calcite cement, other components are cortoids and bioclasts; scale = 1 mm.

species of rugose corals were identified, *Stauromatidium* aff. *marylandicum* (Swartz) and *Fasciphyllum* sp. Important accessory reef biota are algae (Fig. 9), brachiopods, trilobites, gastropods and bivalves.

DISCUSSION. — The crinoidal sand banks probably formed at a site of the shelf or ramp where shallowing resulted in accumulation of sand bars that became quickly lithified. Storm events caused rip-up of partially lithified sand-aggregates that was piled up as rubble banks (much like present day 'motus') with large open space structures. Subsequent cementation resulted in formation of elevated structures that provided holdfasts for crinoids and other marine organisms (brachiopods, algae). The crinoid facies becomes progressively enriched with stromatoporoids and corals, which probably formed patch reefs on a well-aerated high-energy subtidal shelf. The large amount of calcareous algae seen in the thin sections are in contrast to the Koneprusy Limestone (CZ), which is time-equivalent to the Hohe Warte Limestone but more reefal in character.

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EMSIAN BIOSTROMES, TAMWORTH BELT, AUSTRALIA

LOCALITY. – Late Emsian subtropical ramp, intra-oceanic Island Arc Complex, Tamworth Belt, N.S.W., Australia.

STRATIGRAPHY. – Sulcor and Yarramanbully Limestone Members, Silver Gully Formation, Tamworth Group, northern Tamworth Belt. Limestone outcrops of Emsian age occur between Manilla and Attunga in isolated limestone bodies at Yarramanbully, Sulcor and Burdekin. They are surrounded by volcanoclastic sediments of the Silver Gully and Yarrimie formations and attain up to 450 m in thickness. Facies changes are rapid along strike but the bodies are thought to be principally *in situ*. The limestone successions are largely comprised of different types of biostromes (Pohler 1998, 1999).

FACIES AND MICROFACIES (Figs 11-17). – The Emsian biostromal facies can be subdivided into four different types: Facies I. Aggregate biostromes with dominantly ramose stromatoporoids, Facies II. Stratified biostromes with dominantly tabular growth forms of stromatoporoids and tabulate corals, Facies III. Mixed aggregate-stratified biostromes with intercalated layers of ramose and stratified growth forms of tabulate corals and stromatoporoids, Facies IV. Algal biostromes. All biostrome types have a micritic matrix and can be classified as bafflestones, bindstones, boundstones and wackestones (Pohler 1998).

BIODIVERSITY AND TAPHONOMY. – The tabular and laminar growth forms of stromatoporoids and tabulate corals are usually preserved in life position, ramose growth forms, algae and sponges are *ex situ* and diagenetically altered.

Biodiversity is highest in Facies III, whereas Facies I is composed of large mono- or oligospecific aggregations of *Amphipora* and *Stachyodes*. Facies II consists dominantly of laminar colonies of alveolitid corals and tabular stromatoporoids. Between the colonies occur thin interbeds with fasciculate, hemispherical and ramose tabulate corals, and solitary and cerioid rugose corals. Accessory organisms are echinoids,

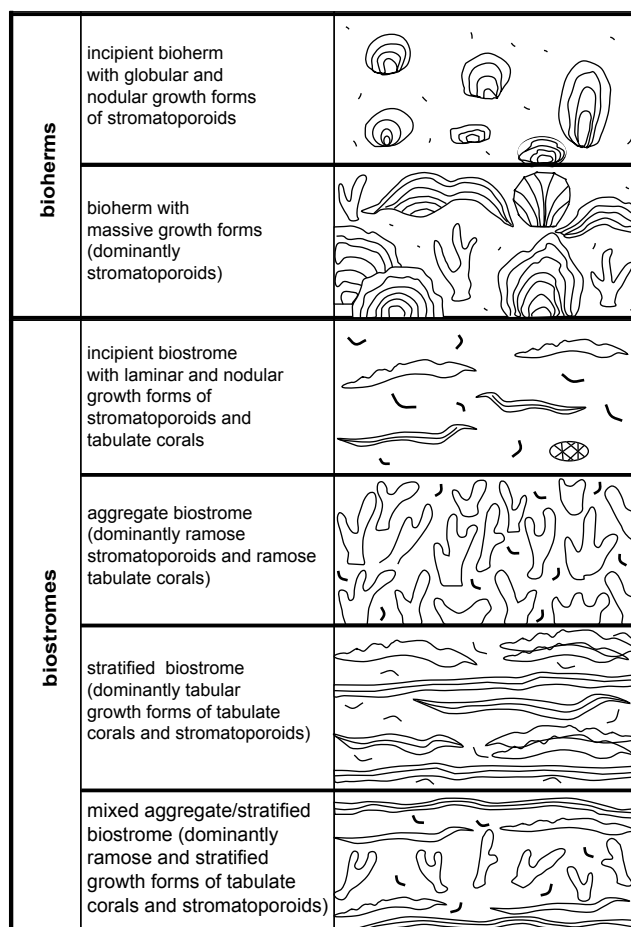
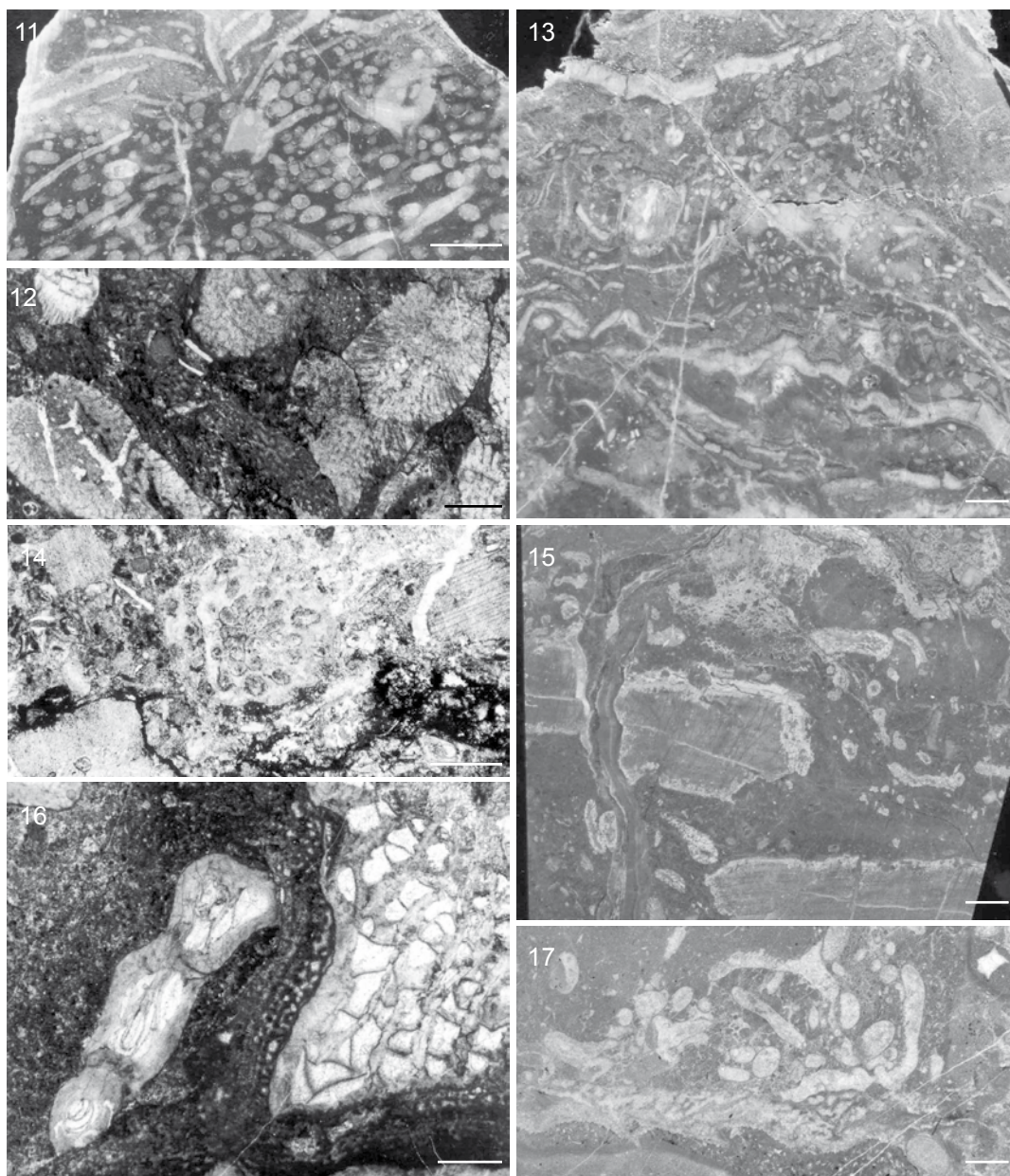


FIG. 10. Types of Emsian biostromal facies described in the text.



FIGS 11-17. **11**, Ramose *Amphipora* and *Stachyodes coenostea* form aggregate biostromes characteristic of Facies I. Emsian outcrops of Sulcor Ls. Member near 'Damflat'. Polished slab; scale = 3 cm. **12**, Thin-section of sample described under Fig. 10 with *Amphipora* sp. Plane light; scale = 0.5 cm. **13**, Laminar stromatoporoids and alveolitids building the stratified biostrome (Facies II) at the top of the Sulcor Limestone Member, Sulcor. Polished slab; scale = 5 mm. **14**, Small ramose tabulate corals such as this *Cladopora* species are common in the intervals between the stratified colonies of tabulate corals and stromatoporoids in both, Facies II and III. Yarramanbully Limestone Member near top of succession at Yarramanbully. Thin-section, plane light; scale = 3 mm. **15**, Laminar and tabular stromatoporoids and alveolitids characterize the stratified portions of Facies III (mixed aggregate/stratified biostromes). Yarramanbully Limestone Member near top of succession at Yarramanbully. Polished slab; scale = 1 cm. **16**, Juvenile solitary rugose coral (right of image) growing on *Pseudamplexus princeps* (partially visible at base of image). The juvenile coral is encrusted by a stromatoporoid that in turn is overgrown by *Syringopora* ex gr. *crispa* Schlüter. Multiple generations of encrustations are common in Facies II and III and an important mechanism for upward growth of the biostromes. Yarramanbully Limestone Member near top of succession at Yarramanbully. Polished slab; scale = 1 cm. **17**, Facies IV occurs at the base of the Yarramanbully Limestone Member. Only recrystallized algal thalli appear to be of dasycladale algae. Yarramanbully. Thin-section, plane light; scale = 3 mm.

crinoids, bryzoans, ostracodes, brachiopods and udoteacean algae. Facies III is similar to F. II but stratification is on a decimetre to meter scale and diversity is greater. Facies IV occurs at the base of the Yarramanbully Limestone Member only. Algal thalli are recrystallized but appear to be of dasycladale algae similar to those observed in the Middle Devonian of the Wyaralong region (Mamet & Pohler 2002).

DISCUSSION. — The succession of the different Emsian biostromal facies in the Tamworth limestones recurs in the Middle Devonian. However, in the Middle Devonian biohermal buildups play a larger role than biostromes (Pohler & Kim 2001).

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EMSIAN-GIVETIAN STROMATACTIS-CORAL HYDROTHERMAL MUD MOUNDS, TAFILALT-MAIDER, MOROCCO

LOCALITY. – Emsian to Givetian, warm temperate mixed siliciclastic open carbonate ramp (Tafilalt-Maider Basin, Morocco). Northern continental margin of the West-African Craton (40-70° S).

STRATIGRAPHY. – Kess-kess mounds and Hollard mound from Hmar Laghdad. 48 mounds starting at different levels are observed in an 0.5 x 3.5 km area. The mounds are cone-shaped, subcircular in horizontal cross-section and up to 50 m high. Flanks are steeply dipping (35-60°) (Brachert *et al.* 1992). The formation developed on the top of a Lochkovian 100 m-thick basaltic volcanic high. The upper surface of this volcanic high was first colonized by crinoids (~180 m of crinoids sands, of Praguian-Early Emsian age), then by the mounds themselves. Kess-kess mounds were buried by Emsian shale. Later, a second mounding event is represented by the Eifelian-Givetian Hollard mound (Mounji *et al.* 1998).

