The Odivelas Limestone: evidence for a Middle Devonian reef system in western Ossa-Morena Zone (Portugal)

GIL MACHADO[1*], JINDŘICH HLADIL[2], LEONA KOPTÍKOVÁ[2,4], PAULO E. FONSECA[3], FERNANDO T. ROCHA[1] and ARNOŠT GALLE[2]

[1]GeoBioTec, Geoscience Department, University of Aveiro, 3810-193 Aveiro, Portugal; [*]machadogil@gmail.com; frocha@geo.ua.pt
[2]Institute of Geology, Academy of Sciences of the Czech Republic, v.v.i., Rozvojová 269, 165 00 Praha 6-Lysolaje, Czech Republic; hladil@gli.cas.cz; koptikova@gli.cas.cz; galle@gli.cas.cz
[3]Geology Department and CeGul, Faculty of Sciences of the University of Lisbon, Edifício C6, Campo Grande, 1749-016 Lisbon, Portugal; pefonseca@fc.ul.pt
[4]Institute of Geology, Faculty of Science, Charles University in Prague, Albertov 6, 128 43 Praha 2, Czech Republic

Abstract: The Odivelas Limestone constitutes one of the few records of Middle Devonian sedimentation in the western Ossa-Morena Zone. Although deformed and metamorphosed the limestones have an abundant fossil content which allows their positioning as late Eifelian/early Givetian in age and to relate the reef fauna with the typical Rhenish facies for the same time period. Magnetic susceptibility analysis was attempted and is in agreement with the biostratigraphy, but the limited extent of sections and the metamorphism precludes firm correlations. The field evidence, petrographic and geochemical analysis point to a close paleogeographical relation and dependence of the reef system on volcanic structures which are included in the Beja Igneous Complex. The age of part of the volcanic and sub-volcanic suite of this complex is thus constrained.

Key words: Eifelian/Givetian, Paleozoic orogens, Ossa Morena Zone, Beja Igneous Complex, biostratigraphy, reef fauna, carbonate petrology, magnetic susceptibility.

Introduction

Geotectonic setting

The Ossa-Morena Zone (OMZ) is a major geotectonic unit located in the southern sector of the Iberian Massif (Lötze 1945; Julivert & Martínez 1983; see Figs. 1 and 2), forming, together with the Central-Iberian Zone, the Iberian Autochthon (IA) of the so-called Iberian Massif (e.g. Ribeiro et al. 1990). The Iberian Massif, located in the western half of Iberian Peninsula, represents the largest and one of the most complete and continuous exposures of Variscan Belt in Western Europe. The OMZ involves a complex tectonic scenario with the development and closure of an ophiolitic complex — the so-called Beja-Acebuches Ophiolitic Complex (BAOC; Fonseca & Ribeiro 1993; Fonseca et al. 1999; Mateus et al. 1999; Figueiras et al. 2002). Moreover, the OMZ southern border comprises highly deformed exotic terranes of an oceanic nature (including the "Pulo do Lobo" Accretionary Terrane (PLAT) and the BAOC), as complex tectonic melanges (Almeida et al. 2001; Araújo et al. 2005; Booth-Rea et al. 2006). These formations are rimming an early main Variscan suture in the southwest of the Iberian Massif and they accreted to the Iberian Autochthon before the Middle/Late Devonian times (Fonseca & Ribeiro 1993; Fonseca et al. 1999). The BAOC separates the OMZ and the South-Portuguese Zone (SPZ), which is regarded as another exotic terrain, originating from a so-called "Southern Paleo-continent" and accreted to the IA during Carboniferous times (Dallmeyer et al. 1993).

It has been proposed (Crespo-Blanc & Orozco 1988; Fonseca 1995, 1997; Fonseca et al. 1999; Crespo-Blanc 2007) that a major ocean (Rheic Ocean) was closed by subduction/obduction leaving some remainder ophiolitic slices: the Lizard suture in SW England and the Beja-Acebuches suture zone, represent, respectively, the northern and southern branches of the same ocean (Fonseca et al. 1999; Ribeiro et al. 2007).

Data acquired during different research projects clearly shows new dismembered ophiolitic slices in the OMZ (Internal Ossa-Morena Zone Ophiolitic Sequences — IOMZOS, Fonseca et al. 1999), which corresponds to allochthonous klippen resting on top of the lower Paleozoic sequences (Ribeiro et al. 2007).

Upper Paleozoic sedimentation in Ossa-Morena Zone

During the Early Devonian, as well as for most of the early Paleozoic (except for the Cambrian), the sedimentation in the OMZ was generally occurring in a passive margin setting (Quesada 1990; Robardet & Gutiérrez-Marco 1990, 2004). These rocks occur in wide areas from Portalegre to Cordoba (Robardet & Gutiérrez-Marco 1990, 2004) and more to the south in the Barrancos-Estremoz area (Robardet & Gutiérrez-Marco 1990, 2004; Oliveira et al. 1991; Piçarra 2000), Terena syncline (Piçarra 2000) and Valle synclines, Venta de Ciervo and Cerron del Hornillo in Spain (Robardet & Gutiérrez-Marco 1990, 2004). Fine siliciclastics dominate the sequences but some calcareous levels occur (Robardet & Gutiérrez-Marco 1990, 2004) characterizing proximal deposits to deep fan tur-
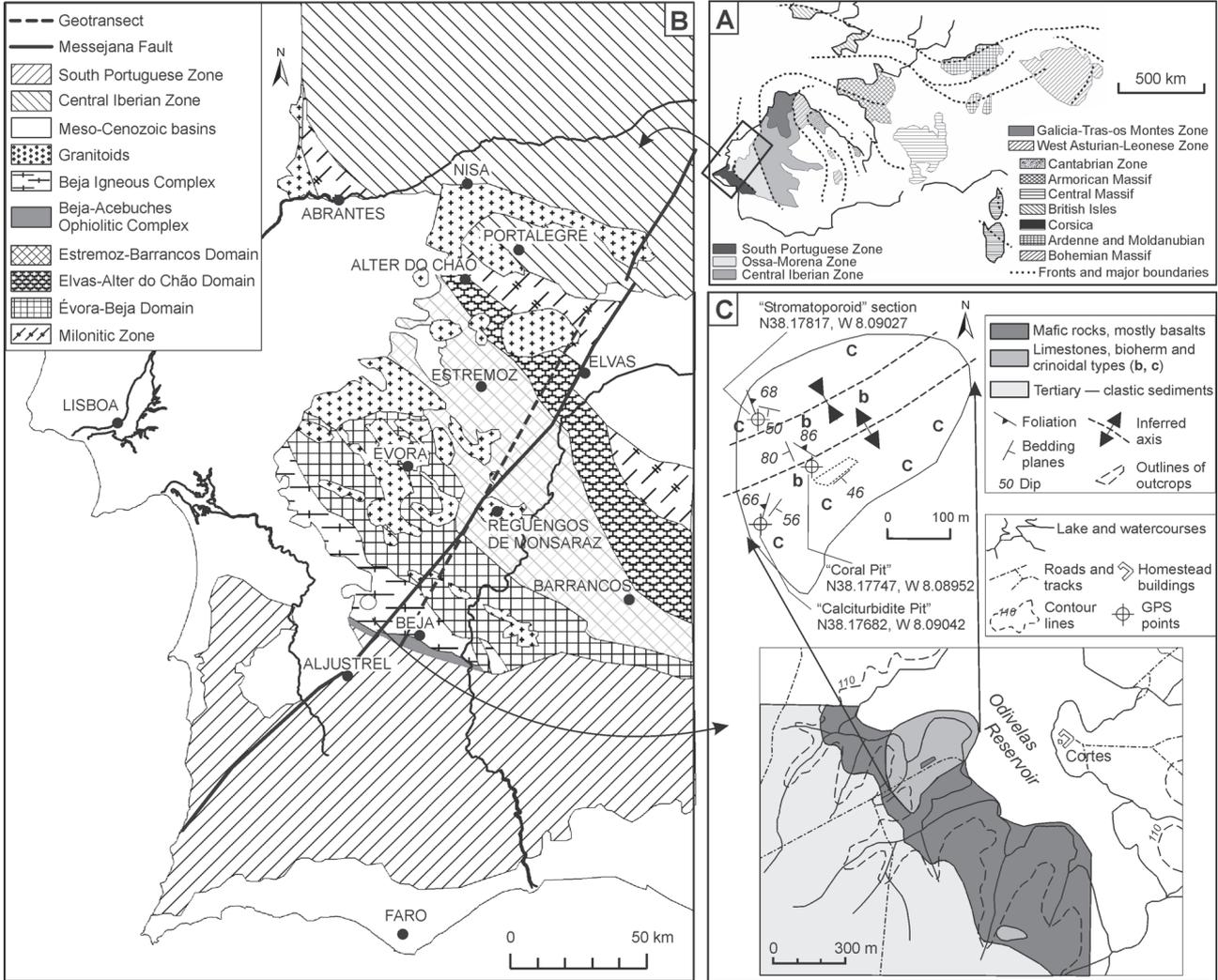
Fig. 1. Geological setting of the Cortes locality, Odivelas Reservoir. **A** — Geotectonic units of European Variscides (adapted from Ribeiro et al. 1996). **B** — SW Iberia geotectonic units and the several domains of the OMZ (adapted from San-José et al. 2004; Borrego et al. 2005 and Oliveira et al. 1991); Geotransect line refers to text figure 2. **C** — Detailed geological map of the Cortes locality.
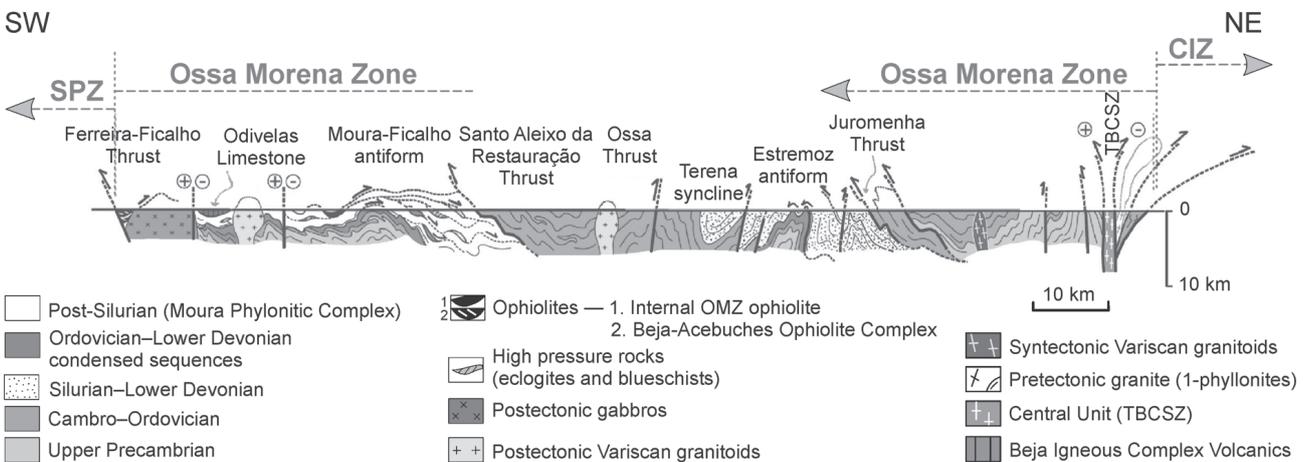