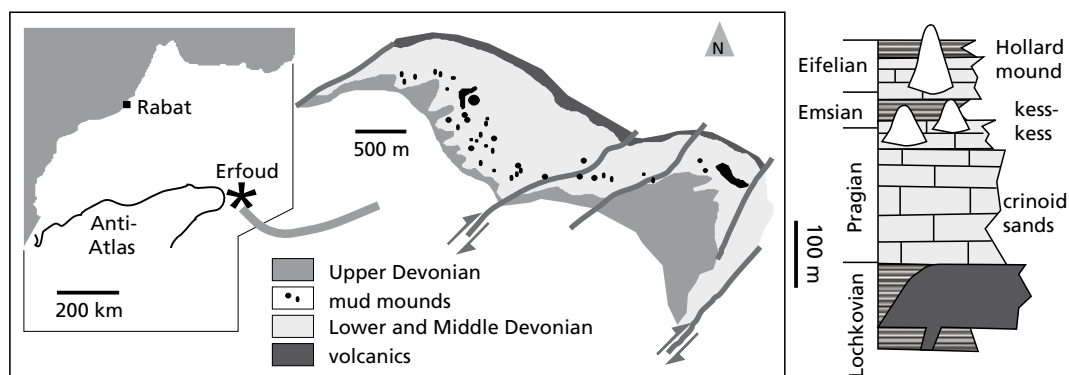
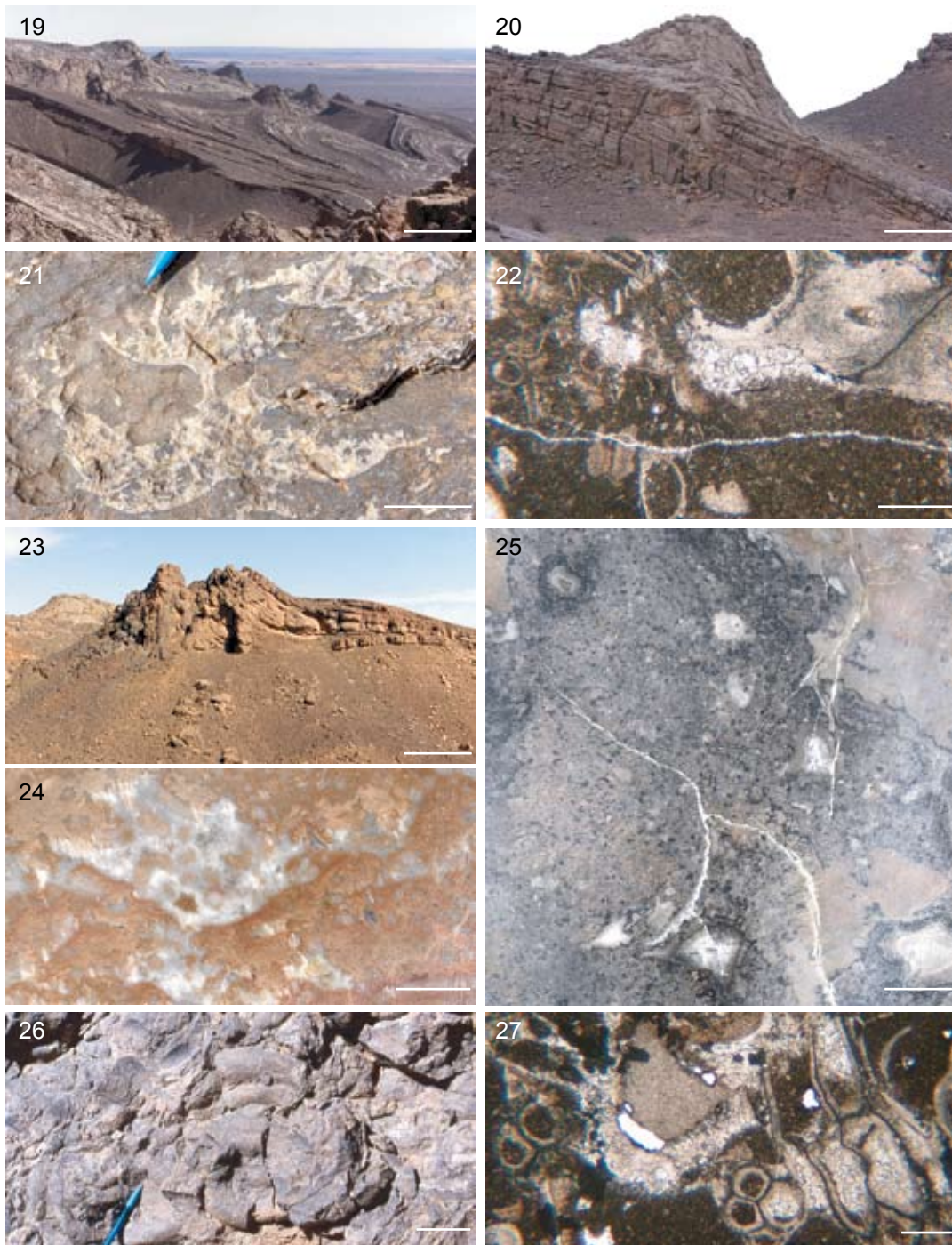


FIG. 18. Geological sketch of the Tafilalt-Maider area and stratigraphic sketch with setting of mud mounds.

FACIES AND MICROFACIES (Figs 11-17). – Grainstones and packstones with crinoids and subordinate brachiopods, trilobites, bryozoans, tentaculitids and tabulate coral form the sole of the kess-kess mounds. The kess-kess cores are massive mudstones to wackestones with tabulate corals (auloporids, thamnoporids, favositids) and subordinate crinoids, trilobites, brachiopods and tentaculitids. Early marine cemented fenestrae (including stromatactis) are frequent. Intermound facies correspond to well-bedded tentaculitid-coral mudstones and wackestones. The younger Hollard mound shows approximately the same core facies as the kess-kess, with additional dissolution cavities, central dykes and large bivalves communities. Cover beds of the Hollard mound are reddish fine-grained limestones with fenestrae. Syndimentary fracturing of mound, intermound and sole limestones are dated as Emsian to Famennian.



FIGS 19-27. **19**, The Emsian kess-kess mounds of Hmar Laghdad; scale = 25 m. **20**, A 20 m-thick kess-kess interfingering with well-bedded intermound limestones; scale = 10 m. **21**, Kess-kess facies: fine-grained limestone with stromatactis and tabulate corals; scale = 3 cm. **22**, Kess-kess facies: wackestone with auloporidae, brachiopods, fenestra; thin section, plane polarized light; scale = 1 mm. **23**, The Eifelian-Givetian Hollard mound; scale = 20m. **24**, Hollard mound cover beds: fine-grained reddish limestones with stromatactis and corals; scale = 1 cm. **25**, Hollard mound, core facies: dark grey peloidal spar in probable dissolution cavities; scale = 0,5 cm. **26**, Hollard mound, core facies: bivalves embedded in vent carbonates; scale = 7,5 cm. **27**, Hollard mound cover beds: wackestone with tabulate corals, crinoids and fenestrae; plane polarized light; scale = 1 mm.

BIODIVERSITY AND TAPHONOMY. — All Hmar Laghdad mounds are dominated by a rather homogeneous tabulate corals-crinoids community. No vertical or lateral differentiation is observed. Inter-mound beds show the same community with a more developed fine-grained bioclastic fraction. The Hollard mound shows dykes-associated bivalve communities in the central part of the core (Belka 1998; Mounji *et al.* 1998).

DISCUSSION. — The conical shape and the location of the mounds itself suggest an accretion related to a hydrothermal venting system, due to thermal flux above the volcanic rock pile (Mounji *et al.* 1998). Circulation of fluids through the dykes was responsible for precipitation of synsedimentary cements and mud. Lack of algae and minor reworking by waves point to a relatively deep-water setting, under the photic zone and storm wave base. The isotope geochemistry of the Hollard mound suggests a possible contribution from thermogenic methane (Belka 1998).

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EIFELIAN-FRASNIAN AMPHIPORA LIMESTONES, BIOSTROMES AND BIOHERMS, MORAVIAN KARST, CZECH REPUBLIC

LOCALITY. – Middle Eifelian to Late Frasnian platforms (\sim *costatus/australis* to late *rhenana/linguiformis* conodont zones) were rimmed by deep seas and ocean, S of the East Silesian Massif (Moravian Block, Czech Republic). The platforms drifted during this time span toward the NW, from the position on palaeolatitude ~ 18 to $\sim 13^\circ$ S.

STRATIGRAPHY. – Macocha Formation (15 000 km², densely drilled, outcrops 2 %, e.g., Moravian Karst, mean thickness ~ 450 m) is a Middle-Upper Devonian complex of platform limestones with reefs that consists of nearly all facies reported worldwide. Grey coloured limestones are very pure: carbonate 97 %, dolomite 5 %, TOC 0.2 %, Fe 0.01%, in average. This formation is underlain by a blanket of continental (and rarely marine) siliciclastic sediments of end-Ediacaran to Devonian ages (hiatuses, features of arid weathering). With demise of reefs the inner parts of these platforms were emerged (eolianites, paleokarst – K), but the sliding, subsiding and truncated margins (neptunian dikes – N, olistoliths on outer side) were overlain by bio- and lithoclastic calciturbidites (15).

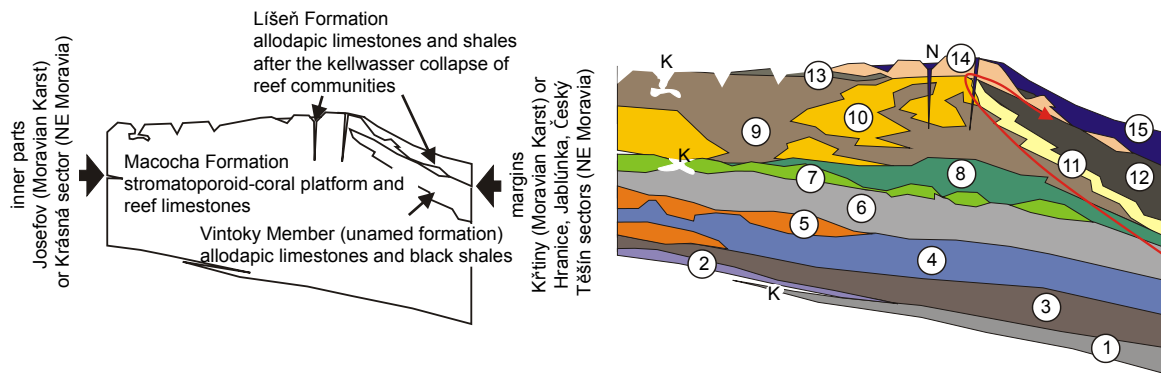
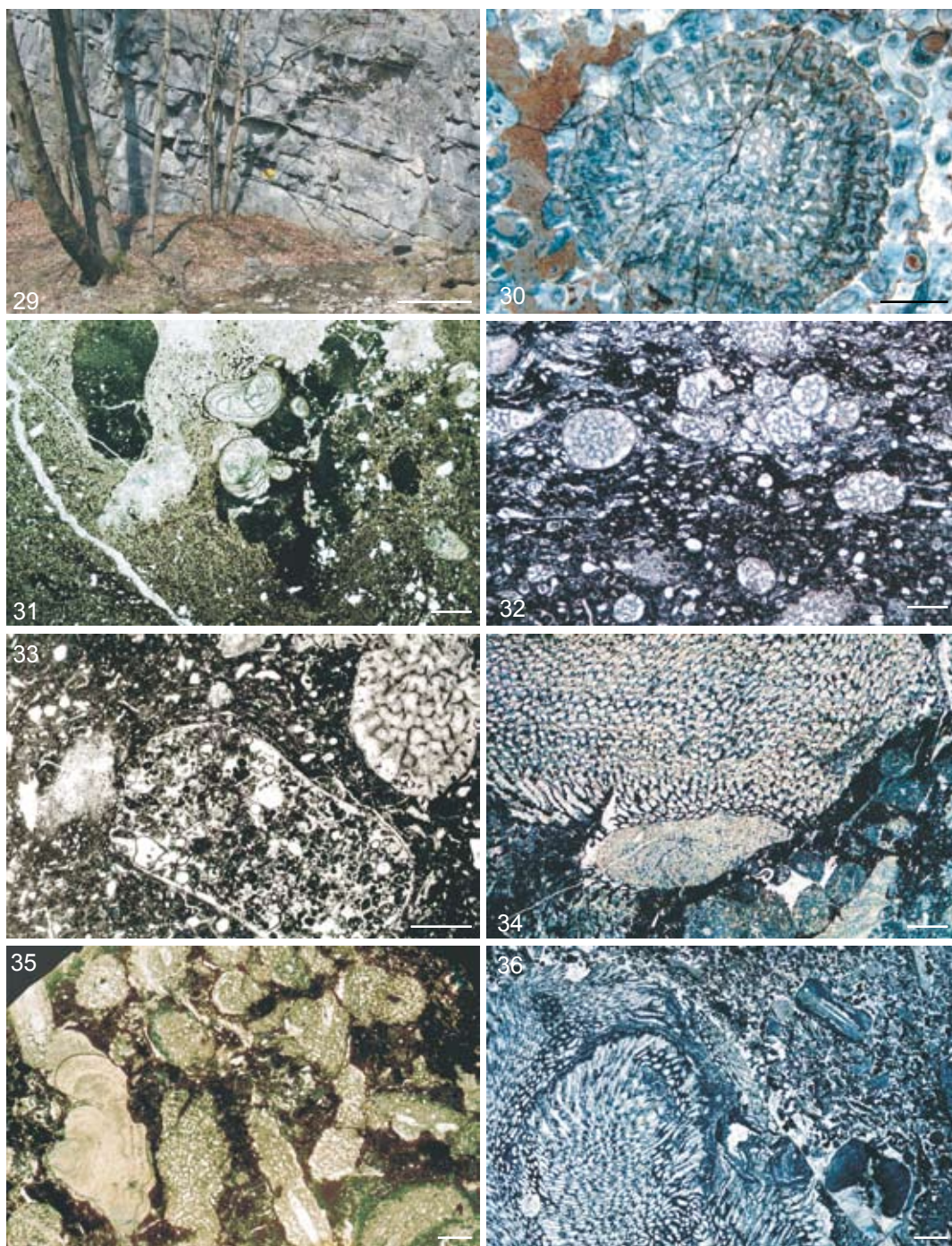


FIG. 28. Sedimentary architecture of the facies described in the text.

FACIES AND BIOFACIES (Figs 28-36). – Skeletal packstones with type-Celechovice (*Favosites*) fauna (fig. 28, 1); lenses with thick-shelled brachiopods *Bornhardtina* (fig. 28, 2); clayey wackestones/packstones with gastropods, sedentary worms, iron-oxidizing bacteria, coral *Hillaepora* (fig. 28, 3); rhythmically arranged *Amphipora ramosa* beds, rich in limestone mud (fig. 28, 4); micritized grainstones covered by sheets of platy stromatoporoids (fig. 28, 5); poorly washed grainstones, predominantly *Amphipora angusta* beds, with stachyodids (fig. 28, 6); *Trupetostroma-Hermatostroma* bioherms, coenostea and coralla of dimensions 0.1-1.5 m, late stage of abundance of *Caliopora battersbyi*, detritus fills (fig. 28, 7); litho- and bioclastic, pyritized grainstones with *Parathurammia* foraminifers, abraded amphiporids, alternation of blackish and light beds, hiatuses (fig. 28, 8); *Amphipora laxeperforata* – *A. rudis* beds, dark grey coloured sediments, sheltered lagoons with moderately diversified faunas (fig. 28, 9); algal, stromatoporoid and coral bioherms,



FIGS 29-36. **29**, *Amphipora ramosa* beds, Josefov-Barova section, Lower Givetian; scale = 1 m. **30**, First *Scoliopora denticulata* overgrown by aulopoid coral, Slavkov-2 borehole, end-Eifelian levels; scale = 1 m. **31**, *Trypanopora* worm, Slavkov-2, base of the Givetian, spots of dolomite; scale = 1 mm. **32**, *Amphipora angusta*, Tri Kotle – Habruvka, skeletal chips and various larval stages; scale = 1 mm. **33**, Younger example of latter, Moravka NP828, Upper Givetian, semilithified rounded clast coated by a thin bacterial biofilm; scale = 1 mm. **34**, A thick-walled *Alveolites* on fragment of *Stachyodes*, Middle Frasnian bioherms near Krtiny; scale = 1 mm. **35**, *Amph. moravica* with Solenoporaceae algae, Mokra, Upper Frasnian; scale = 1 mm. **36**, Margin-reef detritus with *Alv. elongatus* and crinoid columnals, Upper Frasnian reef-cap facies from Brno-Sumbera; scale = 1 mm.

Crassialveolites (fig. 28, 10); wild reef structures of platform-reef edge (fig. 28, 11); black-coloured allodapic limestones and shales, forereef slope (fig. 28, 12); deposits of lagoon, with *Amphipora moravica*, *Scoliopora tetralobata* and algae (fig. 28, 13); marginal reefs and fore-reef bioherms on the slope, rugose corals *Frechastraea*, foraminifer *Nanicella* (fig. 28, 14); non-reef cover of fossil-platform margins, nodular, thin-bedded limestones and breccias (fig. 28, 15). Boundaries: Eifelian/Givetian ~ [1/2]; Givetian-Frasnian ~ [8/9(10)], upper Frasnian ~ [12/14] and in [13] (very nearshore). For details of bioconstructions see Zúkalová (1971) and Hladil (1983, 2002) with references.

BIODIVERSITY AND TAPHONOMY. — The estimates of minimum number of stromatoporoid and coral species are about 80 and 130, respectively. However, the amphiporids strongly predominate and bulbous coenostea of *Actinostroma*, *Trupetostroma* and *Hermatostroma* have also great abundance. These stromatoporoids with *Issinella*-like green algae provided the main mass of fine skeletal chips that were mixed together with intensively precipitated calcite crystallites of micrometer size. The type-framestone bioconstructions are rare (2%), and a number of skeletons were redeposited for short distances (floatstones and bafflestones). Mutual overgrowths and competition for settling on scattered hard substrates were habitual strategies of the faunas. The endolithic sponge borings *Entobia* are common in skeletons (not in the rocks); microborings are rare.

DISCUSSION. — Stromatactis limestones are extremely rare (middle Frasnian, North Moravian Karst, ~ 0.5 x 10 m only).

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EIFELIAN-GIVETIAN STROMATOPOROID-CORAL REEFS, BELGIUM

LOCALITY. – Late Eifelian ramp-early Givetian platform carbonate succession, Wellin, southern border of Dinant Synclinorium, Belgium.

STRATIGRAPHY. – Hanonet and Trois-Fontaines formations (Figs 39-41), bioherm and reef bank, 45 m thick (core 30 m), 100 m long, associated with flanks of same magnitude. The succession records a regression from open marine near SWB/FWWB and dysphotic/euphotic zone to inter-supratidal lagoon with emersion (beach-rock). The stromatoporoid-coral buildup is stabilized by early marine isopachous cement. Two types of flanks are composed by udoteacean packstones and stromatoporoid-brachiopod floatstones.

FACIES AND MICROFACIES (Figs 37-46). – The stromatoporoid-coral buildup is composed of 10 microfacies from 1 to 10.

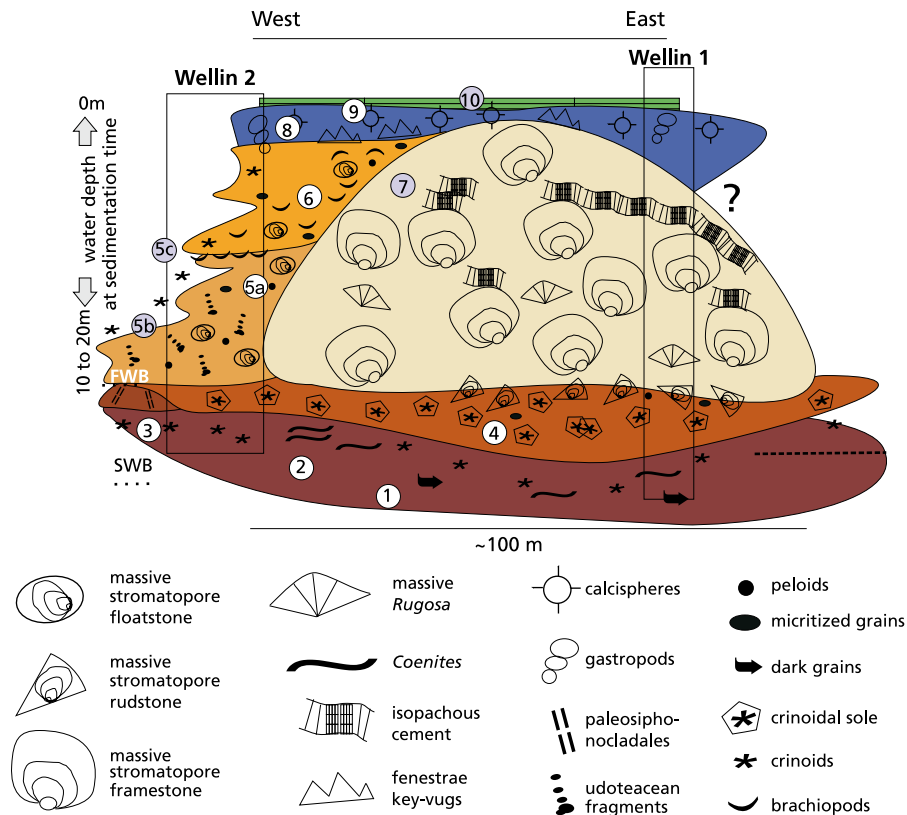


FIG. 37. Sedimentary architecture of the 10 recognized microfacies described in the text.

BIODIVERSITY AND TAPHONOMY. – Distribution of fossil communities and assemblages with emphasis on algae. Fig. 38, 1: Sphinctozoa (filtration); 2, Bryozoa (encrustment, filtration); 3, Trilobita (dwelling, bioturbation); 4, Serpulid worms (encrustment); 5, Crinoidea (filtration, grain production); 6, Brachiopoda (dwelling); 7, Mollusc (dwelling); 8, Ostracoda (dwelling); 9, Foraminifera (dwelling); 10, Rugosa (dwelling, construction, filtration); 11, Stromatoporoida (construction, encrustment, filtration); 12, Cyanobacteria (encrustment, micritization, mats); 13, Pseudoudoteacea (encrustment); 14, Udoteacea (grain formation, encrustment); 15, Dasycladales (grain formation); 16, Calciphaerae (kysts); 17, Solenoporae (dwelling); 18, Sphaerocodiaceae (grain formation).

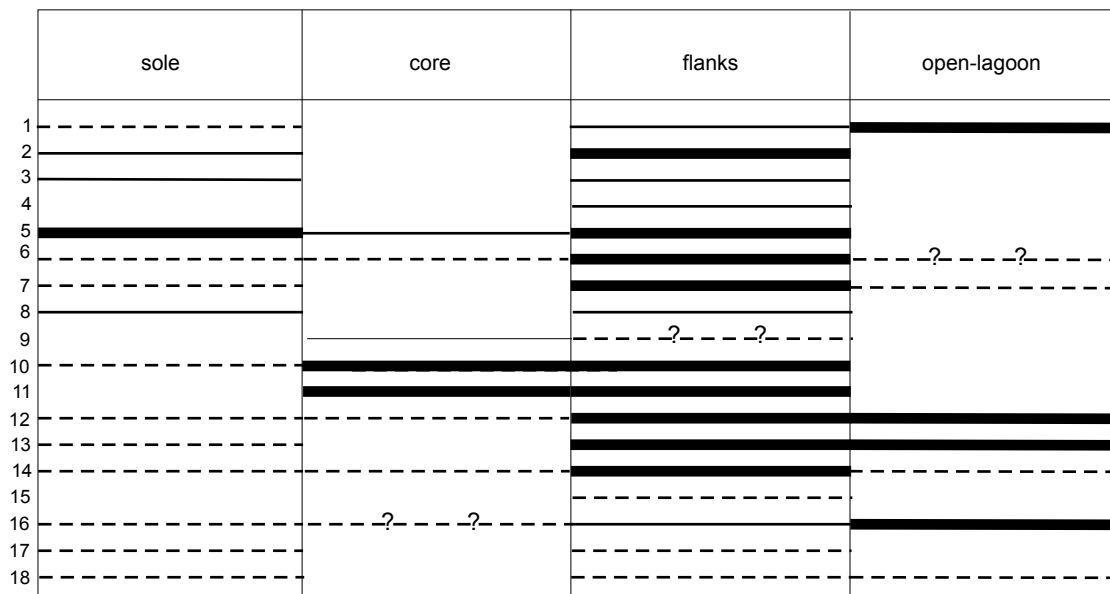
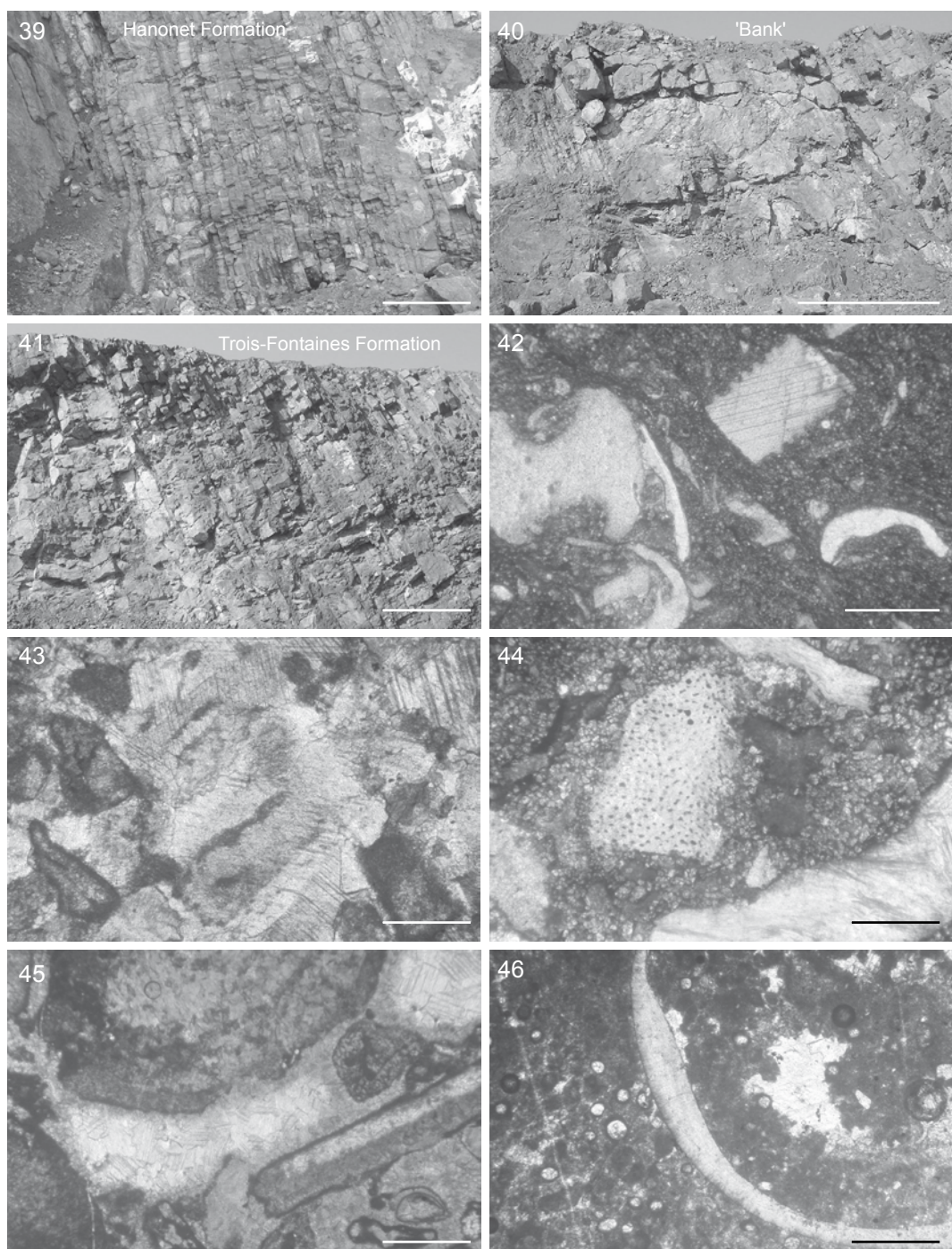


FIG. 38. Distribution of fossil communities and assemblages according to 18 microfacies (fig. 37) described in the text.

DISCUSSION. – Eustatism *versus* subsidence: correlation between the sections indicates that the morphology (central core and flanks) is quite planar (Figs 39-41). The total thickness of the regressive succession is about 70 m. The dysphotic-euphotic boundary (Mamet & Boulvain 1992) is indicated here by the algal flora and suggests a depth of about 20 meters for the starting of reef growth. Accommodation is mainly related to local subsidence.