Fig. 2. SW–NE geotransect through the Ossa Morena Zone in Southern Portugal with the geological location of the Odivelas Limestone (adapted from Ribeiro et al. 2007).

bidites (Oliveira et al. 1991; Piçarra 2000; Borrego et al. 2005). Reefal sedimentation is known from the Lower Devonian of the OMZ as reported by May (1999) and Rodríguez et al. (2007). The Middle Devonian is generally absent in the OMZ. This has been interpreted as a consequence of the first pulses of the Hercynian orogeny and generalized uplift of this area during the Middle Devonian (Robardet & Gutiérrez-Marco 1990, 2004; Oliveira et al. 1991). In the Évora-Beja Domain, the Pedreira de Engenharia calciturbidite outcrops (near Montemor-o-Novo) provided Eifelian conodonts (van den Boogaard 1973), but the relation of these with the surrounding siliciclastic sediments remains unclear (van den Boogaard 1973; Pereira & Oliveira 2006). The overlying limestone lenses interbedded with shales of the Cabrela Complex dated as Frasnian (van den Boogaard 1983) have been shown to be olistoliths in Visean shales (Pereira & Oliveira 2003, 2006). In the same sector and within the Beja Igneous Complex (BIC), the only known Middle Devonian sediments are the Odivelas Limestone (Conde & Andrade 1974) which are the subject of the present work. Other rare occurrences of limestones in the same domain are reported in the contact area with the South Portuguese Zone near the Caerinha mine, Pena, Atalaia, Monte das Cortes and Alfundão (Pereira & Oliveira 2006; Oliveira et al. 2006), but the age of these lenses is unknown and the relation with the surrounding Carboniferous Toca da Moura volcano-sedimentary complex remains obscure.

The Upper Devonian and Carboniferous sedimentation is controlled by the pulses and geometry of the oblique collision occurring between the South-Portuguese Zone and the OMZ in a clear synorogenic phase (Quesada et al. 1990). According to the same authors these sediments can be divided into foreland basin flyschs and molasses (mostly Upper Devonian and Mississippian), synorogenic intermontane terrestrial deposits (Pennsylvanian) and late orogenic intermontane deposits (uppermost Carboniferous and Permian), all of which have a greater development in the eastern areas of the OMZ. Close to the studied area (western OMZ) the Cabrela and Toca-da-Moura complexes are the representatives of the Mississippian foreland basin deposits (Pereira & Oliveira 2006) and the Santa Susana Coal Basin of the intermontane Pennsylvanian deposits (Sousa & Wagner 1983; Wagner 1983; Wagner & Sousa 1983).

Other Devonian and Carboniferous sediments (mostly black shales) are present in the northern parts of the OMZ along the Porto-Tomar shear zone but their deposition seems to be controlled by a quite different geodynamic setting (e.g. Fernandes et al. 2001; Chaminé et al. 2003; Fernández et al. 2003; Vázquez et al. 2007) and will not be dealt with any further in this work.

Local geological setting

The Odivelas Limestone site near Cortes is composed of several natural and artificial outcrops and a wide area of abundant loose boulders. The limestone was quarried and processed locally as can be seen by the ruins of an old lime mill. Nearly all the outcrops and most of the loose boulder area are flooded during the winter season. Although outcrops are scarce a limestone zonation is observable with bioherm lime-

stones mainly in the centre and calciturbidite with crinoid fragments on the edges of the body (Fig. 1). Together with geometric information from bedding planes and foliation it is possible to infer that the limestone body corresponds to a small, badly defined, anticline structure.

The main limestone body is surrounded by massive lava flows and rare pyroclastic deposits comprised in the Rebolado Basalts (Andrade et al. 1976). The same authors considered these to be the volcanic equivalents of the Casa Branca Dolerites that crop out to the W and SW due to the similar chemistry. These dolerites were studied in more detail by Jesus et al. (2003, 2007) and Mateus et al. (2001) who give the relatively young ages in the 355–320 Ma interval (~Famennian/Tournaisian to Visean).

The chronological relation between the basalts and limestones is unclear. Field evidence of the contacts is scarce, but the structural interpretation (and also facies) suggests that the limestones overlay the basalts. The presence of a small dyke intruding the limestones is indicative that at least the final part of the magmatic activity that generated the volcanic and sub-volcanic suite of the Beja Igneous Complex is posterior (clearly intruding) to the limestone deposition. Chemical analyses show that the limestones deposited contemporaneously with extrusive volcanic activity (see geochemical and petrographic analysis).

A second, smaller, sector with limestone occurrences is present to the SE of the main one (Fig. 1). No outcrops are visible, just abundant loose limestone boulders, mainly calciturbidites. It is possible that this location is an old quarry or lime mill filled in with tailings and local detritus.

The Tertiary deposits cover most of the northern area of the Odivelas reservoir and significant parts of the southern area. They unconformably overlie the volcanic suite and seem to have a topographic control leading to a local restriction of Beja Massif outcrops to valleys and other low land areas.

Previous work

Several short communications, papers and regional field trip guides (e.g. Andrade et al. 1991), mention the Odivelas Limestone and also the carbonates that occur near the reservoir wall but all of them refer to the original work by Conde & Andrade (1974). This was, therefore, the only work so far that described the paleontology and location of the site and proposed a tentative limestone zonation. The fossil content described in Conde & Andrade (1974) includes stromatoporoids, corals, crinoids, brachiopods, bryozoans, conodonts and trilobites. The presence of fossils compared with *Athyris concentrica* and *Thamnopora boloniensis* (brachiopod and tabulate coral) was then regarded as evidence of a Middle or Late Devonian age. The only described conodont taxa was *Polygnathus* sp. and no stratigraphical implication for this finding was made.