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FIGS 39-46. **39-41**, Field aspect of the Hanonet (scale = 2 m), 'Bank' (scale = 6 m) and Trois Fontaines (TF; scale = 2 m) outcrops. **42**, Bioclastic wackestone with echinoderms and spicules in a tempestite. Hanonet Formation, MF1; scale = 390 μm . **43**, Echinodermal grainstone with micritized grains and peloids. TF Formation, MF4; scale = 390 μm . **44**, Brachiopod floatstone, Trois-Fontaines Fm. MF6; scale = 950 μm . **45**, Stromatoporoid framestone with 'micritic box' (pelecypod shell) and bioclasts (stromatoporoids). Micritization is well developed and the thin dark layers are probably of bacterial origin. Marine cementation started with early isopachous non-luminescent calcite and is followed by non-luminescent drusy calcite (white). The isopachous cement corrodes the stromatoporoid. The 'micritic box' is also filled by two cementation phases. Trois-Fontaines Fm., MF7; scale = 950 μm . **46**, Lagoonal calciphaerid peloidal wackestone with *Leperdicopida* (ostracode), Trois-Fontaines Fm., MF9; scale = 390 μm .

GIVETIAN CORAL-STROMATOPOROID AND ALGAL-SPONGE-WORM BUILDUPS,
BOULONNAIS, FRANCE

LOCALITY. – Middle Devonian, middle Givetian (Lower *varcus* Zone) shelf carbonates developed in subtropical marine environment. Palaeozoic Massif of Ferques, Bas-Boulonnais, France.

STRATIGRAPHY. – The Griset Member (lower member of the Blacourt Formation, about 220 m thick) is a bedded-carbonate succession (about 170 m visible) with well-developed buildups (Brice *et al.* 1979). At least seven bioherms or patch reefs are present. Three (fig. 47: 2, 5, 7) are classical coral-stromatoporoid buildups, up to 12.5 m thick. The other four (fig. 47: 1, 3, 4, 6) are smaller, up to 1 m size. Algae, worms and/or sponges are the main frame-builder organisms, although numerous other biostromal beds with corals and stromatoporoids occur.

FACIES AND MICROFACIES (Figs 48-59). – In all the buildups, the microfacies present a repetitive succession. Pre-buildup sediments (stabilization phase) are usually represented by coarse-grained deposits, and grainstones or rudstones, which provided the stability of the substrate; the components are largely diversified according to the different bioconstructions (skeletal limestones with brachiopod shells, crinoidal ossicles, etc., but also ooidal reworked pebbles, intraclasts, etc.). Stabilisation, colonisation, diversification and domination stages can be more or less recognized.

<i>n</i> ^o	<i>references</i>	<i>situation from the base of Griset Member</i>	<i>thickness</i>	<i>organisms</i>
[7]	bioherm x1 (Brice <i>et al.</i> 1977) 3 rd reefal level (Mistiaen <i>et al.</i> 2001)	+ 166.00 m	10 m	rugosa (2 species) tabulata (about 5 species) stromatoporoid (15 species)
[6]	stromatolitic level (Brice & Mistiaen 1988)	+ 131.00 m	0.10 m	stromatolithe, <i>spirorbis</i>
[5]	R IV (Devos 1961; Magne 1964) NR4 (Pelhâte & Poncet 1988) 2 nd large reefal level (Brice & Mistiaen 1988)	+ 104.60 m	7-10 m	rugosa (12 species) tabulata (about 5 species) stromatoporoid (12 species) algae (<i>Sphaerocodium</i>)
[4]	small bioherms (Mistiaen & Poncet 1983a, b) NR3 (Pelhâte & Poncet 1988)	+ 95.60 m	1 m	worms (<i>Trypanopora</i> , <i>Spirorbis</i>), algae
[3]	NR2 (Pelhâte & Poncet 1988) (Mistiaen & Poncet 1989)	+ 72.40 m	0.10-0.60 m	algae (3 species) worms
[2]	R I (Devos 1961; Magne 1964) = 1 st large reefal level	+ 34.50 m	8-12.50 m	rugosa (12 species) tabulata (about 10 species) stromatoporoid (12 species) bryozoans

FIG. 47. Summary of the stratigraphic and biodiversity patterns described in the text.



FIGS 48-59. All pictures from Griset [GR], Banc Noir [BN] quarries and Ferques railway cut [FR]. **48**, General view of an algal/worm (*Spirorbis* and *Trypanopora*) patch reef. [4-BN]; scale = 1 m. **49**, Surface of stromatolitic level, with *Spirorbis* [6-GR] and a detail; scale = 10 cm. **50**, Surface of the 3rd large reefal level with numerous massive stromatoporoids [7-FR]; scale = 10 cm. **51**, Intraclast of micritic limestone with fixed worms and algal micrite; prebuildup sediment [5-GR]; scale = 500 μ m. **52**, Intraclast of oolitic limestone (delimited by arrows) covered by algal laminae with small epigenized anhydrite crystals and worms; pre-buildup sediment [6-GR]; scale = 500 μ m. **53**, Detail of Fig. 50: arrows show sectioned oolites at the pebble boundary; scale = 100 μ m. **54**, Grainstone (biosparudite) with highly diversified bioclasts: crinoids (c), brachiopods (b), worms (w), gastropods, etc., or coated grains; pre-buildup sediment, [1-GR]; scale = 500 μ m. **55-56**, Rugose coral (*Disphyllia* sp.) covered by different algae [5-GR]; scales = 1 mm. **57**, Stromatolitic column of *Sphaerocodium magnum* associated with some *Spirorbis* [5-GR]; scale = 1 mm. **58**, Tangential section of stromatolitic columns associated with numerous *Spirorbis* and some *Trypanopora* [4-BN]; scale = 1 mm. **59**, Epigenized evaporitic crystal in pteropod-rich packstone; post-buildup sediment [4-BN]; scale = 500 μ m.

BIODIVERSITY AND TAPHONOMY. — The three classical buildups are mainly composed of rugose and tabulate corals; stromatoporoids present a large biodiversity (Mistiaen 1975, 1988a, b; Rohart 1988; Mistiaen *et al.* 2001). On the contrary, in the second one [fig. 47: 5], algae (Poncet 1988) are largely associated with massive rugose corals in the lower part, whereas massive stromatoporoids are more abundant in the upper part. The four smaller buildups with algae, sponges and worms show low-biodiversity patterns.

DISCUSSION. — In the Frasnian of Boulonnais, bioconstructions are also well developed (the Noces Member of the Beaulieu Formation, and the Fiennes, du Bois and Parisienne members of the Ferques Formation), usually as biostromes, one to several metres thick. Organisms are also very abundant, but comparatively much less diversified than during the Givetian.

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GIVETIAN-FRASNIAN STROMATOPOROID-CORAL-MICROBIAL ISOLATED REEFAL PLATFORMS, ALBERTA, CANADA

LOCALITY. – Late Givetian *norrisi* zone through Late Frasnian *triangularis* zone. Tropical to subtropical reefal platforms deposited in southern hemisphere trade wind belt, now in western Alberta, Canadian Rocky Mountains.

STRATIGRAPHY. – The Miette and Ancient Wall platforms are approximately 400 m thick (Fig. 60). Miette's aerial extent was about 165 km², while Ancient Wall was approximately 1200 km² (Mountjoy 1989; Geldsetzer 1989). Reefal units include the Flume, Cairn, and Southesk formations (Belyea & McLaren 1957; Mountjoy 1965) (Fig. 60). The Southesk Formation consists of the Peechee, Grotto, Arcs, and Ronde (Miette) or equivalent Simla (Ancient Wall) members (Fig.60) (Belyea & McLaren 1957; Mountjoy 1965).

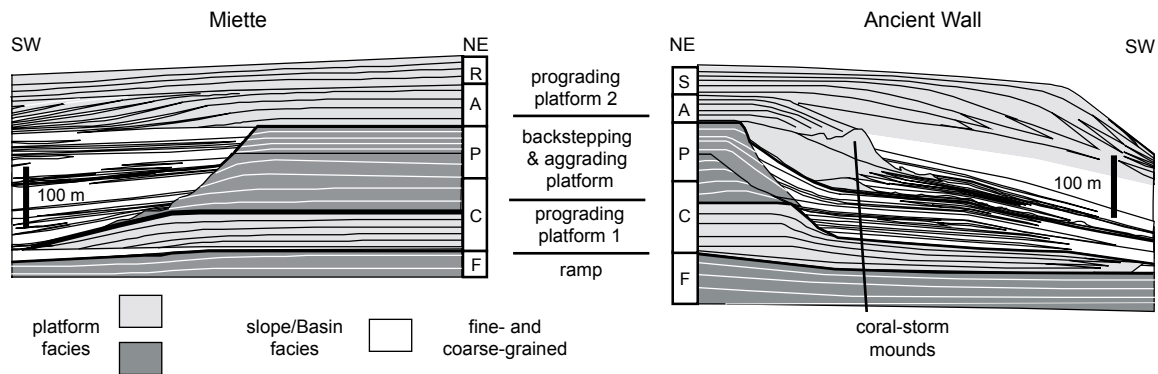


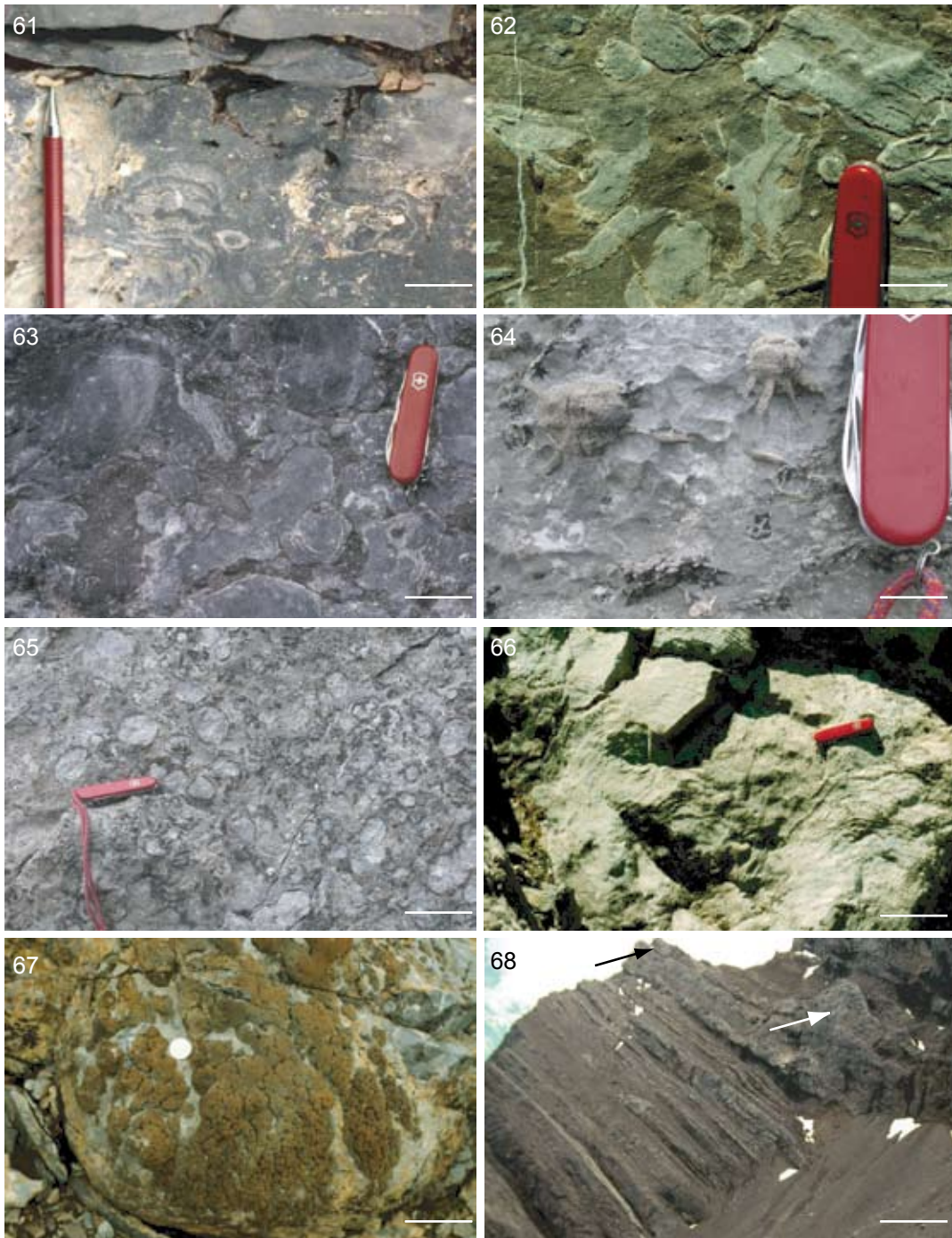
FIG. 60. Cross-sections of the southeast margins of Miette and Ancient Wall illustrating different phases of platform development. Key to unit abbreviations: F = Flume, C = Cairn, P = Peechee, A = Arcs, R = Ronde, S = Simla.

FACIES AND MICROFACIES (Figs 61-68). – A platform-to-basin transect reveals: (1) peritidal, (2) subtidal, (3) platform margin, and (4) slope and basin facies associations (Whalen *et al.* 2000a, b). Stromatoporoid-dominated reefal facies are found in subtidal lagoons and along platform margins. Reefal facies comprise stromatoporoid framestones, *Stachyodes* float-rudstones, and bioclast, intraclast, peloid pack-, grain-, float-, and rudstones. Cryptic microbial cementers and binders commonly inhabited reef cavities (Whalen *et al.* 2002). These platforms underwent four phases of development (Fig. 60): a regionally extensive, aggrading ramp, an isolated prograding platform 1, a backstepping-aggrading isolated platform, and a final prograding platform 2 (van Buchem *et al.* 1996; Whalen *et al.* 2000a, b).

BIODIVERSITY AND TAPHONOMY. – Aggrading ramp biostromes consist of broad, domal-spherical stromatoporoid framestones up to 1 km wide. Prograding platform 1 displays similar, but narrower reefal margins. The aggrading platform's very narrow reefal rim is characterized by massive, tabular stromatoporoid framestones. Seaward of the

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FIGS 61-68. 61-64, Miette, 65-68, Ancient Wall. **61**, Flume Formation, stromatoporoid biostrome overlain by ramp-flooding nodular mudstones; scale = 2 cm. **62**, Alveolitid coral rudstone deposited on the upper slope, note the overturned coral colonies; scale = 1 cm. **63**, Subtidal lagoon stromatoporoid-*Amphipora* rudstone, Cairn Formation; scale = 2 cm. **64**, Parasitic sponges within a bulbous stromatoporoid, Flume Formation; scale = 0,5 cm. **65**, Domal stromatoporoid framestone, Cairn Formation. Note overturned stromatoporoids; scale = 5 cm. **66**, Massive tabular to domal stromatoporoid framestone, Cairn Formation; scale = 5 cm. **67**, Silicified *Renalcis* colony that grew on the underside of a small reef mound associated with late Frasnian progradation; scale = 5 cm. **68**, Outcrop photograph of the southeast margin of Ancient Wall illustrating the stromatoporoid-coral mud mound (white arrow) deposited during late Frasnian progradation (see Fig. 60). The *Renalcis* colony illustrated in Fig. 67 is located near the black arrow; scale = 15m.

sand-dominated margin of prograding platform 2 are local coral-stromatoporoid mud mounds (Figs 60-68). Reefal facies contain abundant overturned or transported skeletons indicating agitated, turbulent water within fair-weather wave base. Many stromatoporoid interiors are inhabited by parasitic boring sponges (Figs 61-68)

DISCUSSION. — The Miette and Ancient Wall platforms developed during a Late Devonian 2nd order rise in sea level. Platform development reflects this control with the thickest aggrading reefal margins deposited during the maximum rate of sea level rise (Whalen *et al.* 2000a, b). A decrease in rate of rise and eventual fall resulted in late Frasnian platform margin progradation. Major reef development appears to have terminated during the first Kellwasser event and most stromatoporoid frame builders met their demise by the end of the second Kellwasser event.

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FRASNIAN STROMATOPOROID-ALVEOLITID-CRYPTOMICROBIAL MUD MOUNDS, HOLY CROSS MOUNTAINS, POLAND

LOCALITY. – Lower-middle Frasnian (Upper Devonian), subtropical waters, gentle slopes of carbonate platforms ('table reefs', exemplified by the Dyminy reef complex) over the South Polish carbonate shelf (typically in the Kielce facies region, southern Holy Cross Mountains).

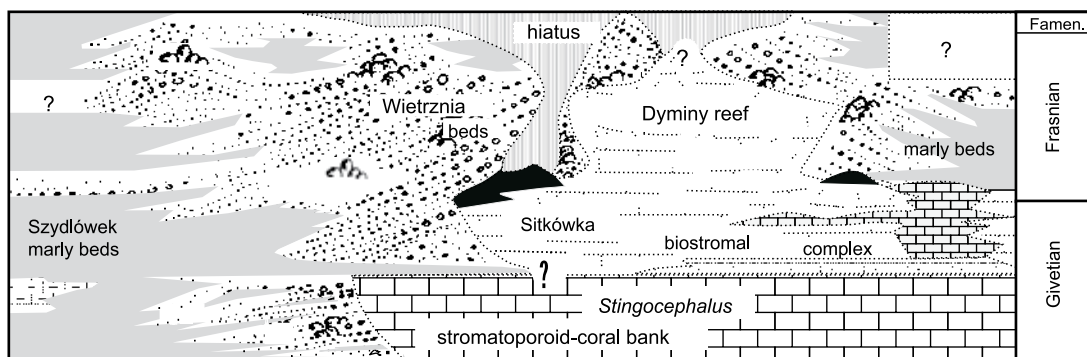
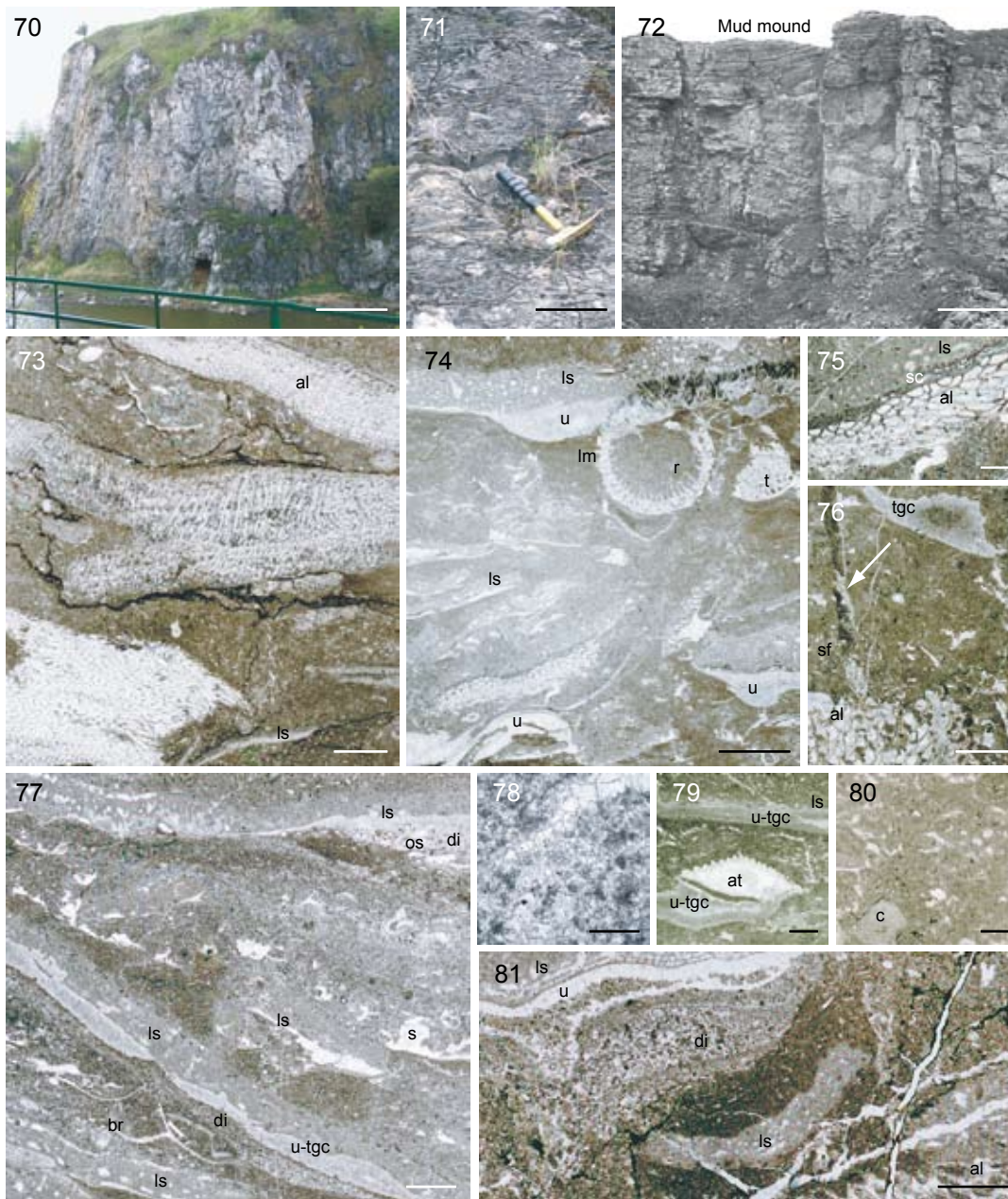


FIG. 69. Geometric relationships of the formations and frame-building units described in the text.

STRATIGRAPHY. – Kadzielnia Limestone Member of Kowala Formation. Isolated meter-size bioherms, over 50 m thick in the stratotype site (Fig. 70), scattered along a linear tract parallel to the platform margin, and intercalated with inter-reef peri-reefal coral biostromes, and massive stromatoporoid (*Actinostroma*) facies corresponding to reef-core and/or talus-like deposits during a foundation stage of the Dyminy Reef (Racki 1993; Łuczyński 1998; Racki & Sobstel 2004).

FACIES AND MICROFACIES (Figs 70-81). – The mound core formed by light grey (to red) stromatoporoid-alveolitid bindstone (1), with stromatoid, clotted and spongostromate fabric of fenestral mudstone to wackestone matrix that record possibly significant microbial contribution to localized framework accretion (Bednarczyk *et al.* 1997). Intra-reef debris contains irregular intercalations of fine-grained grainstones with shelly and/or echinoderm admixture (2). Early cementation of shelter ('umbrella') bedding-parallel and stromatoid cavities contributed to the quick lithification of interstitial muds. Alveolitid bindstone (3) and alveolitid-dendroid coral bafflestone developed on the low-relief buildup flanks (Szulczewski & Racki 1981).

BIODIVERSITY AND TAPHONOMY. – Sheet-like stromatoporoids and laminar to tabular alveolitids, as well microbial aggregations (facies 1 and 3) preserved in life position; other rarer morphotypes of corals and stromatoporoids differentially preserved. In addition to autochthonous brachiopod nests, most brachiopods, crinoids and ostracodes



FIGS 70-81. All pictures from Holy Cross Mts, Poland, active Kowala quarry (72-73, 81) and abandoned Kadzielnia quarry, Kielce (70-71, 74-80). **70**, Karstified Kadzielnia biohermal limestone; scale = 2 m. **71**, Photo of the buildup showing prominent bindstone appearance due to resistant fibrous cement crusts, and a larger alveolitid coral (al); scale = 25 cm. **72**, Stromatoporoid-coral bioherm, ca. 4 m thick, embedded within coral biostromal beds; scale = 2 m. **73-81**, Variety of mud-mound microfacies ranging from alveolitid bindstone (Fig. 73, facies 3) to stromatoporoid bindstone (Fig. 77, facies 1) with many fine-grained grainstone streaks (di; facies 3), grading into brachiopod (br) and ostracod (os) coquina partings, and early cementation visible particularly in umbrella structures (u), locally with distinctive two-generation, partly radial void fillings (tgc). Note diversity of variously preserved skeletal grains (ls = laminar stromatoporoid, r = rugosan, t = dendroid tabulate, c = crinoidal element, at = atrypid brachiopod) and differentiated, in places hematite-rich and stylo-brecciated (Figs 78, 81) micrite matrix, that comprises laminated (lm), stromatactoid (s), as well as clotted to spongiostomate fabrics (see close-up in Figs 78, 80). A neptunian micro-dike filled with micrite and bioclasts (arrowed; Fig. 76), and intergrowth consortia (Fig. 75) of *Sphaerocodium* cyanophytes (sc) and metazoans are noticeable characters as well. All thin-sections in non-polarized light; scales = 0,5 cm (Figs 73, 74), = 500 μ m (Figs 75, 78, 80) and = 2,5 mm (Figs 76, 77, 79, 81).

are disarticulated and fragmented (facies 3). Uniquely diverse and mostly endemic mud-mound dwellers embrace many eleutherozoan echinoderms, mollusks (mostly gastropods), octactinellid sponges, foraminiferans, ostracodes, scutellid trilobites and bryozoans, as well as many microproblematica jointly with peculiar tube-like forms (Szulcowski & Racki 1981; Racki 1993).

DISCUSSION. — Some parts are coloured red by hematite, probably derived from microaerophilic iron bacteria (cf. Boulvain *et al.* 2001). Neptunian dikes cut through bioherm and ascending post-mound strata at the type site. The largest buildup persisted as a topographic high, and afterward was a place of a prolific production of late Frasnian flank deposits, with cryptomicrobial-algal-*Stachyodes* patches (Bednarczyk *et al.* 1997). The eroded Kadzielnia mound finally capped by the Famennian condensed *Cheiloceras* limestones (Szulcowski 1971).

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FRASNIAN LAMELLAR STROMATOPOROID BIOSTROMES, BELGIUM

LOCALITY. — Upper Devonian, Middle Frasnian (*punctata* to *jamieae* conodont zones), subtropical carbonate platform, South of the Brabant Massif, Rheic Ocean. Rhenohercynian fold and thrust belt, Dinant Synclinorium and Philippeville Anticlinorium.

STRATIGRAPHY. — Lustin and Philippeville Formations: meter thick biostromes, interbedded with open facies and lagoonal deposits. These biostromes are particularly well exposed in the Tailfer quarry, on sawn quarry walls (Figs 82-83) (da Silva & Boulvain 2002; 2004 and 2006).