Lithotypes and stratigraphy

Petrographic and geochemical analyses

Several outcrop samples were cut to produce thin sections and polished hand samples to be observed optically and to
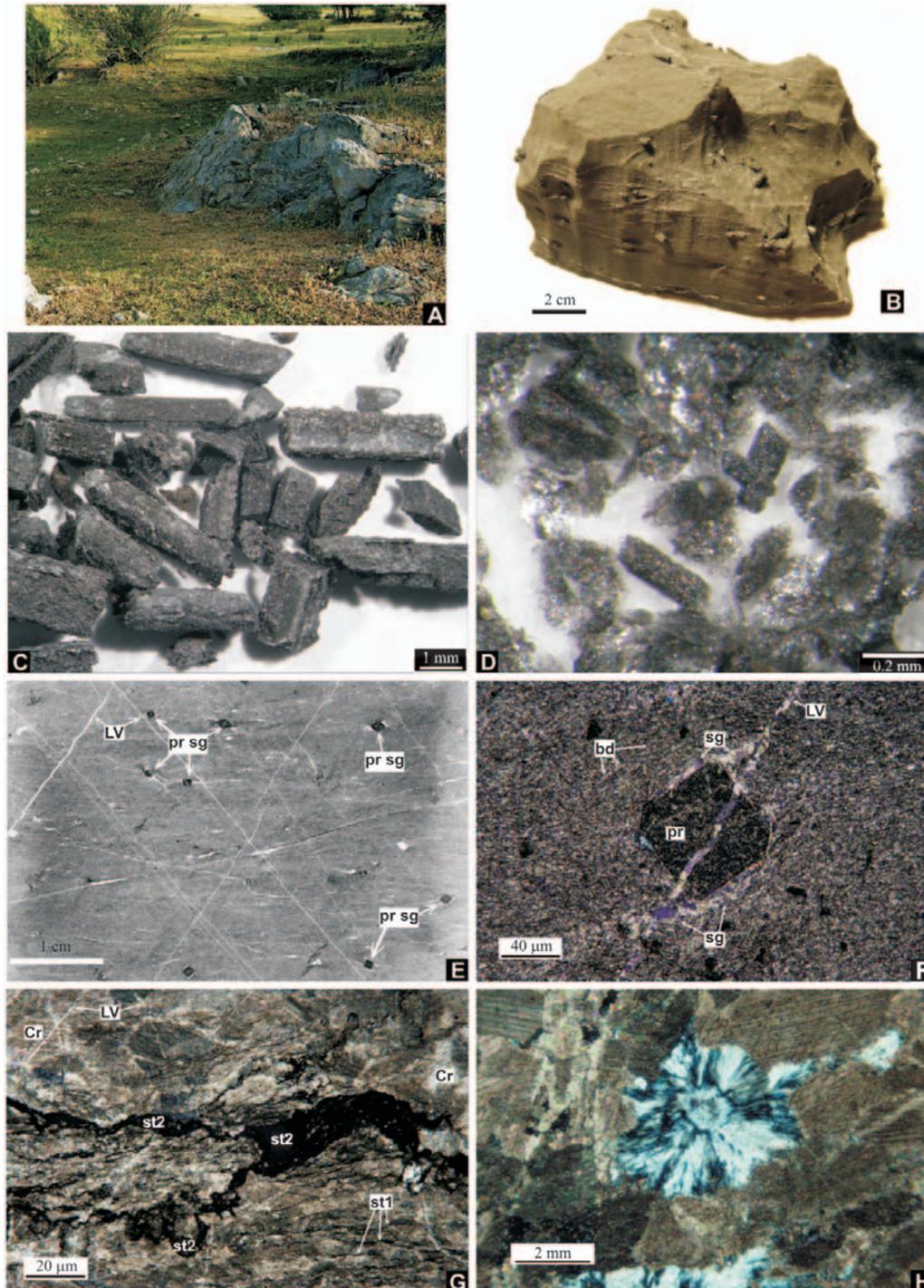
Fig. 3. Outcrop and hand sample images and photomicrographs of thin sections. Legend: **bd** — bedding (emphasized by first order stylolites); **cr** — probable crinoid element fragment; **LV** — late carbonate vein; **pr** — black prismatic particle; **pu** — pumpellyite crystals; **sg** — sigmoid structure shadows; **st1** — first generation stylolite; **st2** — second generation stylolite. **A** — Natural outcrop and surrounding landscape. **B** — Partially undissolved calciturbidite limestone block after acetic acid treatment. Note the black prismatic particles. **C** — Isolated prismatic particles (from acetic acid residue) showing overall shape and texture. Note the inner area and outer envelope in some of the particles. **D** — Finner fraction of the acetic acid residue showing the dismembered outer envelope fragments of larger prisms and very small prisms. **E** — Thin section image showing the general appearance of the calciturbidite limestone. Note the scattered prismatic particles acting as centers for delta and sigmoid structures. Late carbonate veins cut all the previous structures. **F** — Photomicrograph of a sigmoid structure around a prismatic graphitic particle. Note the latter vein cutting all the previous structures. Calciturbidite limestone. Crossed polars. **G** — Photomicrograph of a large scale stylolite (second generation). Subsidiary stylolites are visible (same stage) and previous ones (marking the bedding fabric). Crinoid(?) skeletal pieces are visible in the upper part of the image. Bioherm limestone. Crossed polars. **H** — Photomicrograph of a pumpellyite rosette surrounded by calcite crystals and a recrystallization area. Crossed polars.

perform EDX and microprobe analyses. The bioherm limestone is dominated by biogenic particles in a micritic matrix (see the paleontological record section). The calciturbidite limestone has a homogeneous crypto- to microcristalline texture (Fig. 3E). In both lithotypes six main petrographic features were observed: 1) lamination (marked by ghosts of often well recognizable bioclasts and a first generation of stylolites); 2) feldspar sub-euhedral crystals; 3) second generation stylolites (Fig. 3G); 4) white and grey coarsely recrystallized areas and small veins; 5) pumpellyite/prehnite and quartz rosettes (Fig. 3H); 6) late generations of veins with carbonate and feldspar, and finally but only in calciturbidites; 7) prismatic black particles (Fig. 3B to D and F) in size range from tenths of millimetre to centimetres. Original sedimentary features seem to be the abundant, mostly non-authigenic feldspar crystals and the lamination, later marked by a sub-parallel generation of stylolites. The WDS microprobe and EDX analyses indicate that up to 30 % of the finer and darker limestones are composed of volcanic derived minerals such as chlorite, albite, oligoclase, microcline, titanite, rare micas and altered pyrite, although only the feldspars and pyrite were observed optically.

The black acicular prismatic crystal pseudomorphs which occur only in the calciturbidites can (in some levels only) constitute up to 20 % of the limestone; their length ranges from 0.1 mm to 5 cm long (Fig. 3C and D), but the width of the largest specimens never exceeds 2.5–3 mm. Simple prisms prevail, but occasionally complex shapes are also present (Fig. 3D). The transverse section is square, rhombic or irregularly hexagonal. The microprobe analyses show a core composed of hexagonal platelets of white-mica and phlogopite retaining, most likely, the original compositions of unknown mineral precursor as well as a very faint cleavage plane (001) which is sub-perpendicular to the prism axis. The high content of Al (up to 25 %) is explained due to nanometric inclusions or mixed phases between the mica layers, although this could not be confirmed. This core is interpreted as forming in an early heating stage due to the contact metamorphism of the surrounding subvolcanic suite. The core is surrounded by an irregular, partially hollow cylinder composed of Mg-rich mi-

cas. The outer envelope defining the hexagonal prism is composed of chlorite and tosudite. These two outer layers are interpreted as diachronically forming or pseudomorphosing during late diagenesis and metamorphism. Some of the prisms have a porous structure which is filled by calcite, hematite and other minerals. Semi-graphitic organic matter is often concentrated at the surface of these pseudomorphs. Occasionally planar cracks and fissures (sub-perpendicular to the axis of the needle) are filled by calcite. This fracturing corresponds to otherwise plastic shear deformation which is parallel to the original lamination and can be compared to that which was observed on rare thin-sectioned conodonts. This deformation can start as early as with compaction of the rocks and early burial diagenesis.

The major recrystallization areas and second generation of stylolites cut or affect the previous features. These represent a second phase of pressure solution and recrystallization of carbonate, contemporaneous with the main deformation phase as can be seen by the delta and sigmoid structures formed around the prismatic particles (Fig. 3E and F, Fig. 4). Finally, a second generation of veins (carbonates, perthitic alkali feldspars and rare quartz) cut the entire structure. They are usually thicker and with a more regular orientation which suggests fracture filling formed during a late deformational event (Fig. 3E and F, Fig. 4) or by adiabatic decompression.

Magnetic susceptibility

In one of the artificial outcrops a small mostly undeformed sequence (ca. 2.4 m) of thin-bedded crinoidal calciturbidites was preserved. This section was sampled for magnetosusceptibility stratigraphy at ca. 10 cm intervals and for palynology in widely spaced intervals. The results are summarized in Fig. 5. According to the structural interpretation the measured section (light grey shade) would be overlaying the bioherm beds (dark grey shade, Fig. 5), but the positioning is merely tentative.

The data obtained from a short section with condensed stratigraphy can be tentatively assigned to the end-Eifelian segment 37–43 m of the MS Reference Section Moravian

	Sedimentation	Diagenesis	Metamorphism/Deformation D$_n$	Exhumation/Deformation D$_{n+1}$
Sub-euhedral feldspars	━━━━━━━			
Bedding and 1st generation stylolites	━━━━━━━━━━			
Prismatic particles		▬ ▬ ▬ ▬ ▬ ▬ ▬ ▬		
Recrystallization areas			▬ ▬ ▬ ▬ ▬ ▬ ▪	
2nd generation stylolites			▬ ▬ ▬ ▬ ▬ ▬ ▬ ▮	
Pumpellyite rosettes				━━━━━
Late veins				━━━━━━━

Fig. 4. Graphical chronology of the observed petrographic features. Solid lines refer to chronologically well defined processes and dashed lines to doubtful chronologies.

Karst (Hladil et al. 2006; Fig. 5 herein). This position seems to be determined by extremely low MS magnitudes together with medium amplitude "coarse brush patterns". The compared point in the reference section was originally held close to the base of *Polygnathus ensensis* stratigraphic correlatives (Hladil et al. 2006), but the most recent Belgian data (F. Boulvain et al., pers. commun. 2008) are highly indicative of slightly younger ages for this point, namely with *Polygnathus hemiansatus* age correlatives.

Although the latter is quite concordant with the paleontological record, several concurrent problems exist. A crude visual estimation of the proportion of the small black prisms in the magnetic susceptibility samples show a good correlation with the obtained MS curve. The measured MS values in isolated prims vary from 7.9 for complete specimens to 84.6 ($\times 10^{-9}$ [$m^3 \cdot kg^{-1}$]) for the minute flakes composing their outer envelopes (Fig. 3D). Additionally, the not negligible proportion of fine-grained, mostly altered volcanic admixture (?volcanic ash and recycled microdetrital material) is expected to modify the MS record. In this context, however, the mean MS values which are smaller than 1×10^{-9} are very surprising and we explain this by early diagenetic trapping of iron by pyrite and its late weathering alteration to iron oxyhydroxidic subcrystalline mixtures. Metamorphism, although low grade probably adds other noise or overprints the sedimentary MS variations. The obtained curve can, therefore, reflect the combination of several processes which may have modified the comparability of the original, wide regional to global (climatically induced) magnetosusceptibility stratigraphic record.