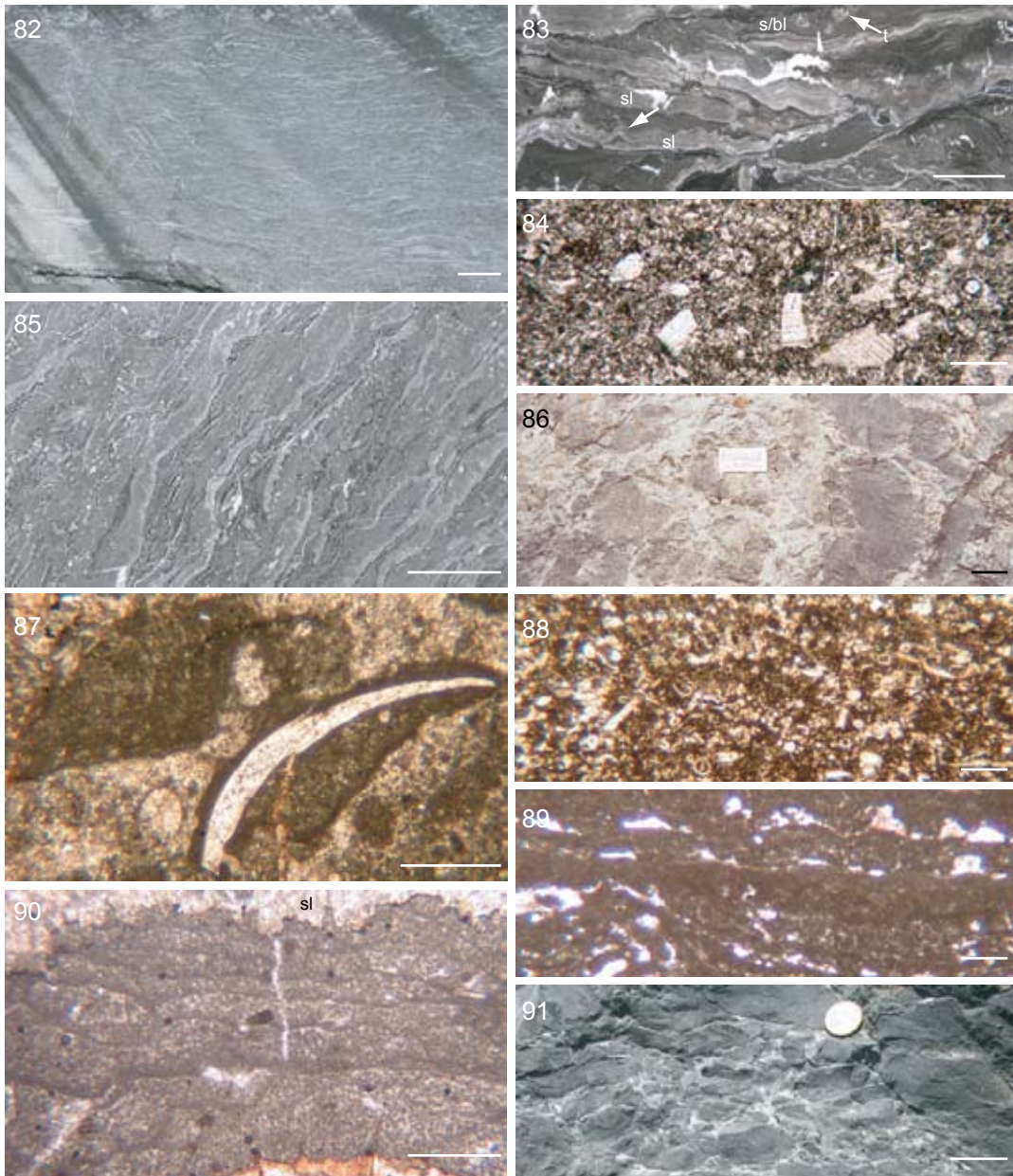
FACIES AND MICROFACIES (Figs 82-91). — The biostromes consist of lamellar stromatoporoid coverstones (Figs 82-85). The stromatoporoids are well preserved and occur in life position or overturned. They have well developed astrorhizal mamelons (Fig. 83). The stromatoporoids are accompanied by tabulate and rugose corals, brachiopods, ostracodes, crinoids, calcispheres and sponges spicules. The matrix is a light grey micrite, rich in small bioclasts or shows a clotted, even locally laminated peloidal (Fig. 90) or encrusting (Fig. 87) aspect that can be related to microbial or algal activities. The good preservation of this matrix and the stromatoporoids preserved in life position suggest low energy deposition, under the fair-weather wave base. The frequent occurrence of broken corals or brachiopods and overturned stromatoporoids suggests episodic reworking by storms.

BIODIVERSITY AND TAPHONOMY. — The base of the biostrome in Tailfer presents a lot of broken and overturned reef builder organisms. These reef builders are stromatoporoids, rugose and tabulate corals with different morphologies (massive, branching, encrusting and lamellar). The diversity of these reef builder organisms decreases after the first decimetre of sediment. In the main part of the biostrome, lamellar stromatoporoids are dominant; they are generally well preserved, in life position or overturned.

DISCUSSION. — These biostromes are stacked into regressive metre-cycles. These cycles begin with crinoidal packstones (open facies, Fig. 84) followed by the biostromes and capped by proximal deposits (mudstone with algae in the subtidal zone (Fig. 88) and laminated peloids in the intertidal zone (Fig. 89) or by paleosols (Fig. 91). In some sections, the lamellar stromatoporoid biostromes are replaced laterally by high domical stromatoporoid beds (Fig. 86). These stromatoporoids are often broken and were probably deposited in an area of moderate to strong wave energy, around the fair-weather wave base.

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FIGS 82-91. **82**, Biostromes with lamellar stromatoporoids, Tailfer quarry, Lustin Formation; scale = 25 cm. **83**, Scan of sample, lamellar stromatoporoid coverstone. sl are lamellar stromatoporoids and s/bl are broken lamellar stromatoporoids, t are tabulate corals and the white arrows point to the astrorhynchal mamelons. Tailfer section, Lustin Formation; scale = 0,75 cm. **84**, Open facies, crinoidal packstone. Thin-section, plane polarized light, Villers-le-Gambon railway, Philippeville Formation; scale = 250 μ m. **85**, Close-up on the sawn wall of the Fig. 82, lamellar stromatoporoids facies; scale = 10 cm. **86**, High domical stromatoporoids biostromes, the stromatoporoids are commonly broken and overturned. Aywaille, Dieupart quarry, Lustin Formation; scale = 2,5 cm. **87**, Lamellar stromatoporoids biostrome, brachiopod encrusted by algae, in a clotted fabric. Thin-section, plane polarized light, Tailfer quarry, Lustin Formation; scale = 1 mm. **88**, Proximal facies, subtidal zone, paleosiphonocladale wackestone. Thin section, plane polarized light, Villers-le-Gambon railway, Philippeville Formation; scale = 500 μ m. **89**, Proximal facies, intertidal zone, laminated grainstone with peloids. Thin section, plane polarized light, Aywaille, Dieupart quarry, Lustin Formation; scale = 500 μ m. **90**, Lamellar stromatoporoids biostrome, laminated clotted peloids between two lamellar stromatoporoids (sl). Thin section, plane polarized light, Tailfer quarry, Lustin Formation; scale = 1 mm. **91**, Proximal facies, supratidal zone, brecciated limestone, paleosols, Tailfer quarry, Lustin Formation; scale = 4 cm.

FRASNIAN CORAL-STROMATOPOROID-MICROBIAL ATOLLS, BELGIUM

LOCALITY. – Middle Frasnian (*Palmatolepis transitans*-*P. jamieae* conodont zones) subtropical outer ramp, S of the London-Brabant Massif (S border of the Dinant Synclinorium and Philippeville Anticline, Belgium) (Fig. 92A).

STRATIGRAPHY. – Arche and Lion members (Fig. 92B); the mounds are 150 to 200 m thick and 600 to 1000 m in diameter (Fig. 92B-C). They are surrounded by argillaceous limestone and topped by shale.

FACIES AND MICROFACIES (Fig. 92C, Figs 93-101). – Above a sole consisting of argillaceous limestone with rugose corals, mound facies consist of: pink limestone with stromatactis, corals and crinoids (Fig. 92C: 2); grey limestone with fenestrae, corals and stromatoporoids (Fig. 92C: 3); grey limestone with corals, peloids and dasycladales (Fig. 92C: 4); grey microbial limestone (Fig. 92C: 5); grey limestone with dendroid stromatoporoids (Fig. 92C: 6); grey fenestral limestone (Fig. 92C: 7); grey bioturbated limestone (Fig. 92C: 8); In the vicinity of the mounds, lateral time-equivalent sediments include a high amount of reworked material from the surrounding buildups (Fig. 92C: 9); farther, it grades into fine-grained argillaceous limestone and nodular shale (Fig. 92C: 10).

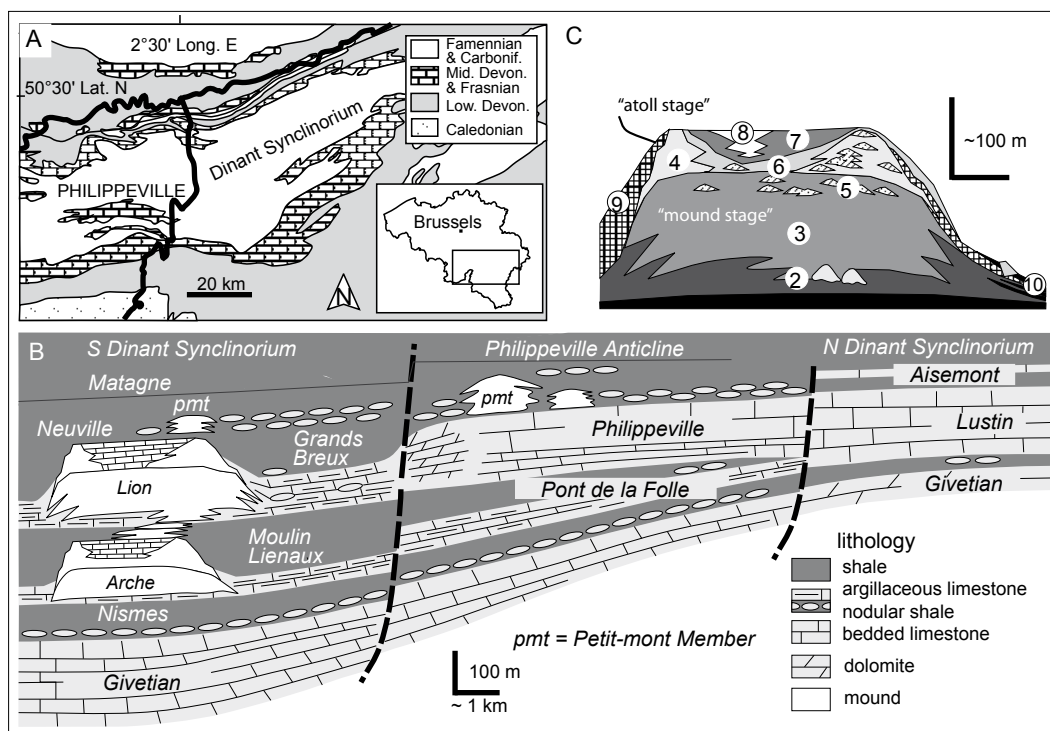
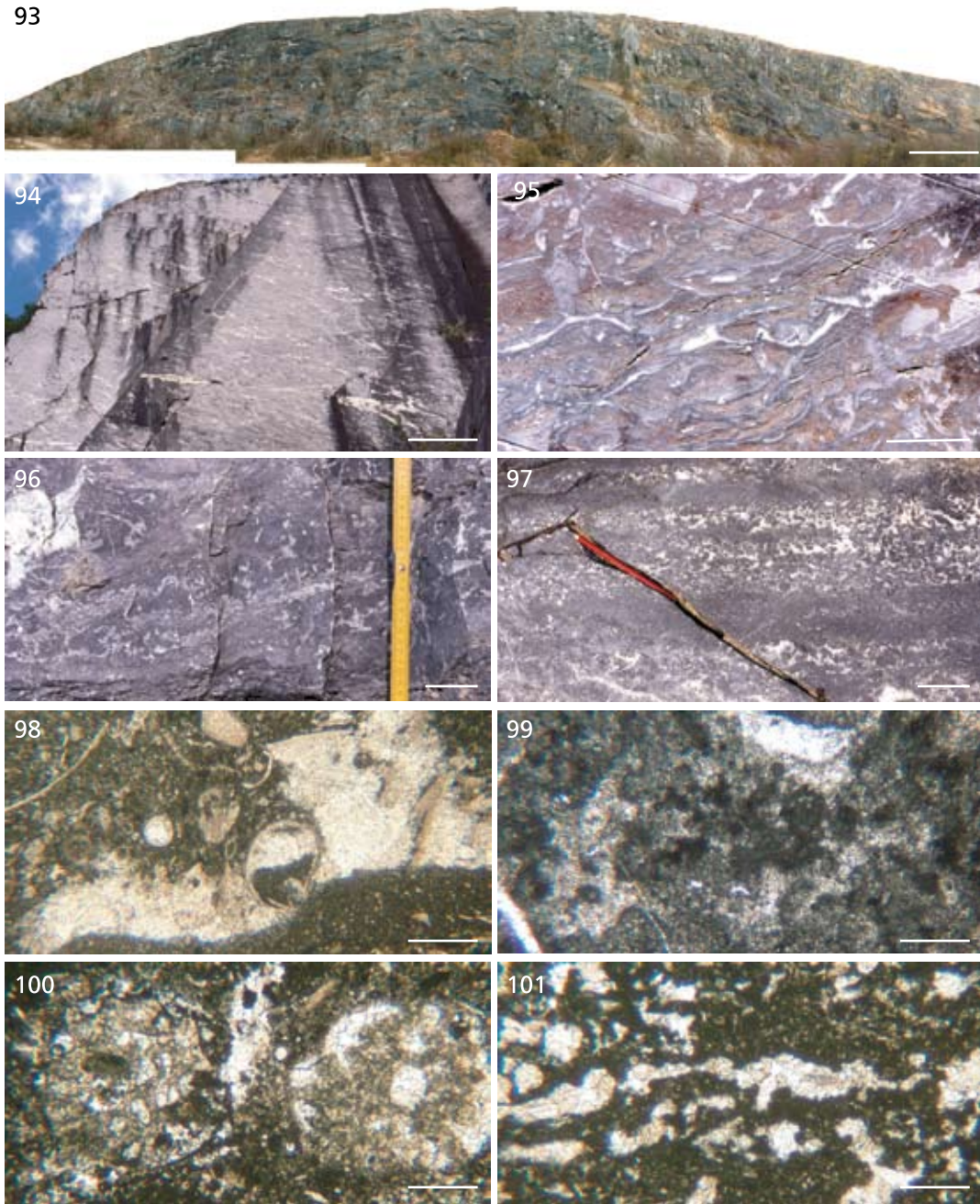


FIG. 92. A. Geologic setting of the Belgian atolls reported in the text. B. Facies geometries. C. Sedimentary architecture of the Frasnian formations with setting of main buildups (description in the text).