Paleontological record

Macrofauna

Crinoids

Very common columnals of the crinoid genus *Cupressocrinites* are visible on the weathered rock surfaces or in slabs of the limestone sampled from relatively well preserved layers and boudins. These remarkable fossils are present across all discernible original sedimentary facies of the Odivelas Limestone in its type occurrence outcrops (i.e. from bioherms to calciturbidites). The largest about 5–7 mm wide columnals were regularly found with the coral-crinoid-brachiopod bioherm and biostrome relict structures. The large and medium sized columnals can be compared, according to their rough morphology, with *Cupressocrinites* cf. *crassus*? (Goldfuss, 1831) or at least very similar forms — Fig. 6A–C. Some of small columnals with well separated peripheral canals may
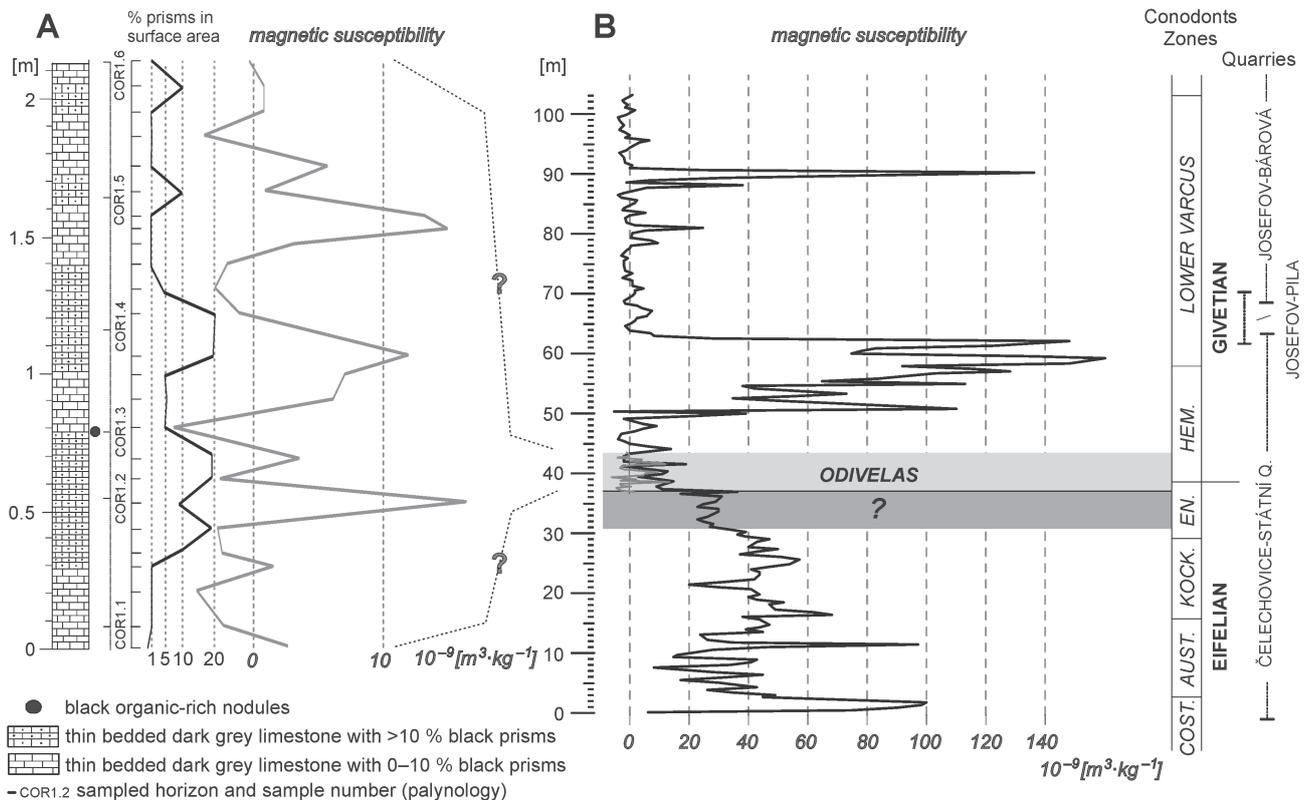

Fig. 5. Sampled section for magnetic susceptibility and palynology with reference to the sampled horizons and possible correlation with the already published magnetic susceptibility curves for the same time interval (Hladil et al. 2006) and estimated conodont zone time equivalents (still under improvement by interregional correlation). The biostratigraphic correlatives for the indicated point (base of *Polygnathus ensensis* Zone) can be updated by means of the most recent Belgian results (slightly younger, in *Pol. hemiansatus* Zone; Bultynck et al., pers. commun. 2008).

also be compared with *Cupressocrinites* sp. M? Le Menn, 1999 (in Ureš et al. 1999). The columnals having similarity to the latter taxon are found mainly in tempestites–calciturbidites which are interpreted as an original cover of the underlying biohermal-biostromal facies. These *Cupressocrinites* species occur together, for example, in the lowermost Givetian part of the Čelechovice Limestone in Moravia, Czech Republic (e.g. Bouček 1931; Remeš 1939; Ureš et al. 1999; V. Petr, internet comments on the *C. crassus* 2007). They are especially abundant in the Middle Devonian and particularly Eifelian–Givetian strata worldwide (i.e. among North Gondwana, South Baltica, Urals and Siberia basins and terranes) but they typically mark the Rhenish facies together with parallel, closely adjacent Variscan facies-tectonic belts on the inner side of the former and having a partial resemblance to pre-closure Rheic passages. Such a high abundance of *Cupressocrinites* remnants coupled with the presence of dark grey coloured coral and stromatoporoid limestones is, therefore, a not negligible indication that these sediments deposited in the middle of Variscan belts, and according to stratigraphic position close to the Eifelian/Givetian stratigraphic boundary. In spite of the predominance of these crinoid columnals, the presence of other crinoid genera is quite possible. Most of these genera, however, cannot be seriously determined on the basis of the random sections, due to imperfectly preserved features of facet, areola, latus, etc. The only exception is for *Gasterocoma*? sp. because its "rounded, double-axial-canal" in columnals and cirral ossicles which is clearly visible in the sections.

We use the term "*Cupressocrinites*" because we have no solid data on possible exoplacoid layer covering the plates of cup and arms (cf. also *Robustocrinites* and *Abbreviatocrinites* Bohatý, 2005, newly defined but considerably sympatrical forms). In spite of general uncertainty about the crinoid columnal determination, the illustrated morphology is considerably different in comparison with any older (Emsian-Eifelian) or younger (Givetian-Frasnian) crinoid columnals which possess four accessory canals, e.g. "*Tetraptocrinus*", "*Tetraxonicrinus*" or similar forms. In addition, it is particularly important that rich and diversified columnals assemblages of both the older and younger ages are completely absent in reef-collar biostromal/biohermal and upper slope facies at this volcanic elevation. The cupressocrinitid columnals strongly predominate.

Tabulate corals

Owing to the local thickening of originally calcite corallite walls the branches of *Thamnopora* tabulate corals belong to the most spectacular fossils which can be found in the less deformed layers and boudins of biohermal limestone facies. The whitish colour and positive weathering surfaces of these corals are eyecatching during collecting of the fossils, and this may lead to a slight overestimation of their relative abundances in comparison with other coral-stromatoporoid fauna of softer, Mg-calcite or aragonitic and thus less preservable skeletons. The present analysis of newly collected *Thamnopora* specimens does not confirm the previous determinations (Conde & Andrade 1974) but suggests that majority of these branched coralla and their fragments most likely belong to *Thamnopora*

cf. *irregularis* Lecompte, 1939 (Fig. 6D–L). The main evidence for the revision of the previous determination as *T. boloniensis* (Gosselet, 1877) lies in the capability of this coral for frequent rejuvenations and irregular arrangement of the corallites as well as irregular budding and often imperfectly developed (or missing) separation of the thick-walled peripheral zone. The other supportive arguments for this determination are based on full agreement of the coralla and corallite shapes and mural pore dimensions with the type populations of *T. irregularis* which were described from the "Gia" levels (Lecompte 1939) [in the present stratigraphic terms: Hanonet Formation/Trois Fontaines Member in the Dinant Synclinorium, Belgium ~ *Polygnathus hemiansatus* Zone]. Besides this dominant species, some small and rare forms and one medium-sized form are also present, but their determination is very difficult. These forms resemble in some of their poorly preserved features *T.* cf. *compacta minima*? Sharkova, 1981, *T.* cf. *incerta perpussila* Hladil, 1984, *T.* cf. *vermicularis*? (McCoy, 1850) and *T.* cf. *bilamellosa*? Ermakova, 1960. Although the presence of these species remains highly problematic, it is interesting that all these possible links are also focused in the Eifelian–Givetian ages, and are also indicative of the same paleogeographical space as the above mentioned high abundance of the *Cupressocrinites* crinoid remains.

Other prominent component among tabulatomorphic (but not tabulate) corals are colonies of *Heliolites*. Domical and short cylindrical colonies prevail. Also the colonies with several centimeters thick overgrowths by undetermined massive coenostea of stromatoporoids are commonly seen in the bioherm-biostrome facies in the central part of the Odivelas Limestone type occurrence outcrops, but their subtle skeletons were often and considerably damaged by recrystallization. A few uncoated colonies with at least partial preservation of visible internal structures (Fig. 2A–F) were classified as *Heliolites* cf. *porosus bilsteinensis*? Iven, 1980, but we must also consider a certain similarity to *Heliolites* "Typus C" Hubmann, 1991 and partly also to the youngest forms of the problematically defined *H.* cf. *vulgaris* Tchernyshev, 1951 (e.g. Hladil & Lang 1985). The morphologies like *H. porosus bilsteinensis*, and considering also these three morphologically related forms are quite indicative of the Eifelian–Givetian and particularly the earliest Givetian ages. On the other hand, there is no evidence for the presence of the typical septate heliolites as *H. porosus porosus* (Goldfuss, 1826) or *H.* "*intermedius*" Le Maître, 1947 which are also typical for these stratigraphic levels but occur rather in thicker limestones around platforms than in thin limestone layers on volcanic substrates. In spite of a certain tendency toward the reduction of coenenchymatic tubulae, the possible comparison with *H. barrandei* Penecke, 1887 is hindered by the absence of rudimentary but thickened bases of septa as well as local thickenings of the parts of the skeleton as a whole (compare, e.g. Fernández-Martínez 1999).

The small favositid-like, nodularly or domically shaped centimeter-sized coralla often have characteristics of caliaporids (rotation of parallel corallites, presence of battens, indications of squamulae). However, the presence of *Calipora battersbyi* (Milne-Edwards & Haime, 1851), *Mariusilites chaetetoides* (Lecompte, 1939) or their Eifelian precursor species lack unambiguous evidence in this recrystallized coral materi-
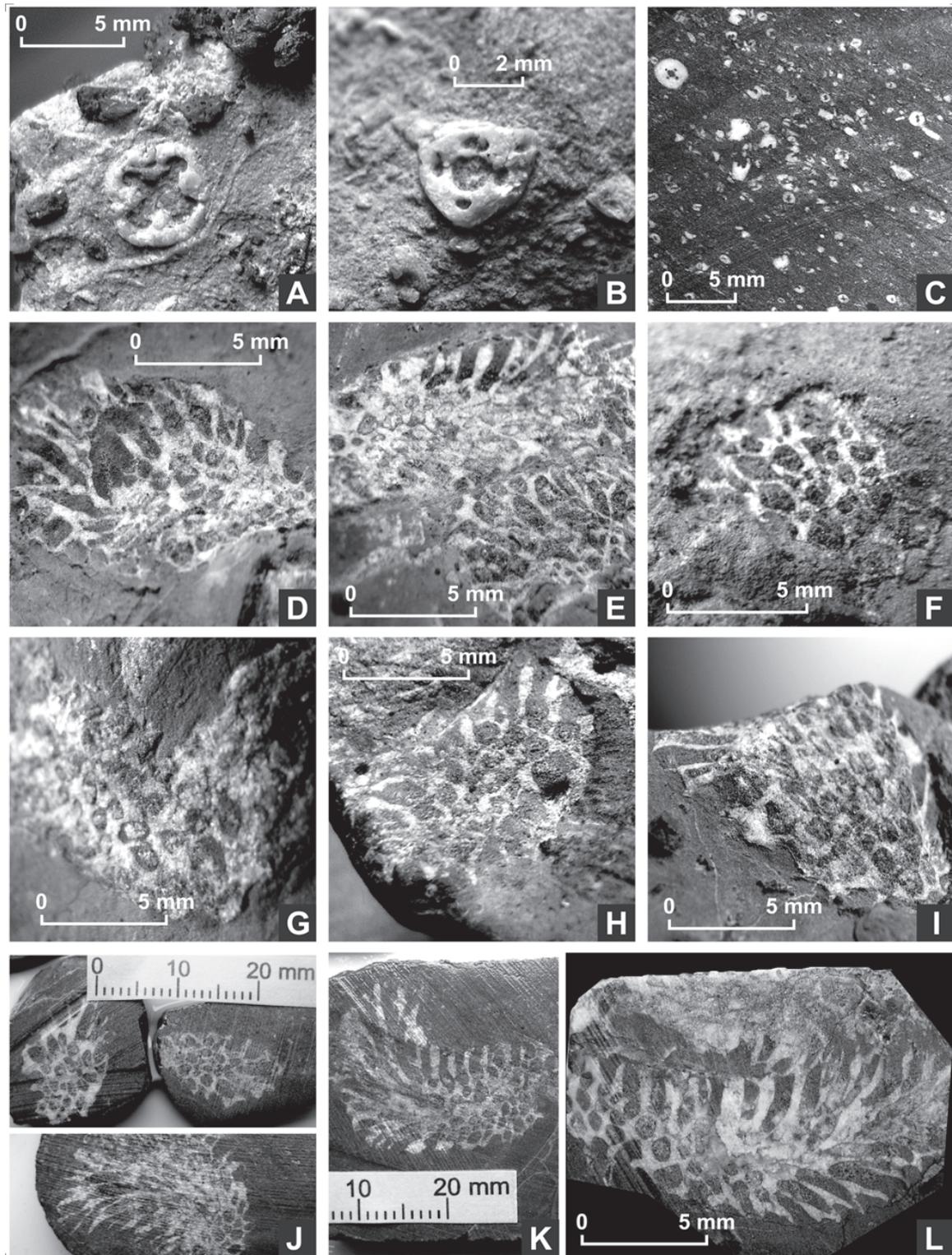
Fig. 6. A–C — *Cupressocrinites* sp. remains, echinoderms. A — A wide but low columnal has an extremely opened lumen that originated due to interconnection of the axial and four peripheral canals. The specimen shape is indicative of a distal internodal. The obliteration of the articular facet was caused by recrystallization of the calcite-filled skeleton tissue, as well as by recent corrosion/erosion of the rock surface. The porous, 1–5 mm thick, dark grey coloured fossils with positive relief are silicified fragments of amphiporid stems. B — A middle sized but high crinoid columnal corresponds to a nodal from a middle part of the stem. Cirrus with dichotomically branched cirral canals was inserted on the latus. This nodal was embedded in packstone where detritus of shelly fauna, crinoids and corals prevail. C — Assemblage of numerous, small cupressocrinitid and/or gasterocomids columnals, accompanied by less abundant *Gasterocoma*, together with detritus of other, mainly brachial crinoid parts.

al. In contrast to this, several colony remains (perhaps randomly preserved?) provided sufficient indications that one of these caliaporids can be labelled as *Caliapora*? cf. *plagiosquamata* Hladil, 1981 (Fig. 7G–I). This coral has all the evident though moderately reduced *Caliapora* type features. Its occurrence is typical of the Givetian stage, ranging in Moravia from the Eifelian–Givetian to Middle Givetian strata.

Many observed and analysed colonies must likely be encompassed within the alveolitids, specifically between the genera *Squameoalveolites* and *Spongioalveolites*. The best evidence was found for several coating to low domical colonies of relatively compact skeleton which were determined as *Squameoalveolites* cf. *fornicatus* (Schlüter, 1889) — Fig. 7J-M. Corallites have a clear alveolitid shape where densely spaced and well opened mural pores are on the lateral sides and are regularly alternated by couples of thick, tongue-shaped skeletal protrusions which resemble formations of "squamulae or spines". Again, the species is very typical for the Eifelian–Givetian and lowermost Givetian strata worldwide and especially in the Rhenish and adjacent marine basins.

Other fossils apparent among well preserved, thick skeleton branched tabulate corals are scolioporids with subdominant *Scoliopora denticulata denticulata* (Milne-Edwards & Haime, 1851) cf. *alpha* morfotype Hladil, 1984 — Fig. 8A–D. The corallites elongated in the transverse section have flattened, rounded-rectangular to bean shapes, and despite and in spite of the corallite rotation after the budding they tend again to be sub-parallel near the colony surface. Septal ridges are always clearly visible, as well as the typical galleries of tube-like pores. The morphology of these corals is in agreement with that of the old Givetian populations from the Lažánky-Zrcadla locality in Moravia. The presence of this species is quite interesting from two points of view. First, this coral in Moravia usually occurs on platforms and their slopes and, second, it is rather indicative of earliest Givetian ages than the late Eifelian. As this coral most likely belongs to the very slowly and consistently growing microsuspension feeders which can also considerably exceed the territorial ranges of typical reef communities (e.g. settling on slopes, and vice versa, in the sheltered environments only with amphiporids) it is not surprising that these *Scoliopora* branches were also here preferentially embedded in originally ?micritic–micropeloidal sediments that have relatively low admixture of skeletal debris.

Rugose corals

There was a rich, moderately diversified assemblage of these corals in the materials collected from the fragmentary bioherm–biostrome structures in the centre of the type Odivelas Limestone locality. Corals which were determined as *Pseudamplexus*? sp. (Fig. 8F-I) are slightly dominant. Most of these corals occur in clusters and accumulated in lenses, where complete specimens are more abundant than millimeter to centimeter detritus of their calices. Typical original sediments were most likely ?ostracod packstones/wackestones, although more diversified skeletal packstone varieties occur as well. It seems that some populations differ in shape, as we can find longer conical shapes with less cemented skeleton and also forms with deeper and more opened calices where the skeletons were filled and coated by early cements, but the more detailed taxonomic conclusions are restricted by poor preservation of most of the internal structures.

Among well represented groups mainly the Digonophyllinae must be mentioned. Large conical to keg-shaped corals filled by large dissepiments are labelled as *Cystiphylloides*? sp. (Fig. 8K). Large rugose corals with relatively well indicated length and arrangement of septa were determined as *Mesophyllum*? sp. (Fig. 8L).