FIGS 93-101. **93**, NE-SW panorama of the Lion quarry, Frasnés; highest point of the quarry is 40 m high; scale = 20 m. **94**, Arche mound, Frasnés, showing grey algal and microbial bindstones and bafflestones (facies 4-5); stratification is nearly horizontal and the high of the quarry wall reaches 20 m; scale = 4 m. **95**, Base of the Arche mound, characterized by red coverstones with stromatactis and shelter cavities, zebra, tabulate corals, crinoids, brachiopods and stromatoporoids (facies 3); scale = 10 cm. **96**, Grey limestone with stromatactis, corals and crinoids (facies 2); Nord quarry, Lion Member, Frasnés; scale = 5 cm. **97**, Fenestral limestone (facies 7); La Boverie quarry, Lion Member, Jemelle; scale = 5 cm. **98**, Wackestone with fenestra, crinoids and brachiopods (facies 3); thin-section, normal light; La Boverie quarry, Jemelle, Arche Member; scale = 1 mm. **99**, Bafflestone with thrombolites and *Renalcis* (facies 5); thin-section, normal light; Humain section, Lion Member; scale = 1 mm. **100**, Floatstone with dendroid stromatoporoids (facies 6); thin section, normal light; La Boverie quarry, Lion Member; scale = 1 mm. **101**, Fenestral limestone (facies 7) thin section, normal light; La Boverie quarry, Jemelle, Lion Member; scale = 1 mm.

BIODIVERSITY AND TAPHONOMY. — Fossils are generally preserved in life-position in facies (Fig. 92C: 2-3). Wave activity disturbs facies (Fig. 92C: 4-6). Fenestrae are generally related to growth-cavities.

DISCUSSION. — Facies (Fig. 92C: 2) and (Fig. 92C: 3) developed close to the storm wave base, in a subphotic environment. Facies (Fig. 92C: 4), occurring near the fair weather wave base in the euphotic zone, includes lenses with stromatolites and thrombolites (Fig. 92C: 5). Facies (Fig. 92C: 6) corresponds to a slightly restricted environment and shows a transition to the fenestral limestone (Fig. 92C: 7). This facies was deposited in a moderately restricted intertidal area. Facies (Fig. 92C: 8) developed in a quiet lagoonal environment. After the construction of the lower part of the buildups during a transgression ('mound stage'), a lowstand forced reef growth along the edge of the buildups (Fig. 95), starting the development of atoll crowns during the following transgressive stage ('atoll stage') (Boulvain *et al.* 2004; Boulvain 2007).

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LATE FRASNIAN STROMATACTIS-CORAL-MICROBIAL CARBONATE MOUNDS, BELGIUM

LOCALITY. – Late Frasnian (top of early *rhenana*-base of late *rhenana* conodont zones) subtropical outer ramp, south of the London-Brabant Massif (Southern border of the Dinant Synclinorium and Philippeville Anticline, Belgium) (Fig. 102).

STRATIGRAPHY. – Petit-Mont Member, Neuville and Valisettes Formations (Fig. 102). In the Philippeville Anticline (proximal belt), mounds are 40-80 m thick and 150-250 m in diameter, flattened or hemispherical carbonate lenses isolated in shale and nodular shale; in the southern border of the Dinant Synclinorium (distal belt), mounds are 30 m thick and 150 m in diameter (Fig. 103).

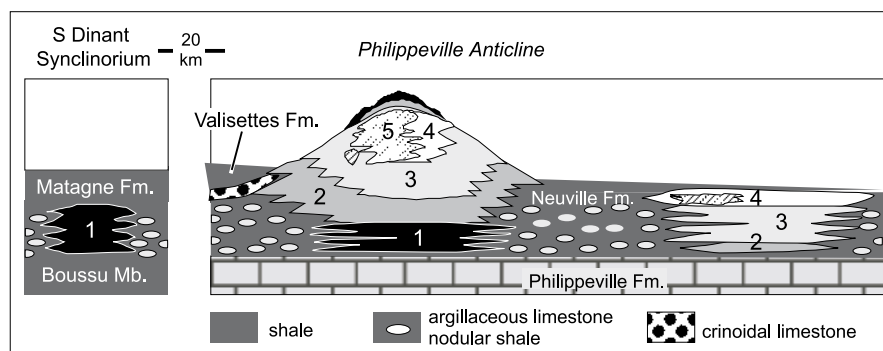
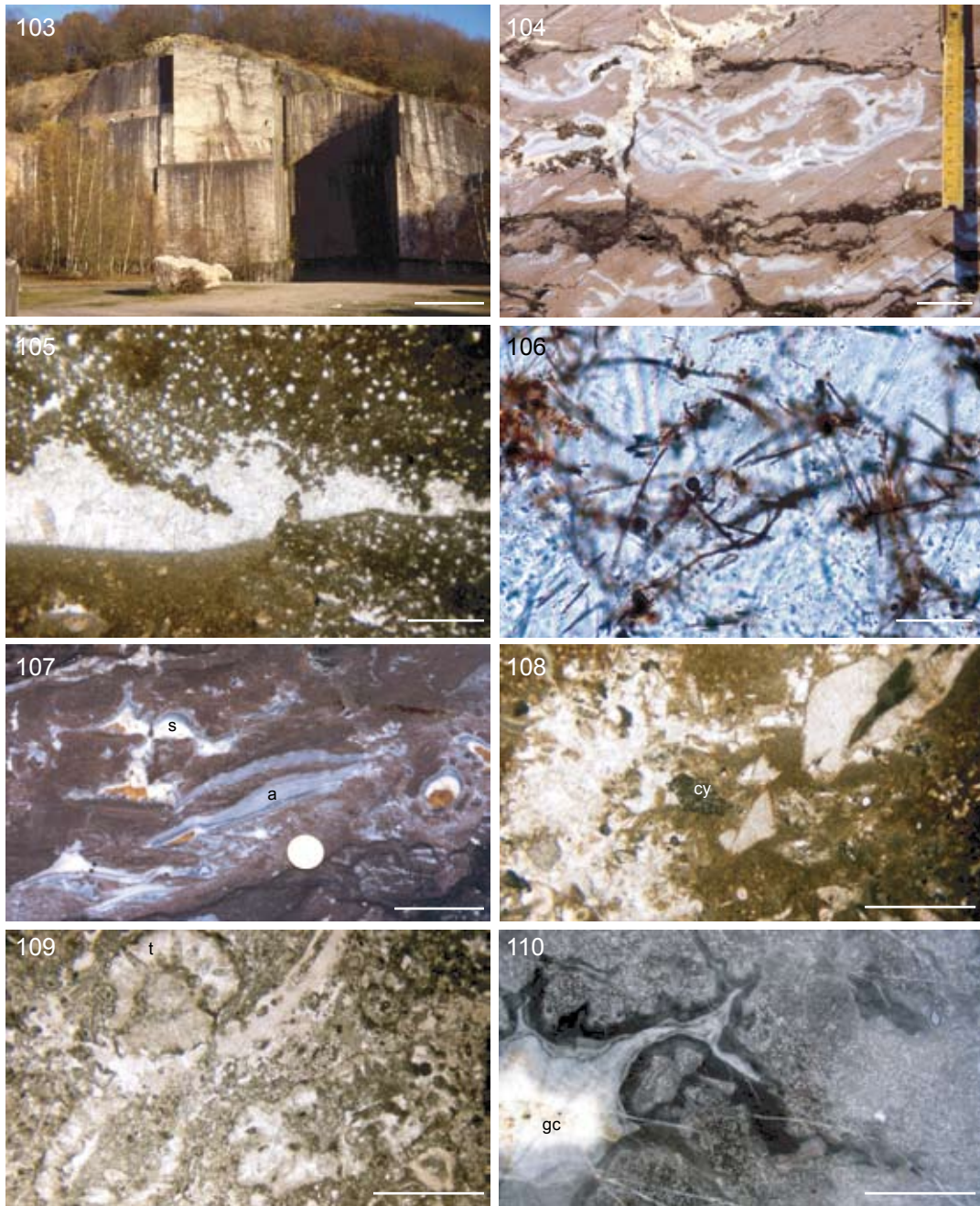


FIG. 102. Sedimentary architecture of the facies described in the text in the Dinant Synclinorium and the Philippeville Anticline.

FACIES AND MICROFACIES (Figs 103-110). – Proximal belt: above an argillaceous limestone substrate, the first carbonate mound facies consists of spiculitic wackestone with stromatactis (1), which becomes progressively enriched in crinoids and corals (2), then in peloids, stromatoporoids and cyanobacteria (3). (4) consists of algal-coral-peloid wackestone and packstone with green algae and thick algal coatings. A core of algal and microbial bindstone (5) sporadically occurs within large mounds. The uppermost part of these mounds may show a recurrence of facies (2) and (1). (1) to (3) are coloured red by hematite derived from microaerophilic iron bacteria; (4) and (5) are grey. Mounds from the distal belt are characterized by spiculitic wackestone with stromatactis (1) only.

Appels figures à identifier soit Fig 102: 1, soit Fig 103: 1, etc...

BIODIVERSITY AND TAPHONOMY. – Fossils from facies (1) to (3) are generally preserved in life position. Upper facies (4, 5) are characterized by local reworking by waves. Bioturbation is very uncommon in mound facies, but well developed in lateral argillaceous facies. Biodiversity increases from (1) to (4), then decreases with facies (5) (domination stage). In these mounds, stromatactis formed from sponge degradation in a relatively coherent sediment (Bourque & Boulvain 1993). The lower part of the mounds is coloured red by hematite derived from microaerophilic iron bacteria (Boulvain *et al.* 2001).



FIGS 103-110. All pictures come from the Petit-Mont Member, Philippeville Anticline. **103**, Upper 30 m of the Beauchâteau quarry, Senzeilles; scale = 4 m. **104**, Red limestone with stromatactis (facies 1), Les Croisettes quarry, Vodecée; scale = 5 cm. **105**, Red mudstone with stromatactis and sponge spicules (1), Hautmont quarry, Vodelée; thin section, plane polarized light; scale = 2 mm. **106**, Microaerophilic iron bacteria, preserved in a cavity from facies (3), Rochefontaine quarry, Franchimont; thin-section, plane polarized light; scale = 50 μ m. **107**, Red limestone with stromatactis (s), corals and crinoids (facies 2); supported cavities filled with radiaxial cement occur below *Alveolites* (a); Beauchâteau quarry, Senzeilles; scale = 5 cm. **108**, Wackestone with stromatactoid fenestrae, crinoids (c), fenestellids and fragments of cyanobacteria coatings (cy) (facies 3); Tapoumont quarry, Neuville; thin section, plane polarized light; scale = 2 mm. **109**, Packstone with peloids and *Trelonella* (t, Udoteaceae) (facies 4), Tapoumont quarry, Neuville; thin-section, plane polarized light; scale = 2 mm. **110**, Grey algal and microbial bindstone (5) with growth cavities (gc), Hautmont quarry, Vodelée; scale = 5 cm.

DISCUSSION. — The transition from the aphotic to the cyanobacterial photic zone is recorded in the succession (2)-(3); the transition from the cyanobacterial to the green algal photic zone is recorded by (3)-(5). Storm wave base was reached within (3) and fair-weather wave base within facies (5) (Boulvain 2001). Beyond that, hypoxic conditions are indicated by the sponge and iron-bacteria consortium in the lower parts of the mounds. This is in agreement with the general assumption of stratified water masses during late Frasnian, preceding the prominent Lower Kellwasser crisis

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FAMENNIAN MICROBIAL-SPONGE REEFS, CANNING BASIN, AUSTRALIA

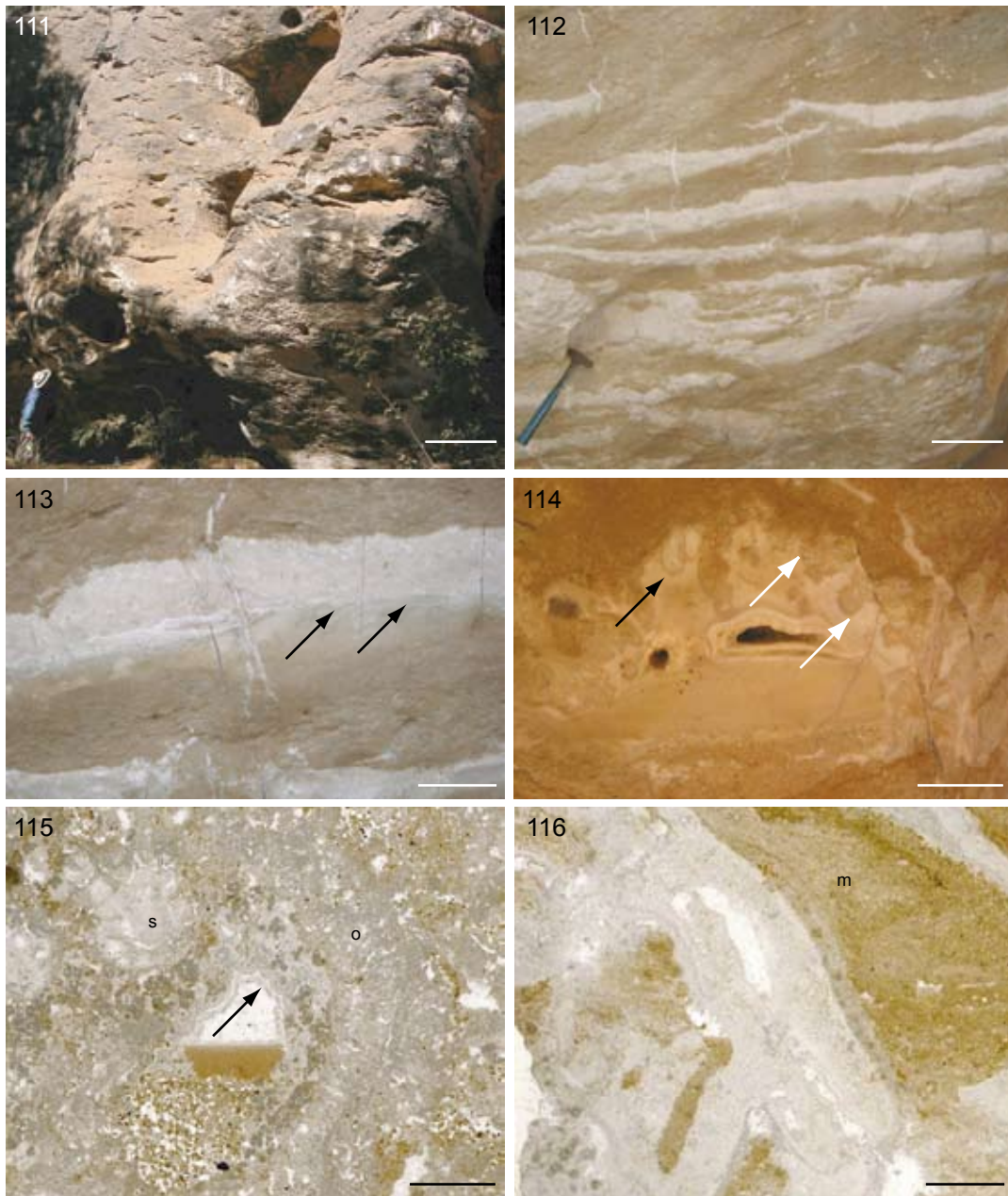
LOCALITY. – Early Famennian (*triangularis* zone), fore-slope reefs; 0-900 m on the north and south sides of the western entrance of Windjana Gorge, Canning Basin, Western Australia. Plate reconstructions place this region in an arid subequatorial belt some 10-15°S (Scotese 1984). The rimming reefs of Windjana Gorge were flanked by steeply-dipping (up to 30°) marginal-slope deposits composed largely of platform derived sediments, including allochthonous blocks indicative of collapse of the early-cemented platform margin.