The presence of other genera, such as the phillipsastreids *Disphyllum*? sp., locally also *Thamnophyllum*? sp. and *Peneckiella*? sp. is quite possible due to observed general growth forms but the evidence based on preserved internal skeletal structures is lacking. The same is true for possible but not definitely confirmed occurrences of *Acanthophyllum*? sp.

On the other hand, the sub random preservation and sectioning of limestones provided tentative evidence for the presence of various other rugose corals: for example, *Calceola* cf. *sandalina* (Linné, 1771) — Fig. 8M, *Pseudodigonophyllum*? sp. — Fig. 8N, *Holmophyllum*? sp. (*Holmophyllum*? cf. *uralicum* Zhavoronkova, 1972) — Fig. 9A, or *Cyathopaedium*? sp. — Fig. 9B.

Occurrences of *Pseudamplexus*, *Cystiphylloides* and *Mesophyllum* correspond well to the Eifelian–Givetian ages, and the occurrences of other very briefly mentioned genera are not in conflict with this age determination. In addition, the single finds and determinations of other rugose corals support these ideas about the age of this fauna. *Calceola sandalina*, although relatively rare, is an important cosmopolitan marker for these ages and a very characteristic species of Rhenish and adjacent seas. *Pseudodigonophyllum*? sp. and *Holmophyllum*? cf. *uralicum* also confirm these ages, and *Cyathopaedium*? sp. shows a parallel to the occurrences of *Cyathopaedium paucitabulatum* (Schlüter, 1879) in the upper part of the Newberria Formation, lower Givetian of western Sauerland, Germany (May 2003).

Fig. 6. *Continued from previous page.* **D–L** — *Thamnopora* cf. *irregularis* Lecompte, 1939. Tabulate coral. The variability of the colony and corallite growth shapes is illustrated using eleven, relatively undeformed coral fragments in rock slabs. D — The thamnoporid displays its former capability of easy overgrowing of damaged/attacked parts in the apical part of the branch as well as on its sides. E — A considerable irregularity in budding and arrangement of corallites is regularly present, and according to these relatively well preserved specimens this cannot be alternatively ascribed only to possible environmental extremes or effects of tectonic deformation. F-G — The irregularity of budding is directly reflected by irregular shapes of the corallites that also differ in the number of neighbouring corallites (number of wall parts) and also in corallite diameters. H-I — Also the pseudo-arching of parts of corallite walls in transverse or oblique sections is indicative of incongruent growth domains and layers in the skeleton of the colony. J-L — The terminal parts of the densely branched coralla have regularly the shapes and lengths which can be best described as the shape of a "human thumb".
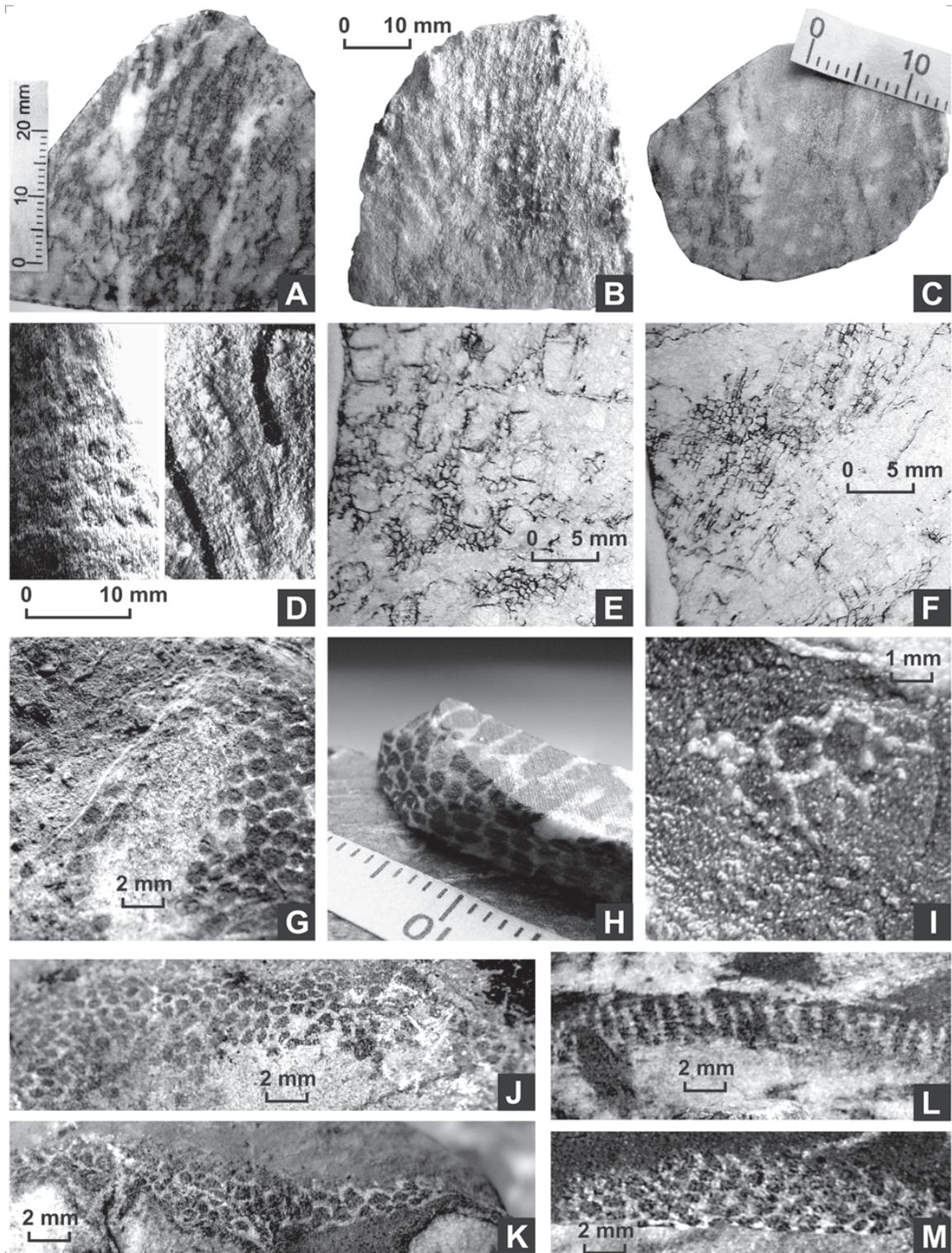
Fig. 7. A–F — *Heliolites* cf. *porosus bilsteinensis*? Iven, 1980 (? = *Heliolites* Typus C Hubmann, 1991). Small bulbous and domical colony shapes prevail, both usually a little protracted, as it is seen in their longitudinal, oblique and transverse sections (A, B and C), A and C are slabs, B is a broken and weathered colony. D — Close views on two other weathered sections (transverse and longitudinal, left and right in this picture. E–F — Rare silicified areas found in the thin sectioned colonies give more contrast to the skeleton details, but there is also evident that the deformation locally caused some breakage and secondary reduction of the coenenchyme width. **G–I** — *Caliapora*? cf. *plagiosquamata* Hladil, 1981. Tabulate coral. G — The transverse section shows regular arrangement of corallites with only slight rotation of corallites, so that an overall appearance is somewhere among usual favositid, caliaporid and alveolitid appearances. H — The slabs are indicative of the presence of pores in short distances and only rudimental squamulae (longitudinal sections) and some transverse sections have rotated, four to six walled corallites, even though they grew parallel to the growth of their neighbours, without any strong lateral increase of the colony.

Stromatoporoids (and amphiporids)

The stromatoporoids are certainly an important faunal component of the bioherm–biostrome structures in the central part of the Odivelas Limestone type locality, but their originally aragonitic to Mg-calcitic skeletons were recrystallized during both the diagenesis and slight metamorphosis to a degree which even precludes their generic identification. Only some of the observed relict structures allow us to speculate about possible occurrence of *Actinostroma*? (or *Plectostroma*?) [thick, well separated pillars], *Salairella*? [preponderance of regular coenosteles], *Atelodictyon*? [strongly expressed laminated features of coenosteum] and *Clathrocoilona*? [very densely structured coatings on corals]. However, this must be considered only in a category of tentative and disputable opinions, not of facts which could be supported by unequivocal evidence.

It is significant that the abundance of stromatoporoids and their overall shape diversity rapidly increased at the transition between the bioherm–biostrome structures and overlying tempestites and calciturbidites. Judging only on the basis of coenosteal outer morphologies in the rock slabs, we can speculate about the possible presence of ?*Stachyodes* together with massive and coating coenostea of the genera with easily recrystallizable skeletons (e.g. ?*Stromatopora*, ?*Taleastroma*, ?*Stromatoporella*, ?*Anostylostroma*, etc.).

The poor preservation of this fauna therefore means nothing more than that stromatoporoids are certainly present, but we can hardly use them for any detailed estimates in terms of systematics, stratigraphy and paleogeography.