STRATIGRAPHY. – Windjana Limestone (Figs 111-112). Reef mounds are either elevated platy structures up to 4 m in diameter and 0.35 m thick, or mounds up to 15 m in diameter.

FACIES AND MICROFACIES (Figs 101-116). – These fore-slope reef communities exposed in Windjana Gorge flourished in high-energy mixed siliciclastic-carbonate environments dominated by coated grain sediments, and where rapid, early lithification was pervasive. Beds are up to 1.5 m thick, composed of medium-coarse quartz-feldspathic sandstone, peloidal limestone and mudstone, coated-grain (ooids and peloids) packstone, and some grainstone and wackestone. The peloidal limestone is composed of fine sand-sized, round to subangular peloids, intraclasts and skeletal debris, and abundant coarse, angular, quartz-feldspathic clasts. Many neptunian dykes and fissures are common, which are filled with ooids and early cements. The reef communities described here grew within proximal-slope settings characterised by silty-sandy, ooidal grainstone beds dipping from 10 to 30° (Fig. 112). These may represent turbidites and debris flows. Some horizons contain eroded, possibly embayed, allochthonous clasts of reef talus ranging from 10 to 250 mm in diameter. Within this setting are common beds up to 2.5 m thick consisting of peloidal fenestral limestones. The irregular fenestrae from 10 to 110 mm in length and from 2 to 15 mm in width form stromatactis structures and swarms subparallel to the sedimentary surfaces (Wood 2004).

BIODIVERSITY AND TAPHONOMY. – Diverse *in situ* calcimicrobes together with algae, crinoids, bryozoans, brachiopods, and abundant sponges (stromatoporoids, inozoans, sphinctozoans, lithistids and hexactinellids) (Fig. 116) formed the reef framework. This framework was dominated by a complex intergrowth of calcimicrobes, where *Rothpletzella* formed the primary framework, *Ortonella*, and *Girvanella* were secondary encrusters, and *Shuguria* sp. occupied small crypts from 2-30 mm in diameter (Figs 114-116). At least 14 morphospecies of spicular sponges are now identified from the Windjana Limestone (Wood 2004). Contiguous columnar stromatolites up to 50 mm in height and 1 m in width grew upwards from substrate sheltered beneath large sheltered primary cavities (Fig. 113). The elevated platy community is inferred to have grown in conditions of episodic siliciclastic sediment input; the reef mounds grew during either episodes, or in localised areas, of low sedimentation.

DISCUSSION. – The Famennian proximal reef-slope communities within the Windjana Limestone, Canning Basin, Western Australia, shows that notwithstanding the loss of large metazoans, novel ecologies were established relatively rapidly in this setting by a rich biota of survivor and progenitor taxa (Wood 2000). The reef-slope communities of the



FIGS 111-116. Windjana Limestone, Windjana Gorge, Canning Basin, Western Australia, Reef slope facies. **111**, Field photograph of reef mounds and plates within the reef slope facies; scale = 1 m. **112**, Field photograph of plates and small mounds of microbialite-calcimicrobe-sponge reef communities; scale = 50 cm. **113**, Field photograph of two laminar growths of *Rothepletzella*, *Girvanella*, *Shuguria*, and other calcimicrobes, forming cavities. Stromatolites (arrowed) are growing upwards from the sediment within the protected cavity; scale = 2,5 cm. **114**, Field photograph of cavity formed by arching growth of *Rothepletzella* with pendent *Shuguria* (white arrows) and attached cryptic brachiopod (black arrow); scale = 2,5 cm. **115**, Photomicrograph of primary cavity with geopetal infill. The framework is formed by encrusting *Ortonella* (o) to which is attached *Solenopora geikei* (s). Pendent *Shuguria* (arrowed) grew from the ceilings and walls, and in turn was encrusted by microcrystalline cement; scale = 2 mm. **116**, Photomicrograph of pendent, branching sponge, *?Playfordiella*, encrusted by laminar microbialite (m) on the upper surface, with cryptic *Shuguria* attached to walls and ceilings of primary cavity (arrowed); scale = 1 cm.

Windjana Limestone offer little evidence to support the ideas of resurgence or invasion of taxa from deeper waters after the Frasnian/Famennian extinction, and there is evidence to suggest that similar microbial-sponge communities were already established in margin and reef slope communities in the latest Frasnian.

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LATEST FAMENNIAN (STRUNIAN) STROMATOPOROID BIOSTROMES, BELGIUM AND GERMANY

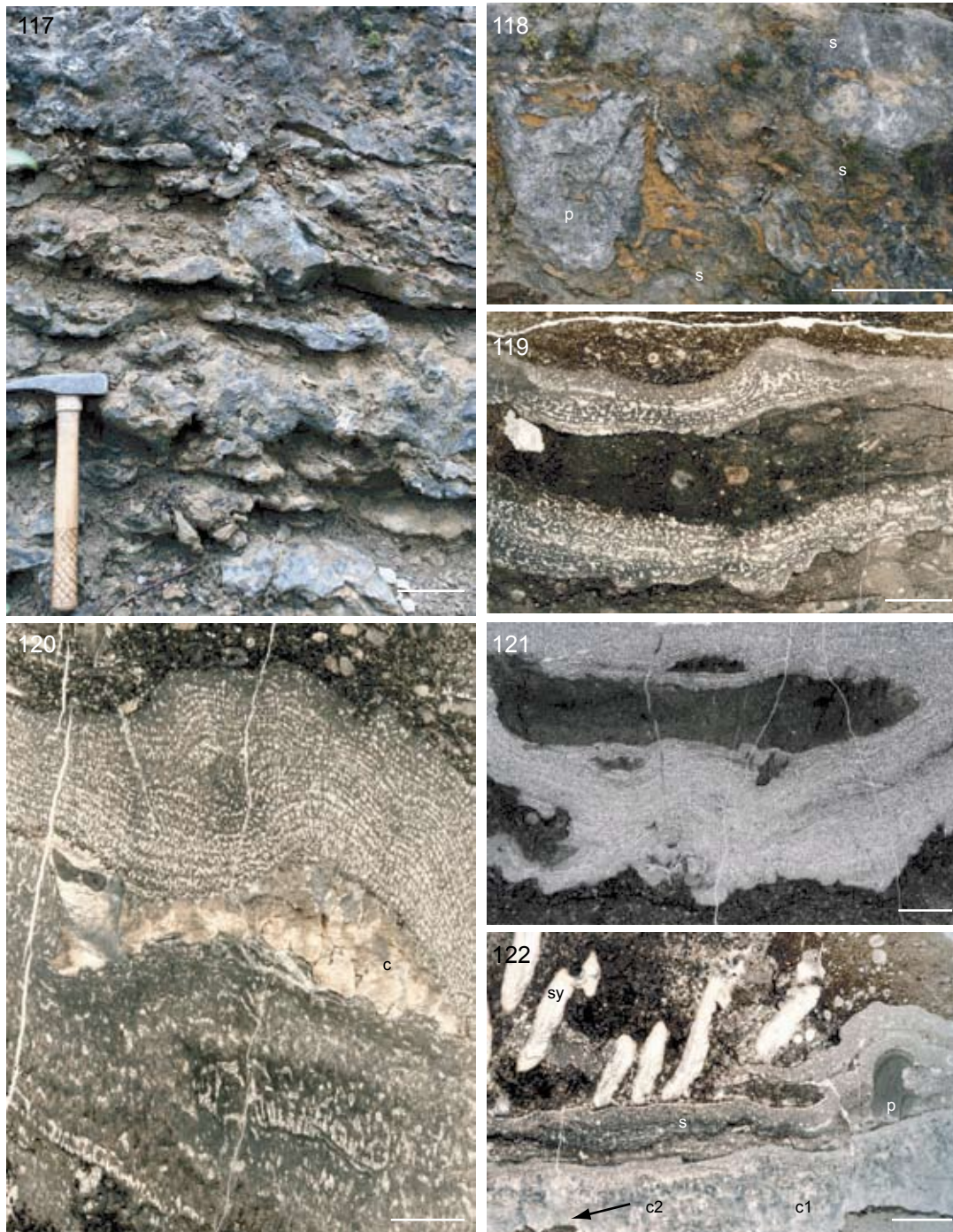
LOCALITY. – Late Strunian (latest Famennian; *Quasiendothyra kobeitusana* - DF3E foraminiferan subzone, LV spore zone), subtropical proximal ramp, southeast of the London-Brabant Massif (Vesdre area, eastern Belgium and western Germany).

STRATIGRAPHY. – Dolhain Formation. Biostromes are 1 m to several metres thick (Fig. 117) and have plurikilometric lateral extensions. The biostromes developed in relatively proximal areas, between terrigenous-influenced tidal flats and lagoons, and more open marine, shallow-water carbonate facies. They are commonly interbedded with argillaceous limestones. Small isolated domal knobs (less than 1 m high) are known in proximal facies influenced by argillaceous inputs.

FACIES AND MICROFACIES (Figs 117-122). – In the biostromes, stromatoporoid bindstones are the dominant building facies (Figs 119-122), whereas bafflestones are confined to some fasciculate tabulate corals (syringoporoids; Fig. 122) and rare *Amphipora*. Framestones are only known in the small stromatoporoid knobs. The stromatoporoids developed on bioclastic, more or less crinoidal packstones to grainstones or on calcareous shales and siltstones. Their pattern is lamellar to domal, from some mm to 30 cm thick, and they contain commonly cavities filled with sediments (Fig. 121) or with sparry calcite or dolomite (Figs 119, 122).

BIODIVERSITY AND TAPHONOMY. – Stromatoporoids are diversified and belong to 10 genera (Weber 2000). They are usually preserved in living position and encase commonly sediments (Fig. 121) or are ragged, suggesting episodic high rates of sedimentation. Building guild comprises also some rugose and tabulate corals and *Pseudochaetetes* in living position (Figs 117-122). The bound sediment is rich in solitary rugose corals (no compound is known), fasciculate tabulate corals, brachiopods, gastropods, bryozoans, pelmatozoans, algae, foraminifera, ostracodes and trilobites. Bioturbation is common. Cavities filled with sparry calcite possibly result from the decay of sponges; there is no record of stromatactis. The community lived in the fair weather wave zone with episodic argillaceous limestone inputs.

DISCUSSION. – After the crises affecting the corals and the stromatoporoids and the demise of the bioconstructions during the late Frasnian, it was not before the late Famennian (Strunian, *Quasiendothyra regularis* – DF3E foraminifer subzone, middle *costatus* conodont subzone) that stromatoporoids reappeared in the Namur-Dinant marine Basin. The increase of the carbonate fabric during the late Famennian is linked to the climatic warming after the early-middle Famennian cooling and to a third-order transgressive system tract (Strunian transgression). The stromatoporoids and the rugose corals reached their maximum of diversity in the latest Strunian, but the Hangenberg event, which is marked by a sudden and relatively short fall of the sea level, stopped their recovery and cause the demise of the firsts and a major crisis for the seconds (Poty 1999).



FIGS 117-122. Figures 117-118 and 120-121 from the Dolhain Formation at Dison (Vesdre area, Belgium) and figure 119 from the same formation at Stolberg (Aachen area, western Germany). **117**, View of the core of the stromatoporoid biostrome; scale = 10 cm. **118**, A rugose coral (*'Palaeosmilia' aquisgranensis*, p) in growth position and encased in stromatoporoids (s); scale = 3 cm. **119**, Stromatoporoids binding packstones; scale = 5 mm. **120**, Stromatoporoid bindstone with an internal cavity (filled up with sparry calcite); scale = 5 mm. **121**, Stromatoporoid bindstone including lenses of packstones; scale = 5 mm. **122**, Syringoporoid (sy) bafflestone and stromatoporoid (s) bindstone encasing a *Pseudochaetetes* sp. (p); the stromatoporoid overlies a cavity filled with sparry calcite (c1) and with a late dolomite (c2); scale = 5 mm.

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