In comparison with the major part of these undeterminable stromatoporoid skeletons, the preservation of some rare amphiporids is better. They occur only in relicts of some biostromal structures, in the centre of the limestone body and close to the basalts, and they were locally preserved in a very specific way. The coating by algal-bacteria? "stockings" together with burial in the lime-mud led to a post-mortem concentration of the organic matter in the porous but closed skeleton resulting in a reduced carbonate cementation and increased silicification. The analysis of weathered silicified fragments in combination with unsilicified accumulations of these fossils in rock slabs and thin sections suggests the presence of *Amphipora*? cf. *spissa* Yavorsky, 1957 (Fig. 9C–K). Concerning the stocking-like coatings we must consider both the cyanobacteria and algal coatings, i.e. *Wetheredella*? sp. (*sensu* Kazmierczak & Kempe 1992) and *Gymnocodium*? sp., respectively. Relicts of both structures were preserved. Particularly the silicified fragments and some of the appropriately weathered surfaces provided an undoubted image of the amphiporid skeleton structures. The quite regular internal structures, large size of these branches and irregular occurrences of axial canals in

them actually point to *Amphipora*? *spissa* or closely related forms. These forms are particularly common in the Eifelian-Givetian limestones, where they are either accompanied or alternated by the cosmopolitan species *A. ramosa* (Phillips, 1841). Several small silicified fragments of thin cylindrical specimens with roughly structured skeleton tissues (indicating the "sabre"-shaped pillars), regular axial canal and well separated outer gallery of chambers were also found, but it is difficult to decide whether they really represent *A. ramosa* or only some morphological extremes within the population of *A. spissa* (or other amphiporid). It is possible, that a few stachyodid or coral branches were also admixed in the more recrystallized accumulations of these ca. 0.5 cm wide cylindrical fossils.

Amphiporids dominated the sheltered areas of platforms, but in small amounts they were also found on isolated, drowning elevations with basalts (e.g. at Horní Benešov in Moravia; Galle et al. 1995).

Brachiopods

The accumulations of brachiopod shells are relatively common at the base of biohermal structures, and were observed in several places in the centre of the type locality. Rare fragments of these coquinas (together with coral and coral-stromatoporoid facies) were also found in rock fragments around the eastern Odivelas Limestone body, although this body is characterized by preponderance of crinoidal calciturbidites. In spite of their relatively common occurrences we cannot confirm according to our newly collected material the presence of *Athyris concentrica* (von Buch, 1834) reported by Conde & Andrade (1974).

Especially the largest and thickest brachiopod shells (7 to 12 cm long specimens) have internal structures which cannot be compared with this species, and in addition they do not correspond to the basic structures of many of the commonly known brachiopod genera (consulted with by U. Jansen 2007). We report these brachiopod shells under the working name Brachiopoda gen. et sp. indet. (Type Y) — compare Fig. 9L–O. These very thick shells are preferentially preserved, and this corresponds to the assumption that they were thicker and larger than the opposite valves, so that one can speculatively infer that they were most likely pedicle valves on the ventral side of the brachiopod. The most spectacular feature of these valves is the presence of extremely thick ventral medium septa. The cross-sections of their posterior parts, where these shells have typically a width of 3–5 cm, show commonly a thick septum which is closely connected with other connate skeletal elements, forming the typical bulky shapes of "capital Y". It is interesting that these brachiopod shells were not yet documented by systematic paleontology. These shapes were observed on two localities of the Czech and Polish Sudetes, and

◄——————————————————————————————————►

Fig. 7. *Continued from previous page.* I — Some slightly bent parts of the wall seem to be thicker than the other parts, resembling the "batten" structures of caliaporids. **J–M** — *Squameoalveolites* cf. *fornicatus* (Schlüter, 1889). Tabulate coral. Coating and low domical colonies. J–K — The bent upper walls are undoubtedly dominant, being regularly, unidirectionally arranged in the colony. L — The longitudinal section cutting the lateral walls with pores suggests the regular presence of the couples of squamula-like swellings of wall, alternating with these mural pores. M — An oblique section of a colony gives other evidence about presence of thick spines and squamula-like swellings on the corallite walls.
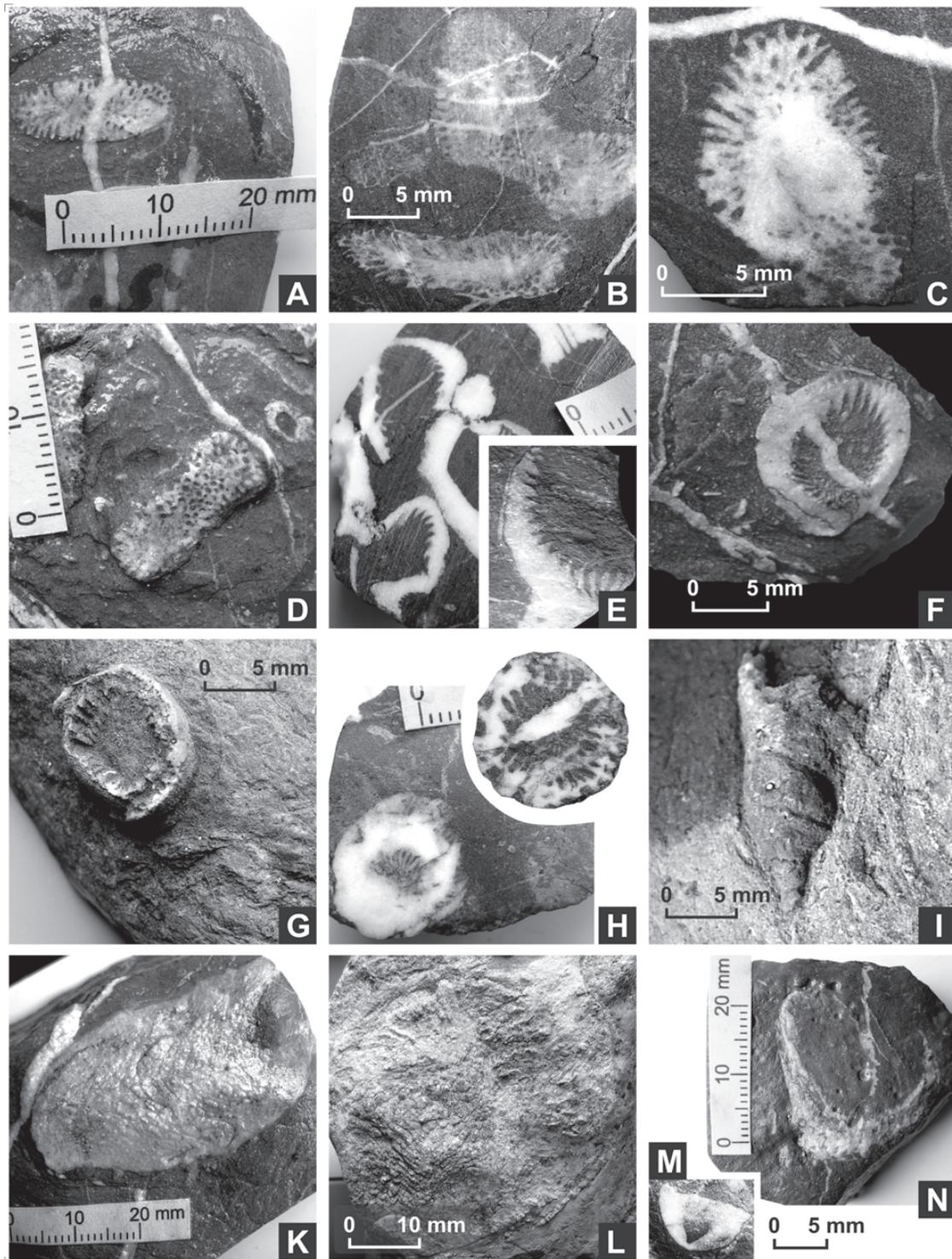
Fig. 8. A–D — *Scoliopora denticulata denticulata* (Milne-Edwards & Haime, 1851) cf. "alpha morphotype" Hladil, 1985). Tabulate coral. Small, thick-walled corallites are elongated to 0.5 ratio in the transverse section and tend to be sub-parallel near the colony surface. Wall thickening from axial to peripheral zone of the branch is gradual. Arrangement of pores in galleries is visible, as well as swelling of walls between them. Rugose corals. **E–I** — *Pseudamplexus*? sp. E–F — Sparite-filled calicional parts of this coral in brachiopod skeletal packstone. Slab and weathered rock surface (E), weathered surface (F). G–I — The higher and not so steeply conical specimens from ostracod packstones/wackestones are congeneric but do not necessarily belong to the same species. **K–L** — Examples of two possible digonophyllids (*Digonophyllinae* Wedekind, 1923). K — *Cystiphylloides*? sp.; a conical (and then keg-shaped) coral specimen on weathered rock surface typically shows large and dish arranged, bubble shaped dissepiments. L — *Mesophyllum*? sp. Transverse section, weathered surface. **M–N** — Other fragmentary rugose corals. M — *Calceola* cf. *sandalina* (Linné, 1771). N — An oblique section across a calicional margin of a coral. Possibly *Pseudodigonophyllum*? sp.
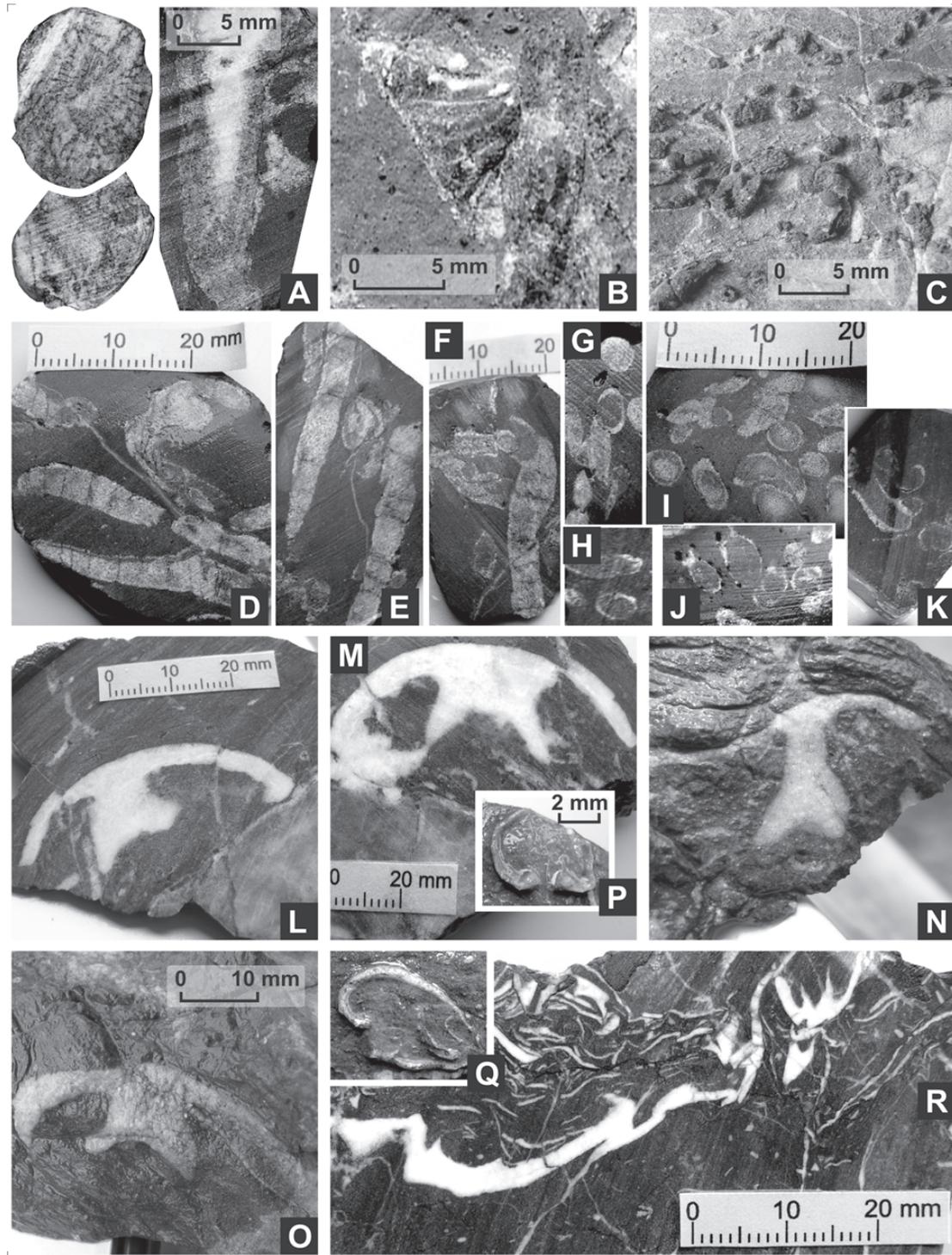
Fig. 9. A–B — Other fragmentary rugose corals (continuation). A — *Holmophyllum*? sp. (*Holmophyllum*? cf. *uralicum* Zhavoronkova, 1972). Well separated, flabellacanthine-like trabeculae are indicated on the images. B — An undeterminable rugose coral, tentatively a young specimen of *Cyathopaedium*? sp. attached on a broken part of an amphiporid stem. Amphiporids. **C–K** — *Amphipora*? cf. *spissa* Yavorsky, 1957. C — Some broken parts of amphiporid stems were silicified. D–E — The stems (branches) of typical 5 mm width are locally coated by thickened vesicular and/or multiple-tube structures which may be compared with cyanobacteria and algal products *Wetheredella*? sp. (sensu Kazmierczak & Kempe 1992) and *Gymnocodium*? sp., respectively. Separation of these coatings is seen on figure E. F–I — Four slabs illustrate that growth of such a bacteria-algal stocking can also continue on necrotic amphiporid tissues. J–K — Some terminations of these stockings show features of division. This morphology must rather be ascribed to unknown temporary inhabitants of these hollows than to the self-organizing capability of the bacteria-algal structures. Brachiopods. **L–O** — Brachiopoda gen. et sp. indet. (Type Y). **P–Q** — Small, undetermined brachiopod valves as they were leached by natural weathering on the rock surfaces. R — An accumulation of thick brachiopod shells. Different types of shell morphologies prevail. Presence of fragmentary *Kaplex* and *Stringocephalus* shells is possible, but any strong evidence for this assumption is absent.

both of these localities have very similar successions of Givetian limestones deposited on submerging basalt seafloor highs (Padouchov in the Ještěd Mountain Ridge — Chlupáč & Hladil 1992; and Malý Bożków in Klodzko area — Hladil et al. 1999). Similarity of these brachiopods within this Variscan belt structure resembles the conclusions which can be reached on the basis of the Odivelas coral faunas.

The small brachiopod shells found as positive relief on the weathered rock surfaces (Fig. 9P–Q) were left without determination, because there is no more than one shell. Very speculatively, there is a possibility to compare these shells with *Cranaena*? sp. or similar brachiopods. With similarly low validity of assumptions we can speculate about the presence of *Kaplex* or *Stringocephalus* shells in the deformed brachiopod coquinas (e.g. Fig. 9R), but also without any direct evidence. It is caused mainly by the tectonic deformation of these shell accumulations which make it difficult to successfully reconstruct the shapes of the valves on the basis of such haphazardly oriented and deformed sections.

Micropaleontology

The site was sampled for conodont and palynology studies. For the palynology analysis several samples were collected from the site, mostly from the calciturbidite limestone (Fig. 3). HCl attack destroyed nearly all the mineral fraction. Concentrated HF attack was performed but it had little effect on the residue. The organic residue was quite abundant. Black opaque heavily thermally altered (sensu Batten 1983) amorphous organic matter was the most abundant component of the residue. Rare complete leiosphere-type palynomorphs were observed. Skeletal remains of acritarchs and grey organic tissues were more commonly seen. None of these could be assigned to a specific genus or group. It is difficult to exercise on the original palynological assemblage, but the relative abundance of prasinophyte and acritarch fragments suggests a rather diversified assemblage that was partially destroyed due to the long exposure to high pH geological environments (Traverse 2007) and the metamorphism and deformation that affected the limestones.

Three samples from different outcrops (two from the bioherm type and one from the calciturbidite type) were collected for conodont studies and dissolved with 10% acetic acid. The 30 and 120 μm fractions were thoroughly examined after acetic acid dissolution but none produced conodont elements. Rare ghosts of conodont elements found by means of thin-sectioning were partly dephosphatized and fragmented. The residue was composed of a carbonaceous material, probably organic matter. Small amounts of quartz crystals were present as well as pyrite (heavily corroded). From the calciturbidite sample, the coarser fraction (>120 μm) was dominated by black prismatic particles, usually less than 2 cm in length (see petrographic analyses).

Discussion and conclusions

From the described fauna it is possible to constrain the age of the Odivelas Limestone to an interval between the upper-most Eifelian and lowermost Givetian. The most frequently indicated ages of the sediments dominate the main body of the classical Odivelas Limestone and seem to be centred roughly about stratigraphic equivalents of the *Polygnathus hemiansatus* Zone. However, it cannot be completely excluded that closely adjacent limestone occurrences would also contain some subordinated, stratigraphically condensed partial sequences (or lenses) of older (?Eifelian) and younger (?Givetian) ages. The magnetic susceptibility results do not clarify the stratigraphical positioning and their correlation with the Kačák Event lowest MS magnitudes and possible patterns is only tentative, having only slight supportive weight in comparison with the biostratigraphical indications. It is mainly due to volcanic admixture in limestones and their slight metamorphism.

The field, petrographic and geochemical data indicate that volcanic and subvolcanic activity took place before, during and after the limestone deposition and that at least part of subvolcanic activity was syn or post-deformational.

The deposition of limestone was most likely dependant on a volcanic structure, with the shallower areas supporting a bioherm-biostromal system with calciturbidite-type sedimentation on the flanks and in the surrounding deeper areas. The described faunal assemblages dominated by crinoids, heliolitids, solitary rugose corals and brachiopods are suggestive of sedimentation on basalt seafloor highs developed along the inner side of the central Variscan facies-tectonic belts as recorded elsewhere in Europe and particularly in the Rhenish facies areas. The relevant paleogeographical constraints are inferred, for example from the occurrences of *Cupressocrinites*, *Calceola* and spectrum of possible tabulate coral taxa.

The Odivelas material also revealed something about climatic conditions. The numerous and highly diversified stromatoporoids, increased production of micrite and burial of organic matter may be indicative of relatively high surface water temperatures, and it may correspond to re-establishment of reefal communities after the Kačák Event. The seasonal growth rhythms observable on walls of rugose corals are quasi-regular or regular, with rapid strangulations of "short duration". No double-monsoon yearly patterns have been observed.

The Pedreira de Engenharia Formation (Évora-Beja Domain, Ossa-Morena Zone), comprising calciturbidites and providing Eifelian conodonts can tentatively be compared with the Odivelas Limestone setting, but the paleogeography and paleoenvironmental conditions of the latter are unknown and contemporaneous volcanic activity in the area has not been recognized. Further work in the Pedreira de Engenharia area is needed to assess the relation between the two areas.

The new data presented here contributes to the better understanding of the paleogeography of the southern border of the Ossa-Morena Zone and the Variscan deformation in SW Europe.

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